Measurements of the Elemental Composition of Galactic Cosmic Ray Nuclei with $6 \leq Z \leq 28$ from the Cosmic Ray Isotope Spectrometer on ACE

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Abstract

The elemental abundances of galactic cosmic rays (GCR) observed near Earth provide information about the composition of the cosmic ray sources as well as their propagation history. The Cosmic Ray Isotope Spectrometer (CRIS) onboard the Advanced Composition Explorer (ACE) spacecraft measures the elemental and isotopic composition of GCRs with energies $\sim$ 50 - 500 MeV/nucleon with high statistical accuracy ($\sim$ 5000 stopping nuclei heavier than helium per day) due to its large geometrical factor. The CRIS data are used to derive cosmic ray abundances at the lowest level of solar activity during the last solar minimum. We present elemental abundances measured by CRIS, compare them with previous measurements, and discuss the plausible origins of the disagreement.

1 Introduction:

The Cosmic Ray Isotope Spectrometer (CRIS) onboard NASA's Advanced Composition Explorer (ACE) launched in August 27, 1997 delivers abundant information about isotopic and elemental composition of galactic cosmic rays (GCR). The CRIS abundances reported here for elements with $6 \leq Z \leq 28$ provide opportunity to differentiate between competing models of the GCR origin and their propagation, namely, whether the enhancement of some elements over others is related to low first ionization potential (FIP) or volatility. The comparison of CRIS data with other measurements of elemental abundances at higher energies allows the study of the dependence of secondary-element production on kinetic energy.

2 Experiment and Data Analysis:

The CRIS instrument uses multiple measurements of dE/dx and total energy deposited in one of four stacks of 8 circular silicon detectors to determine mass of the stopping particles (Stone et al., 1998). An additional detector on the bottom of each stack rejects penetrating particles. A scintillating optical fiber trajectory (SOFT) hodoscope located above the silicon detectors consists of 3 x and 3 y planes of scintillating fibers providing information about particle trajectory. An additional single x, y plane of fibers above the hodoscope is a part of the CRIS trigger.

The events whose analysis are presented here were collected between December 18, 1997 and April 19, 1998. CRIS thresholds remained constant during this time period and the solar activity was still at its lowest level with the mean daily average counting rate of the Climax neutron monitor equal to 4264 or 0.988 of the 1954 solar minimum rate. Since April 20th the intensity of GCR has been decreasing due to increased solar activity (Wiedenbeck et al., 1999) indicating the beginning of the new solar cycle.

The charge of the particle detected by CRIS is derived using the method described by Stone et al. (1998). Figure 1 shows well separated charge distributions obtained after applying loose selection criteria. Those criteria require each pair of three x, y coordinates to line up and the resultant projected trajectory must be within the two top detectors and detector located just below the stopping detector. In addition, charges derived using three different combinations of penetrating and stopping detectors must agree and the projected range in the stopping detector must be more than $500\ \mu\mathrm{m}$ from its top and bottom surface to eliminate events in which the particle stops in or near dead layers. The structure in the peaks reflects the isotopic mix of nuclei for each element.

