GAW (Gamma Air Watch): a novel imaging Cherenkov telescope

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ABSTRACT. GAW (Gamma Air Watch) is a new imaging Cherenkov telescope designed for observation of very high-energy gamma-ray sources. GAW will be equipped with a 3 meter diameter Fresnel lens as light collector and with an array of 300 multi-anode photomultipliers at the focal plane. The pixel size will be 4 arcmin wide for a total field of view of 10.5 degrees. Whith respect to the planned imaging Cherenkov telescopes (CANGAROO III, HESS, MAGIC, VERITAS) GAW follows a different approach for what concerns both the optical system and the detection working mode: the Cherenkov light collector is a single acrylic flat Fresnel lens (instead of mirrors) that allows to achieve wide field of view; the photomultipliers operate in single photoelectron counting mode (instead of charge integration). The single photoelectron counting mode allows to reach a low energy threshold of $\sim$ 200 GeV, in spite of the relatively small dimension of the GAW optic system.

1. Introduction

At energies around 0.03 TeV the emission from galactic and extragalactic sources is too weak to be detected by instruments onboard satellites because of their poor effective area. Actually, since the flux of an astronomical source decreases as the energy increases, observations at higher energy need a huge effective area that is not feasible with space detectors. Only ground-based experiments achieve enough effective area to observe the very low intensity and the soft spectra emitted in this extreme energy band. Observations 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 component of the shower. The spread of the secondary particles and the intrinsic Cherenkov light cone aperture (1.3 degrees in air) allow a strong increase of the effective area being the detectors sensible to gamma rays whose trajectory is hundreds of metres far from them. Imaging Cherenkov telescopes, thanks to their large collection area ($\sim 10^5$ m^2) and 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 250 GeV.

In this paper we present a novel imaging Cherenkov telescope, GAW (Gamma Air Watch) designed to observe gamma-ray sources above 200 GeV. The main components of the telescope (optics, focal surface detector and operative mode) are described in Sect.2; the performance is presented in Sect.3.

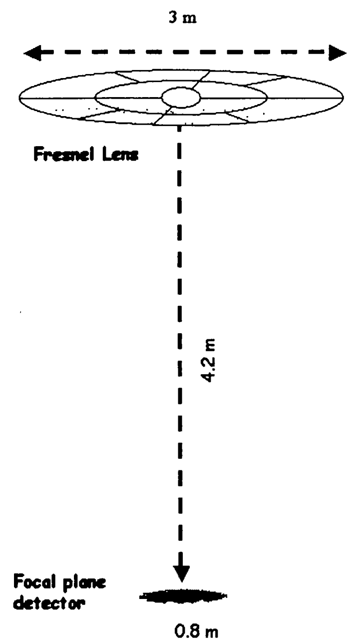

Fig. 1. Schematic view of GAW telescope.

2. GAW: technical description

Current and next planned imaging Cherenkov telescopes use large spherical mirror reflectors to collect light. The field of view (FOV) of these telescopes ranges from 3 to 5 degrees. A larger FOV can not be achieved with reflective systems because of the rapid increase of aberrations for off-axis angle. Since the FOV has the same order of magnitude as the Cherenkov light cone, the conventional Cherenkov telescopes can observe only one source each time and they must point to a different sky position to measure the diffuse background in the FOV loosing on-source observing time. These telescopes are not suitable for surveys and for discovery of rapid, transient phenomena or serendipity TeV sources. A sensitive survey of the galactic plane at TeV energies has to be undertaken yet. So, the development of wide angle optics for Cherenkov telescopes would be very important in the very high-energy astronomy. Wide FOV observations with a ~200 GeV low energy threshold is the goal of the GAW project.

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

- optic system: the Cherenkov light collector is a single acrylic flat Fresnel lens instead of mirrors.
- photomultiplier operation mode: the photomultipliers work in single photoelectron

counting mode instead of charge integration.

A schematic view of the telescope is shown in Fig. 1; the baseline is summarized in Table 1.

The Cherenkov light collector of GAW is a Fresnel lens. Optic systems with Fresnel lens have the advantage to provide large FOV with moderate angular resolution (Lamb et al. 1998); they do not suffer from central obscuration by the focal detector; they are lightweight and highly transparent. Moreover, the much more isochronisity of the refractive system with respect to mirrors allows us to take advantage of the short duration of the Cherenkov pulses (~ 2-5 ns) lowering the signal integration time and reducing the night sky background, with consequently decrease of the telescope energy threshold. The optical performance required for GAW is obtained with a single flat Fresnel lens with a diameter of 3 meters, a thickness of 3 mm and a f# of 1.4. The lens is made of ultraviolet transmitting acrylic with a transmittance of about 95% from ultraviolet to near infrared. Chromatic aberration, present in the Fresnel lens, is minimized using a diffractive plane in the optics design.

