Very high energy gamma ray astrophysics

In the last ten years the number of known sources of very high energy gamma rays has passed from four to a hundred or so, thanks to the Cherenkov, H.E.S.S., MAGIC and VERITAS telescopes. The recent arrival in orbit of the new space telescope Fermi and the inauguration of the new ground-based stereoscopic MAGIC-II detector are bringing further discoveries and knowledge.

The stereoscopic Cherenkov system MAGIC-II, inaugurated on La Palma in April 2009. [MPI, Robert Wagner]

Classical astronomy and astrophysics are concerned with thermal radiation from the Universe. In general, stars emit radiation at energies of order 1 electron volt (eV), characteristic of visible light. Hotter objects emit thermal radiation at energies thousands of times higher than that of visible light. We know, however, that non-thermal processes that involve much higher energies (like for example nuclear and sub-nuclear processes) are at the root of thermal radiation (and therefore supply the energy that heats the stars) and also that these play an important role in the dynamics of the Universe.

The first access to these phenomena occurred with the discovery of cosmic rays by the Italian Domenico Pacini and the German Victor Hess in 1912. In 1938, the Frenchman Pierre Auger first observed the particle showers caused by the impact with the atmosphere of cosmic rays with energies of order 10^{15} eV. To give some idea, on the basis of the well-known relation $E=mc^2$, 1 GeV = 1 billion eV, is about the energy needed to create a single hydrogen atom. 1 TeV corresponds to 1000 GeV: a 1 TeV particle can create 1000 hydrogen atoms. Until now, particles with energies as high as 10^{20} eV (16 joule) have been detected. Such energies, billions of times greater than those reached by the particle accelerators we have made on Earth, cannot be created by thermal processes in the present day Universe; other mechanisms must be responsible.

The identification of the sources of such energies requires the study of particles that are not deviated by Galactic or intergalactic magnetic fields: photons. It has in fact been shown that photons are among the particles produced by these acceleration mechanisms (with energies ranging from ten to a hundred times lower than those of the protons).

Recently it has become possible to make instruments able to study very high energy photons, the so-called gamma band photons or gamma rays. In this way many gamma ray sources have been discovered, both Galactic and extra-Galactic, as well as a diffuse background of very high energy photons.

Astrophysical investigations of these sources have contributed to the development of so-called astroparticle physics, which in recent years has gathered many important results, thanks also to the de-

velopment and application of cutting-edge technology used in the particle detectors in the terrestrial laboratories. Just like at the beginning of the 20th century, today elementary particle physicists have turned to using cosmic sources as accelerators, gain-ing access to energies unattainable in the laboratory.
With the detection and study of particles of ever higher energies astroparticle physics is expanding our understanding of the most violent events in the Universe. The frontier lies at the energies of gamma rays, the highest energy photons, but the field of investigation is widening also thanks to the detection of new messengers: in the near future it is predicted that astronomical observations of neutrinos and, perhaps, the hypothetical gravitons, the carriers of gravitational interaction, may be possible.
In recent years high energy astrophysics has had some impressive developments with important results mainly from ground-based telescopes such as H.E.S.S., MAGIC and more recently VERITAS.
The potential of this field is not limited to pure astrophysical observations but also allows significant contributions to the field of particle physics and cosmology.

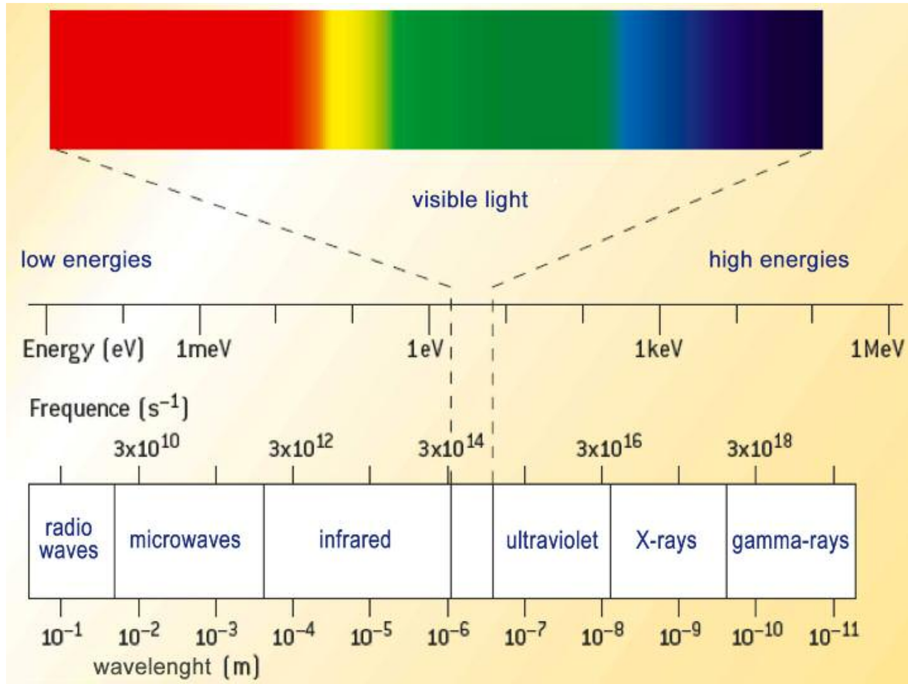
What are gamma rays?

The "multi-frequency" aspect of astrophysics (or the study of electromagnetic radiation at various frequencies) permits the study of a range of physical processes. Emission in the optical band is characterized by sources such as stars, with surface temperatures of the order of thousands of degrees, and is explainable via thermal phenomena. Radiation at X-ray wavelengths, with energies thousands of times greater than those of the optical band, is characterized by electromagnetic interactions within sources. The gamma ray spectrum, that by convention starts at the energy necessary to produce an electron (about half a million eV, hundreds of thousands of times that of photons visible to the human eye), can be explained by even more energetic processes, such as those characteristic of strong interactions. The very high energy (VHE) spectral region extends conventionally from about 10 GeV to around 30 TeV, but the energy range of gamma rays is not limited to this.

