The Trans-Iron Galactic Element Recorder(TIGER): A Balloon-borne Cosmic-Ray Experiment

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Abstract

TIGER is a balloon-borne cosmic-ray experiment designed to measure the elemental abundances of Galactic Cosmic Rays (GCRs) in the charge range 26$\leq$ Z $\leq$40 with better than 0.25 charge unit(cu) resolution. The experiment consists of a combination of plastic scintillators, plastic and aerogel Cherenkov detectors, and scintillating fiber hodoscopes. TIGER was flown from Fort Sumner, NM aboard a high-altitude balloon on September 24, 1997 at geomagnetic cutoffs between 4.2GV and 3.2GV, and atmospheric depths between 3g/cm^2 and 6g/cm^2. The 23.5-hour balloon flight provided a statistically significant sample of GCR nuclei up through Ni and achieved charge resolution capable of resolving Co from the much more abundant Fe.

1 Introduction:

The Trans-Iron Galactic Element Recorder (TIGER) is a balloon-borne cosmic-ray experiment that utilizes plastic scintillation counters, plastic and aerogel Cherenkov counters , and scintillating optical fiber hodoscopes. It was designed to show that the elemental abundances of Ultra-Heavy GCRs, cosmic rays in the charge range 26$\leq$ Z $\leq$40, could be measured with resolution better than 0.25 cu over a large energy range. This version of TIGER is a prototype for the Charge Identification Module (ZIM) on the Advanced Cosmic Ray Composition Experiment for the Space Station (ACCESS) (Binns *et al.* 1997, 1999) and for the experiment selected for the Ultra-Long Duration Balloon Flight Demo2000 (Link *et al.* 1999) which will fly for 100 days in the year 2001. TIGER was flown from Fort Sumner, NM on September 24, 1997 at atmospheric depths between 3g/cm^2 and 6g/cm^2 for approximately 23.5 hours. The vertical geomagnetic cut-off varied from about 4.2 GV to 3.2 GV.

We have been able to measure the Co/Ni abundance ratio using data from this flight. This is an interesting and important measurement because it can put limits on the time between the nucleosynthesis and acceleration of cosmic rays. The Cosmic Ray Isotope Spectrometer (CRIS) on the Advanced Composition Explorer(ACE) has measured isotopes of Co and Ni at energies $<$ 500 MeV/nucleon. That measurement found that ^{59}Ni, which decays only by electron capture, has all decayed to ^{59}Co, implying that acceleration occurred more than 10^5 years after nucleosynthesis (Weidenbeck *et al.* 1998). At higher energies, isotopic data are not available, but elemental abundances can put constraints on the decay of ^{59}Ni. Englemann *et al.*(1990) measured a Co/Ni ratio of $\approx$ .12 at about 1 GeV/nucleon. Balloon measurements of this ratio, extrapolated to the top of the atmosphere, have been 0.17$\pm$0.05 (Dwyer & Meyer, 1985), and 0.26$\pm$0.11 (Esposito *et al.* 1992). The measurement TIGER makes of the Co/Ni ratio will help resolve this discrepancy.

2 The TIGER Instrument:

The TIGER instrument contains three scintillation counters with wave-length-shifter-bar readout and three

Cherenkov detectors: 1 acrylic (n = 1.5) radiator in a light box , 1 aerogel (n = 1.04) radiator in a light box, and 1 wavelength-shifter-bar readout Cherenkov detector with an acrylic radiator. (See Figure 1.) The latter detector is a new model being tested for possible use on ZIM . The scintillation counters and the two light-box Cherenkov counters together provide charge and velocity measurements of the cosmic rays, provided that pathlength through the instrument can be determined. The 68 Photomultiplier Tubes (PMTs) from the scintillators and Cherenkov detectors are each individually pulse-height analyzed.

