GAW - A very large field-of-view Imaging Atmospheric Cherenkov Telescope

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GAW (Gamma Air Watch) is a pathfinder experiment in the TeV range to test the feasibility of a new generation of Imaging Atmospheric Cherenkov Telescopes (IACT). It combines high flux sensitivity with large field-of-view (FoV = 24°×24°) using Fresnel lenses, stereoscopic observational approach and single-photon counting mode. This particular counting mode, in comparison with the usual charge integration one, allows the triggering of events with a smaller number of collected Cherenkov photons keeping a good signal/background separation. GAW is conceived as an array of three identical imaging telescopes with 2.13 m diameter placed at the vertices of an equilateral triangle of 80 m side. The telescope will be built at the Calar Alto Observatory site (Sierra de Los Filabres - Almeria Spain, 2168 m a.s.l.) and is a joint effort of research institutes in Italy, Portugal and Spain. The main characteristics of the experiment will be reported.

1 Introduction

High energy gamma-rays are a powerful probe for several astrophysical quests. During the recent years a new window has been opened in the observation of gamma-rays from about few tens of MeV up to EeV thanks to the availability of new photon detectors built using technologies imported from experimental particle physics. Satellites cover the lowest energy range of detection (few MeV up to few tens GeV) while ground-based detectors like Imaging Atmospheric Cherenkov Telescopes (IACTs) and Extensive Air Shower (EAS) arrays cover higher energy regions (the former from 50 GeV up to more than 10 TeV and the latters with a threshold at 0.5-1 TeV). The aim of this article is to introduce a Research and Development experiment for the construction of a new IACT to detect very high energy (VHE) gamma-rays. Although this is a young research field, VHE gamma-ray astronomy is a well established discipline with several identified sources, steady and variable, galactic and extragalactic.

The existing and planned ground-based IACT observatories aim to lower the energy threshold to few tenths of GeV to overlap with satellite detection region. The second goal is to improve the flux sensitivity in the region above 100 GeV through a stereoscopic observational approach. Another important purpose is to do a full sky coverage since astronomical events can occur at unknown locations and/or randomly in time. A current IACT telescope consists of an optical system with few degrees field-of-view (FoV ≤ 5°) and of a pixelized camera placed at its focus. They can not achieve larger FoV due to mirror optical aberrations that rapidly increase with off-axis angles. Moreover, the increasing of the detector area required to cover large FoV would

\[\text{As a rule of thumb, VHE } \gamma \text{-rays are classified as } \gamma \text{-rays with energies from } \sim 30 \text{ GeV up to } \sim 30 \text{ TeV} \]
unavoidably produce a strong reduction of the light collecting area due to the shadow of the detection matrix onto the reflector. Such limitation has to be overcome to significantly improve the capability of surveying large sky areas since detection of transient phenomena is a goal. An alternative solution might be the usage of refractive optics like Fresnel lenses as light collectors instead of the classical mirror. Fresnel lenses enable large FoV, they have good transmittance and avoid the shadow problem. Since they are easy to replicate Fresnel lenses appear as an affordable solution however chromaticity should be controlled. The study of the feasibility of such solution is the aim of the GAW experiment as explained below.

1.1 The GAW experiment

The design of the GAW telescope includes a Fresnel lens and a focal surface detector formed by a grid of MultiAnode pixelized (8x8) PhotoMultiplier Tubes (MAPMT) coupled to light guides. A schematic view of the GAW telescope is depicted in Figure 1. A detailed description of the GAW detector is given in reference [2]. The design of the GAW experiment was made to prove the feasibility of the usage of a Fresnel lense as an efficient light collector allowing an enlargement of the field of view. Another innovative idea is that instead of the usual charge integration method, GAW front-end electronics design will be based on single photoelectron counting mode [3]. In such working mode, the effects of the electronic noise and the photomultiplier gain differences are kept negligible. This method strongly reduces the minimum number of photoelectrons (p.e.) required to trigger the system and, consequently a low telescope energy threshold (∼700 GeV) is achieved despite the relatively small dimension of the Cherenkov light-collector (2.13 m diameter). The pixel size is small enough (3.3425 mm) to reduce the photoelectrons pile up within intervals shorter than sampling time (10 ns). Current camera design is comfortable with a threshold of 14 p.e per event per trigger-cell (2 ×2 multianode photomultipliers) since the expected night sky background (NSB) contribution is 2-3 p.e. per sample per trigger-cell.

The light collector is a non-commercial Fresnel lens with focal length of 2.56 m and 3.2 mm thick. The lens is made of UltraViolet transmitting polymetacrilate with a nominal transmittance of ∼95% from 330 nm to 600 nm. The lens design is optimized for the maximum wavelength of photon detection (λ ∼360 nm). The lens is composed of a central core (∅ 50.8 cm) surrounded by a corona of 12 petals extending for 40.6 cm and by a second level of 20 petals for the outer corona extending for more 40.6 cm. A mechanical spider support will keep all pieces together.

