

The Advanced Gamma-ray Imaging System (AGIS): Simulation Studies

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Abstract. The Advanced Gamma-ray Imaging System (AGIS) is a next-generation ground-based gamma-ray observatory being planned in the U.S. The anticipated sensitivity of AGIS is about one order of magnitude better than the sensitivity of current observatories, allowing it to measure gamma-ray emission from a large number of Galactic and extra-galactic sources. We present here results of simulation studies of various possible designs for AGIS. The primary characteristics of the array performance - collecting area, angular resolution, background rejection, and sensitivity - are discussed.

Keywords: gamma-ray observatory; new instruments; simulations

I. INTRODUCTION

Ground-based gamma-ray astronomy has seen a revolution in the present decade with the operation of new instruments like H.E.S.S., MAGIC, and VERITAS. The impressive discoveries of these instruments have demonstrated the scientific potential of the field. This rapid progress is expected to continue with the recently launched Fermi Space Telescope and the next generation of gamma-ray observatories. The new ground-based detectors will consist of large arrays of imaging atmospheric telescopes (IACTs), forming instruments with about 10 times the sensitivity of current-generation gamma-ray observatories, an energy range from 10 GeV to 100 TeV, and a much improved angular resolution of 1-3 arcmin. Two such observatories are currently in development: the Cherenkov Telescope Array (CTA¹) in Europe and the US-led Advanced Gamma-ray Imaging System (AGIS²).

AGIS will consist of a large array of medium sized imaging atmospheric Cherenkov Telescope covering an area of about 1 km² on the ground. The conceptual design for AGIS is an array of 36 wide field-of-view (FOV; 8°) telescopes, each of which has an effective light collection area of 100 m². The wide FOV of the AGIS instruments is motivated scientifically, e.g., to provide a sensitive Galactic plane survey and the mapping of extended sources and is an integral part of the array design. The wide FOV improves the background rejection and angular resolution, because it increases the number

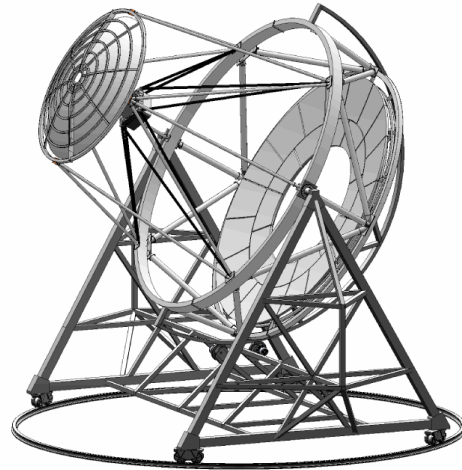


Fig. 1. Model of a AGIS Schwarzschild-Couder telescope and its two-mirror aplanatic optical system.

of telescopes participating in the event reconstruction. This improves the amount of information available for recognizing the nature of the primary (gamma-ray or cosmic ray) and also significantly improves the angular resolution (illustrated in Figure 6). The wide FOV, large array design of AGIS provides significant improvements over a simple \sqrt{N} extrapolation (N = telescope number) that one would expect from simple scaling from current small arrays (VERITAS, H.E.S.S.). Table I lists the preliminary specifications of the 36 element AGIS array.

TABLE I
SPECIFICATIONS OF THE 36 ELEMENT AGIS ARRAY.

	Target
Telescope Spacing	100 - 150 m
Effective Mirror Area per Telescope	100 m ²
Field of View (FOV)	8 deg
Pixelation	0.05 - 0.10 deg
Effective Collection Area	1 km ²
Energy Threshold ³	100 GeV
Angular Resolution	0.02 - 0.05 deg

AGIS uses a two-mirror telescope with a Schwarzschild-Couder optical system [8] [9] combined with a compact modular camera (see Figure 1). This design achieves an excellent point-spread function across the wide FOV and allows at the same time a considerably shorter focal length than traditional IACTs. The compact camera will be equipped with small-sized, integrated photo-sensors such as multianode

