

Experimental approaches for 100 TeV astronomy

Pierre Colin¹, Stephan LeBohec¹ and Jamie Holder²

¹Department of Physics, University of Utah, Salt Lake City, Utah, USA

²Department of Physics and Astronomy, University of Delaware, Newark, Delaware, USA

E-mail: colin@physics.utah.edu

Abstract. The high energy end of γ -ray source spectra might provide important clues regarding the nature of the processes involved in γ -ray emission. Several galactic sources with hard emission spectra extending up to more than 30 TeV have already been reported. Measurements around 100 TeV and above should be an important goal for the next generation of high energy γ -ray astronomy experiments. Here we present several techniques providing the required exposure ($\sim 100 \text{ km}^2 \cdot h$). We focus our study on three Imaging Atmospheric Cherenkov Technique (IACT) based approaches: low elevation observations, large field of view telescopes, and large telescope arrays. We comment on the advantages and disadvantages of each approach and report simulation based estimates of their energy ranges and sensitivities.

1. Introduction

Questions about the origin of galactic Cosmic Rays (CR) have motivated the development of γ -ray astronomy over 100 GeV as γ -rays from π^0 decay were expected to trace CR acceleration sites [1]. However, measured TeV spectra are most generally explained in terms of Inverse Compton (IC) scattering of photons by high energy electrons. Current observations do not allow to unambiguously identify a hadron component in γ -ray spectra [2]. At higher energy, synchrotron cooling of electrons becomes more important and should cause the IC component of spectra to soften. A cutoff is expected below or around 100 TeV. The γ -rays resulting from hadron processes may not display a similar cutoff [3]. Their contribution could extend up to several hundred TeV depending on CR acceleration maximum energy in the source. Spectral measurements around 100 TeV could provide clear discrimination between electron and hadron processes.

Current experiments are not likely to reach 100 TeV because their limited collection area makes the required exposures unreasonable. It required 5 years ($\sim 400 \text{ h}$ of observation) with the HEGRA experiment [4] to measure the Crab nebula spectrum up to 80 TeV, the highest astrophysical γ -ray energy ever reported. From extrapolating galactic source spectra measured with HEGRA and HESS [5], it appears future projects need to achieve at least $100 \text{ km}^2 \cdot h$ (Figure 1) to obtain meaningful measurements at 100 TeV.

2. Techniques to Obtain the Required Exposure

2.1. Shower front samplers

Ground detectors arrays like Milagro [6] detect charged particles in the air-shower tail. They benefit from a close to 100% duty cycle and with their large field of view they can observe each source for $\sim 1500 \text{ h/year}$. Milagro already offers a large exposure ($\sim 40 \text{ km}^2 \cdot h/year$), but its

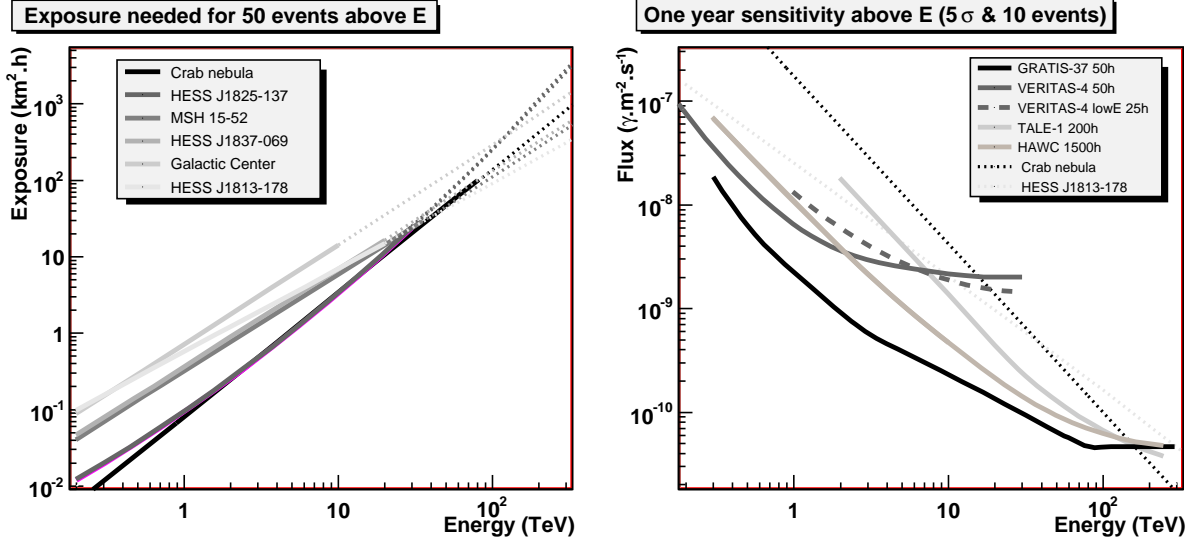


Figure 1. The left-hand side shows the exposure for detecting 50 γ -rays from galactic sources as a function of the energy. The right-hand side shows the sensitivities of several projects (described in the text) compared to a few galactic source spectra.

sensitivity is limited by its angular resolution and its CR discrimination. The HAWC project [7] should be a strong improvement over this. Its effective collection area was estimated up to 10 TeV and is expected to remain constant ($\sim 0.07 \text{ km}^2$) at higher energy. HAWC will reach a $100 \text{ km}^2 \cdot \text{h}$ exposure per year.

