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The Trans-Iron Galactic Element Recorder for the Ultra-Long Duration Balloon Project Demo 2000

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Abstract

The Trans-Iron Galactic Element Recorder (TIGER) for the Ultra-Long Duration Balloon project Demo2000 (TD2K) is designed to measure the abundances of all elements in the Galactic Cosmic Rays (GCRs) with $26 \le Z \le 40$ and energies above 300 MeV/nucleon. TD2K's flight is expected to approach 100 days in length. Launch will be from New Zealand in 2001. TD2K will have sufficiently good resolution to measure the individual abundances of the odd-Z elements between Z=26 and Z=40 for the first time. Measurements of odd-Z nuclei are important for distinguishing between the effects of first-ionization potential and volatility in the injection process for ultraheavy GCRs, for models of nucleosynthesis, and constraining models of cosmic-ray propagation at short pathlengths. TD2K uses a combination of Cherenkov and scintillation counters to determine the atomic number and energy of incident cosmic rays, and a coded scintillating-fiber hodoscope for trajectory corrections. TD2K is an improved version of the TIGER instrument flown in 1997, results from which are reported at this conference (Sposato et al., 1999). We will present the status of the TD2K instrument and of the ULDB program as it affects the Demo 2000 flight.

1 Introduction:

While the exact source and acceleration mechanism of galactic cosmic rays (GCRs) is unknown, there is convincing evidence that all but perhaps the most energetic of cosmic rays originate in and are confined to our galaxy. There is a general consensus that those cosmic rays with an energy per nucleus below about 10^{14} eV are accelerated by exploding supernova. (Ginzburg & Syrovatskii, 1964) The source of the material for the cosmic rays is still an outstanding question in astrophysics. With the TD2K experiment we hope to be able to produce new data that will put constraints on the possible GCR source.

A key piece of information as to the source of GCR is the comparison between the general abundances of elements in the solar system and the measured cosmic-ray abundances observed here at Earth, which can be corrected for the effects of fragmentation during propagation to give the abundances at the GCR source. Observations of the galactic cosmic rays have led to two possible sources for the material of GCR: stellar atmospheres and interstellar material enhanced by material from interstellar dust grains. To differentiate between these two sources we must determine whether first ionization potential (FIP) or volatility governs GCR abundances.

In comparing the cosmic-ray source abundances relative to the solar system abundances it has been noted that the abundances of low-FIP (FIP less than about 10 eV) elements are roughly four times that of elements of high-FIP (FIP greater than about 10 eV). This observation has lead to the theory that the source of GCR are nuclei in stellar atmospheres at temperatures of about 10^4 K where elements of low-FIP are much more likely to be ionized than elements of high-FIP. (Casse & Goret, 1978) In this model cosmic-ray fractionation is governed by the FIP of the element.

An alternative model (Cesarsky & Bibring, 1981) suggests instead the source is interstellar gas, enriched by atoms sputtered off of interstellar dust grains. In this model volatility governs cosmic-ray fractionation and refractory elements are enriched in the cosmic rays. The elemental abundances in GCR expected to be observed from this model have recently been shown to be very close to solar system abundances (Meyer et al., 1997; Ellison et al.,1997). Since almost all of the low-FIP elements observed to date are also refractory, differentiation between these two models cannot be reliably distinguished looking at current data on cosmic ray elemental abundance.

To differentiate between these two processes and hence the possible source of GCR, we need to look for those rare elements that are either not high-FIP but refractory or are low-FIP but volatile and are present in sufficient numbers for observation. One such element is $_{37}$Rb, which is a low-FIP element that is not refractory. The TD2K experiment will have sufficient collection power and charge resolution to provide a definite measurement of the $_{37}$Rb abundance in the GCR.