¹http://www.cta-observatory.org

²http://www.agis-observatory.org

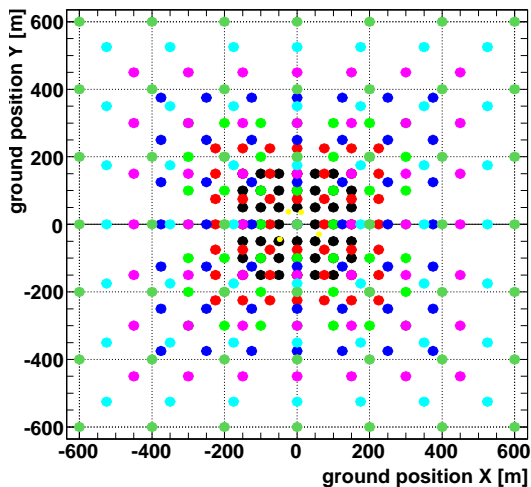


Fig. 2. Telescope positions used in the CORSIKA simulations.

photomultiplier tubes.

II. SIMULATIONS

Detailed simulation studies for optimizing the key performance parameters of the AGIS array are currently in progress; first results are given here. The computations include full air-shower simulations based on CORSIKA [3] [2] and a complete model of the optical and electronic response of the telescopes⁴. The simulations are built on established software tools that have been successfully used for characterizing the VERITAS performance (see e.g. [7]).

The key features of the wide-field-of-view AGIS telescopes, i.e. excellent optical properties and fine pixelation, are taken into account. The simulations show, for example, that an optical point spread function of 0.05° or better can be achieved at any point in the focal plane.

The analysis steps incorporated in the simulation include pedestal calculation, image cleaning, image parameterization, source reconstruction, and calculation of mean-scaled variables for (cosmic-ray) background suppression, similar to those used in the analysis of VERITAS data (see e.g. [1]). The analysis of AGIS events is not yet optimized for the larger number of pixels and telescopes, and therefore, our results are a conservative estimate and are likely to improve.

Different AGIS configurations with pixel sizes between 0.05 deg and 0.20 deg and telescope distances between 50 m and 200 m have been simulated. In order to use computing power most effectively, a large library of simulated CORSIKA events with a 'hyper-array' configuration is currently being generated (see Figure 2). Sub-arrays are selected from this hyper-array in order to optimize angular resolution, effective area and background suppression.

⁴<http://www.physics.utah.edu/gammaray/GrISU/>

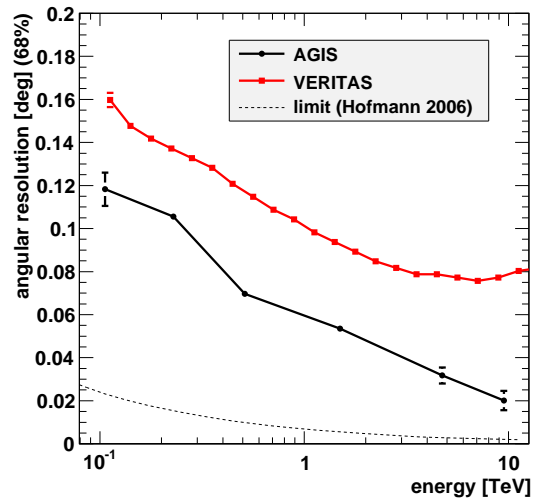


Fig. 3. Angular resolution (with 0.1 deg camera pixels) vs energy for a 36 telescope array with telescope distances of 125 m compared with VERITAS [6] and the theoretical limit as derived in [5].