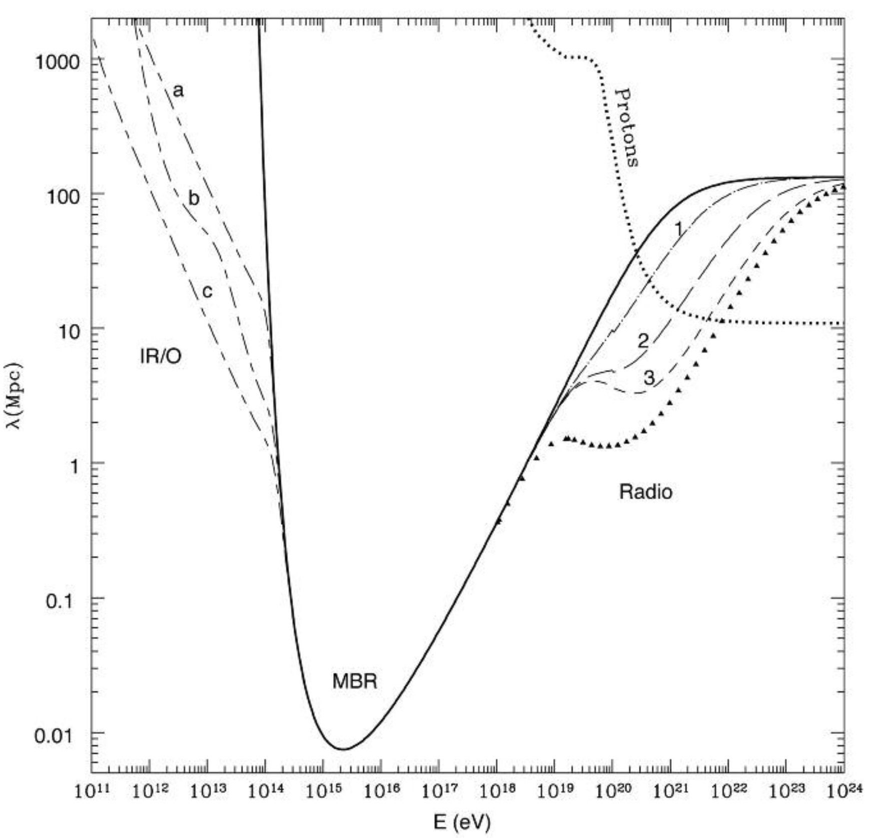
Why study gamma rays?

The astronomical study of gamma rays allows the study of various fields of astrophysics and cosmology, and is both helping to resolve many problems and making many new discoveries.

SOURCES OF COSMIC RAYS. Our Galaxy is pervaded by a magnetic field (of strength about 1 microgauss, or a millionth of the terrestrial field) sufficiently strong to deviate the path of charged cosmic rays (protons, helium nuclei, electrons) such that information on their direction of origin is lost. Gamma rays, on the other hand, being neutral, are not deviated by magnetic fields: their observation therefore allows us to identify the celestial positions of sources of cosmic rays.



The electromagnetic spectrum. [From "Le scienze" and adapted by Danilo Sossi]



The mean free path of electromagnetic radiation of various energies. Note that the interaction length for gamma ray photons at 200 TeV is about 1 Mpc so that these gamma rays can only be detected from sources in our own Galaxy or the nearest galaxies.

STUDIES OF ACCELERATION MECHANISMS. In 1949, Enrico Fermi developed a model explaining the acceleration of cosmic rays. In this model, still valid today, clouds of plasma in the interstellar medium act as magnetic lenses accelerating charged particles, mainly electrons and protons. Gamma rays are generally witnesses of the processes of acceleration of charged particles, and from their observation we can understand the mechanisms that accelerate cosmic rays. High energy gamma rays are produced in two main ways.

1) High energy electrons curving in a magnetic field generate synchrotron radiation, emitting photons with energies between the optical and X-ray bands (depending on the energy of the electron and the intensity of the magnetic field); photons so produced can acquire further energy (up to more than 1 TeV) by rebounding off electrons of extremely high energy (the inverse Compton effect). Essentially, the photons are produced by electrons when they followed curved paths in a magnetic field and subsequently gain energy via collisions with the same electrons.

This model of acceleration is called the "standard model" for the generation of energetic photons and is technically referred to as Synchrotron Self-Compton (SSC).

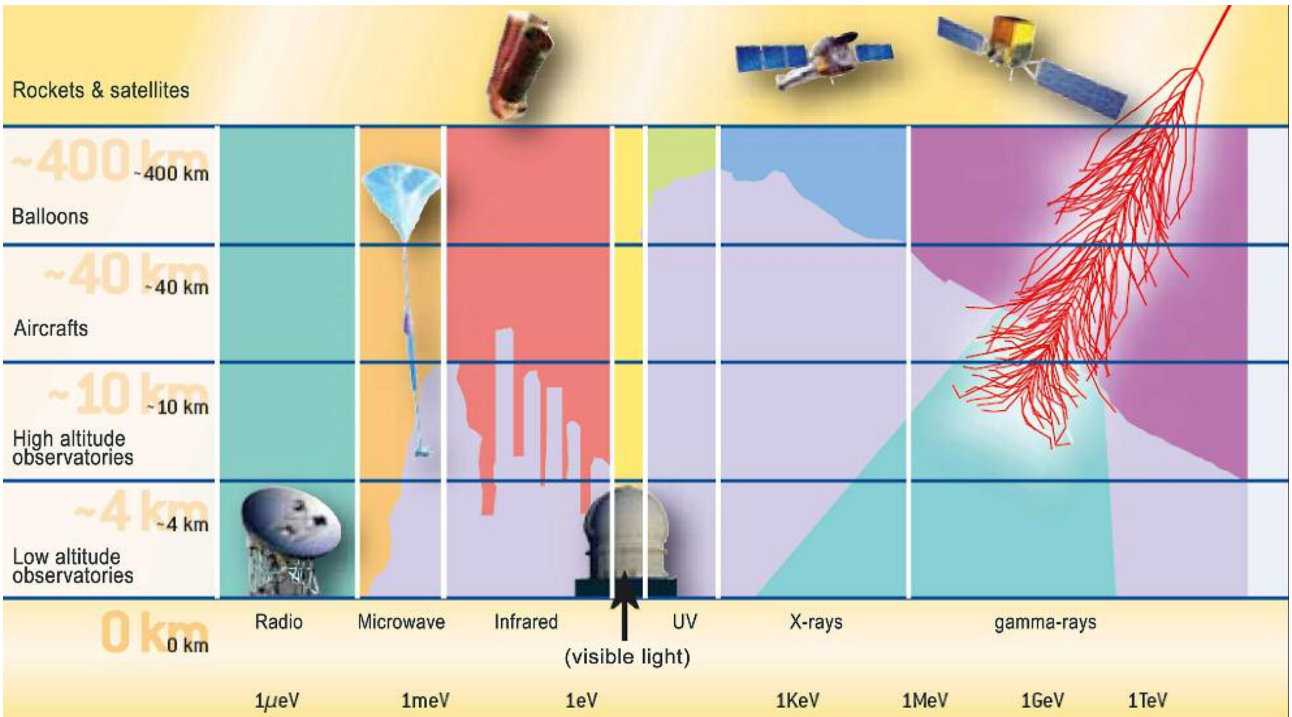
2) Energetic photons can also be produced via strong subnuclear interactions, especially during the decay of the pi-zero particle (that decays into two photons).

