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Introduction: The OASIS Hadron Calorimeter is intended to measure the cosmic ray hydrogen and helium spectra from 10^{12} eV to $>10^{16}$ eV.

Astrophysicists have known for decades that particles below 10^{14} eV have different characteristics than particles above 10^{16} eV, as shown in figure 1. The slope of the energy spectra of particles above 10^{16} eV is slightly steeper than those below 10^{14} eV. The energy 10^{15} eV seems to be a "knee" in this curve. The primary objective of OASIS is to investigate this "knee" to find how it is related to the mechanisms of cosmic ray acceleration and propagation -- one of the major questions in particle astrophysics today.

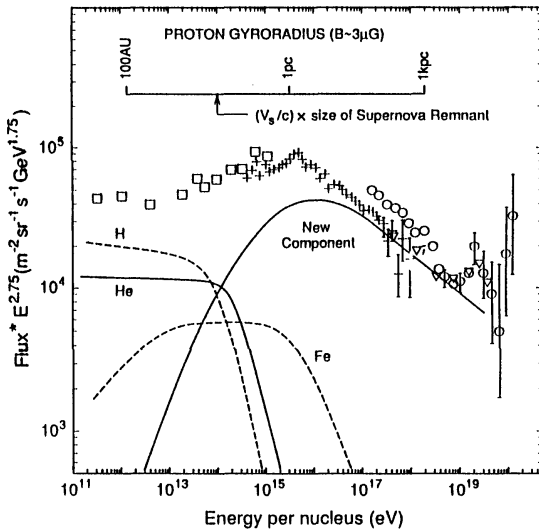


Figure 1: The differential galactic cosmic ray all-particle spectrum (note that the vertical axis is flattened by a multiplicative factor of $E^{2.75}$). The figure shows how the spectrum steepens just below 10^{16} eV. Also shown are predictions of the individual elemental spectra for H, He and Fe and a hypnotized new component needed to explain the spectrum at higher energies.

As can be seen in Figure 1, an extrapolation of the measured cosmic ray elemental spectra to higher energies, based on models for shock acceleration of cosmic rays by supernova blast waves, falls short of accounting for the measured all-particle spectrum above 10^{14} eV. This shortfall can be made up by introducing a new component as shown in figure 1 or in other ways such those reviewed in [1].

The idea of using a calorimeter in space to make direct measurements of high energy cosmic rays is an old one. The first such measurements were made by N. L. Grigorov in the four Proton satellite missions back in the 1960's. Since then there have been many proposals for cosmic ray calorimeters in space. The most recent concept, ACCESS has been extensively studied (see [2]). OASIS is designed to extend spectral measurements one log decade beyond ACCESS so that the spectra above the "knee" can be measured directly.

Cosmic Ray Calorimeter Design: Calorimeters make cosmic rays exhibit their energy by causing them to shower in a massive target. The nuclear charge of the cosmic ray is measured before it enters the target. The target must be thick enough in interaction mean free paths to interact the cosmic ray. This interaction will produce π^0 's and other particles. The interaction needs to occur with enough residual range in the target for the shower past its maximum. The π^0 's from the interaction decay producing gamma rays that give rise to an electromagnetic (electrons and gamma rays) cascade. This is the principle source of particles in the shower. To develop this shower past its maximum, the target material needs to be thick in radiation lengths also.

Because of the large number of electrons and gamma rays created in the electromagnetic cascade, the target needs good tracking of the shower axis so that the trajectory of the incident cosmic ray can be predicted. To measure the nuclear charge of the incident cosmic ray, it is necessary to use a highly pixilated dE/dx detector so the signal of the incident cosmic ray can be measured separately from the signals due to backscatter.

The Mission Concept: The plan for the OASIS mission is to launch it on the first test flight of ORION V, NASA's cargo launch vehicle [3]. The payload capacity of Aries V to orbit is 130 metric tons. This will allow us to launch a calorimeter that is 5 meters in diameter and 6 meters in height. The mass of target will be water. Water has a relatively short interaction nuclear interaction mean free path.

Water is the most valuable resource in space. It can be used for life support, energy production, propulsion and radiation protection. This calorimeter will be

available as a >100 metric ton reservoir of water for use in space after the experiment is finished.

The Instrument Concept: The nuclear interaction mean free path in water is 84 cm for protons. The height of the target will be 600 cm or 7 interaction mean free paths for protons.

The radiation length in water is 36 cm. The target will be constructed with cylindrical tanks containing the water. The walls of these tanks will incorporate tungsten. The radiation length in tungsten is 3.5 mm so the tungsten tanks walls will shorten the average radiation length of the target. This is needed to develop the electromagnetic cascades so the showers can be followed past their maxima in the calorimeter.

These tanks will be separated by scintillating fiber layers to provide tracking of the shower and sampling of the developing cascade. Phototubes can also be used to collect Cherenkov light from the water in the tanks to improve the energy resolution of the calorimeter.

There will be two-layer matrices of pixilated silicon detectors on the top and bottom of the target volume. These silicon matrices will be used to measure the nuclear charge of the incident cosmic ray, separating it from the signals due to backscattered particles from the shower in the target. The pixilated silicon detectors for these matrices have been developed by us for the Zero Degree Detector System [4].

The geometry factor for particles entering either end of the cylindrical target on trajectories that would exit the opposite end of the cylinder is $18.6 \text{ m}^2\text{-ster}$. The exposure needed to reach 10^{16} eV at 30% statistical accuracy for each charge group is $\sim 55 \text{ m}^2\text{-ster-yr}$. This can be achieved with three years of operations.

The instrument described here will produce data from scintillating fiber, Cherenkov signals in the water tanks as well as the dE/dx signals from the silicon layers. Each event will contain perhaps 4 kbits of data but the event rate will be quite low due to the low cosmic ray flux at these energies. The result will be a low average data rate for the instrument.

Summary: This white paper describes an instrument concept that utilizes a test launch of the Aries V launch vehicle to place a large cosmic ray calorimeter in space that is capable of extending direct measurements of galactic cosmic rays beyond the “knee” of the cosmic ray all-particle spectrum. Such a data set would allow us to test the various theoretical models for the “knee”. These models include ones that predict the discovery of new cosmic ray sources, new modes of acceleration, acceleration in special classes of supernovae and propagation effects as the cause of the “knee”.

References:

[1] Biermann Peter L., Moiseenko Sergej, Ter-Antonyan Samvel and Vasile Ana, p. 489 - 516 (2003), *astro-ph/*

[2] Streitmatter R. E. and Swordy S. P., “ACCESS: A Cosmic Journey”, published by NASA/GSFC (2000), available at <http://access.uchicago.edu/access.pdf>.

[3] Aries V Cargo Launch Vehicle Fact Sheet <http://www.nasa.gov/centers/marshall/pdf/151451main8-40599-CaLV.pdf>

[4] Adams J. H., Christl M. J., Howell, L. W. and Kuznetsov, E., submitted to *Nuclear Instruments and Methods* (2006).