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Characteristics and Performance of the GAW Experiment for a Large Field of View Čerenkov Gamma-ray Telescope

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Abstract One of the intents of the ground-based gamma-ray astronomy is to obtain a sky survey in the TeV energy region, and nowadays this target can be reached with giant arrays of telescopes, which however need many pointings due to their small field of view. A different approach is on the basis of GAW, acronym for Gamma Air Watch, an array of three relatively small Čerenkov telescopes which differentiate from the existing and presently planned telescopes for two main features: the adoption of a refractive optics system as light collector with a large field of view capability, and the use of single photoelectron counting as detector working mode. During a first phase, the focal plane detector of the GAW telescopes will be implemented in a reduced configuration to test the sensitivity and to prove the feasibility of the method; then the focal plane will be enlarged to cover a field of view of $24° \times 24°$; pointing along different North-South directions, GAW would reach a survey of $360° \times 60°$ region of the sky. In this paper, the GAW expected performance are reported as evaluated in the case of the Calar Alto site, Spain, 2150 m a.s.l., where GAW is planned to be located within 2007. GAW is a collaboration effort of Research Institutes in Italy, Portugal and Spain.

Key words: techniques: Čerenkov telescope – Very High Energy γ-ray

1 INTRODUCTION

Despite its youngness, Very High Energy (VHE) gamma-ray astronomy is considered a legitimate astronomical discipline with established sources, steady and variable, galactic and extragalactic, providing deep implications in the theoretical models. Presently, the main objectives of the ground-based VHE gamma-ray experiments are: the improvement of the flux sensitivity above 100 GeV to increase the number of VHE gamma-ray sources and give more details on their properties; the extension of the observation range towards lower energies (few tenths of GeV) to meet and overlap the energy window proper of the gamma-ray satellite experiments. The first objective is achieved using arrays of telescopes as VERITAS (Weekes et al. 2002), HESS (Bernlöhr et al. 2003, Vincent et al. 2003), or CANGAROO III (Kabuki et al. 2003, Enomoto

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et al. 2002) which, thanks to their stereoscopic observational approach, furtherly increase the sensitivity capability of IACT telescopes. A lower energy range is being exploited with arrays of solar heliostats as STACEE (Chantell et al. 1998), Solar-2 (Tümer et al. 1999), CELESTE (Quebert et al. 1995), or GRAAL (Arqueros 2003); moreover, the telescope MAGIC (Baixeras et al. 2003), with its 17 m aperture, is going to achieve a similar low energy threshold using the Imaging Atmospheric Čerenkov Technique (IACT).

Nevertheless, astronomical events can occur at unknown locations and/or random in time, and a large field of view (FoV) is then needed to increase their detection probability. To collect light, the present IACT telescopes use large mirror reflectors characterized by FoV of the order of few degrees; they cannot reach larger FoV due to the mirror optical aberrations, rapidly increasing with off-axis angles, and to the shadow of a larger detector onto the reflector. A large FoV is also a basic requirement to perform sensitive survey of the Galactic Plane as well as an estimation of the celestial gamma-ray diffuse emission. Such a survey cannot be easily performed by the ground-based IACT telescopes: as a result of their reduced FoV, such telescopes can survey the sky only if long exposure times are considered.

To overcome such limitations, an alternative solution could come from the use of refractive optics, as the Fresnel lenses: they can achieve large FoV with imaging capability suitable to the quite coarse structure of the Čerenkov image; they maintain imaging stability against deformation; there is no central obstruction of the detector at the focal surface.

GAW, acronym for Gamma Air Watch, is a "path-finder" experiment to test the feasibility of a new generation of IACT telescopes that join high flux sensitivity with large field of view capability using Fresnel lens, stereoscopic observational approach, and single photoelectron counting mode.

2 THE EXPERIMENT

GAW is conceived as an array of three identical IACT telescopes disposed at the vertexes of an equilateral triangle, ~ 80 m side. A detailed description of GAW is given in [1]; here we report two specific main features of the array as R&D experiment for a new generation Čerenkov telescopes.