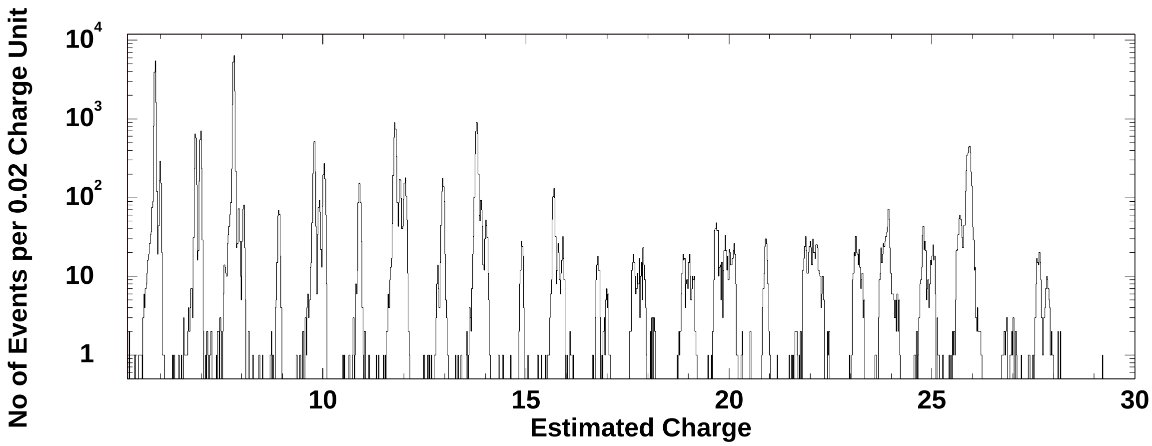

Figure 1: Charge distribution of events from all telescopes stopping in detector 4 with trajectory zenith angle $\leq 30°$.

The energy bins for each element are selected according to the kinetic energy required for this element to stop in the particular detector. The raw number of events within the energy bin with trajectory zenith angle $\leq 30°$ are corrected for the instrument acceptance, livetime of the instrument buffer corresponding to the particular stopping detector, and the efficiency of the CRIS fiber hodoscope.

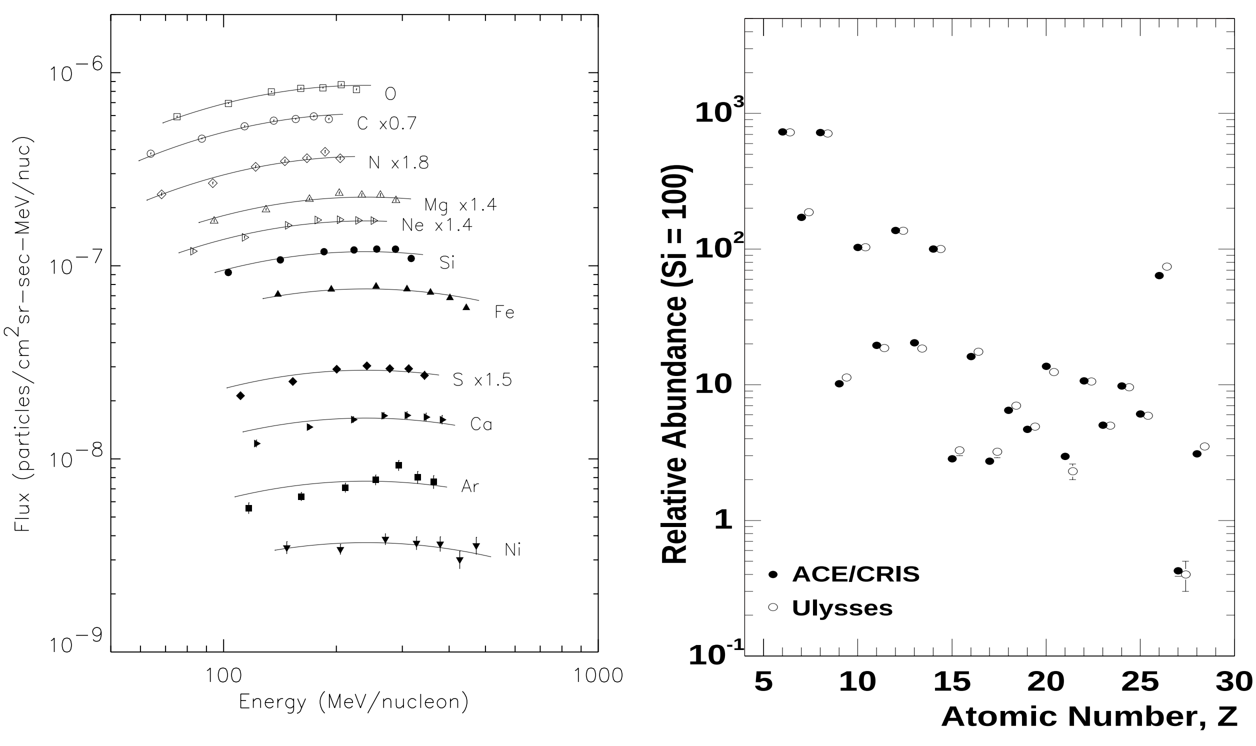

Figure 2: CRIS spectra of selected elements (left panel). CRIS and Ulysses elemental abundances (right panel).