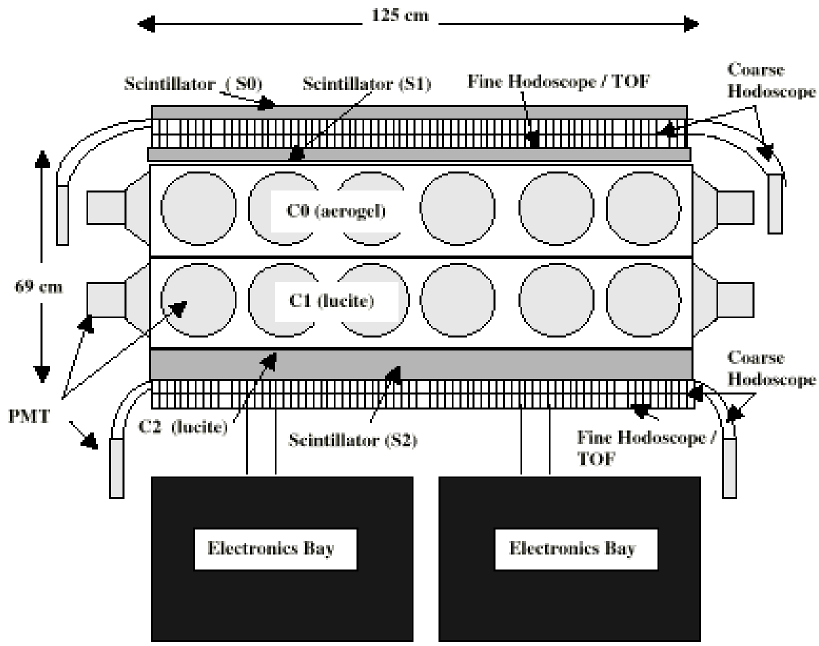

Figure 1: Cross-section of the TIGER instrument

The trajectory of each cosmic ray through the instrument is measured to within a few millimeters using a Coarse Hodoscope and a coded Fine Hodoscope. Each consists of two planes of 1.5mm x 1.5mm square scintillating optical fibers, one at the top of the stack and one at the bottom. Each plane has two layers of fibers, one each in the X and Y directions. The Coarse Hodoscope determines position to within 8cm and the Fine Hodoscope determines position to within 6mm. (Lawrence, 1996; Sposato *et al.* 1997)

3 Data Analysis:

We first corrected the data from from the 1997 balloon flight for variations in pathlength using the hodoscopes. The angle (θ) with which the particles traverse the instrument was determined, and then each of the scintillator and Cherenkov signals was divided by sec(θ). Next we corrected the data for areal response variations. After the initial sec(θ) correction was applied, the data still showed a residual sec(θ) dependence. This effect was greatest in the scintillator at the top of the stack, while the data from the scintillator at the bottom of the stack did not show this effect. This residual dependence is probably related to the change in energy deposition of knock-on electrons with depth in the detector stack. We removed this effect by empirically fitting the angle dependence of the Fe peaks in the top two scintillators.

We then made cuts to reject particles that interacted in the detector stack. Two criteria were used for selection. First, the charge measured in S0 and S1 must agree to within 0.7 cu. Then the average of (S0 + S1) must agree with S2 to within 0.7 cu. Figure 2 shows the data after the aforementioned cuts and corrections were made. On the ordinates of A and B, we plot $S^{0.59}$ where S = (S0 +S1 + S2). We obtained the exponent empirically: $S^{0.59} \propto Z$. The exponent is not 0.50 because of scintillator saturation. On the abscissa of A, we plot $(C_{1.5})^{0.50}/ S^{0.59}$, which is a function of energy, independent of charge. On B, we plot $(C_{1.04})^{0.50}/ S^{0.59}$ for the same reason. There is no saturation in either of the Cherenkov detectors, so $C^{0.50} \propto Z$. A small number of events with $(C_{1.5})^{0.50}/S^{0.59} < 0.28$ (energy $<$ 0.8 GeV/nucleon) were removed from the data-set.