A refractive optical system characterizes GAW: its light collector is a non commercial Fresnel lens (ø 2.13 m) with focal length of 2.55 m and standard thickness of 3.2 mm. The lens material is UltraViolet (UV) transmitting acrylic with a nominal transmittance of $\sim 95\%$ from 330 nm to the near InfraRed; this material joins high transmittance and small refraction index derivative at low wavelength, reducing chromatic aberration effects. The lens design is optimized to have, at the wavelength of maximum intensity of the Čerenkov light convolved with the detector response ($\sim$ 360 nm), a quite uniform spatial resolution up to 30° (full angle) suitable to the requirements of the Čerenkov imaging. The baseline optics module for the GAW prototype is a single-sided, flat Fresnel lens optimized for a $\pm 12^\circ$ field of view. The project of the optical system is a joint effort of the IASF/INAF Institute in Palermo and of the Fresnel Technologies, Fort Worth, Texas, which will manufacture the lens.

The second main feature characterizing GAW is the detector working mode. In its baseline configuration the focal surface detector of each telescope consists of a grid of MultiAnode PhotoMultiplier Tubes (MAPMT) manufactured by Hamamatsu, series R7600-03-M64; the number of active channels (order of 10^4) forming the detector at the focal surface makes it basically a large UV sensitive digital camera with high resolution imaging capability. The large dead area of the MAPMT induces a reduction of the detection efficiency of $\sim 50\%$ on photon detection. In order to correct that, each MAPMT pixel is coupled to a Light Guide which allows to uniformly cover the FoV with a 20% average absorption (due to the Light Guide). The specific feature is that the GAW electronics design is based on single photoelectron counting mode (front-end), instead of the charge integration method widely used in the IACT telescopes, and on free-running method (data taking and read-out). The single photoelectron counting mode method is used to measure the number of output pulses from the photosensors corresponding to incident photons. Small pixel size is required to minimize the probability of photoelectrons pile-up within intervals shorter than the given sampling time of 10 ns (GTU, Gate Time Unit). In such working mode the electronics noise and the MAPMT gain differences are kept negligible allowing lowering the trigger threshold.

The single photoelectron counting mode, together with the stereoscopic observational approach, will guarantee an energy threshold of the order of few hundreds of GeV in spite of the relatively small dimension of the lens.

GAW is planned to be located at the Calar Alto Observatory (Sierra de Los Filabres, Almeria, Spain, 2150 m a.s.l.). Two phases are foreseen for the project:

- Firstly, only part of the GAW focal detector will be implemented to cover a FoV of $6^\circ \times 6^\circ$; the detector will be mounted on a rack frame allowing shifting it along the full size of the focal surface. Under this configuration the sensitivity of the telescopes will be tested observing the Crab Nebula with on-axis and off-axis pointings up to 20°. GAW will also monitor the VHE activity of some flaring Blazars.
- In a second phase, once the feasibility of the method proposed has been proved, the focal plane detector will be enlarged to cover a FoV of $24^\circ \times 24^\circ$. We plan to survey a region of $360^\circ \times 60^\circ$ of sky pointing along different North-South directions.

3 GAW PERFORMANCE

To evaluate the GAW expected performance, a complete end-to-end simulation has been developed, starting from the physical process to the event reconstruction and analysis. The first step of the simulation chain, performed by using the CORSIKA code [2], mainly concerns the generation of Čerenkov light, at level of single photons, associated to air showers induced by different primaries including the effects of the atmospheric absorption. The simulated events are then analyzed by a proper code that includes detector peculiarities: the GAW geometrical configuration, the optics absorption and its spread function, the effect of the light guides, the detector efficiency, as well as the trigger electronics and the average expected value of light diffuse background are included. A threshold of 14 photoelectrons per event in each telescope, together with the coincidence in the other two telescopes is applied; this choice reduces the fake trigger rate due to the diffuse background to a negligible level.