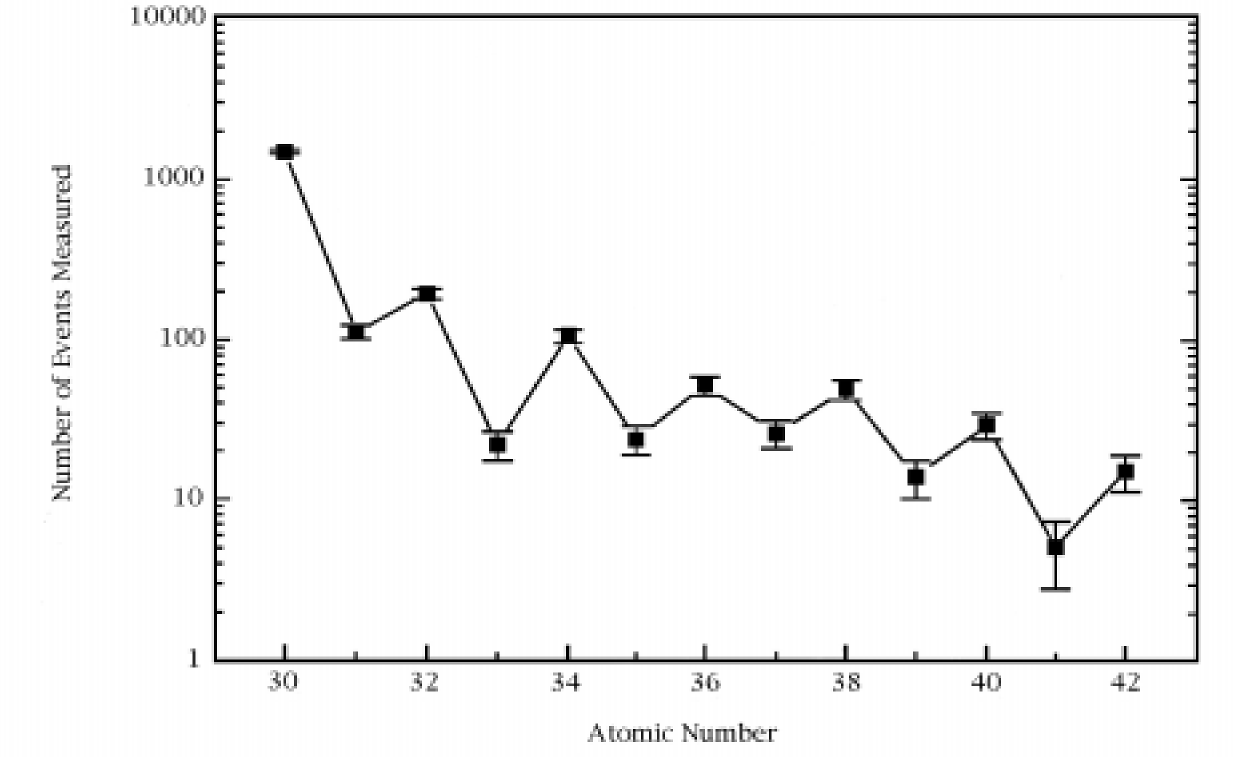

Figure 1: Expected UH events observed by TD2K during a 100 day flight based on charge pair information from the HEAO-C3 experiment and results of a propagation of solar system material from the cosmic ray source to the top of the atmosphere. (Waddington, 1998)

In addition to being able to provide insight to the GCR source, the TD2K instrument will also be able to provide a test for current cosmic-ray propagation models. Currently these models are largely based on data from lighter primary and secondary elements (Waddington et al., 1997). The best test of these models comes from measurements of individual elements whose abundances are expected to be low in comparison with the abundances of heavier elements. Among UH elements, some of the best such elements are the odd-Z elements, which have not previously been measured by any instrument. The TD2K instrument will allow us to have a first look at some of these odd-Z elemental abundances and see if the current propagation models are valid with these results. More extensive measurements of the UH odd-Z elements will be possible with instruments such as the ZIM, a detector based on the TIGER and TD2K detectors being developed for deployment on the International Space Station. (Binns et al., 1997, 1999)

2. Instrumentation

2.1 The TIGER-DEMO2000 Instrument (TD2K)

The TD2K instrument is a cosmic-ray telescope utilizing four plastic scintillation counters, two Cherenkov counters with radiators of different refractive indices and a scintillating fiber trajectory detector (hodoscope). These elements have been successfully tested on a 23-hour balloon flight from Ft. Sumner NM in September of 1997 (Sposato et al., 1999). The TD2K detector stack measures 160cm x 160 cm x 60 cm yielding an active area of 115cm x 115cm and a total geometry factor of 2 m^2sr.