For events with $(C_{1.04})^{0.5}/ S^{0.59} <0.13$, energy below the Aerogel threshold of $\approx$ 2.5 GeV/nucleon, (region 1, Figure 2B.), we fit the $S^{0.59}$ vs. $(C_{1.5})^{0.5}/ S^{0.59}$ Fe with the following 2^{nd} degree polynomial to correct for variations of $S^{0.59}$ with energy:

$$S^{0.59} = 710.01 - 1101.18 \times (C_{1.5}{}^{0.5}/S^{0.59}) + 1226.06 \times (C_{1.5}{}^{0.5}/S^{0.59})^2.$$

The charge resolution in energy region 1 is 0.25 cu. (See Figure 3.)

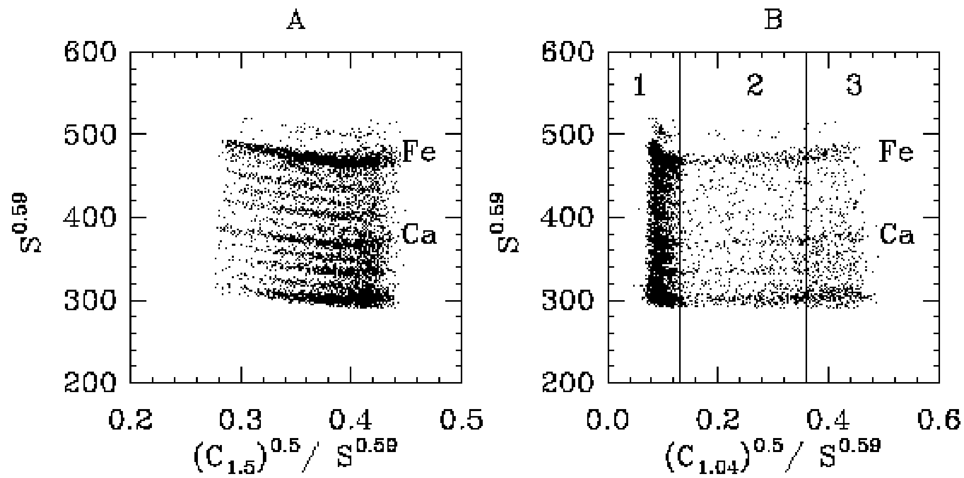

Figure 2: **A:** Data from the acrylic Cherenkov detector and the scintillators. **B:** Data from the aerogel Cherenkov detector and the scintillators. (See text for more details.)

For events with 0.13 $<(C_{1.04})^{0.5}/S^{0.59}<$0.37, energies of 2.5 - 7.5 GeV/nucleon, (region 2, Figure 2B.) we fit the $S^{0.59}$ vs. $(C_{1.04})^{0.5}/S^{0.59}$ Fe with the following 2^{nd} degree polynomial to correct for $S^{0.59}$ variations:

$$S^{0.59} = 474.12 - 63.90 \times (C_{1.04}{}^{0.5}/S^{0.59}) + 176.07 \times (C_{1.04}{}^{0.5}/S^{0.59})^2.$$

The charge resolution in energy region 2 is 0.3 cu. (See Figure 4.) Analysis of energy region 3 is in progress and will be presented at the conference.

The Co/Ni ratio measured at the instrument (TIGER) and at the Top of the Atmosphere(TOA) are shown in Table 1. We have used empirical curves from Israel *et al.*(1979) for Mn/Fe versus atmospheric depth, assuming that Mn/Fe and Co/Ni have the same atmospheric dependence. The Mn/Fe ratio grows with atmospheric depth(x) as exp(x/Λ), where Λ^{-1} = 0.0343 $\pm$0.0052.

