Status of MAGIC and the CTA project

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Abstract The MAGIC telescope collaboration has built the worlds largest single dish Imaging Atmospheric Cherenkov Telescope, which is operative in the ORM observatory at the Island of La Palma since 2004. It covers the energy range from around 50-60 GeV up to several TeV. A second MAGIC telescope is presently under construction at the same site, its completion is foreseen for September 2008. We show the present and expected performance of MAGIC and the status of the project. At the same time MAGIC, with most of the European Very High Energy (VHE) Astrophysics Community, is preparing the new Cherenkov Telescope Array (CTA) project. It will be the first global VHE open observatory, with vastly improved sensitivity over existing telescopes. We sketch its design and outline the physics goals pursued.

1 Very High Energy Astronomy

The realm of Very High Energy Astronomy can be approximately defined by the region of photon energies above 10 GeV, $10^{10} eV$. At these energies the radiation and secondary particles produced by photon interactions in the atmosphere can be detected from ground level, opening one of the few existent windows for Astronomy from Earth, the latest to be opened up to now.

Primary photon interactions in the atmosphere and the re-interaction of the secondary particles thus created feed the development of Extensive Air Showers (EAs) of electromagnetic origin. They are composed of electrons, positrons and gamma rays moving towards the ground at relativistic speeds, created through bremsstrahlung and pair creation. The charged particles in the showers emit Cherenkov radiation in the atmosphere when their speed surpasses that of light in the medium. Cherenkov light from Extensive Air Showers illuminates a circle of around 120 me-

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ters radius, making possible the detection of the primary particles at big distances from their projected impact point. Light pulses created by EAS last a few nanoseconds.

A similar process to that followed by photons, but based in nuclear interactions, affects the much more numerous cosmic rays that fall on Earth, creating a huge background of Extensive Air showers of hadronic origin. These particles are not useful for Astronomy due to the deflection of cosmic rays (which are charged) in the magnetic fields they find in their way, which spoils the directional information they contain.

Imaging Atmospheric Cherenkov Telescopes (IACTs) concentrate the light produced by EAS in cameras made of fast photo-multipliers. Images of EAS are used to separate those of hadronic origin from the ones created by photons and to estimate the energy and direction of the primary particle. Their strength lies in the high effective detection areas they reach more than $10^5 m^2$, while their main drawback is the high background they suffer due to charged cosmic rays. It is important to stress that IACT do not observe the primary photons, but at the EAS they produce. Therefore any improvement in the EAS detection or reconstruction improves the performance of the telescope.

The first high significance detection of a source using the atmospheric Cherenkov technique was achieved in 1989 [1]. Since then the number of known VHE sources has grown to more than 70 at the end of 2007, a good review of the field can be found in [2].

2 The MAGIC Telescope

The MAGIC telescope is presently the worlds largest single dish Imaging Atmospheric Cherenkov Telescope. It consists of a dish of 17 meters diameter, covered with tessellated mirrors which concentrate the light on a camera of 577 fast photomultipliers (PMTs). It has been operating in the ORM observatory at the Island of La Palma since 2004. In standard trigger mode it reaches an energy threshold of around 50-60 GeV and can detect a flux of 1.5% of the Crab flux in 50 hours. MAGIC has produced important scientific results discovering and measuring several galactic and extragalactic sources, a summary of both aspects is presented elsewhere in these proceedings in [3] and [4].

Technological improvement, as a mean to boost scientific output, has always been one of the lines guiding the MAGIC collaboration since the first design of the instrument. The telescope is pioneer in several technologies, as the lightweight mount or the optical transport of the signal from the camera to the digitisation room. Two hardware modifications introduced lately in the system have led to sensible improvements in the sensitivity and energy threshold of the telescope.

2.1 Signal timing information

One of the features introduced recently and which is now yielding results is the use of fast Flash ADC digitisers. 2 Gigasamples/s Flash ADCs are used to digitise the signal of the PMTs since late spring 2006. They allow for a very precise determination of the shape of the Cherenkov signals, making possible to measure accurately the time of arrival of the light front at each PMT. This information adds a third dimension to the image, time.

Timing information is used in two ways in the analysis in the images. First at the level of *image cleaning*, where a selection is made of the pixels belonging to the image, it allows to discriminate better noise pixels. Only pixels whose time signal is coincident within a narrow time window with that of their neighbours are selected. In second place, using the time information, the software extracts variables which define the time development of the image in the camera. The most important one is the time gradient along the image. Images of gamma rays are characterised, among other things, because they point to the region of the camera where the source is located. Still some images due to cosmic rays can also be aligned along the direction joining them to the source position. As the reason of this alignment is just chance, for some of them the part of the image closest to the source will correspond to the beginning of the shower (head) and for some to the end (tail). For gamma images the head is always closest to source position reflecting that they are really emitted by the source. Images being approximately elliptical, head and tail are difficult to recognise geometrically. This effect is called the head-tail ambiguity and solving it can lead to close to a 50% background reduction. It turns out that the time gradient can solve the ambiguity in many cases. Its introduction among the variables used for background discrimination if MAGIC has lead to an increase in sensitivity of the order of 20%. More details can be found in reference [5].