Therefore, collisions between high energy protons (or heavier nuclei) are needed. This method of gamma ray production is known as the Hadronic mechanism.

The study of the emission spectrum of gamma rays can therefore reveal the origin of cosmic rays, by establishing the relative importance of Hadronic mechanisms and SSC.

In general, the energy, E, of the radiation produced by gamma ray sources with these mechanisms has an intensity spectrum that falls as $E^{-\alpha}$, with spectral index alpha between 2 and 3.

THE STUDY OF ASTROPHYSICAL OBJECTS. VHE gamma ray sources constitute one of the frontiers of modern astrophysics. Two types of objects that certainly emit in this spectral band, supernova remnants and active galactic nuclei (AGN), contain compact objects, such as neutron stars and black holes. The most recent observations seem to indicate that many X-ray emitters (including Galactic binary systems and pulsars) also emit gamma rays. The emis-



The atmosphere absorbs electromagnetic radiation in different ways depending on the wavelength. Gamma rays, in particular, can only be detected directly by satellite or balloon borne instruments, while ground-based telescopes use indirect methods such as the detection of particle showers. [From "Le scienze" and adapted by Danilo Sossi]

sion of gamma rays seems to be a general property.
Massive black holes in the centre of AGN can produce VHE gamma rays: the gravitational collapse of large masses towards a black hole releases enormous quantities of energy, a fraction of which (between 1 and 0.1%) is emitted in the form of gamma rays. The TeV band is therefore an ideal place to identify and study black holes.
The study of the diffuse gamma ray background detected by current observations could result in the identification and resolution of many other sources, not necessarily similar to those already known.
Another reason for interest in VHE astrophysics is the study of gamma ray bursts (GRB), the most intense emissions in the Universe since the Big Bang. Their distribution, random in time and position, implies that they have an extra-Galactic origin. What causes these bursts is not yet clear, even if one sub-class (the so-called short gamma ray bursts) seem to be caused by the final collapse of neutron stars in binary systems, while another (the so-called long gamma ray bursts) seem to be linked to the collapse of giant stars (hypernovae). Given the short duration of GRBs (from a few seconds to few minutes) the rapid pointing of detectors (like the MAGIC telescope) is crucial for their study.

STUDY OF THE EXTRAGALACTIC BACKGROUND. The diffuse Extragalactic Background Light (EBL) includes the infrared and optical photons emitted by stars and galaxies, the Cosmic Microwave Background (CMB) at 2.7K, and the radio background. This absorbs gamma rays that traverse it, limiting the distance from which gamma ray signals can reach us. The absorption of gamma ray photons is linked to the resonant photon-photon interaction about the invariant mass equal to twice the electron mass (about 1 MeV). In particular, gamma rays are absorbed in interactions with the low energy photons of the EBL: the Universe is therefore ever more opaque to gamma rays as their energy rises up to around 1000 TeV

(see graph on page 10), modifying the observed spectral energy distribution with respect to that emitted, to the point of completely screening the most distant gamma ray sources.
Given that direct measurement of the EBL is strongly affected by the corrections applied for emission from the solar system and Milky Way the study of the attenuation of gamma rays from the most energetic sources also provides information on the extragalactic medium traversed, contributing to the determination of its characteristics and constraining cosmological models.

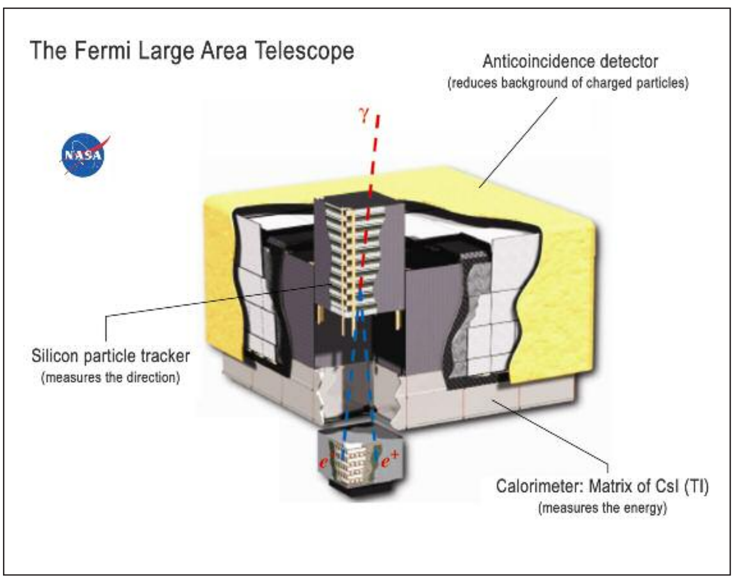


Diagram of the LAT (Large Area Telescope), the heart of the gamma ray detector mounted on the orbiting Fermi telescope. [NASA/DOE, Fermi LAT collaboration]

THE SEARCH FOR DARK MATTER. Another contribution of gamma ray astrophysics to fundamental physics is the possible detection of events related to dark matter (DM) annihilation. It is thought that this matter makes up approximately 90% of the total mass of the Universe: even though its gravitational effects are evident in many astronomical phenomena it has never been directly detected.
It is thought that DM annihilation produces characteristic gamma ray emission around regions of mass accumulation such as the Galactic centre, and gamma ray telescopes could detect these signals, providing confirmation or constraints on DM theories yet to be verified. In this sense the observations of the Cherenkov telescopes are complementary to those of the Large Hadron Collider (LHC) at CERN.

Methods and instruments for the detection of cosmic gamma rays

Luckily for us, the atmosphere shields us from cosmic gamma rays: on contact with air molecules the photons interact, giving rise to particle cascades called showers, in which the energy is dispersed to the point where the secondary particles (mainly electrons, positrons and photons) are absorbed, at altitudes of a few kilometers above sea level. To detect gamma rays it is therefore necessary to position the telescope beyond the atmosphere, or, if one wants to put the instrument on the ground, detect the particle showers that they produce on interaction with the atmosphere.