2.2. Imaging Atmospheric Cherenkov Technique

IACT can be used only during clear, and usually moonless, nights. The duty cycle is about 10%. Maximal observation time for a source is 200-300 h/year. In order for their science program to be diversified, small field of view (FOV) IACT generally are not dedicated to any given source for more than 100 h/year. To achieve $100 \text{ km}^2 \cdot \text{h}$ exposure per year, future IACT experiments need to offer effective collection areas of at least 1 km^2 with a small FOV or 0.5 km^2 with full-sky survey capability.

The ground level light density is relatively constant within the central plateau ($\sim 130 \text{ m}$ radius for vertical showers) of the Cherenkov light pool and decreases rapidly with the distance from the shower core outside the central plateau. At large zenithal angle the plateau radius is much larger ($>400\text{m}$ at 20° of elevation). The three approaches we identified to use the Cerenkov light distribution are discussed in the next section.

3. Simulation of IACT approaches

3.1. Low elevation observation

At low elevation showers are developing much further away and a single telescope can reach a 1 km^2 collection area even with a small FOV (4°). This observation technique is common [8], providing large collection areas at very high energies. However, several problems and difficulties appear: small images provide poor discrimination and shower reconstruction, large base lines are still necessary for good stereoscopic views, atmospheric monitoring becomes critical and the observing program is much more constrained. For these reasons, a dedicated low elevation experiment does not seem very appealing. Figure 1 shows our estimate of VERITAS [9] 25h sensitivity at low elevation.

3.2. Large field of view telescopes

In order to exploit the tail of the Cherenkov light pool at high elevation, IACT telescopes need a large FOV ($\sim 12^\circ$ for 1 km^2 effective area) [10]. We simulated an 11 m^2 telescope with a $16^\circ \times 16^\circ$ camera based on the design of the TALE project [11] which includes a "Fly's Eye" air fluorescence telescope for the study of CR around 10^{17} eV . With an improved 0.5° pixel camera and 20MHz FADC, the energy threshold is estimated at $\sim 2 \text{ TeV}$ in the plateau and increase as a function impact parameter (10 TeV at 400m and $\sim 100 \text{ TeV}$ at 800m). The effective collection area increases with energy advantageously for sensitivity but makes spectral analysis strongly Monte-Carlo dependent. The angular resolution is about 0.25° at 10 TeV and less than 0.15° over 30 TeV . Assuming a yearly observation time of 200 h (time expected for an all sky-survey over 30° elevation), we estimate the point source sensitivity of a TALE like experiment (see figure 1). This curve does not include the effects of γ -ray shower image shape discrimination capabilities which still have to be studied.

3.3. Large Telescope arrays

A large area telescope array (CTA, HE-Astro [12], TenTen [13], GRATIS) could be made to indefinitely extend the collection area. Projects of this type are expensive and challenging because of the large number of units involved. They also offer the best γ -ray discrimination and reconstruction capabilities [14]. The Gamma-Ray Astrophysical Telescope Imaging System (GRATIS) is a minimal approach to a 0.3-100 TeV large array, consisting of 37 5.4 m diameter telescopes with 4° FOV ($253 \text{ } 0.25^\circ$ pixels), covering 1 km^2 in a 200 m spaced hexagonal lattice. Any point in the array is less than 115 m from a telescope ($<$ Cherenkov plateau radius). From simulations of just one triangular cell we estimate the energy threshold ($\sim 300 \text{ GeV}$), angular resolution ($\sim 0.15^\circ$ at 1 TeV and $\sim 0.05^\circ$ above 10 TeV) and CR rejection. Figure 1 shows the GRATIS sensitivity of the 54 triangles in the array. This sensitivity is conservative at high energies as showers do trigger more than 3 telescopes improving rejection and angular resolution, and because γ -rays with impact parameters outside the array are not included in this estimate.

4. Conclusion

Recent findings in the field of TeV astronomy provide motivation for extending the covered energy range to more than 100 TeV where γ -ray emission models can be better discriminated. Simulation-based estimates of various experimental approaches to 100 TeV astronomy are compared. Large arrays of IACT telescopes seem the most attractive from the point of view of the sensitivity they offer. Even a relatively low cost ($\$ 17\text{M}$) project such as GRATIS provides sufficient sensitivity to measure many galactic source spectra from 300 GeV to more than 100 TeV. With their all sky survey capability in an uncharted energy window, projects like HAWC or even TALE have a great and complementary exploratory potential.

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