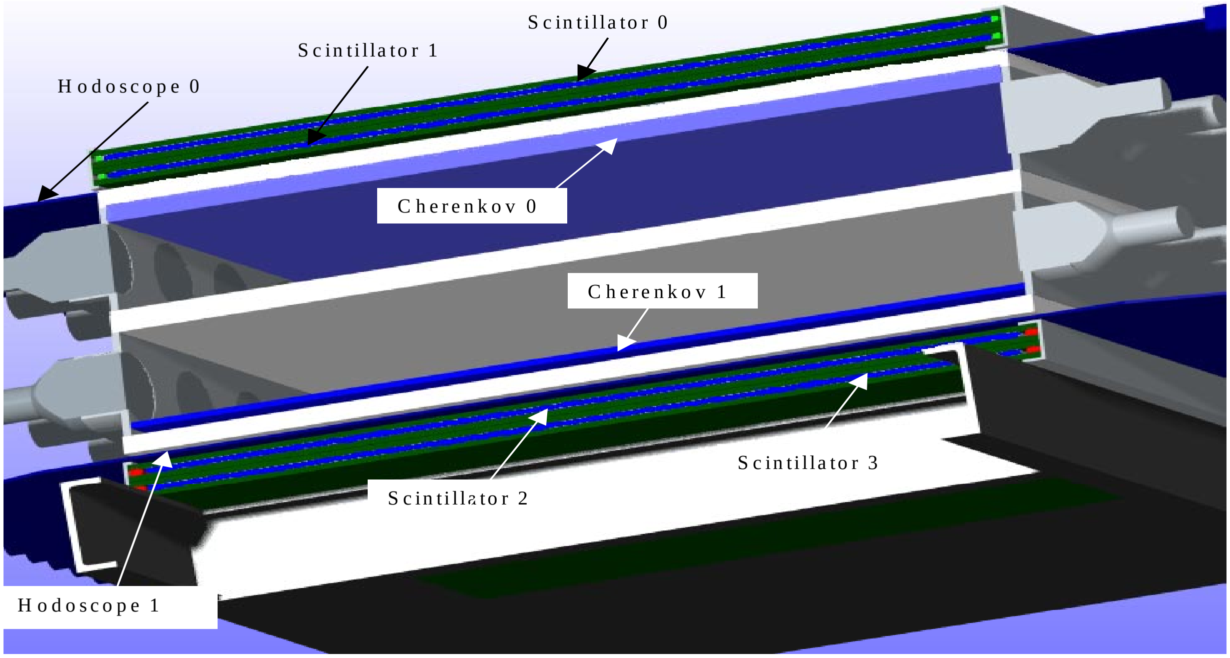

Figure 2: Cross Section of the TD2K Instrument

The two scintillation counters over the top hodoscope provide a primary dE/dx measurement while the bottom scintillators determine whether or not particles have interacted as they have passed through the detector. The scintillator signal depends on the Z, E and angle of the particle passing through it. The scintillators consist of an 8mm-thick radiator viewed on edge by four wavelength shifter bars (WLSB). A fraction of the scintillation light produced from particles passing through the scintillator is light piped to the edge of the scintillator by total internal reflection and into the WLSB along its edge. The WLSB are surrounded on 3 sides by aluminized mylar to optimize the conversion of light in each bar. The light entering the WLSB is absorbed and then re-emitted isotropically; a portion of the re-emitted light is lightpiped to the end of the bar. Each WLSB has a PMT coupled to each end. The light measured by the PMT is proportional to the energy lost in the radiator and the light collection efficiency of the area of scintillator the particle passes through.