SATELLITE OBSERVATIONS. Placing gamma ray telescopes on satellites requires new and complex technology with respect to other instruments in orbit. In contrast to visible light, in fact, it is not possible to concentrate gamma ray photons with mirrors or lenses. In addition, gamma rays, being electrically neutral, can go through material without leaving a direct trace unless they are absorbed and transformed into charged particle pairs made up of a positive electron (positron) and a negative electron.
A gamma ray detector on a satellite works in the following manner: a tracker-converter converts the gamma rays into electron-positron pairs and records the

path taken by the pairs; thereafter, an electromagnetic calorimeter absorbs the charged particles, measuring the total energy deposited. The entire instrument is enclosed in a detector that measures the charge of the incident particle, determining whether it was a photon or a charged cosmic ray. The most recent telescope of this type is the Fermi GST (Gamma ray Space Telescope) put into orbit in June 2008. In particular, its main detector (LAT, Large Area Telescope) is made up of 16 modules (towers) of layers of silicon detectors, sandwiched between tungsten plates for the conversion of the gamma rays, followed by a cesium iodide crystal calorimeter to measure the energy deposited.

The entire detector is shielded by a covering of scintillatory material to eliminate the background signal due to charged cosmic rays, and weighs about three tons. The LAT, with a sensitive area of over 80 square metres of silicon, is the largest detector of its type ever put into space: its construction has been a great technological and scientific challenge, as well as a point of collaboration between research and industry, largely Italian. The Fermi GST is also equipped with a second detector (GBM, Gamma ray Burst Monitor) that takes the sensitivity range of the telescope from about 10 keV to beyond 300 GeV, a range never achieved by other detectors.

As a whole, the capabilities of Fermi GST exceed by two orders of magnitude those of previous instruments put into space to detect gamma ray point sources, both in terms of source localization and determination of the energy of the signal.

The rapid reduction of the cosmic gamma ray flux with increasing energy and the technical and economic limitations implicit in the construction of satellite borne instruments, renders them, however, inefficient for detection beyond 10 GeV or so. This has lead to the development of ground-based telescopes, based on different mechanisms to those in orbit.

GROUND-BASED OBSERVATIONS. As far as ground based telescopes are concerned, two indirect detection techniques have been developed to detect gamma rays, both based on the observation of the atmospheric particle showers produced by incident gamma rays (see the diagram on page 11).

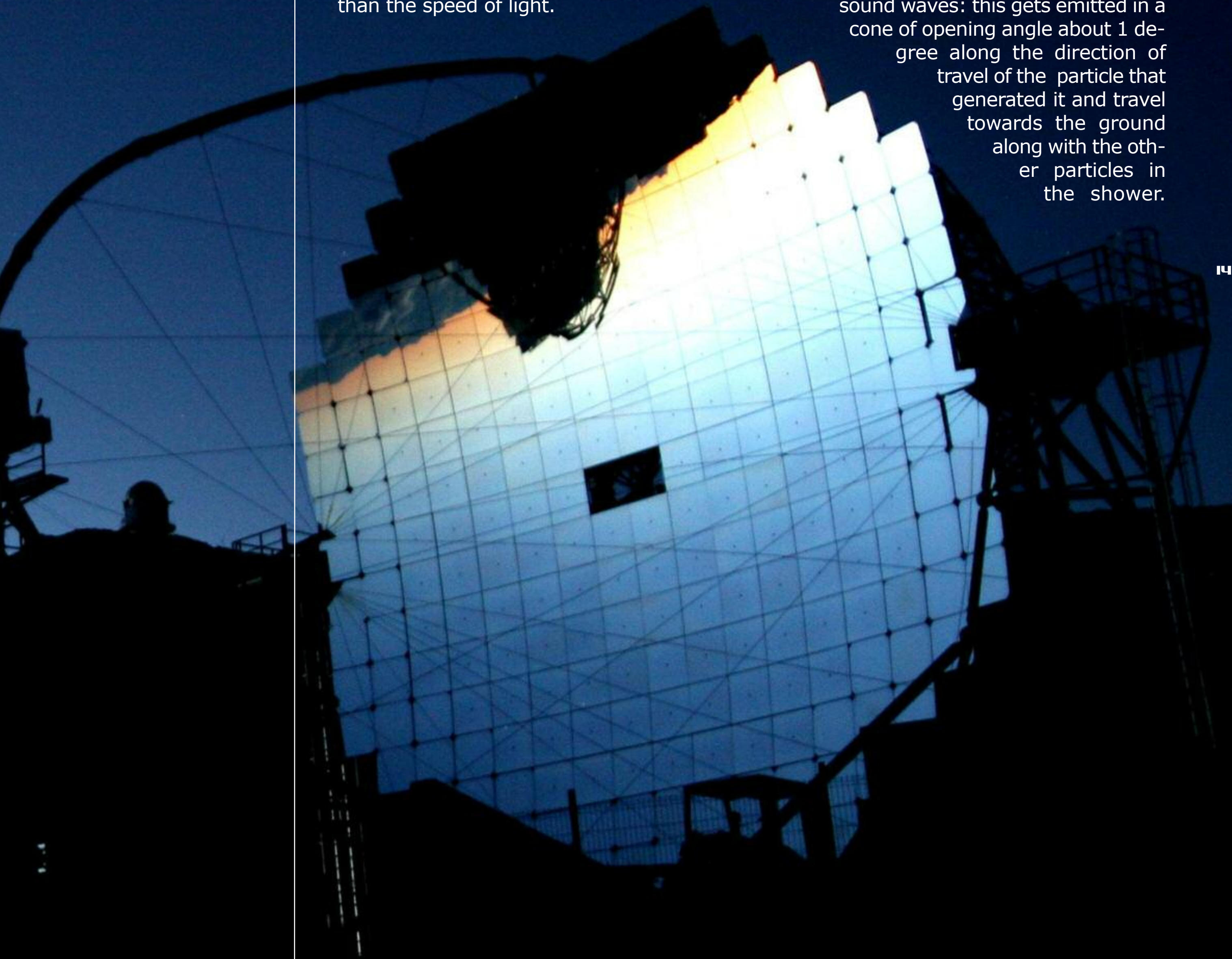
The first is the direct detection of the secondary electrons and positrons of extended showers (EAS, Extensive Air Shower); this utilizes charged particle detectors. The main telescopes currently operating that use this principle are the Italo-Chinese ARGO, situated in Tibet at over 4000 m above sea level, and the American MILAGRO in New Mexico. These telescopes have a large field of view (of order 40 degrees), but the need to catch the shower particles means that they need to be built at high altitudes: the maximum of a 1 TeV shower occurs at 8 km above sea level.

