THE MAGIC TELESCOPE FOR GAMMA-RAY ASTROPHYSICS ABOVE 10-30 GEV

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An overview of the status of the 17 m diameter MAGIC telescope project will be given. During phase I, the telescope will reach a threshold of 30 GeV and a sensitivity of 6.0 10^{-11} cm^{-2} s^{-1}. First light is foreseen in mid 2001 and first observations in 2002. The expected capabilities of the telescope for high energy astrophysics and fundamental physics will be reviewed.

1 Introduction

Imaging Air Cherenkov Telescopes (IACTs) have established in recent years the existence of a few galactic and extragalactic sources above 300 GeV[1] (the so-called Very High Energy gamma ray range). New technical developments currently allow to reduce the threshold of this kind of telescopes to energies around 30 GeV, thus overlapping those typical of γ-ray satellites like EGRET or the forthcoming GLAST and AGILE. Here we describe a new generation 17 m diameter IACT dubbed MAGIC[2,3] (Major Atmospheric Gamma Imaging Telescope) with a threshold of 30 GeV in its first development phase (phase I) and around 10 GeV in phase II.

2 The general design

MAGIC is a second generation IACT with a number of improvements and innovative elements to reduce the energy threshold and the different backgrounds.

2.1 The reflector

Thanks to its 17 m diameter disk, MAGIC will collect three times more light than a typical first generation 10 m diameter IACT. The shape of the reflector is parabolic, hence isochronous: this improves the light background reduction. A carbon fiber mount, weighing less than 10 tons, is instrumental in rapid repositioning the telescope in the search for GRBs. This material makes the disk also hard to deform (sagging $<$ 3mm). In addition, an active mirror control system[5] provides maximum shape stability. The reflector is tessellated,

with 50 cm × 50 cm all-alluminium, diamond-turned, quartz-coated, mirror elements[6] of 85% reflectivity in the 300-650 nm wavelength region.

2.2 The camera

New compact (2.5 cm, 0.1° diameter) photomultipliers[4] with approximately 20% quantum efficiency (QE) in the 300-500 nm range and minimal time dispersion shall be used in phase I. In order to minimize the impact of DC like night sky background (NSB) and moonlight the dynodes were reduced to six and operated with a total gain of only 15000. The camera of 4° diameter is composed of 600 PMTs with coarser sampling in the outer region.

In phase II the camera will be provided with Hybrid Photo Detectors of $<QE> \sim 40\%$ in an wider wavelength range of 330-650 nm. Extending the light detection range to red wavelengths is particularly useful for high zenith angle observations where most of the short wavelength photons are absorbed. Finally, in its phase III, MAGIC aims at equipping the camera with Avalanche Photo Diodes, provided with an extremely high $<QE> \sim 80\%$ (330-680 nm).

2.3 The readout

Cherenkov light pulses are typically very short (in the order of 1-2 ns). However as the pulse shape contains important physical information and can be used for NSB and hadron reduction, it is crucial to register it faithfully. MAGIC endeavors to do so by applying a number of improvements. To begin with the signal is transported over optical fiber[7]. Apart from negligibly dispersing the pulse, optical transport reduces cable weight and enables optical decoupling and noise immunity.

In addition, the pulse is digitized using very fast (300 MHz, and 1 GHz in a second phase) 8 bit FlashADCs[8]. The maximum sustained event rate will be 1 kHz (with zero deadtime). Dual ranging of the analog signals at the FADC inputs extends the range of the FADCs to about 70-80 dB.

2.4 Sensitivity and performance of MAGIC phase I

The telescope will have a threshold of about 30 GeV (peak of the differential flux) for phase I. The gamma-ray sensitivity ranges from $\sim 10^{-10}$ at around 10 GeV (set by the cosmic electron background[9]) down to $8 \cdot 10^{-12}$ cm^{-2} s^{-1} at 1 TeV (determined by the cosmic hadron background). The collection area flattens at around 10^5 m^2 above 100 GeV. Close to the threshold the energy resolution will be around 30% and improve to around 10% at 1 TeV[10].

In the presence of moonlight, the threshold has to be increased to 60-100 GeV (half-moon, $> 30^{\circ}$ away). Operation under moonlight significantly increases the potential of the telescope to detect GRBs and follow up other transient sources.

