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GAW (Gamma Air Watch): A new type of imaging telescope.

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Abstract. The Cherenkov imaging technique is the most effective tool to detect and observe gamma-ray cosmic emission above 100 GeV. We propose an imaging Cherenkov telescope, GAW (Gamma Air Watch), designed for observations of very high-energy gamma-ray sources. GAW will be equipped with a 3 meter Fresnel lens light collector and an f/# ~1.9, and with an array of about 300 multi-anode photomultipliers at the focal plane. The pixel size will be ~2 arcmin wide, for a total field of view of ~5.2°. GAW respect to the next planned imaging Cherenkov telescopes (CANGAROO III, HESS, MAGIC, VERITAS) follows a different technique approach being different for what concerns both the optical system and the smaller pixel size. Thanks to the smaller pixel size, the photomultipliers will operate in single photoelectron count mode (instead of charge integration) lowering the photoelectron threshold needed for the cosmic-ray background rejection technique: this consequently allows a low energy threshold in spite of the relatively small dimension of the GAW optics system.

1 Introduction

At energies beyond 0.03 TeV the emission from galactic and extragalactic sources is too much weak to be detected by instruments on board satellites because of their limited effective area. Only on-ground experiments could have enough geometrical area to observe the very low intensity and the very soft spectra emitted in this extreme energy band.

Since the atmosphere is not transparent at these wavelengths, on-ground experiments can indirectly detect the gamma-ray sources. This can be performed either by detecting the shower of secondary particles produced by the interaction of gamma-ray entering into the high atmosphere, or by detecting the Cherenkov light emitted by the relativistic charged particles along with their path down through the atmosphere.

Imaging Cherenkov telescopes, thanks to their great collection area (~10^5 m^2) and especially to their very high efficiency in rejecting the cosmic ray background, have turned out to be the most sensitive instruments for the observation of astrophysical sources above 100 GeV.

Being the rate of cosmic-ray events in the field of view of a Cherenkov telescope about 400 times higher than the rate of the Crab Nebula, hadron initiated showers represent a strong source of background. Nevertheless, the Cherenkov telescopes can reject a large percentage of the background, taking advantage of significant different properties between showers initiated by a gamma ray or by a hadron. Secondary particles produced in the first few interactions of a shower initiated by a hadron have much higher transverse momentum than their counterparts in a shower originated by a gamma-ray that consequently move closer to the arrival direction of the primary. Moreover, the hadrons penetrate deeper into the atmosphere with respect to a gamma ray with similar energy; as consequence of this, secondary particles are much more subject to Coulomb scattering because of the higher density in the low atmosphere. All this produces strong evident differences in the morphology of the images at the focal plane of a Cherenkov telescope (see Hillas 1985, Weekes et al. 1987 for details). The imaging Cherenkov telescopes exploit differences in image shape parameters to discriminate between gamma and hadrons. By analysing the shape of these images, more than 99.7 % of hadrons are rejected, keeping more than 50 % of gamma-rays (Reynolds et al. 1993).

In this paper we present a novel imaging Cherenkov telescope, GAW (Gamma Air Watch). The main components of the telescope (optics, focal surface detector and operative mode) are described in Sect.2; performances are presented in Sect.3.

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2 GAW: technical description

Current and next planned imaging Cherenkov telescopes use large mirror reflectors to collect and concentrate the Cherenkov light onto an array of photomultipliers with angular size of the order of 10-15 arcmin/pixel working in charge integration mode. The integration time interval is fixed at ~15 ns, and signals are translated in photoelectrons number. The conversion from total integrated charge to photoelectron number is affected by large statistical errors due to the electronic noise and non uniformity gain among neighbouring photomultipliers. Therefore, in suck kind of telescopes, the background rejection technique needs signals with intensity much higher than the noise fluctuations with consequent increase of the telescope energy threshold. For example, Whipple with a mirror of 10 meter diameter can perform the imaging background rejection technique only on images with at least 300-400 photoelectrons. This image intensity corresponds to a telescope energy threshold for gamma-ray events of about 250 GeV (Weekes et al. 1989). The energy threshold can be lowered by increasing the amount of Cherenkov signal collected, as in the telescopes now under construction (e.g., CANGAROO III, VERITAS, MAGIC, HESS) by maximizing the mirror size or the collection efficiency.