2.2 Sum Trigger

One of the key ingredients of the Atmospheric Cherenkov technique is the need to trigger the acquisition system. EAS occur following the arrival of the primary particles, at very well defined moments, and Cherenkov pulses are very fast, therefore their light is concentrated in fast (nanosecond) flashes over the random fluctuations of the Light of Night Sky (LONS). The trigger system has to decide when one of these flashes has occurred in order to record the event, while it avoids to record random coincidences of pixels whose signal is due to the LONS. This demanding task is left to dedicated trigger electronics. Up to now the most common trigger criteria has been to look for sets of neighbouring pixels giving signals coincident within a narrow temporal window. In this scheme the signal of each of the considered pixels must be over a predefined threshold and the geometry imposed is typically that of close packed neighbours. This technique is very successful suppressing background, but it is not able to detect images where the light is shared among several nearby pixels, each of them relatively close to the levels produced by LONS.

The problem was identified several years ago and a proposal developed among former members of the MAGIC Collaboration [6]. It consist of predefining zones of the camera where the signal is more likely to be found due to the geometry of EAS light emission (a ring of patches around the camera center) and summing all the light collected in each of them. The Data Acquisition system is triggered when the sum surpasses a predefined threshold. Later on the proposal was refined to suppress the effect of big signals in single PMTs, often due to after-pulsing, which could drive up the sum without the presence of real events. At the end of 2007 an electronic setup to implement this system was installed at La Palma and dubbed the *Sum Trigger*

Data taking with the sum trigger more than triples the trigger rate of the telescope, about 600 events are recorded per second, compared to the usual 150-200. Conversely, the energy threshold achieved goes down from the previous value of around 50-60 GeV to close to 25 GeV. The first tests were carried out with observations of the Crab Nebula and pulsar. Our goal was to search for the spectral cutoff in the gamma ray emission from the pulsar. Using the Sum trigger data a periodic signal was clearly seen at energies of 25 GeV in a search which used the pulsar ephemeris. It is the first time that the periodic signal from a pulsar is detected at these energies and becomes a powerful test of present pulsar models. An *Astronomers telegram* [7] was issued to announce the discovery and a publication is in preparation.

A low energy threshold as the one provided by the large mirror area of MAGIC and the use of the sum trigger strategy will undoubtedly benefit many physics analysis. Further pulsar observations, the study of the spectra of distant blazars and more complete characterisation of Galactic sources are some of them. Still the goal is not complete, low energy events are not lost in the trigger any more, but it is left to prove how good spectral information can be extracted from them and what is the telescope sensitivity at these energies. This is currently one of the hottest issues for IACTs.

2.3 MAGIC II

Extensive Air Showers are extended objects, which develop some kilometres above the Telescope. Observations with only one telescope do not provide a complete view of them. In particular the distance from the shower to the telescope and its arrival angle are not fully determined. Stereoscopic imaging using at least two telescopes eliminates some of this ambiguity, as it does in the human visual system. The HEGRA CT-system did herald this technique showing its superiority in what regards sensitivity and energy resolution [8].

The MAGIC collaboration is building a second telescope in the ORM to be able to perform stereoscopic observations. In most aspects it is a clone of the existing one, sharing the same mirror diameter, optics, a similar mount, and the same version of the data acquisition system. Keeping the same size the camera will be upgraded to use finer pixels, all of them of equal diameter, the total number of pixels will we above one thousand. Pixels are built as high efficiency PMT tubes grouped in clusters of seven units, there are plans to replace part of this clusters by new photonsesors as HPDs. MAGIC II is Located at 80 meters of the actual MAGIC. Both telescopes will be able to operate individually or in coincidence. In this mode images are only recorded when both instruments are triggered.

Monte Carlo simulations show that the sensitivity of both detectors operating jointly will be around 40% better that the one currently achieved. The first light for MAGIC II is foreseen for the end of 2008.

Fig. 1 Photograph the two telescopes at the MAGIC site. Credit: R. Wagner.

3 The Cherenkov Telescope Array

The Cherenkov technique is quickly becoming adult. More than 70 sources are already known, a number which is presently comparable to the approximately 300 known sources at the energies of gamma-ray satellites. If a curve representing the number of sources found versus the discovery year is drawn, its shape is very similar to the same plot for different established branches of Astronomy as X or gamma-rays, to so-called *Kifune plot* in recognition to T. Kifune, see for example the recent review of [9]. A growing feeling in the Cherenkov community asks for the building of the first open observatories based in this technique, which would integrate into the main body of Astrophysics. Inside Europe the movement has crystallised in the CTA project which we briefly describe.

The aim of the CTA project is to build an array of Cherenkov Telescopes which covers a wide spectrum of energies, from 10 GeV to 100 TeV, with a sensitivity better than 1% of the Crab flux in 50 hours, up to at least 10 TeV. Its design is based in a large array containing around 100 telescopes of possibly different sizes with different separation among telescopes dependent on their size. A core of large diameter, closely packed telescopes would cover the low energies, while smaller telescopes placed further away would provide the effective area needed to access the highest energies where fluxes are very small. To cover the whole sky two observatories would be built: one in the North and one in the South Hemispheres.

Even though the CTA design project is still not finished, first studies indicate that it can be built with existing technologies at a fraction of the price of a space gamma-ray observatory. Moreover its operation would provide access to a window of the electromagnetic spectrum which is not accessible by any other mean. More information can be found in [10].

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