Characteristics of Ultra-Heavy Cosmic ray Nuclei in the PeV-EeV Energy Region

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Abstract

We discuss the possible presence of Ultra Heavy (UH) (Z> 26) nuclei in the cosmic ray flux in the PeV-EeV region. Although there are no existing measurements of these nuclei in this energy region, there are suggestions that the UH nuclear flux could be 10^{-3} of the cosmic ray flux in this energy region. We discuss possible signatures of this flux in existing cosmic ray measurements, and describe future simulation work needed to translate these existing measurements into meaningful upper limits. Results from this simulation work will be presented at the Conference.

1. Science of UH nuclei in EHE cosmic ray region

The canonical theoretical model of cosmic ray origin between 1 GeV and 1 PeV includes obtaining source material from supernova, acceleration of the material by multiple scattering in the shock wave generated by the expanding envelope of a supernova remnant (SNR) [3,5] and propagation through the interstellar medium to the observation point at Earth. This model naturally predicts a power law energy spectrum with the proper spectral index as well as the observed spectral cutoff above 100 TeV[11]. If the average propagation length continues to decrease above 100 TeV, the model predicts a heavy composition at the cutoff energy[12].

UH elements emerge from late stage evolution processes of stars, most notably through supernova r-process and s-process nucleosynthesis. Consequently, the relative fluxes of these nuclei are sensitive probes of elemental conditions during the supernova, and may well be affected by recently observed neutrino flavor oscillation. The presence of UH nuclei in the PeV-EeV cosmic ray flux therefore may provide strong evidence for GZK energy acceleration regions nearby UH nuclear sources such as supernova remnants.It should be noted that that TeV gamma ray observatories have yet to unambiguously observe TeV gamma rays in SNR due to pion production/decay from cosmic ray interactions with the ambient SNR material [1].

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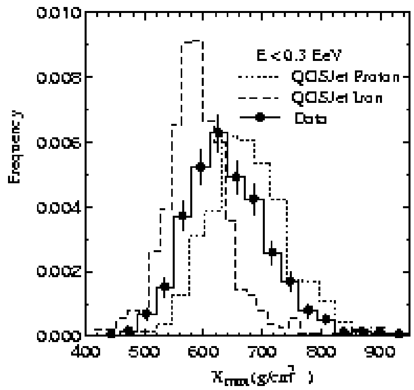

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Fig. 1. Best fitting primary composition model to generate measured X_{max} distributions in various energy bins from the HiRes detector[2]. the presence of a strong flux of UH nuclei would generate a distribution of points to the left of the Iron distribution (and to the left of the measured distributions), The absence of observed events can be translated into a meaningful flux limit.

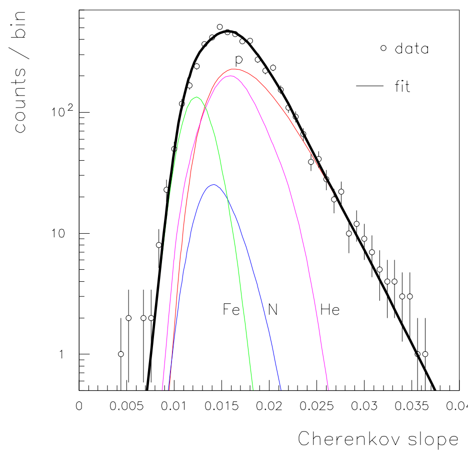

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Fig. 2. Best fitting primary composition model to generate measured distribution of slope parameter from BLANCA experiment[6]. Small Excess of distribution at small slope parameter is in approximate location where UH nuclei may be expected to be located. These points will likely provide limitation in extending sensitivity to 10^{-3} of the cosmic ray flux, where UH nuclei should begin to be observable.

Predictions for the level of UH nuclei in the cosmic ray flux have been made [10] by extrapolating UH measurements made by the HEAO-3 satellite in the GeV range [4] to the PeV energy range using a leaky-box propagation model with a saturated pathlength distribution [13]. The flux of these particles is about 10^{-3} of the primary flux at PeV energies, which should be observable if sufficient statistics and charge resolution are present in the experimental data sample.

