Characteristics and performance of GAW, Gamma Air Watch – a path-finder of a new generation of Imaging Atmospheric Čerenkov Telescope with large field of view.

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Abstract: GAW, acronym for Gamma Air Watch, is a path-finder experiment designed to test the feasibility of a different technological approach for Imaging Atmospheric Čerenkov Telescopes. GAW differentiates from the existing and presently planned telescopes for two main features: the adoption of a refractive optics system as light collector and the use of single photoelectron counting as detector working mode. The optics of GAW, composed by a custom-made 2.13 diameter single-sided Fresnel lens, will allow to achieve large field of view capability ($8^\circ \times 8^\circ$). The focal surface consists of a matrix of multianode photomultipliers. The large number of active channels (of the order of 10^5) makes it basically a large UV sensitive digital camera with high resolution imaging capability. GAW is being mounted at the Calar Alto observatory, Spain, 2150 m a.s.l., and its calibration phase is planned to start in 2012. GAW is a collaboration effort of several Research Institutes in Italy, Portugal and Spain.

Keywords: Čerenkov Telescopes; TeV astronomy

1 Introduction

The advent of Imaging Atmospheric Čerenkov Telescopes (IACTs) has allowed the access to the TeV energy range opening a new observative window of the sky. A remarkable number of sources were firmly detected since the pioneer detection of Very High Energy (VHE) emission from the Crab Nebula [1]. Among the most exciting recent results we cite the discovery of many new sources in the Galactic plane (see e.g. Ref. [2]), only some of them identified with known astronomical sources, and the detection of some Active Galactic Nuclei (AGN). Because of the sensitivity of the first generation of IACTs, only a handful of sources were detected up to a decade ago. In the last years, arrays of Čerenkov telescopes as HESS [3, 4], MAGIC [5] and VERITAS [6], thanks both to the large diameter of their optics and to the stereoscopic observational approach, have allowed a considerable step forward in sensitivity increasing the number of sources detected in this extreme energy band to nearly one hundred and achieving astonishing discoveries.

At present, IACTs use large single mirror reflectors with f-number around 1.2 characterized by a field of view (FoV) of the order of few degrees. Larger fields of view are difficult to achieve with these single mirror optics: optical aberrations rapidly increase with off-axis angle and larger FoV with a point spread function suitable for imaging analysis would force to increase the f-number at least a factor of 2. These optics, however, are mechanically difficult to realize and would require a large and expensive focal camera.

However, large FoV are highly desirable for several reasons, e.g.: sky surveys; VHE astronomical events can occur at unknown locations and/or random in time and a large FoV is then mandatory to increase their detection probability; the study of extended sources and of the diffuse VHE emission also benefits from a large FoV telescope; the observation of the events at energies of several decades of TeV. The increase of the statistics above some decades of TeV requires collecting events with a large impact distance from the telescope. Only cameras with large FoV allow to record these events without image truncation: the position of the image in the focal camera moves farther from the center of the camera as the distance of the shower's impact point from the telescope increases.

To overcome present technological limitations that force the FoV of single mirror to a few degrees, an alternative solution could come from the use of refractive optics, as the Fresnel lenses: they allow to achieve larger FoV maintaining imaging stability up to 8-10 degrees with a single lens and up to 20 degrees with double lenses [7, 8].

GAW, acronym for Gamma Air Watch, is a path-finder experiment that is testing the feasibility of a new generation of IACT telescopes that join high flux sensitivity with large field of view capability using Fresnel lens and a focal camera consisting of a matrix of multianode photomultipliers working in single photoelectron counting mode. 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) at the altitude of 2150 m a.s.l.. A detailed description of GAW is given in [9]

In this paper, the expected performance and the status of GAW are reported.

2 The GAW experiment

Differently from the present IACT experiments, the optics of the GAW telescope is characterized by a refractive system with a custom-made single side flat Fresnel lens of 2.13 m diameter, focal length 2.55 m (f-number ~ 1.2) and thickness 15 mm. The Fresnel lens is an approximation of the refractive aspherical lens with the advantage of a good transmission performance thanks to the reduced thickness. Moreover, differently from reflective optics, refractive optics does not suffer from obstruction by the focal camera. The lens, made of UltraViolet (UV) transmitting acrylic, has a nominal transmittance of 85% from 330 nm to the near InfraRed. This material is characterized by a small refraction index derivative at low wavelength, thus reducing chromatic aberration effect. A diffractive optics design onto the side of the Fresnel lens containing the grooves will minimize further the chromatic aberration. The lens design is optimized at 360 nm, and it is characterized by a quite uniform spatial resolution suitable to the requirements of the Čerenkov imaging up to 8 degree off-axis. The lens is made of 33 petals maintained in a rigid configuration by a spider structure. The optical system is designed and manufactured by AMOS Ltd (Advanced Mechanical and Optical Systems), Liege, Belgium.

Figure 1: Mechanical structure of the GAW telescope.