Figure 1 shows the differential detection rate of the Crab Nebula as expected to be observed by GAW. The energy threshold of GAW will be about 300 GeV with a peak at about 700 GeV. The performance of GAW is summarized by its integrated flux sensitivity as function of the energy. Figure 2 shows the sensitivity reachable during the 1st phase (FoV $6^\circ \times 6^\circ$). Figure 3 shows the capability of GAW (during the 2nd phase, FoV $24^\circ \times 24^\circ$)) to perform deep sky survey compared with the sensitivity reachable in the same time interval by a small field telescope covering the same FoV with many independent pointings: despite of the small dimension of its light collector respect to the ones of VERITAS, GAW is competitive, mainly at high energy thanks to the gain of a factor more than 100 in the useful FoV.

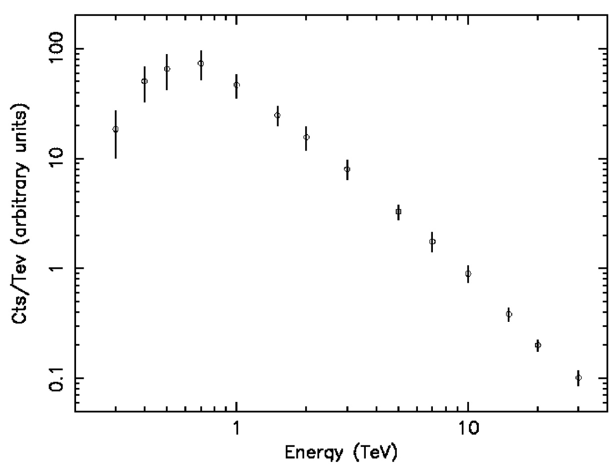

Fig. 1 GAW collecting area has been convolved with a Crab-like spectrum. The fi gure shows the differential detection rate of the Crab Nebula vs energy, which peaks at 0.7 TeV.

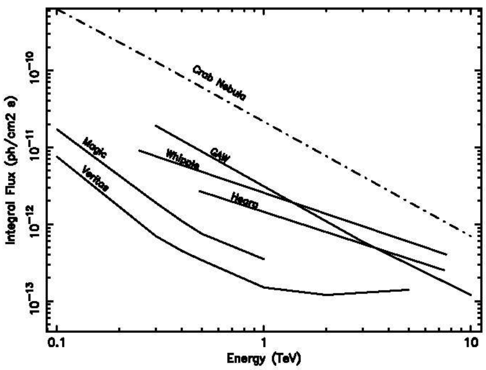

Fig. 2 The sensitivity (5σ) detection of GAW for point-like sources in 50 hours observations.The sensitivity limit is here evaluated in the case of a Crab-like spectrum during the first phase ($6^\circ \times 6^\circ$ FoV) of GAW operation.

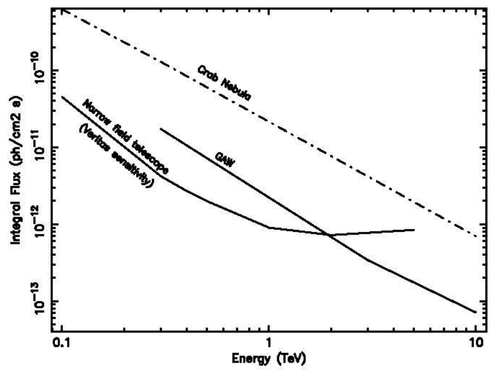

Fig. 3 The capability of GAW to perform deep sky survey with enlarged FoV ($24^\circ \times 24^\circ$). The GAW sensitivity is compared with that reachable in the same time interval by a small field telescope covering the same FoV with many independent pointings.

4 CONCLUSIONS

GAW is and R&D and path-finder experiment to test the possibility of a new generation of IACT telescopes that join high flux sensitivity with large field of view capability using Fresnel lens, single photon counting mode, and stereoscopic observational approach. Thanks to the single photon counting mode, which allows to operate with a very low photoelectrons threshold, an enlargement of the GAW optics diameter could allow a very deep sensitivity observing a field of view one hundred times larger than what the present IACT telescopes can reach.

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