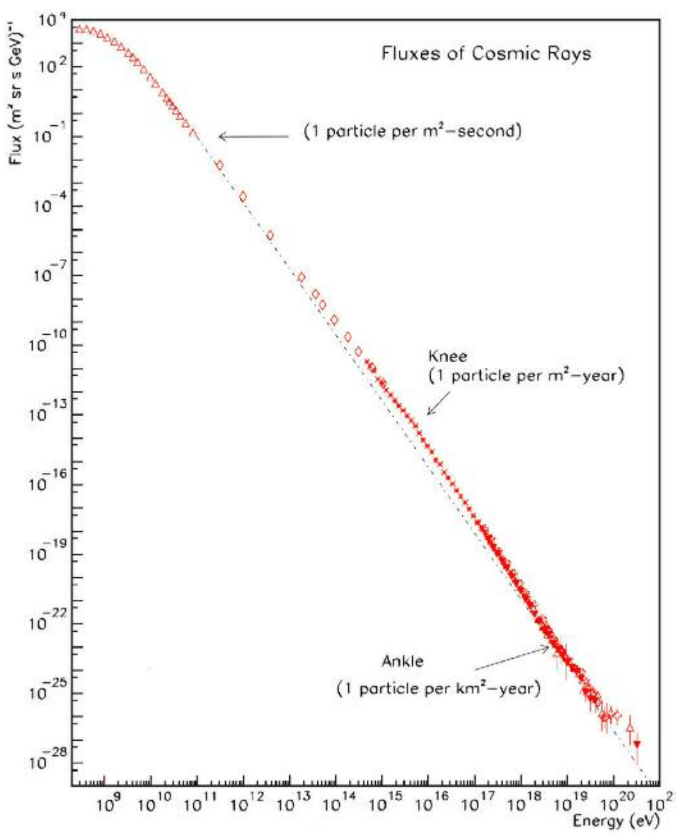
Even satisfying these prerequisites, the minimum detectable energies are around 400 GeV, so that with current sensitivities

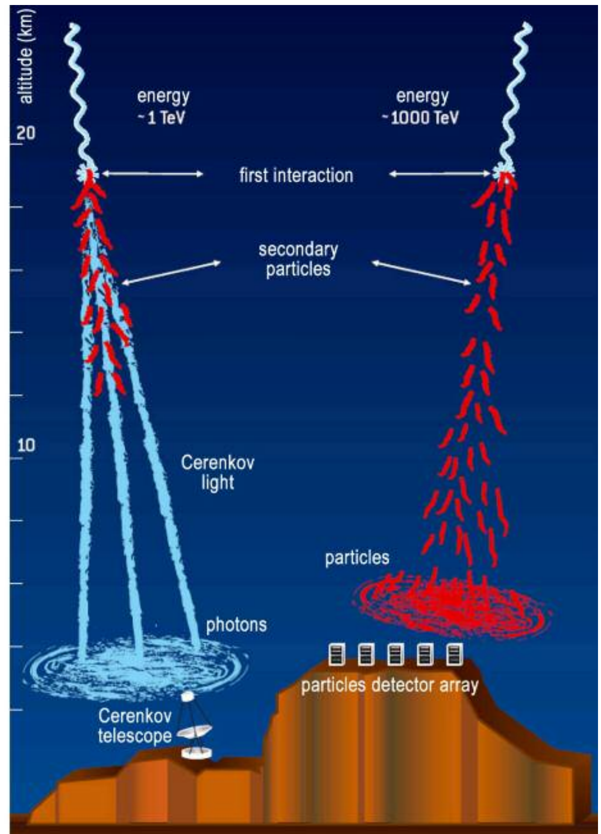
One of the elements of MAGIC-II in the foreground at dawn, La Palma. [MPI, Robert Wagner]

it is not possible to detect sources other than the four or five most intense.
The second is the Cherenkov technique, that takes advantage of the light emission caused by the charged particles in a shower; it is to this technique that the successes in gamma ray astrophysics in recent years are linked.
The secondary electrons and positrons produced by a cosmic ray incident on the atmosphere can travel faster than the speed of light.

(Remember that this does not violate the theory of Relativity because the speed of light in the atmosphere is c/n, where c is the speed of light in a vacuum and n is the refractive index of the air, greater than 1.) In this case, these particles emit a flash of light with a large component in the optical, so-called Cherenkov light (from the Russian physicist that discovered it, Nobel prize 1958). The Cherenkov flash is the optical analogue of the the sonic boom for sound waves: this gets emitted in a cone of opening angle about 1 degree along the direction of travel of the particle that generated it and travel towards the ground along with the other particles in the shower.







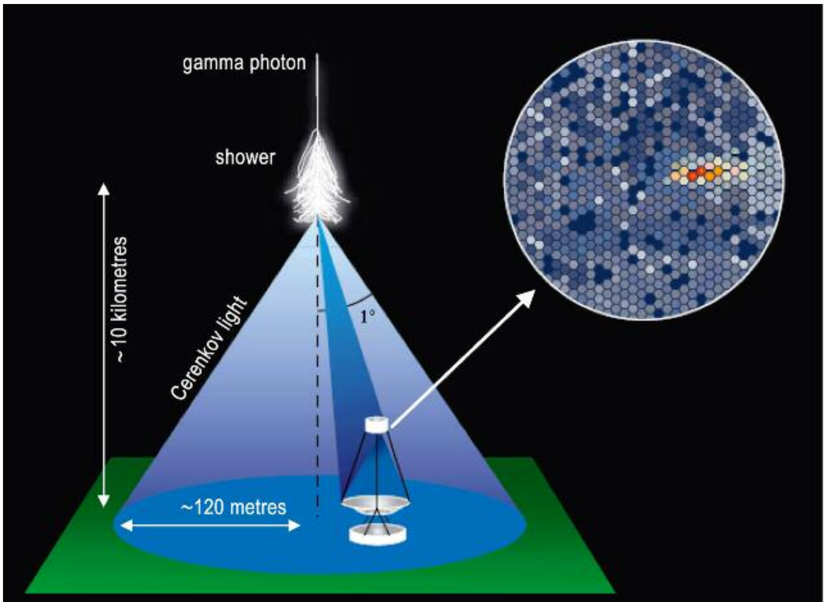
Cherenkov telescopes use large reflecting areas to reflect the weak Cerenkov light onto a matrix of photomultiplier sensors at the focal plane; the information from single photo-multipliers (pixels) is then digitized. In this way the gamma ray is photographed as if it were a kind of shooting star, the light from which lasts only 2-3 billionths of a second, or nanoseconds (ns); the image is recorded by a computer system and stored for data analysis. The different geometry of the electromagnetic (produced by gamma rays) and hadronic (produced by cosmic rays) showers allows a statistical classification of the kind of particle that produced the flash of light. The data analysis techniques used even today in Cherenkov telescopes were originally introduced by physicists at the Whipple telescope in Arizona, a 10 metre diameter telescope with which the first VHE gamma ray source was detected from the ground.