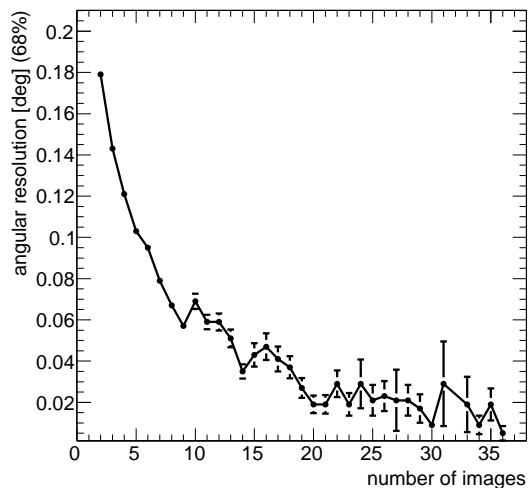


Fig. 4. Angular resolution vs number of images available in the reconstruction at 1 TeV for a 36 telescope array with a telescope distance of 125 m (with 0.1 deg camera pixels).

Figure 6 illustrates the difference between a typical gamma-ray and a cosmic-ray induced air shower. While a gamma-ray event exhibits a consistent image pattern with many telescopes contributing to the reconstruction of the arrival direction, hadronic showers have large fluctuations in their images in different cameras, providing additional background suppression capabilities. Quantitative studies are underway but require very large numbers of hadronic simulations because few events actually pass the primary gamma-ray selection cuts. This already indicates the power of the stereoscopic imaging technique with large arrays.

In addition, by measuring the same shower with many telescopes, a 2-3 times better angular resolution can be achieved for gamma-ray events compared to current

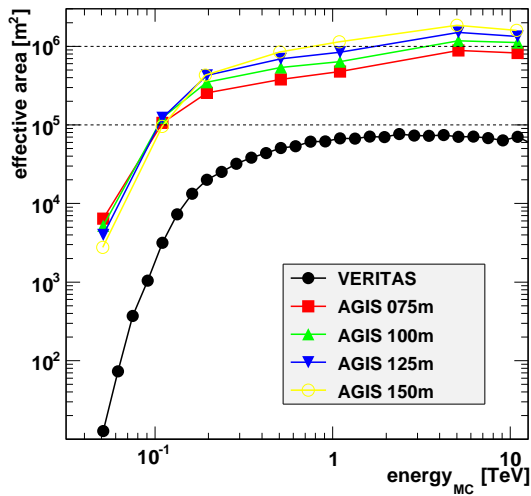


Fig. 5. Effective area vs energy for a 36 telescope array with different telescope distances in comparison with VERITAS [6].

small arrays of IACTs. Figure 3 shows the angular resolution for a 36-telescope array with VERITAS-type telescopes. The improvement in angular resolution compared to VERITAS is due to the larger number of telescopes only, see Figure 4 and [4]. It should be noted that the calculation of the theoretical limit for the angular reconstruction indicated in Figure 3 suggests that an order of magnitude better angular resolution could be possible at higher energies. However, this estimate requires $\approx 10\%$ coverage at the light pool which is impractical while simultaneously trying to optimize the array size. While the full improvement may not be attainable with a real-world instrument, it may be possible to get close to that at multi-TeV energies or at lower energies with a “graded” array composed of telescopes of several different sizes.

Figure 5 shows that an effective area of $\approx 1 \text{ km}^2$ can be achieved with a 36-telescope array. This is a factor of 10 larger than the effective area of VERITAS and results in a factor ≈ 3 improvement in sensitivity by itself. The figure also shows that arrays with small telescope distances ($< 100 \text{ m}$) perform best at energies below 150 GeV, while larger telescope distances are best in the TeV range. The final array layout of the AGIS observatory probably will consist of a dense core surrounded by telescopes at larger distances.

III. CONCLUSIONS

We discussed results from simulations of the next-generation gamma-ray observatory AGIS. It has been shown that compared to the current instruments, a factor of ten improvement in effective area and an angular resolution of 1-3 arcmin can be achieved with the 36 telescope AGIS array.