The MAPMT used for GAW focal surface detector is the Hamamatsu R7600-03-M64 (Figure 2) with 64 anodes arranged in an 8 × 8 matrix. The physical dimension of the tube section is
25.7 × 25.7 mm² while the effective area is 18.1 × 18.1 mm². The tube is equipped with a bialkali photocathode and a 0.8 mm thick UV-transmitting window (from 200 up to 680 nm). This ensures good quantum efficiency for wavelengths longer than 300 nm with a peak of 20% at 420 nm. The Metal Channel Dynode structure with 12 stages provides a gain of the order of 3 × 10⁵ for an applied voltage of 800 V. This PMT provides a fast response (of the order of 10 ns) in order to disentangle the Cherenkov light, which is produced coherently in space and time, from the incoherent but significantly fluctuating NSB.

In order to reduce dead areas between adjacent photomultipliers and consequently to increase the photon collection efficiency, an array of light guides was added, coupled to each photomultiplier. Due to the dead areas between adjacent PMTs around 55% of the photons would be lost without any guiding device. A light guide unit is a pyramidal polyhedron composed of 8 × 8 independent, plastic tubes glued on a plastic plate. The tubes are made of a polymetacrilate (PMMA) from Fresnel Technologies with a refractive index of 1.489 close to the one of the PMT window (n = 1.5). These characteristics were chosen to obtain a transmittance as high as possible over the wavelength range of the PMT detection. The 64 pieces that constitute the light guide, with ten different shapes, are held together by a thin layer (1 mm) on the top made of an anti-reflective PMMA. Inside the light guide, photons are conducted by internal reflections. The light guide unit is optically coupled to the active area of phototube cathode through a 1 mm flexible optical pad. With a total height of 35 mm, and a collecting surface of 26.74 × 26.74 mm², it presents a readout pixel size of 3.3425 mm which renders in a spatial granularity of ∼ 0.1° suitable for Cherenkov imaging. The optimum dimensions have been determined to maximize the photon collection efficiency (≈71%), to minimize the cross talk between adjacent pyramidal frustums (∼6.5%) and to achieve the higher spatial uniformity in the photon collection efficiency (uniform at the level of 0.01). All these parameters were evaluated with simulated samples for the photon incident angles on the top of the light guide within the GAW FoV.

1.2 The GAW project timeline

The chosen site for the telescope placement is the Calar Alto Observatory (Sierra de Los Filabres, Almeria, Spain), at 2168 m above sea level. The civil engineering work at the Calar Alto site is close to be finished and, in particular, the construction of the building to house the telescope is finished as can be seen in Figure 3(b). The telescope mechanical structure, which is depicted in Figure 3(a) and the spider support for the lens petals were manufactured by a specialized company (ASTELCO Systems) and shipped to the site, after validation tests carried at the company headquaters. The telescope and lens commisioning will be undertaken in 2009/2010. The main goal for this stage is to prove the feasibility of the GAW concept, in particular the optics and the data acquisition systems. A reduced Fresnel lens with a single central petal will be installed in the centre of the supporting spider and the lens design will be validated by measuring the spot size with Vega spectrum. The first tests of GAW electronics will also be carried out. Afterwards the project will start with a first phase where only one telescope will be assembled, with a reduced focal surface detector (10×10 MAPMT), covering a FoV of 6° × 6°. This phase, starting in 2010, will be suited to test this detector principle in “on-axis” mode and in “off-axis” observation mode. The focal surface will be mounted on a rack frame (Figure 3(c)) and moved to enable sensitivity measurement by observing the Crab Nebula, on-axis and off-axis, up to 12°, the edge of the GAW FoV. Obtained the R&D results and in case of a successful confirmation of the GAW concept a second phase is foreseen, with a fully equipped focal plane with 24° × 24° FoV. For this phase three identical telescopes will be constructed, placed at the vertexes of an equilateral triangle (80 cm side) and will work in the stereoscopic mode, improving the angular resolution, the capability of identifying gamma-ray induced showers and the determination of the primary photon energy.
Figure 3: (a) GAW telescope mechanical structure. (b) Telescope housing in Calar Alto. (c) Artistic view of the detector focal surface mounted on a rack frame.

2 Summary

IACTs with large FoV will offer two important advantages: they will survey the sky for serendipitous TeV detections and, at the same time, will increase the IACT collection area, triggering events whose core is far away from the telescope axis and therefore improving the statistics of the high energy tail of the source spectra. Presently, GAW is a R&D experiment to build a Cerenkov telescope that will test the feasibility of a new generation IACT that joins large FoV and high flux sensitivity. Large FoV will be achieved by using refractive optics made of Fresnel lens of moderate size. The focal camera will use the single photon counting mode instead of the charge integration mode widely used in the present IACT experiments. This working mode will allow the detector to be operated with a low photoelectron threshold and a consequent lowering of the energy threshold. The stereoscopic observational approach will improve the angular resolution. GAW is a collaboration effort of several Research Institutes in Italy, Portugal and Spain. It will be erected in the Calar Alto Observatory (Sierra de Los Filabres - Andalucia, Spain). The first telescope is foreseen for 2010.

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