Three large Cherenkov detectors, structurally similar, are currently active: MAGIC and VERITAS in the northern hemisphere (in the Canaries and Arizona respectively), and H.E.S.S. (in Namibia) in the southern hemisphere. The detectors are managed by international collaborations of about a hundred people each. The Cherenkov telescopes have excellent angular resolution and sensitivity, but can only be used on the darkest, calmest nights, and then only to observe one source at a time (and only during that part of the year when the source is visible). They are not then suitable for carrying out continuous sky scans, or monitoring episodic emission.

A little history

VHE gamma ray astronomy has its origins in two distinct fields. At the start of the seventies, orbiting detectors extended

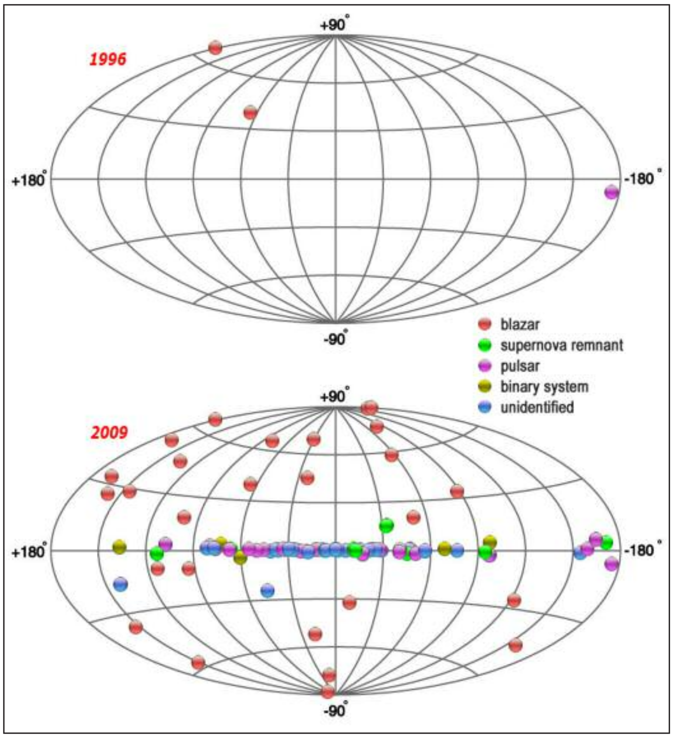
Left: the energy spectrum of cosmic rays. Right: the production of atmospheric showers: detection may be via the collection of Cherenkov light emitted or of the charged particles of the shower.



The Cherenkov light cone and its image on the focal plane of a IACT telescope. [From the MAGIC web site and adapted by Danilo Sossi]

X-ray astronomy towards higher energies, observing some sources emitting photons up to 100 MeV. The study of signals at energies over 1 TeV was developed by physicists with ground-based telescopes as a consequence of cosmic ray studies. Nonetheless, in this field, the application of new detection techniques did not result immediately in the discovery of new sources or phenomena: it was only after the development of new generation telescopes that ground-based studies started to yield results.
Even though the techniques of ground and space-based gamma ray astronomy differ, the observed physical phenomena overlap. In addition, in recent years, the observable energy bands from space and the ground have moved closer together.
Until the advent of particle accelerators (at the beginning of the fifties) high energy experiments were carried out using cosmic rays. Many elementary particles, like the muons, the pi and K mesons (pions and kaons) were discovered in this way. The physicists naturally questioned the origin of cosmic rays and the mechanisms that could accelerate them to such high energies.
Even when the use of accelerators in nuclear physics became usual, research with cosmic rays continued because these could provide particles with energies unattainable in the laboratory.

The discovery of various astrophysical X-ray sources and the possibility that they might also produce high energy gamma rays guided the first steps in gamma ray astronomy. After a few dubious observations in the eighties, in 1989 the Whipple telescope detected the Crab nebula, the first confirmed source of VHE gamma rays.
In the following fifteen years new Cherenkov detectors were built for gamma rays, like CAT in the Pyrenees, CANGAROO in Australia and HEGRA on La Palma in the Canaries.
Despite the great experimental effort, at the end of the twentieth century the number of VHE gamma ray sources detected from the ground was very small, and most of these were suspect observations, with the sole exceptions of the Crab nebula and the AGN Markarian 501 and Markarian 421, from which the existence of extra-Galactic VHE gamma ray sources was deduced.
Towards the end of the nineties the concept of stereoscopic detectors started to affirm itself. These could simultaneously observe the signal from two different directions, improving the sensitivity and spatial precision. HEGRA on La Palma first demonstrated the validity of the stereoscopic technique, later exploited to the full with the construction of H.E.S.S. in Namibia, a system with four Imaging Atmospheric Cherenkov Telescopes (IACT), each 13 meters in diameter, with a 5 degree field of view, finished in 2003. H.E.S.S. is sensitive to gamma ray photons with energies from 100 GeV to 100 TeV, with an angular resolution of 0.05 degrees.
In 2004 the MAGIC telescope began service, that, with its 17 metre mirror, is the largest gamma ray telescope in the world (the largest optical reflector). Italy contributes about one third to the construction and operation of MAGIC, sharing the project with an international consortium in which Spain and Germany are the other two main partners. In particular, Italian physicists and astrophysicists from INFN and INAF and the University of Padua,



A comparison between the VHE gamma ray sources known in 1996 and the current situation.

Siena and Udine are responsible for the optics, trigger electronics and data acquisition of the telescope. MAGIC was joined in 2009 by a twin telescope, with which it now makes up the stereoscopic system MAGIC-II, that further improves the performance with respect to a single detector.
As far as space observations are concerned, before the launch of Fermi GST the most important gamma ray telescope was EGRET, a detector that operated from 1991 to 2000 on the CGRO (Compton Gamma Ray Observatory) satellite, sensitive to photons in the energy range 20 MeV to 30 GeV. In this spectral region, really between X and VHE gamma rays, EGRET produced a catalogue of a few hundred sources, many of which still unidentified, used to this day as a reference for gamma ray observations.