The lowering of the energy threshold can also be obtained through the reduction of the electronic noise contribution that strongly contaminates the quality of the images produced by low energy gamma-ray events. GAW, the Ground Air Watch telescope presented here, follows this approach in alternative to the planned imaging Cherenkov telescopes listed above.

The main differences in GAW with respect to the conventional imaging Cherenkov telescopes are:

- The Cherenkov light collector of GAW is a Fresnel lens instead of a mirror reflector. Optic systems with Fresnel lens have the advantage to provide large field of view with moderate angular resolution compared to the mirrors (Lamb et al. 1998), do not suffer from central obscuration by the focal detector. Moreover, they are lightweight and highly transparent. On the other hand, Fresnel lens suffer, as all refractive optic systems, of chromatic aberration due to the wavelength dependent dispersion of the light in the lens material, unlike of reflective systems that have not chromatic aberration because the light travels in the same medium along with its propagation. The optical performance required for GAW is obtained with a single flat Fresnel lens with a diameter of 3 meters, 3 mm thick and a f/# ~1.9. The lens is made of ultraviolet transmitting acrylic with a transmittance of about 95%, without anti-reflection coating, from the ultraviolet to the near infrared. Chromatic aberrations are minimized using a diffractive plane in the Fresnel optic design.

- The detector consists in an array of about 300 multi-anode photomultipliers manufactured by Hamamatsu, series R5900-00-M64 (Hamamatsu, 1999). Each photomultiplier is equipped with a bi-alkali photocatode and UV transmitting window that assure an average Quantum Efficiecy of 20% in 300-500 nm. The multi-anode photomultiplier is organized as an array of 8x8 independent pixels with each pixel 2 mm wide, corresponding to an angular pixel size at the focal plane of ~2 arcmin. The total array covers a field of view of ~5.2 degrees. Due to the geometrical dead area (~50%), a suitable light collector system is placed at the focal plane above the photomultiplier array to uniform the focal plane detector area. Thanks to the reduced pixel size, the photomultipliers will operate in single photoelectron count mode instead of charge integration. In such a working mode the noise and gain differences are negligible and it is possible to decrease the minimum number of photoelectrons in order apply the imaging background rejection technique. Small pixel size is actually required in order to minimize the probability to pile-up photoelectrons within interval shorter than the dead time (5 ns).

The imaging background rejection technique can be applied to images containing a minimum number of at least ~40 photoelectrons, allowing a low energy threshold in spite of the relatively small dimension of the Cherenkov light collector. Table 1 shows the baseline of the GAW design.

Collector light	Fresnel lens
Lens diameter	3 m
Lens weight	30 kg
Lens geometric area	7 m^2
Lens transmittance	0.95 (300-550 nm)
Angular rms	2 arcmin
Focal length	5.7 m
F/#	1.9
PMT number	300
PMT working mode	Single count mode
Pixel number	19200 (300*64)
Pixel size	2 mm
Focal plane pixels size	3.3 mm / 2 arcmin
Full field of view	5.2°
Mount	Alt-Alt

Table 1. Baseline of the GAW design.

3 GAW performance

The image performance of the optical system is quite uniform along with the field of view with an rms for a point source smaller than 2 arcmin (see Fig.1).

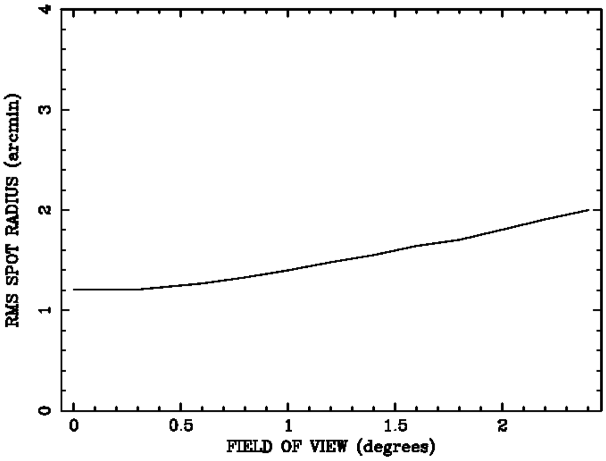

Fig.1. RMS spot radius for a point source versus the field of view.

