GRaNDScan - An Experiment to Study Cosmic Ray Flux and Anisotropy Around and Below EeV

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Abstract

For our understanding of the origin of ultra high energy cosmic rays, the energy region between 10^{17} and 10^{19} eV is of crucial importance. Previous experiments have found indirect evidence that at these energies, the origin of cosmic rays changes from predominantly Galactic to extragalactic. In addition, weak evidence for an excess of cosmic rays from the direction of the Galactic center in a narrow energy band around 10^{18} eV has been claimed.

However, so far there is no additional evidence supporting this scenario. Neither Galactic nor extragalactic sources have been unambiguously established. Given the importance of this energy range, there is a strong case for a dedicated experiment to study the EeV energy region with high precision.

We describe the design and capabilities of a portable air fluorescence detector for stereo viewing of air showers at sub-EeV energies. Located at a site on the southern hemisphere, the instrument proposed here will provide an accurate map of the Galactic center region, long suspected to harbor one or several sources of ultra high energy cosmic rays. It will provide information on the chemical composition of any observed excess, and measure the energy spectrum in the region of the second knee.

1. Introduction

The goal of GRaNDScan* is to study the energy spectrum, chemical composition, and arrival direction of cosmic rays in the energy range from 10^{17} to 10^{19} eV with high sensitivity from a site with good visibility of the Galactic center region.

The case for this study is strong in several respects. By concentrating on this energy range, GRaNDScan will provide data of unprecedented quality in a region where

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* *G*amma *R*ay *a*nd *N*eutron *D*ecay *Scan* of the Galaxy

- the cosmic ray energy spectrum shows features, the ‘ankle’ and (less prominent) the ‘second knee,’
- the chemical composition undergoes an important change from a heavier to a lighter mixture,
- a cosmic ray flux enhancement from the region around the Galactic center has been claimed.

Most of these features have not been studied with a dedicated instrument, and consequently their statistical significance is unsatisfying at this point.

In our current understanding, the changes in composition and energy spectrum around EeV are indicative of a transition in the nature of the cosmic ray origin itself. Whereas cosmic rays below EeV are mostly Galactic in origin, a new extragalactic component becomes dominant at higher energies.

Unfortunately, there is no *direct* evidence that supports this general picture – neither Galactic sources at energies below the ankle nor extragalactic sources at higher energies have been unambiguously detected. The most likely acceleration site in our own Galaxy is the region around the Galactic center, which stands out as its most energetic region. Radio, far infrared and γ-ray data indicate that the star formation and supernova activity of our Galaxy peaks in the center. This general picture is confirmed by studies of other disk galaxies. Correlations of data at radio and infrared wavelengths suggest that the cosmic ray production is generally higher in galactic center regions, just as the star formation rate is higher.

Earlier results from AGASA [1], SUGAR [2], and Fly’s Eye [3] indicate that the Galactic center region may indeed harbor one or several sources of cosmic rays at 10^{18} eV. However, the statistical significance of the results is poor, mainly because these experiments were not optimized for the study of the Galactic center region in this energy range. An important goal of GRaNDScan is to clarify this unsatisfying situation and establish or disprove claims of an enhanced flux from the Galactic center with high significance.

The AGASA and SUGAR results naturally raise the question of the chemical nature of the cosmic ray flux from sources inside our Galaxy. While protons cannot reach us without deflection, it is well known that neutrons with energy 1 EeV can traverse the Galactic field undisturbed and reach us un-decayed from the Galactic center, a mere 8 kpc from the solar system. With higher energies, neutrons could reach us from anywhere in our Galaxy. In short, a properly designed detector could use neutrons as a tool for performing tomographic searches for sources of cosmic rays in our Galaxy. It is therefore of crucial importance that the instrument is able to distinguish the average chemical composition of air showers – we can then compare the region of an observed excess (on source) to