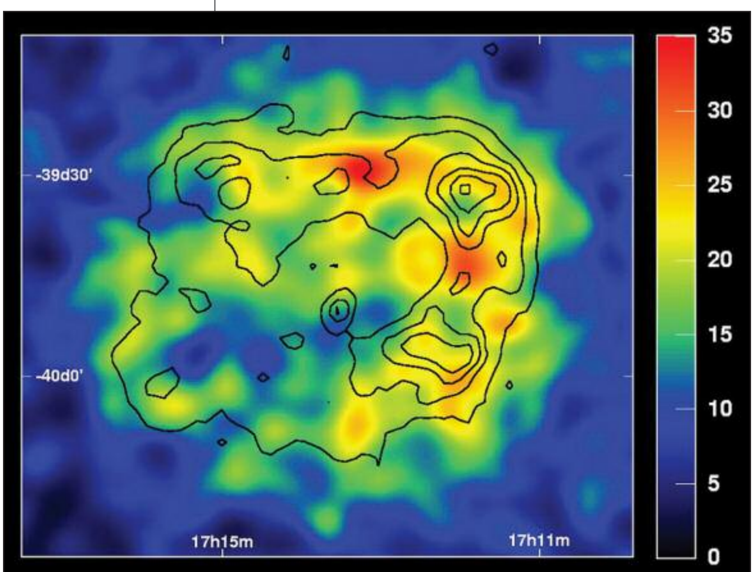
Some results

The number of VHE gamma ray sources is now around 100, above all thanks to the H.E.S.S. and MAGIC telescopes. One of the first successes of the H.E.S.S collaboration was the detection of structure in the VHE gamma ray emission of young supernova remnants, especially via observations of RXJ1713.7-3946.
This results supports the opinion that the generation of Galactic cosmic rays is linked to supernova remnants. H.E.S.S. further found that many young pulsars are surrounded by extended regions from which extremely energetic gamma rays are emitted. The morphology of these regions depends on the energy, in the sense that the region gets smaller as the energy of the emitted gamma rays rises.
If a cosmological particle accelerator is part of a binary system, the interactions of the accelerated particles with the system can be periodic.
Periodic gamma ray emission from this kind of source was observed for the first time in 2006 by MAGIC in the source LSI 61+303 (see image on page 20) and subsequently confirmed by H.E.S.S. and VERITAS. These sources work like "TeV clocks" with periods corresponding to their orbital periods, that are generally of the order of a few days.

FURTHER READING

- MAGIC web site http://wwwmagic.mppmu.mpg.de
- Fermi GST web site http://fermi.gsfc.nasa.gov
- VERITAS web site http://veritas.sao.arizona.edu
- H.E.S.S. web site http://www.mpi-hd.mpg.de/hfm/HESS
- TeV Gamma-rays sources web site http://tevcat.uchicago.edu
- CTA web site http://www.cta-observatory.org

Gamma ray emission from well located sources identify the locations of the cosmic particle accelerators, but it is also possible that there exists a diffuse component of gamma radiation produced as the relativistic particles that recede from their sites of primary production interact with the surrounding Giant Molecular Clouds (GMCs). Observations of the Galactic centre by H.E.S.S. and confirmed by MAGIC show that VHE gamma ray emission does in fact correlate with various GMCs within a 200 pc region around the centre of our Galaxy (see image on next page). In the same region, H.E.S.S. has also detected the source Sgr A*, identified as a Super-Massive Black Hole (SMBH) at the centre of the Galaxy and other SNR, discovered and confirmed during the same observational campaign.



A VHE gamma ray image of the supernova remnant RXJ1713.7-3946, obtained with H.E.S.S. with two telescopes in 2003. The contours correspond to the X-ray intensity in the 1-3 keV band as measured by ASCA.

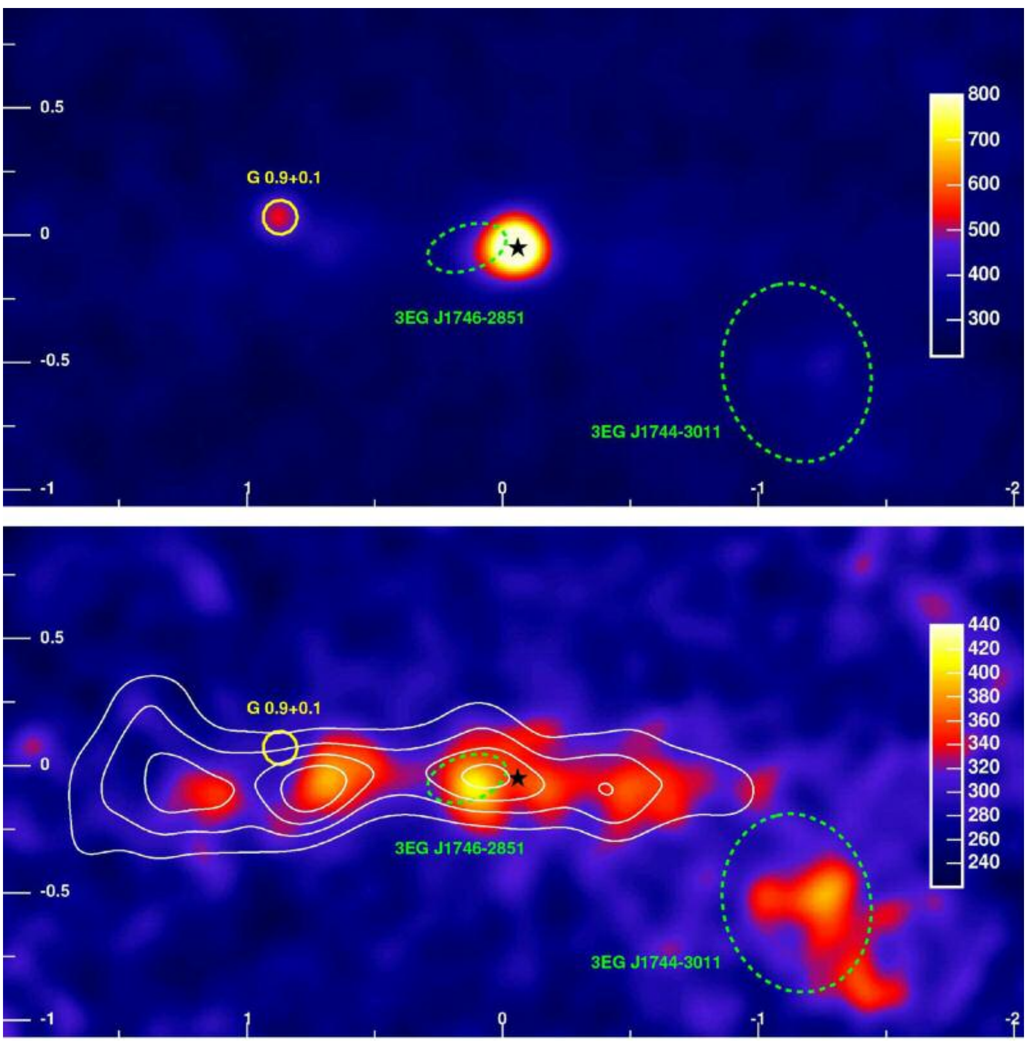
VHE gamma ray emission from supermassive black holes (that is with masses between 1 million and 1 billion solar masses) has been confirmed in other galaxies, with the detection of VHE gamma ray emission also from M87, already known to be a giant radio galaxy, and the discovery of other AGN. The variability of the signal from M87, measured on timescales of days, and studied jointly by MAGIC, H.E.S.S. and VERITAS in 2008, implies a very compact gamma ray source.

