Design of an Air Fluorescence Telescope Sensitive at EeV

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Abstract

The discovery of an anisotropy of comic ray flux coming from near the center of the galaxy is briefly discussed. Several design parameters for a new air fluorescence telescope designed to be sensitive at the anisotropy energies are then studied.

1 Introduction

The majority of cosmic rays observed on Earth are thought to originate from our galaxy. For sufficiently small energies, our present understanding of astrophysics predicts that objects such as black holes and supernova should be sources of cosmic rays. However, for energies greater than $10^{18} eV$, our present understanding of cosmic ray acceleration via galactic mechanisms is poor. This is complicated by the fact that until recently, the observed cosmic ray flux was found to be quite isotropic. There had been no pin pointed sources. For charged cosmic rays, the observed isotropy is at least partially explained by the scrambling of arrival directions via galactic magnetic fields, but for energies between 10^{18} and $10^{19} eV$ and an estimated galactic magnetic field strength of $1 \mu G$, the Larmor radius of a charged particle is on the scale of the size of the galaxy [1] and hence can be confidently traced back to it's source.

The major problem with cosmic ray detection is the low rate of arrival. The observed flux follows the empirical power law of $J \sim E^{-3}$. For cosmic ray energies on the order of $10^{14} eV$, there is enough flux for direct detection with airborne detectors and detectors on spacecraft. But for cosmic ray energies on the order of $10^{18} eV$, the flux is much lower; $J \sim 1 \; particle \; / \; km^2 \cdot year$ which is much too small for direct detection. Fortunately nature provides a great high energy cosmic ray detector; the atmosphere itself. The atmosphere can behave like a giant scintillator. When a cosmic ray enters the atmosphere, if it has a high enough energy, it can interact with the atmosphere creating massive airshowers of highly energetic particles. These particles can emit Cherenkov radiation if charged, and via collisions, can cause the nitrogen in the atmosphere to fluoresce. The fluorescence and Cherenkov radiation is much easier to detect than the original incident particle and can be seen from very far away. Thus a relatively small detector can observe a large portion of the sky for atmospheric scintillation and help make up for the low arrival flux.

In 1999 the Akeno Giant Air Shower Array (AGASA) group reported the discovery of a large anisotropy in the cosmic ray flux coming from near the center of the galaxy [1]. The excess observed flux is 4σ away from the background isotropy [2] and occurs in the narrow energy range of $10^{17.9} - 10^{18.3} eV$ [1]. Thus the observed anisotropy displays characteristics of a point source emitter. This discovery has also been observed by the SUGAR air shower detector as well as by the Fly's Eye experiment in Utah. The exact source and mechanism responsible for the anisotropy is not yet known. The acquisition of data taken from the southern hemisphere and the determination of the cosmic ray energy spectrum is needed.

The proposed new cosmic ray telescope will be an airshower detector designed to be most sensitive at $10^{18} eV$. Proposed to be built in Australia, the telescope design consists of two arrays of 15 spherical mirrors with each mirror having it's own photo multiplier tube camera. Each mirror will view a $15^o \times 15^o$ area of the sky and each array of mirrors will view a 45^o range in the zenith angle and a 60^o range in the azimuthal angle. The two arrays of mirrors are separated by several kilometers in order to get a stereo view of fluorescence tracks in the sky.

2 Analysis

The quantity of interest when designing a telescope is it's aperture defined by

$$A \equiv \Omega\sigma\frac{N_{obs}}{N_{tot}}$$

where Ω is the solid angle of viewed cosmic ray arrival directions, σ in the total area viewed by the telescope and N_{obs}/N_{tot} is the ratio of observed events to the total number of events that occurred. In order for an event to be counted as observed, it must be reconstructible in energy as well as in arrival direction. There are essentially two parameters that can be varied in order to achieve a sensitivity at a particular energy, i.e. maximizing aperture at that energy. These parameters are the separation distance between the arrays of mirrors and the zenith angle range viewed by each array. For example, a low energy cosmic ray will not produce much fluorescence light and will not penetrate the atmosphere much. It's observation would require a telescope that looks very high in the sky and who's mirror arrays are not greatly separated so that each array can observe the dim fluorescence. For a higher energy cosmic ray, the opposite is true. The particle will penetrate deep into the atmosphere before interacting and produce a much more intense atmospheric scintillation. Thus it would require a lower viewing elevation and permit a larger separation distance between the mirror arrays.