2. Existing Measurements

There are no measurements of UH cosmic ray nuclei in the TeV-PeV energy region. The only possibility to measure cosmic rays with such a low flux is to use ground based Extensive Air Shower detectors. Existing composition measurements of PeV cosmic rays by experiments such as BLANCA [6], KASCADE[8] and Hires Fly's Eye [2] have only considered the possibility of nuclei up to iron in their previous analyses. However, the fluctuation distributions of the composition measurables for both of experiments (Figures 1 and 2) cannot rule out the presence of a flux of UH nuclei which could be on the order of up to several percent. In order to establish firm upper limits on the presence of these nuclei, the fluctuation distributions in the measurable composition parameters must be reliably established as these experiments do not possess capability to measure primary charge with high resolution. Recent suggestions concerning the possible use of 'Direct Cerenkov' light to perform high resolution charge measurements [9] may open up the possibility to unambiguously identify UH nuclei in next-generation TeV Imaging Atmospheric Čerenkov arrays such as HESS, CANGAROO, or VERITAS[15].

3. Simulated UH nuclei Longitudinal development

In order to explore whether the BLANCA and HiRes Fly's Eye experiments have sensitivity for detection of PeV to EeV UH nuclei, Monte Caro simulations study must be performed to examine capability of the detectors to identify the primary signature of these nuclei: a higher depth of shower maximum X_{max} than Iron nuclei at a given energy.

The standard air shower development used by HiRes and BLANCA, called CORSIKA[7], is physically unable to simulate nuclei beyond iron. Consequently we have developed a fragmentation code which simulates the breakup of UH nuclei in the atmosphere into lighter fragments which CORSIKA can process, and then sums the resulting outputs of each fragment to generate the full simulation of the UH initiated shower.

A simple example of this simulation can be performed using a fragmentation algorithm with a simple log energy dependent energy splitting and multiplicity algorithm with log increase in total cross section, and nuclear cross-sections scaling as $A^{2/3}$ Figure 3 demonstrates the difference in the longitudinal profile for a 1 EeV very heavy (Uranium) primary nucleus under these simplified assumptions, and compares the longitudinal development with standard proton and iron simulations.

In order to calculate reasonable flux limits from the experiments, a realistic nuclear-nuclear interaction model such as DPMJET, NEXUS or QGSJET extrapolated to UH nuclei, must be employed. The resulting simulated showers must then be passed through the standard analysis packages for the HiRes and BLANCA detectors to establish flux levels/limits for existence of UH nuclei. Results from these simulations will be presented at the conference.

4. References

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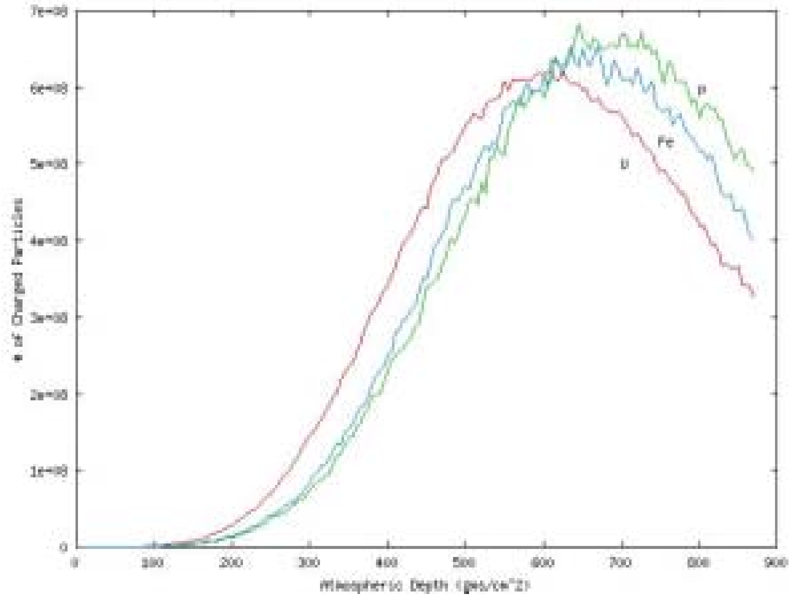

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Fig. 3. Longitudinal Development of three 10^{18} eV primary cosmic rays using the CORSIKA model. P and Fe simulations use standard CORSIKA QGS-jet model; U uses a simplified fragmentation procedure to break the heavy nucleus ($Z > 26$) into lighter ($Z \leq 26$) fragments which CORSKIA can process.

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