Energy(GeV/nucleon)	TIGER	TOA
0.8 - 2.5	0.17$\pm$0.06*	0.13$\pm$0.05
2.5 - 7.5	$<$ 0.15**	$<$ 0.12**
0.8 - 7.5	0.13$\pm$0.04*	0.10$\pm$0.03

Table 1: Co/Ni ratio measured at TIGER and at the TOA. *(*Statistical error only. **1 σ upper limit.)*

4 Discussion:

Our Co/Ni measurement is consistent with that made by Englemann *et al.* at similiar energies and is marginally consistent with those made by Esposito *et al.* and Dwyer & Meyer at similar energies. Webber & Gupta(1990) calculate that if none of the ^{59}Ni has decayed, the Co/Ni ratio at these energies would be about 0.10; the ratio would be about 0.15 if the ^{59}Ni had all decayed to ^{59}Co. Our (and Englemann's) result could thus be interpreted to suggest that cosmic rays observed at a few GeV/nucleon were accelerated in a time $\leq$ the ^{59}Ni electron-capture half-life (8x10^4 yrs). This is in disagreement with the clear ACE/CRIS result for lower-energy cosmic rays where complete decay of ^{59}Ni is observed, indicating an acceleration delay $>$ 10^5yrs. This disagreement suggests that either the cross-sections are incorrect, or the propagation model is incorrect, or differences ex-

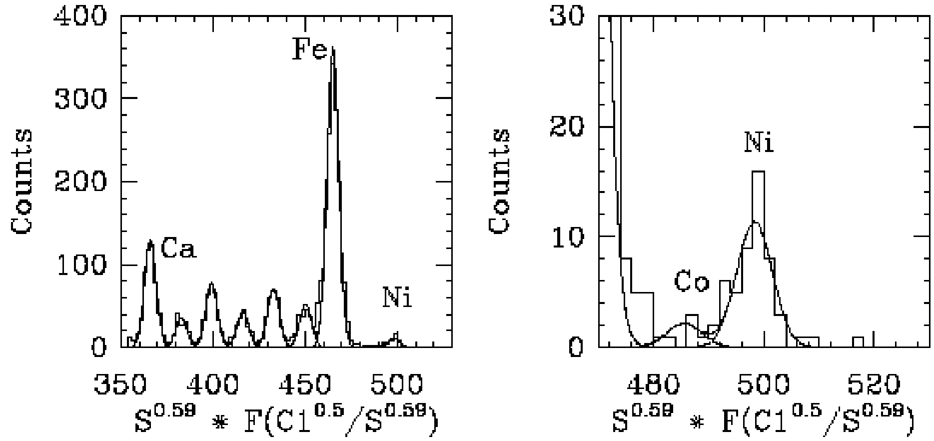

Figure 3: Histogram of Fe region data for energies between 0.8 - 2.5 Gev/n.

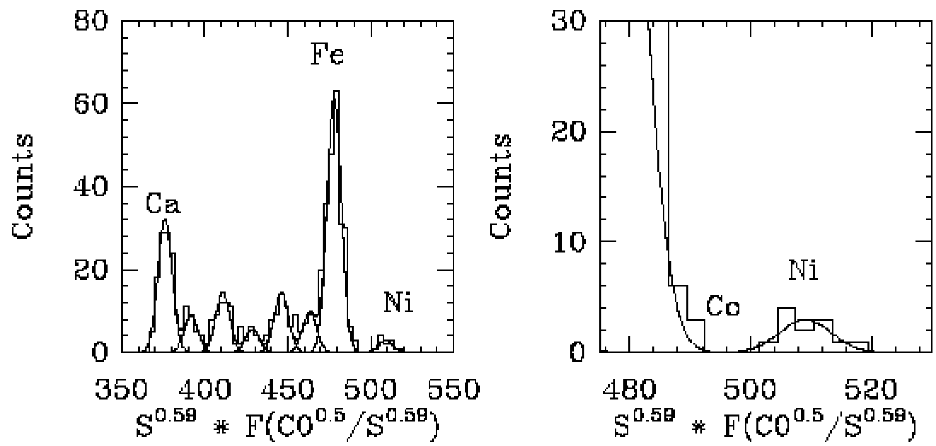

Figure 4: Histogram of Fe region data for energies between 2.5 - 7.5 Gev/n.

ist in the time delay between nucleosynthesis and acceleration for GCRs observed at 500 MeV/nucleon and 1 GeV/nucleon.

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