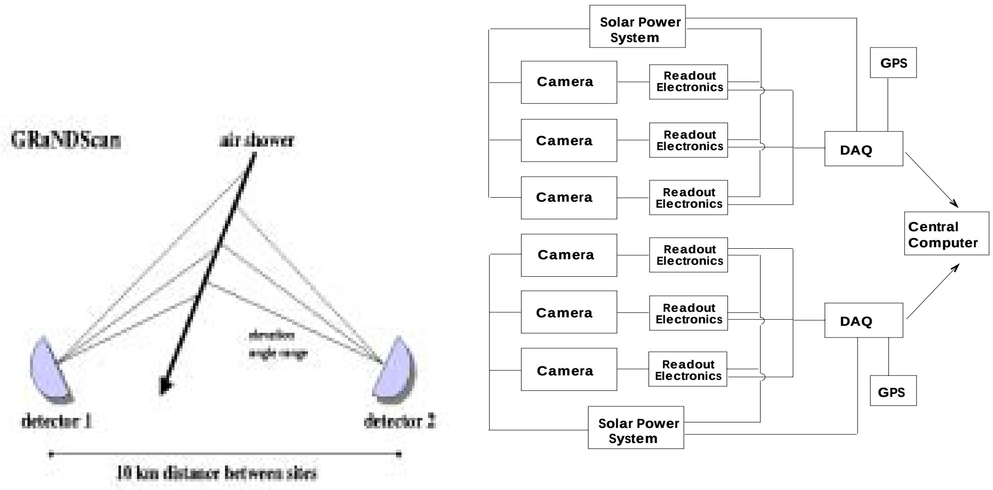

Fig. 1. Scheme of the detector layout.

its surroundings (off source). For a neutron source, we expect a light composition on source and a heavy composition off source.

The basic requirements are therefore excellent energy resolution, good angular resolution, and the ability to discriminate between different primaries, mainly γ's, hadrons, and heavier nuclei like iron. All composition studies rely heavily on the quality of our understanding of the first interaction of cosmic ray primaries in the atmosphere and the development of the shower cascade. However, this dependence can be minimized with a detector that *directly* observes the development of the shower cascade. The air fluorescence technique meets all these requirements, and GRaNDScan is designed as an air fluorescence detector in the tradition of the Fly's Eye and the HiRes experiment.

2. Basic Design

The design for GRaNDScan has been driven by the attempt to achieve a maximum aperture for stereoscopic observation of air showers while keeping the number of telescopes small. In the baseline design, GRaNDScan is an air fluorescence detector with two sites about 10 km apart which are facing each other and therefore view a common volume of atmosphere.

Each site consists of several reflecting telescopes, each with a 3.4 m diameter mirror for light collection and a photomultiplier camera in its focal plane (see [4] for a more detailed description). Each telescope covers a field of view of 30° by 30°. The large field of view has been chosen to keep the number of detector units small. With 3 mirrors at each site, a range of 90° in azimuth and 30° in zenith angle can be covered. The axis of the mirror has an angle to the horizontal of

50°. The number of camera units, the pointing direction in zenith angle and the distance between the sites are chosen to maximize the aperture of the detector in the relevant energy region around 10^{18} eV. Covering a larger range in azimuth and zenith increases the aperture, but at 10^{18} eV, detected showers are mainly "local," *i.e.* close to both detector sites. Most of the sensitivity can be achieved with fewer units if we only consider the atmospheric volume in between the sites.

The experimental challenge for GRaNDScan is to overcome an infrastructure problem. Air fluorescence detectors require sites without light pollution and with excellent atmospheric conditions, which implies remote (desert) areas. The costs for installing power lines to remote locations is prohibitive. However, with recent developments in low power electronics and large analog memories it is for the first time feasible to design and develop an air fluorescence camera that operates on solar power alone. This means that only a minimal amount of infrastructure is required and operating costs are kept at a minimum. The minimal infrastructure also allows the detectors to be easily moved or reconfigured to cover a different energy regime.

A crucial element of GRaNDScan is the light detector used in the air fluorescence camera, which needs to be light in weight for instrumenting a remote detector. Tests with a photomultiplier under consideration are described in [4]. Current off-the-shelf solar power units deliver about 50 W for 5 to 6 hours per 1 m^2 paddel size. Therefore the limit on the average power consumption per channel for an air fluorescence camera with a 30° by 30° field of view and just under 1000 photomultiplier channels running for 6 hours during a typical data taking night is 50 to 100 mW per channel for one or two paddels, roughly two orders of magnitude lower than current current cameras. A camera will ultimately consist of low power and high power elements, the goal is to keep the power consuming elements dormant most of the time and only activate them when an intelligent second-level trigger identifies a shower candidate.

Details on the design of GRaNDScan and results from detector simulations will be presented at the conference. A White Paper is currently available as astro-ph/0303484.

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