MAGIC is under construction in the Roque de los Muchachos Observatory at La Palma (Canary Islands, Spain). First light is expected for summer 2001 and first physics results may be available on 2002.

3 Prospects for Astrophysics and Fundamental Physics

Here are briefly described some of the astrophysics, cosmology and fundamental physics questions MAGIC is expected to address.

3.1 Active Galactic Nuclei

AGNs exhibit their highest variability in X-rays and γ-rays. Multiwavelength campaigns including IACTs have already proved central to understand the physics of the source, specially because GeV γ-rays probably come from very close to the supermassive black hole.

3.2 The cosmological γ-ray horizon

High energy γ-rays are absorbed in the infrared background ($\gamma_{VHE} + \gamma_{IR} \rightarrow e^- + e^+$). This means that there is a maximum observable redshift, $z_{hor}(E)$, which is usually referred to as γ-ray horizon. Only AGNs below this redshift are observable. Due to its extremely low energy threshold, MAGIC will see the bulk of the cosmological AGNs. A large number of detections shall allow to characterize the AGN population as a function of distance and determine if γ-rays are indeed only externally absorbed or there is some internal absorption. If a large enough number of AGNs are detected, a measure of the infrared background may also be attempted.

3.3 The diffuse extragalactic γ-ray background

EGRET has measured the γ-ray background up to 100 GeV. The general opinion is that it is due to AGNs. But it has been proved[12] that AGNs only contribute 25% of the background above 100 MeV. The remaining background may come from FSRQs and BL Lacs[13]. In this case MAGIC may detect more than 100 more sources than EGRET thanks to its higher sensitivity. The background could alternatively arise from topological defects (which may in turn be also the origin of the cosmic rays above 10^{19} eV).

3.4 Pulsars

Three pulsars are among the strongest EGRET sources. Observations at energies above 10 GeV may help clarify the mechanisms producing the γ-rays. The outer gap or polar cap models differ in the maximum energy attainable for the pulse emission. In addition, and owing to its improved angular resolution, MAGIC can clarify if many of the $\sim$ 100 EGRET unidentified sources are associated to pulsars. A special pulsar trigger has been developed to attain a low energy threshold around 10 GeV based on pulsar timing analysis.

3.5 The origin of cosmic rays: shell-type SNRs

It is widely believed that CRs are produced in SNR blast shocks. X-rays and γ-rays are essential probes, since, unlike CRs, they point to the source. There is good evidence of electron acceleration. Synchrotron X-rays and inverse Compton γ_{VHE}'s produced by electrons have been observed in SN-1006. However no firm evidence has been found for hadron acceleration. Observation of γ-rays coming from dense clouds serving as targets for cosmic rays accelerated in the shell (through $p, Fe + N \rightarrow \pi's$ and $\pi^0 \rightarrow \gamma\gamma$) would provide an unambiguous proof of the presence of hadrons in the shell.

3.6 Gamma Ray Bursts

The mechanism producing GRBs have been not resolved yet. MAGIC counts on its huge collection area to detect fast transients with high statistics. The telescope has actually been optimized for GRB searches by ways of its fast repositioning capability. Its potential for GRB detection is illustrated by the very high rates which would have been expected for some typical GRBs. For example, GRB-910503, with a maximum measured energy of 10 GeV and lasting for 84 s, would have produced a rate of $6{\cdot}10^4$ Hz in MAGIC, whilst GRB-930131, reaching at least 1.2 GeV and lasting for 100 s, would have produced around $2{\cdot}10^4$ Hz. Such strong signals allow us to study the details of the light curve and further characterize the source structure.

3.7 Invariance of the speed of light

Several quantum gravity models predict an energy dispersion of the speed of light[14]. This results in a arrival time difference of high energy photons as respect to low energy ones which depends on particle energy and quantum gravity energy scale. By detecting sub-second time differences between e.g. keV and 30-300 GeV photons for z$\sim$0.1-1, energy scales in the order of 10^{18}-

10^{20} GeV are well measurable. A similar analysis may also be applied to pulsar pulsations.

3.8 Cold dark matter

One of the most plausible candidates for dark matter is the neutralino (χ). The particle physics lower limit for m_χ is around 30-50 GeV and further evidence suggests that its mass should be below 1 TeV. An annihilation line ($\chi\chi \to \gamma\gamma$) may thus be expected from the center of our Galaxy[15] in the most sensitive range of the telescope.

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