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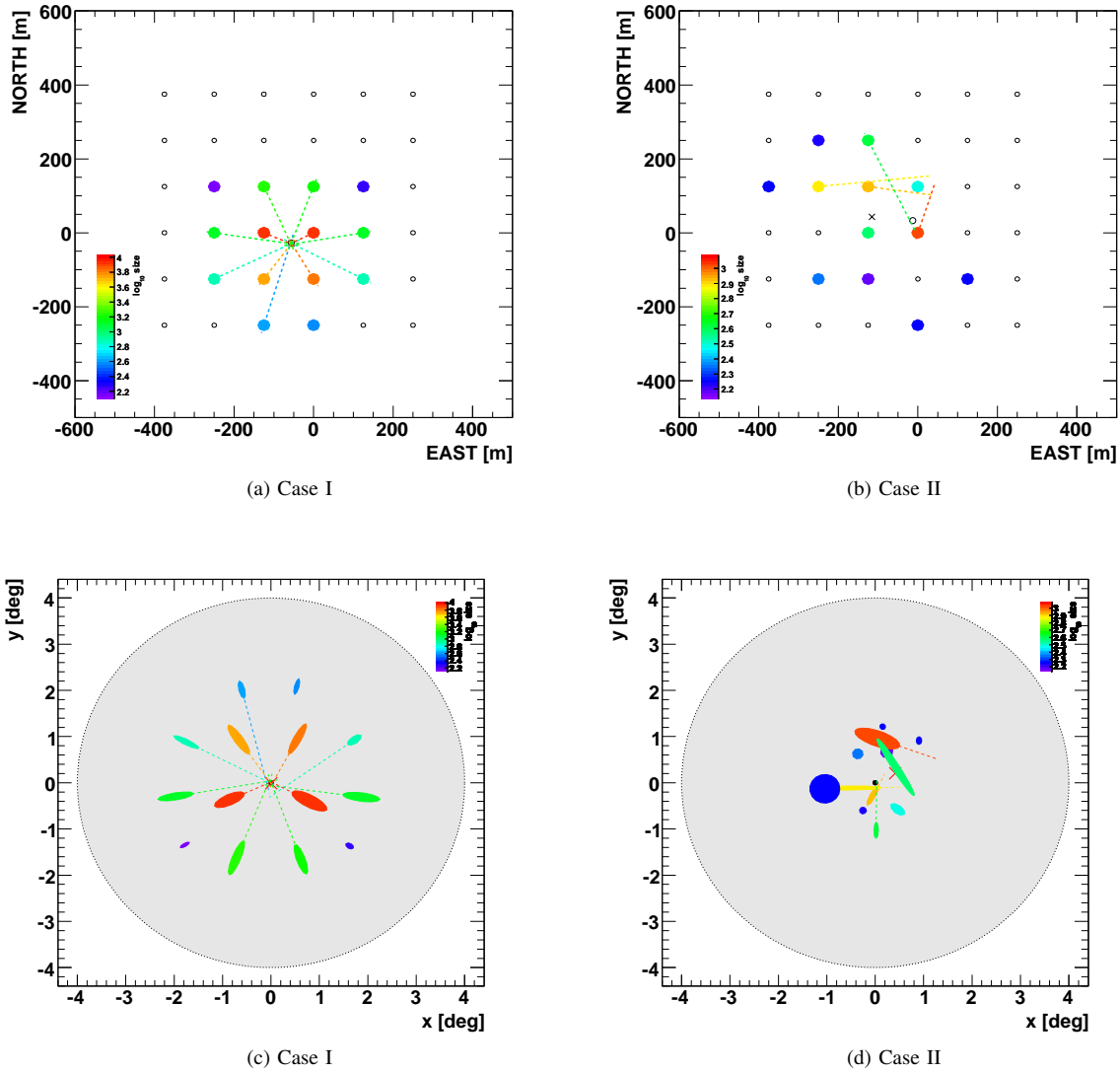


Fig. 6. Detection of a 1 TeV gamma-ray (left figures) and 1 TeV proton shower (right figures) with an array consisting of 36 wide-FOV telescopes. Top: Illustration of the shower core reconstruction (125 m distance between the telescope, which are drawn as black circle. The position of the shower core is indicated by black crosses.) Bottom: Superimposed camera images of the shower from all triggered telescopes. The color code indicates the total number of Cherenkov photons measured by each telescope, the dashed lines show the orientation of the long axes of the images used for core and direction reconstruction.