Energy Spectra and Relative Abundances of Heavy Cosmic-ray Nuclei around 1 TeV/nucleon

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Abstract

We describe a measurement of the intensities of heavy primary cosmic-ray nuclei with the Transition Radiation Array for Cosmic Energetic Radiation (TRACER) up to energies around a few TeV/nucleon. Absolute cosmic-ray fluxes are presented for O, Ne, Mg, Si, and Fe obtained during a one-day test flight from Ft. Sumner, NM in preparation for a 20-day circum-polar balloon flight. The results of TRACER are largely consistent with previous observations in this energy range.

Introduction

Direct measurements of the elemental composition and energy spectra of cosmic-ray nuclei at high energies, beyond a TeV/nucleon, and approaching the cosmic-ray *knee* above total energies of 10^{15} eV, are expected to provide a sensitive test of the current paradigm that all cosmic rays are generated with the same energy spectrum at the source, up to a maximum rigidity around 10^{14} V for shock acceleration in supernova remnants, and that their propagation pathlength through the galaxy decreases with increasing energy. However, new observational data are slow in coming because the low particle intensity necessitates long exposures of very large-area instruments. With this need in mind, TRACER was constructed for a long-duration balloon flight. A successful 30-hour test flight was conducted from Ft. Sumner, NM, in September 1999. A subsequent long-duration balloon flight along the Northern Polar circle could not be accomplished due to lack of required international agreements. The instrument is currently scheduled for a long-duration flight in Antarctica in 2003/4. This report will present and discuss results obtained with the 1999 test flight.

The Instrument

Figure 1 shows the detector arrangement. The main elements are (a) plas-

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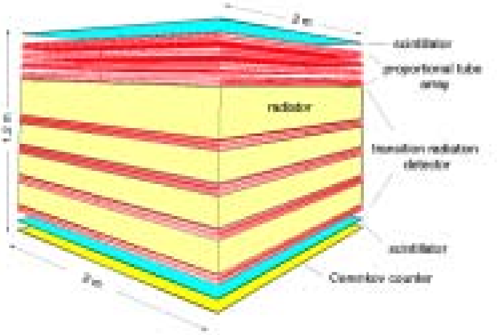

Fig. 1. TRACER schematic

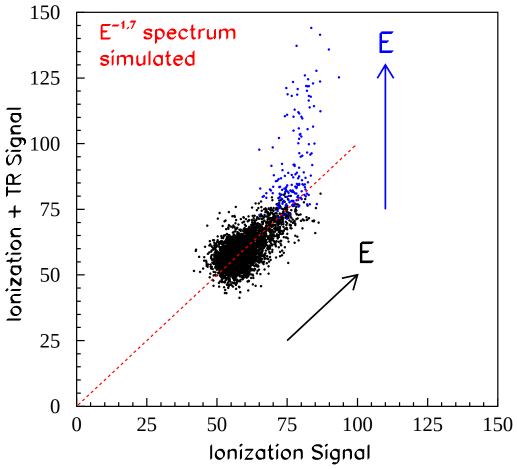

Fig. 2. Identification of TR events

tic scintillators on top and at the bottom of the detector stack, (b) an acrylic Čerenkov counter at the bottom, and (c) eight double layers of single-wire proportional tubes (a total of $\sim$ 1600 tubes, each 2 m long and 1 cm in radius) to measure the specific ionization of traversing cosmic rays, and for the lower four layers, to measure the superimposed transition radiation signals generated in plastic fiber radiators. The scintillators serve as coincidence triggers and measure the nuclear charge, Z. The Čerenkov counter rejects particles with energies below the minimum ionization level and also provides an energy measurement around 10 GeV/nucleon. The proportional tube arrays determine the particle energy from the relativistic increase in the specific ionization, and for Lorentz factors, $\gamma = E/mc^2 > 500$, from transition radiation signals. The tube signals also provide an accurate determination of the trajectory of each particle through the instrument.

1. Data Analysis and Results

After the particle trajectories are reconstructed and the scintillator and Čerenkov signals corrected for zenith angles and spatial non-uniformity in response, the nuclear charge, Z, is determined. The dynamic range available for the signal readout of the tubes limits the current measurement to the charge range from oxygen ($Z = 8$) to iron ($Z = 26$). The further data analysis is aided by extensive Monte Carlo calculations of all details of the detector response based on the GEANT 4 code. Wherever possible, the simulations are verified with data from flight or from accelerator calibrations. Some details are described by Gahbauer et al. (this conference). Figure 2 illustrates the simulated response of the pro-