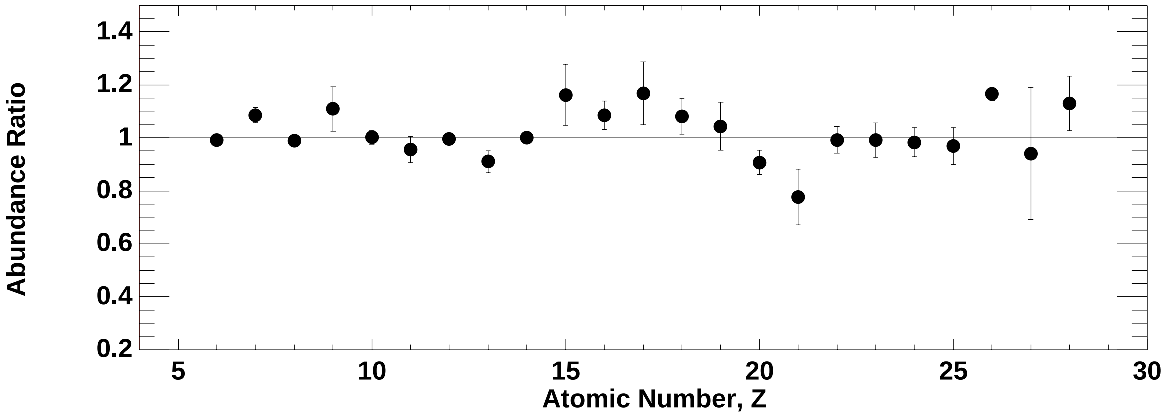

Figure 3: Ulysses/CRIS ratios of elemental abundances.

3 Results and Summary:

Using data like in Figure 1 from all stopping ranges, energy spectra are derived for all elements, $6 \leq Z \leq 28$ (Figure 2). The solid lines are the results of appropriately scaled single second degree polynomial fit to the spectra and these fits are used to determine relative elemental abundances at 200 MeV/nucleon. These abundances are shown in Figure 2. The uncertainties associated with CRIS abundances are purely statistical and in most cases are smaller than the symbols. The systematic uncertainties are being investigated. For comparison, results from the Ulysses spacecraft (DuVernois and Thayer 1996) are also shown in Figure 2 and the ratios of Ulysses to CRIS results are presented in Figure 3. Both measurements of GCR elemental abundances are made by instruments using similar detection methods with comparable kinetic energy range during low (ACE/CRIS) and high (Ulysses) levels of solar activity. The mean Climax neutron monitor daily average counting rate corresponding to the Ulysses dataset is 3889. These two measurements are in agreement within uncertainties for most of the elements, but the Ulysses abundance of Fe and Ni are 20% higher than CRIS.