The focal plane detector of each telescope consists of a grid 14x14 Multi-Anode Photomultipliers Tubes (MAPMT), with 8x8 anodes each, operated in single photoelectron counting mode [10] instead of the charge integration method widely used in the IACT experiments. Čerenkov images will be recorded in binary mode. The high granularity of the focal camera (composed of 12544 active channels per telescope) is fundamental to minimize the probability of photoelectron pile-up within intervals shorter than the sampling time (10 ns). The single photoelectron counting mode offers the advantage of negligible electronic noise and reduced gain differences among the channels. These characteristics allow to achieve a low photoelectron trigger threshold and, as a result, a low telescope energy threshold (~ 0.7 TeV) in spite of the relatively small dimension of the Čerenkov light-collector.

A prototype of the GAW lens with a diameter of 250 mm has been produced to test the optical design. The spot size of this lens was measured with monochromatic light and compared with simulations. The analysis of the measurements result in point spread functions in good agreement with those expected by the simulations. The focal camera covering a FoV of $8^\circ \times 8^\circ$ is being assembled and it will be tested in laboratory by September 2011. The mechanical structure of the telescope (see Fig. 1) has been manufactured and tested. A building in Calar Alto is ready to host the telescope and we plan to assemble it in Autumn 2011. Engineering and calibration phases will start soon after. Afterwards, it is foreseen to install two additional telescopes so enabling stereoscopic observations.

The GAW expected performances were evaluated with a complete end-to-end simulation. The physical processes involved in the interaction of a gamma-ray or a proton in the atmosphere, shower production and development, generation of Čerenkov light and effects of the atmospheric absorption were simulated using the CORSIKA code [11]. Fig. 2 shows the sensitivity of GAW (three telescopes observing in stereoscopic configuration) for a Crab-like point source in 50 hours observation with 5 sigma detection limit as function of the energy. For comparison, the flux of the Crab Nebula and the sensitivity of other TeV experiments are also shown.

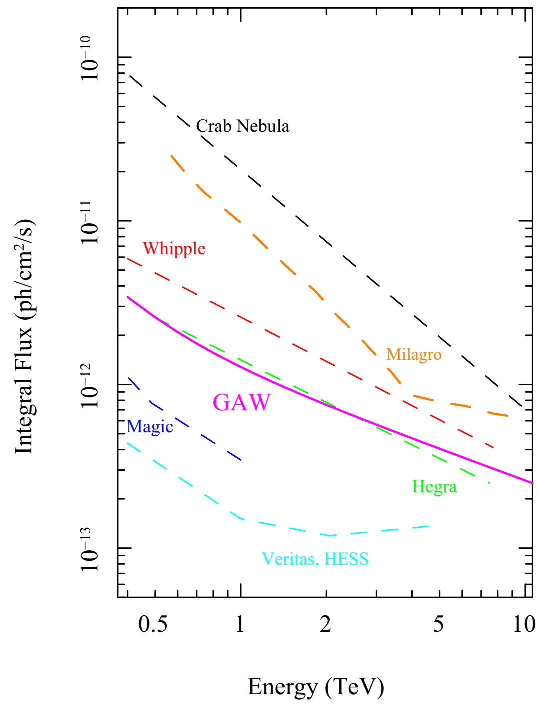

Figure 2: GAW sensitivity limit (5 standard deviation) with three telescopes in stereoscopic configuration for a Crab-like point source and 50 hours of observing. The flux of the Crab Nebula and the sensitivity of other TeV experiments (dashed lines) are also shown for comparison. The Milagro sensitivity is for 1 year of observation.

3 Summary

IACTs with large FoV will offer, at least, 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. GAW is a path-finder experiment that will test the feasibility of a new generation IACT that joins large FoV and high flux sensitivity. Large FoV ($8^\circ \times 8^\circ$) will be achieved by using refractive optics made of single side flat Fresnel lens of moderate size (2.13 m diameter). The focal camera will use the single photon counting mode instead of the charge integration mode widely used in the present IACT experiments. This detector working mode will allow us to operate with low photoelectron threshold allowing to achieve a telescope low energy threshold of ~ 0.7 TeV.

References

[1] T.C. Weekes et al., ApJ, 342:379, 1989

[2] Aharonian, F., et al., ApJ, 636, 777, 2006

[3] Bernlöhr K., Carrol O., Cornils R. et al., Astropart. Phys., 20, 111, 2003

[4] Vincent P., Denance J.P.,HuppertJ.F. et al., in Proc. 28^{th} International Cosmic Ray Conference, , Tsukuba University Accademy Press, Tokio, 2003

[5] Baixeras C., Nucl.Phys.B (Proc.Suppl.) ,114, 247, 2003

[6] Weekes T.C., Badran H., Biller S.D. et al., Astropart. Phys., 17, 221, 2003

[7] L.W. Hillman et al., 28^{th} International Cosmic Ray Conference, 2003

[8] Y. Takizawa et al., 31^{th} International Cosmic Ray Conference, 2009

[9] GAW Collaboration, The GAW Official Web Site, http://gaw.iasf-palermo.inaf.it, 2005

[10] O. Catalano, M.C. Maccarone, B. Sacco, Single Photon Counting Approach for Imaging Atmospheric Čerenkov Telescopes, Astroparticle Physics, 2007

[11] D. Heck anf J. Knapp, http://www-ik.fzk.de/corsika