The gamma ray horizon of the Universe, or rather the gamma ray attenuation length at a certain energy and optical depth, is determined by the interaction of gamma ray photons with the extragalactic background light (EBL). At the very highest energies this is limited to a few hundred megaparsecs by the interaction with the cosmic microwave background. For this reason, the extragalactic VHE gamma ray sources known so far are all relatively nearby AGN with relativistic jets (that is with velocities close the that of light) oriented close to the line of sight (so-called blazars). It is interesting to note the the VHE gamma ray signal detected by MAGIC from distant blazars, especially from the source 3C279, at a distance of 5 billion light years, has resulted in a re-evaluation of previously commonly accepted predictions about the transparency of the Universe to VHE gamma ray photons. 18

In the first months of operation, the Fermi GST telescope has already produced a much more detailed picture of the gamma ray sky and made new discoveries that will provide important information to VHE gamma ray telescopes as to where to focus their searches.

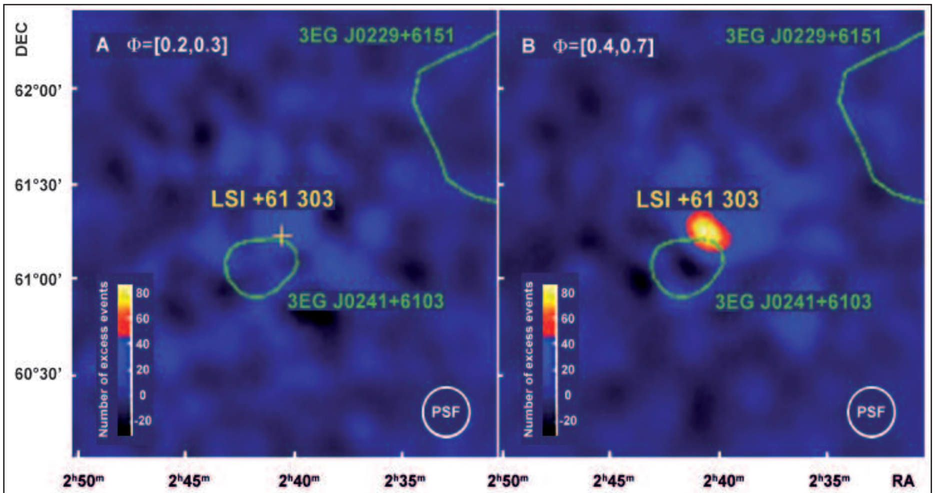
The future

The next ten years will be like a new season for gamma ray astrophysics, that is becoming the new frontier of observational astronomy and fundamental particle physics. As well as the launch of the Fermi GST satellite and the commencement of full operation by the stereoscopic system MAGIC-II, a new 28 metre telescope is nearing completion in Namibia that will be the largest in the world and will integrate the current stereoscopic instrument H.E.S.S., allowing for greater sensitivity. Nevertheless, even with the new configuration of H.E.S.S. and the work of MAGIC-II, the detailed study of spectra and morphology of sources in the very interesting energetic region of tens of TeV, where one expects the energy cut-off for gamma ray emission, will continue to be limited by statistics. To surpass this limit it will be necessary to use coordinated observations with telescope systems that cover large areas of sky. At low energies, where the Universe is transparent to gamma rays and it is therefore possible to study in depth, sensitivities could be improved by the use of large telescopes with gamma ray sources on short timescales, in synergy with the observations of the Fermi space telescope, that will provide the alarm signals for transient phenomena to be subsequently observed by ground-based Cherenkov telescopes. The sensitivity of the CTA should be sufficient to observe, for example, pulsars at the highest energies.



An image of the 200 pc region of the Galactic centre obtained by H.E.S.S. in 2004. Top: map of the counts before background subtraction. Bottom: map of the same region after subtraction of the excess emission associated with Sgr A* (marked with a black star) and G0.9+0.1 (yellow circle). EGRET sources are indicated with green dotted lines.

high sensitivity light detectors. To answer these needs, in the decade from 2010, the building of a large and coordinated system of Cherenkov telescopes is planned, called the CTA (Cherenkov Telescope Array).
CTA will be crucial in the study of variable CTA will be open to the international astrophysical community and will provide an even deeper understanding of the non-thermal Universe at high energies. In particular, the current project predicts an increase of a factor of 10 in sensitivity in



A VHE gamma ray image of the binary system LSI +61 303 obtained by MAGIC in 2006.

the 10 GeV to 100 TeV energy domain. The observatory will consist of two systems of telescopes of different dimensions, one per hemisphere, completely robotized and conceived with the accumulated experience from current observations. The southern hemisphere system will cover the energy range from about 10 GeV to 100 TeV and carry out an in depth study of Galactic sources, in particular in the central regions (but also for extragalactic observations), while the northern hemisphere system, designed for detection of lower energy signals (from about 10 GeV to 1 TeV) will be dedicated mainly to extragalactic sources. Extrapolating current results, CTA should result in the observation of a thousand or so VHE gamma ray sources.

Finally, to get over the limit of Cherenkov detectors, that have a limited field of view, it will be important to develop technologies that allow the coverage of large fields with a sensitivity of order one hundredth the flux observed from the Crab nebula, to allow a scan of the sky and sensitivity to transient signals. The most realistically applicable technique seems to be that of Cherenkov detectors immersed in large water-filled swimming pools.

These instruments, awaited between 2010 and 2020, will constitute a bridge towards astrophysical observations with neutrino telescopes, that will allow the study of even more distant sources, as long as the financial resources can be found to to support a system of neutrino telescopes with volumes of order 1 cubic kilometre. Such telescopes should be situated in the depths of the sea and in the Antarctic ice. Once again the project will be the result of collaboration between astronomy and fundamental physics, two fields that are joining forces in the science of the 21st century.

Alessandro De Angelis, professor at the University of Udine and Lisbon Polytechnic, studied and began his research in Padua. From 1993 to 1999 he was at CERN, Geneva. At Udine since 2000 he moved towards astrophysics, contributing with his group, to the development of the Fermi and MAGIC space telescopes, of which he is the Italian national vice-president.

Francesco de Sabata, graduated from Padua with a thesis on particle physics at CERN, Geneva teaches at the "G. Galilei" science institute in Verona and has been involved for years in the communication of physics. He recently submitted his doctoral thesis at the University of Udine, where he collaborates with the MAGIC group.

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