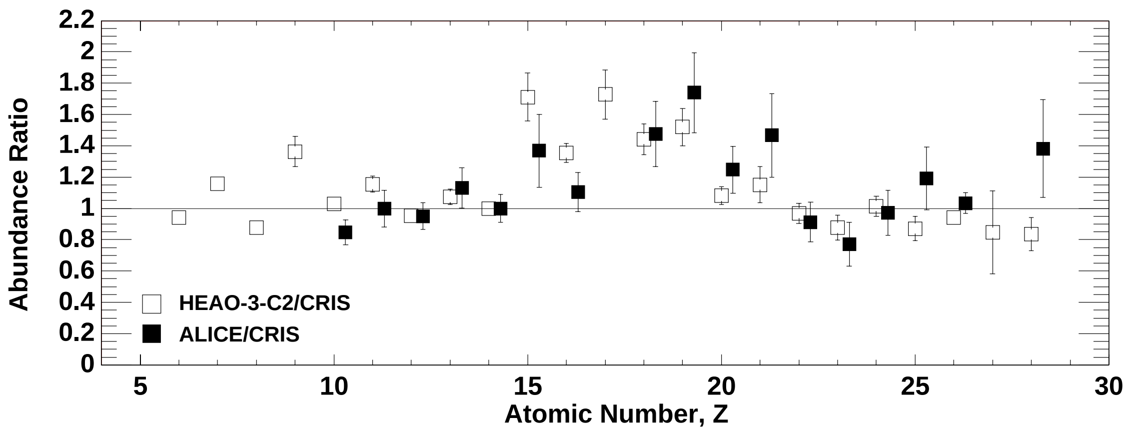

Figure 4: ALICE/CRIS and HEAO-3-C2/CRIS ratios of elemental abundances. ALICE/CRIS ratios for charge 17 (Chlorine) and 27 (Cobalt) are off scale with large error bars. ALICE abundances below Z = 10 (Neon) were not measured.

Figure 4 compares the elemental abundances measured by ALICE (balloon-borne experiment) at kinetic energy 830 MeV/nucleon (Esposito et al., 1992) during a similar level of the solar modulation (Climax daily average 4213) and HEAO-3-C2 (spacecraft borne experiment) at kinetic energy 1000 MeV/nucleon (Engelmann et al., 1990) during the high solar modulation (mean of Climax daily average 3851) with CRIS results. All three measurements are in agreement for the primary and most secondary elements. The disagreement for secondary elements with charge 9 and 15 - 19 is probably related to the energy dependent pathlength of these elements related to the GCR propagation through the confinement region. Elemental production cross sections (Figure 5) at kinetic energies 250 - 450 MeV/nucleon higher than energies measured by the instruments, which accounts for the GCR deceleration in the heliosphere, may also contribute to this disagreement. Note that the elements for which abundances disagree can be produced by spallation of nuclei lighter than Fe like Ca and Ar. These cross sections do not show a strong energy dependence in the energy range 300 - 1200 MeV/nucleon (Knott et al., 1996, Webber et al., 1990). The ACE/CRIS data collected during the approaching solar maximum will be useful to identify whether this disagreement is related to different levels of the solar modulation. Further studies using models of the GCR propagation should give an answer.

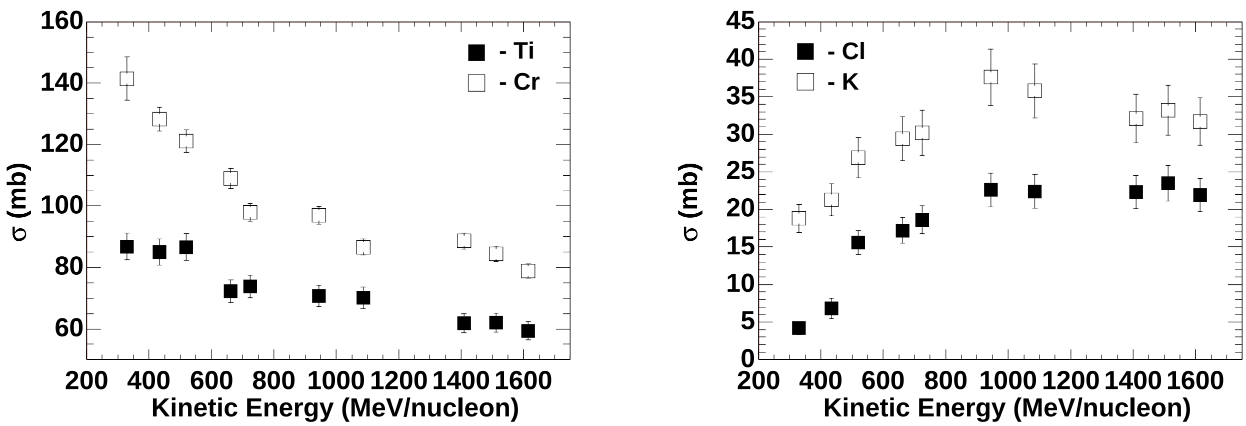

Figure 5: Energy dependent cross sections for production of some sub-Fe secondaries by spallation of the Fe projectile on a hydrogen target (Webber et al., 1990).

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