The two Cherenkov counters are used to determine the velocity (energy) of particles up to about 10 GeV/nucleon. They are also used in conjunction with the scintillators to identify the charge of a particle passing through the detector. Their signal is proportional to Z^2 of the particle passing through it, as well as being a strong function of particle's velocity. Using two Cherenkov detectors with different refractive indices allows us to make a velocity correction to the charge identification from the scintillation detector, which improves the overall charge resolution of our telescope. The first Cherenkov counter consists of a 3cm-thick aerogel (n=1.04) radiator mounted in a light collection box , the second consists of an acrylic (n=1.5) radiator located at the bottom of a light collection box identical to the other Cherenkov counter.

The fiber hodoscope is composed of four 117cm x 117cm planes of scintillating optical fibers. When a cosmic-ray nucleus passes through the detector it will hit one fiber in each of the four hodoscope planes. The fibers scintillate and the light from them is read by the PMTs coupled to the ends of the fiber. The fibers are 1mm square and grouped in tabs of 6 fibers giving us 196 tabs for each hodoscope plane. Rather than couple each fiber tab to a PMT, we use a coding scheme to decrease the total number of PMTs needed for readout. On one end of the hodoscope, tabs 1-14 are coupled to a PMT, then tabs 15-29 are coupled to another tube, and so until all 196 tabs are coupled to 14 PMTs. On the other end we take tabs 1, 15, 29 etc. and couple them to a PMT and then couple tabs 2, 16, 30 etc. to the next PMT and so on until all the tabs on the other edge are coupled to a second set of 14 PMTs. This coding scheme ensures that each fiber tab is read out by a unique pair of PMTs, allowing us to make readout of the active area of all four of the hodoscope planes with only 112 PMTs (28 for each plane). The four fiber planes yield two x and two y measurements allowing us to determine the straight line trajectory of a particle passing through the detector with position segments of 6mm width (corresponding to resolution, $\sigma = 1.7$mm).

Overall we expect to obtain enough events over the duration of our flight to make definitive measurements of cosmic ray elements over a range of $10 \leq Z \leq 40$. Based on tests made of our detectors during the 1997 TIGER flight and a 1998 Brookhaven accelerator test, we expect to obtain a charge resolution of <0.25 charge units which should be sufficient to resolve both even and odd elements up to a Z of 40 and make a definitive measurement of these elements. Although it may be possible to see and identify cosmic rays with a $Z > 40$, we do not expect to see a sufficient number of these events to draw any conclusions. A future instrument related to the TD2K is currently under development for possible deployment on the International Space Station; it will be able to make measurements of the abundances of these heavier elements. The baseline flight profile for TD2K is a 100-day flight at an altitude of 36,600 m (residual atmosphere ~ 4 g/cm^2) at ~43°S latitude in 2001-2002.

2.2 The Ultra Long Duration Slallooncraft (ULDB)

The TD2K instrument will be flown on board the Ultra Long Duration Ballooncraft (ULDB). The ULDB is a new ballooncraft being developed jointly by the Wallops Flight Facility and Raven Industries Inc. The design concept for the ULDB calls for a ballooncraft capable of carrying a 2000 lb. instrument for a total of 100 days aloft. The ballooncraft must be able to survive extreme environmental conditions ranging from a position over the polar ice caps to a near-equatorial position over cold cloud cover.

The original ballooncraft design was spherical in nature, but due to complexities not foreseen in the original design this shape had to be modified to a more ‘pumpkin’ like shape. (measuring 100 meters polar diameter by 200 meters equatorial diameter). A problem arose in this transition that the material needed for a pumpkin shaped balloon is about 20% more than that needed for a spherical one and the resulting increase in material caused difficulty in meeting the design requirement to carry a 2000 lb. instrument to flight altitudes. A lighter material is being developed for the ballooncraft causing the flight of the TD2K instrument to be delayed a year to December 2001.

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