The energy threshold for an imaging Cherenkov telescope depends also on the altitude of the observing level. Actually, higher is the observing level, nearer we are to the maximum of the Cherenkov light production. As consequence, the Cherenkov light density is greater and a lower energy gamma ray produces an image with intensity high enough to allow the use of the background rejection technique. Fig. 2 shows the differential detection rate of the Crab Nebula as expected to be observed by GAW located at two possible different observing levels. We define the detection rate as the rate of gamma-ray events remaining after the cosmic-ray background rejection. The energy threshold of GAW is the energy corresponding to the maximum differential detection rate of reconstructed gamma-ray events. The GAW energy threshold is about 100 and 300 GeV, for the 2000 and 5000 meters a.s.l. observing level, respectively.

The performance of GAW is summarized by its integrated flux sensitivity as function of the energy. Fig. 3 shows the minimum integrated flux for detection of a 5σ excess, with at least more than 10 photons, in 50 hours of observation of a gamma-ray source with a Crab-like spectrum ($dN/dE \propto E^{-2.5}$). For comparison, the Whipple sensitivity is shown in figure together with the integrated Crab Nebula flux.

We claim that GAW, thanks to its finely segmented focal plane detector operating in single count mode has a low energy threshold and flux sensitivity comparable to the Whipple telescope, in spite of the relatively small dimension of the Cherenkov light collector one order lower.

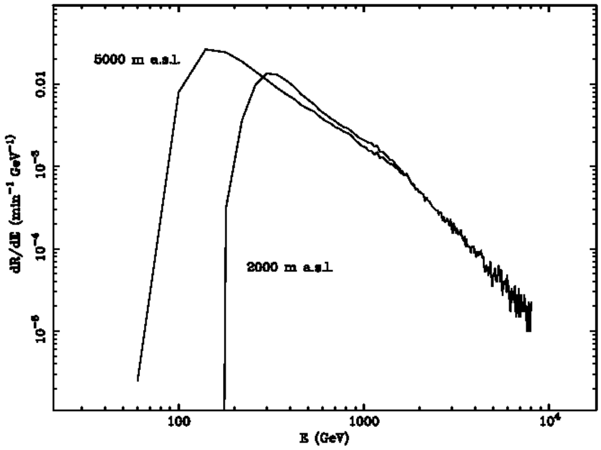

Fig.2. Differential detection rate of the Crab Nebula expected with GAW located at two different observing levels. The peak of the curves gives the low energy threshold of the telescope.

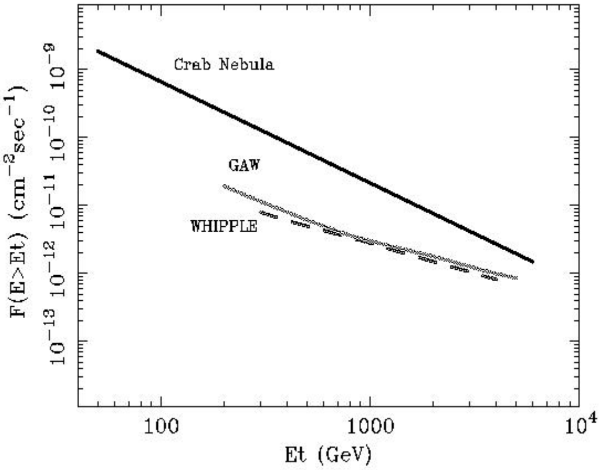

Fig.3. The sensitivity (5σ detection) of GAW for point-like sources in 50 hours of observing. In figure are also reported for comparison the point source sensitivity of Whipple (Weekes et al. 1989) and the integrated Crab Nebula flux.

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