In order to gather statistics on the telescope, Monte Carlo simulations were run at varying separation distances and zenith angles. These simulations were run at energies of 10^{17}, 10^{18} and $10^{19} eV$ in order to determine what set of parameters maximized the aperture at $10^{18} eV$ and how sensitive these values would be to comic ray energy. Both the cosmic ray trajectory and the intensity along it's trajectory were reconstructed from the Monte Carlo data. A histogram of the trajectory angular error per event, defined as the angle between the true trajectory and the fitted trajectory, was created to determine the trajectory angular variance for each telescope configuration. Each histogram bin corresponded to a ring on the coordinate sphere that was at an angle δ to the true arrival direction. The angular width of each bin was defined such that each ring covered the same solid angle of the sphere. The trajectory angular variance was then defined as the 68% point of the resulting histogram.

An event was counted as observed if the shower intensity maximum was detected by at least one array of mirrors. For each array of mirrors, the shower intensity was binned along the angular arc length that the cosmic ray was detected on and a Gaussian curve was fit to the resulting histogram. If the peak of the Gaussian fit occurred in the angular window that the cosmic ray was detected in, the shower maximum was observed and the event itself was counted as observed.

3 Resultsand Conclusions

Figures 1,2 and 3 show plots of aperture verses separation distance for three zenith viewing ranges at 10^{17}, 10^{18}, and $10^{19} eV$ respectfully. For $E = 10^{17} eV$, the optimum zenith viewing range was found to be $19^o < \theta < 59^o$. This range corresponded to an aperture maximum that occurs at an array separation distance of less than $3km$ and a trajectory angular variance of 3^o. At $E = 10^{18} eV$, the optimum zenith viewing range was also found to be $19^o < \theta < 59^o$. This range corresponded to an aperture maximum that occurred at a separation distance of $10km$ and an trajectory angular variance of 1.5^o. Results for $E = 10^{19} eV$ showed that the optimum zenith viewing range is $46^o < \theta < 86^o$. This range corresponded to an aperture maximum that occurred at a separation distance of $30km$ and a trajectory angular variance of 2^o.

For an air fluorescence telescope to be sensitive at $10^{18} eV$, the optimum design parameters will exclude cosmic rays with energies on the order of $10^{17} eV$. In figure 1 at a separation distance of $10km$, it is clear that $10^{17} eV$ is well below the observational threshold. The results for 10^{17} and $10^{18} eV$, show that at these energies, the airshower maximum occurs high in the atmosphere and thus requires a higher zenith viewing angle. From the results for $10^{19} eV$, it is evident that a telescope sensitive to $10^{18} eV$ will have the capacity to observe higher energy particles. Moreover, at $10^{19} eV$ and at a separation distance of $10km$, the optimum zenith viewing range is the same as that for $10^{18} eV$. From all three sets of results, it is clear that a telescope's parameters must be fine tuned to a particular energy.

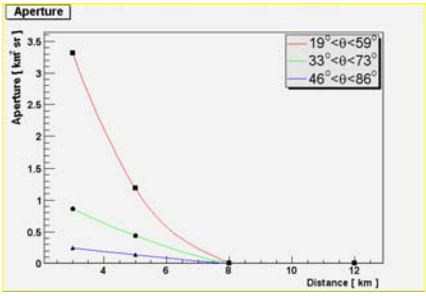

Figure 1. $E = 10^{17} eV$.

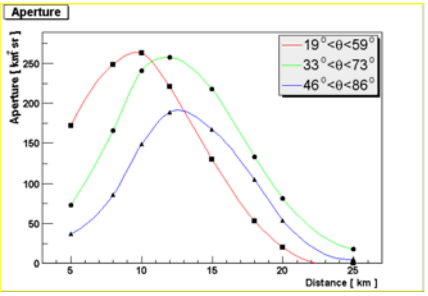

Figure 2. $E = 10^{18} eV$.

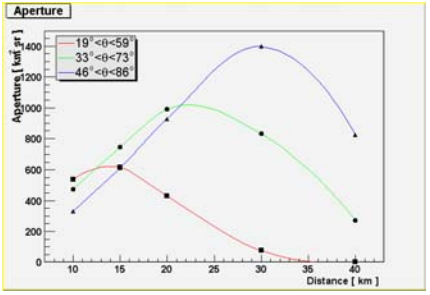

Figure 3. $E = 10^{19} eV$.

References

[1] J.A. Bellido et al., Astroparticle Phys. (2001) 167-175.

[2] N. Hayashida et al.,Astroparticle Phys. (1999) 303-311