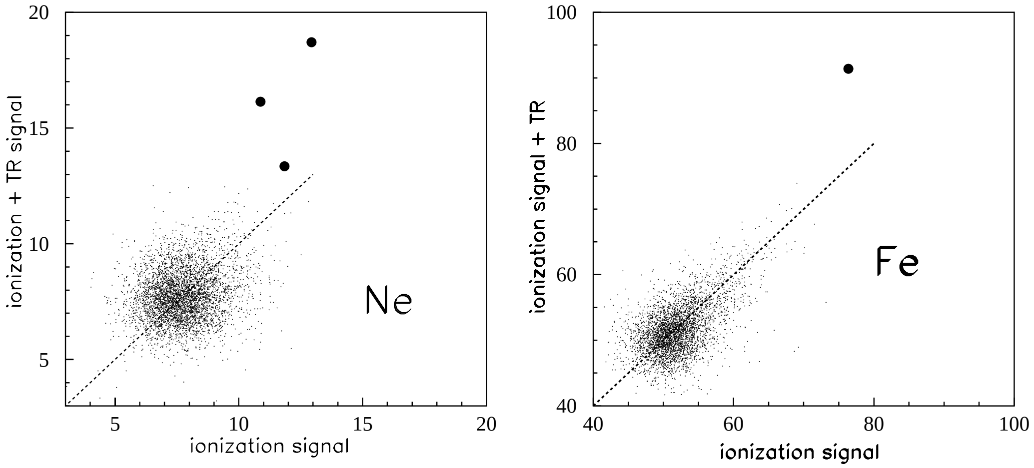

Fig. 3. Identification of highest energy events from the flight.

Neon (left) and iron (right).

portional tube arrays for a power law energy spectrum of incident Fe-nuclei. The signals in the TRD-tubes (measuring specific ionization with TR superimposed) are plotted versus those in the upper tube layers that measure specific ionization only (*ionization signal*). The bulk of the particles are minimum ionizing, but the signal increases with energy for both tube arrays in the same proportion, until the onset of TR production leads to significantly larger signals in the TRD system only. This figure clearly illustrates not only the average trend of the signals with energy, but also the fluctuation levels.

Figure 3 shows measured cosmic-ray data for two primary nuclear species. The short duration of the test flight led to a small yield of nuclei at very high energies. Nevertheless, the lack of background in these satter-plots makes possible a clean identification of even a few high-energy particles.

Finally, we obtain absolute particle intensities at the top of the atmosphere after corrections for detector inefficiencies and for losses due to interactions in the atmosphere or in the detector material, and after deconvolving the non-linear energy response of the detector. These results are shown in Figure 4, in comparison to results previsouly reported from the CRN instrument on the Space Shuttle [1], and from measurements on the HEAO-3 satellite [2]. Within the statistical uncertainties, we notice good agreement between the three data sets, even though the instruments are significantly different. For the spectrum of iron nuclei, Figure 4 also includes a prediction of possible spectra for different galactic propagation models [3]. The available data cannot discriminate between these different possibilities, but improved statistics from long-duration flights should

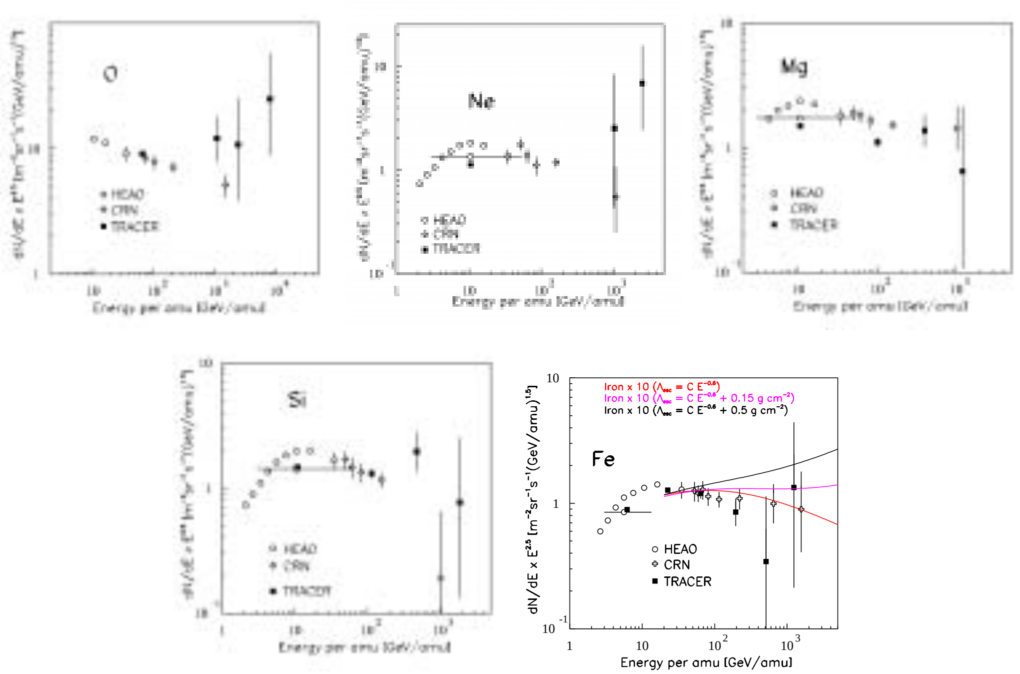

Fig. 4. Spectra for O, Ne, Mg, Si, Fe

lead to meaningful constraints on models such as those illustrated in Figure 4.

Conclusion

The TRACER instrument is different in many design details and response characteristics from previous detectors such as CRN. In particular, the use of proportional tube arrays represents a new approach that makes the use of a pressurized gondola unnecessary. The test flight of TRACER verifies the design, provides new cosmic-ray data in an important energy regime that agree with previous measurements, and gives confidence towards a significantly extended energy coverage in the upcoming long-duration flight.

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