Tab. 1 - Baseline of the GAW design

Collector light	Fresnel lens
Lens diameter	3 m
Lens weight	30 kg
Lens geometrical area	7.06 m^2
Lens trasmittance	0.95 (300-600 nm)
Lens rms	0.1 degrees
Focal length	4.2 m
f#	1.4
Focal plane detectors	MAPMT R7600-03-M64
PMT number	300
PMT working mode	single count mode
Pixel number	19200
Focal plane pixel size	4 arcmin
Total FoV	10.5 degrees
Mount	Alt-Alt

The detector consists in an array of 300 multi-anode photomultipliers (MAPMT) manufactured by Hamamatsu, series R7600-03-M64 (Hamamatsu, 1999). Each photomultiplier is equipped with a bi-alkali photocatode and UV transmitting window that assure an average Quantum Efficiency of 20% in 300-500 nm. The MAPMT is organized as an array of 8×8 independent pixels. The pixel size is ~ 5 mm, corresponding to an angular size of ~ 4 arcmin. The total array covers a FOV of 10.5 degrees. The MAPMT R7600-03-M64 has a geometric dead area of the order of 50%; a suitable light collector system is therefore placed above the MAPMT array to lead photons directed to the dead space to the sensitive area. In GAW, thanks to the reduced pixel size, the MAPMTs can operate in single photoelectron count mode. In such a working mode

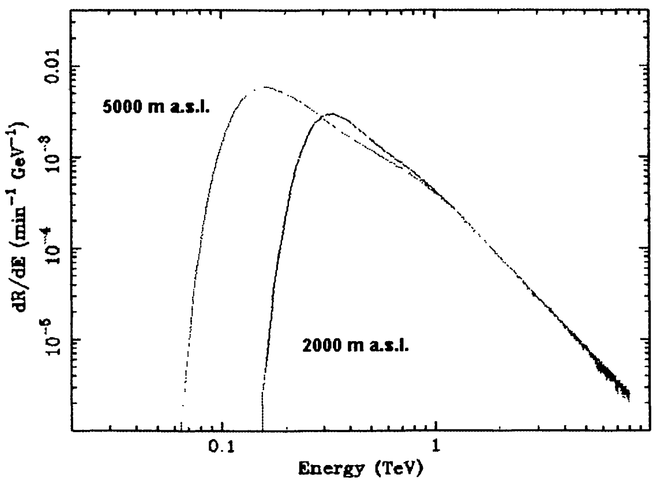

Fig. 2. Differential detection rate of the Crab Nebula expected with GAW located at two different observing level. The peak of the curves gives the low energy threshold of the telescope.

the noise and gain differences are negligible and it is possible to decrease the minimum number of photoelectrons necessary to apply the imaging background rejection technique. Small pixel size is actually required to minimize the probability of photoelectrons pile-up within intervals shorter than the dead time ($\sim$ 5 ns). The imaging background rejection technique can be applied to images containing a minimum number of $\sim$40 photoelectrons. This allows to lower the energy threshold to a value of $\sim$ 200 GeV, in spite of the relatively small dimension of the Cherenkov light collector.

3. GAW performance

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, defined as the energy corresponding to the maximum of differential detection rate, will be about 150 and 320 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 5 σ 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 the figure together with the integrated Crab Nebula flux. 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 (Weeks et al. 1989), in spite of the one order lower geometrical area of the Cherenkov light collector.

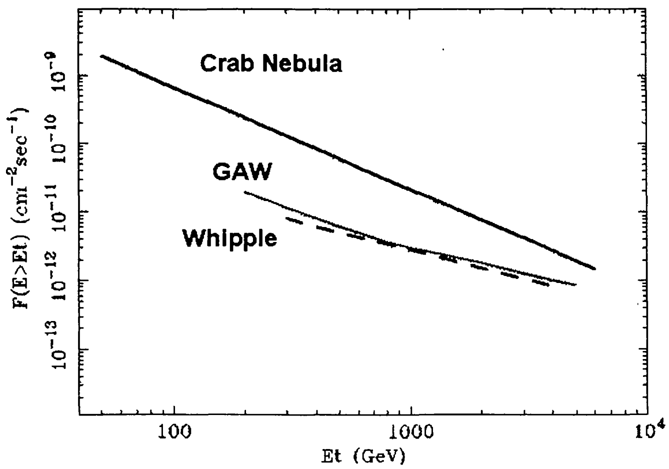

Fig. 3. The sensitivity (5σ) detection of GAW for point-like sources in 50 hours observations. In figure are also reported for comparison the point source sensitivity of Whipple (Weeks et al. 1989) and the integrated Crab Nebula flux.

GAW will be the first wide FOV imaging Cherenkov telescope. It is suitable to survey interesting sky regions as the Galactic Center, the Galactic Plane, the Magellanic Clouds, etc.. Moreover, pointed observations will be performed with good sensitivity and with a low energy threshold comparable to that of the next imaging Cherenkov telescopes.

References

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