Trans--Iron Elemental and Isotopic Abundances from ACE/CRIS

Elements with nuclear charge Z>30 are very rare in both solar system and cosmic-ray material (Z>30/Fe ≈ 4 x 10^{-5} in the solar system). As a result, their abundances are poorly known in cosmic rays because they require long exposure times with a large instrument. However, the abundances of Ultra-Heavy (UH) nuclei are of interest because they were synthesized by neutron-capture processes that occur very rapidly in core-collapse supernovae (r-process), and very slowly in Asymptotic Giant Branch (AGB) stars (s-process). The relative abundances of UH nuclei in cosmic rays provide constraints on the origin of galactic cosmic rays.

Data presented in Figures 1 (elemental histogram) and 2 (isotopic histogram) were collected by the ACE/CRIS instrument from 4 December 1997 to 2 April 2011 excluding only intervals when the CRIS instrument was not in operation due to large fluxes of solar energetic particles. The data plotted in these two figures are precisely the same data but shown with finer binning on slide 2 to reveal the isotopic resolution. These data were presented at the Beijing ICRC (2011)[1,2] but are still considered preliminary since we are still determining the exact energy ranges over which we can measure abundances of nuclei heavier than Zinc.

Figure 3 shows the measured abundances at the top of the detector compared with corresponding TIGER[3] and HEAO3-C2[4] results. The element abundances were obtained from the data as follows: We counted the number of events in each element peak, simply making cuts at the valleys between the peaks. To determine abundances relative to Fe we applied three factors. (1) The probability of losing an event due to a fragmentation interaction in the instrument increases with increasing nuclear mass; so observed numbers were multiplied by a factor ranging from 1.014 for Cu to 1.059 for Sr. (2) The width of the energy interval in which we made these measurements increases with increasing atomic number, and the mean energy at which the measurement is made moves along the energy spectrum; the combination of these effects leads to a correction to the observed numbers of events with a multiplicative factor ranging from 0.953 for Cu to 0.888 for Sr. (3) The CRIS instrument was designed with nuclei of $Z \leq 28$ as the primary objective, so some of the heavier elements were lost from the data analysis as a result of pulse-height-analyzer saturation. Careful modeling of the instrument response resulted in correction factors that depend on Z for $Z > 31$. No correction was necessary for $Z \leq 31$. For heavier nuclei preliminary correction factors were derived that ranged from 1.008 at $Z = 32$ to 1.03 at $Z=34$ to 1.2 at $Z = 36$ to 1.57 at $Z = 38$ to 1.77 at $Z=40$. (Note that these correction factors are slightly different from those in the published Israel et al. ICRC paper[1].)

Figure 4 shows the measured abundances of the $_{29}$Cu, $_{30}$Zn, $_{31}$Ga, and $_{32}$Ge isotopes. This represents the first time that isotopic abundances of Ga and Ge have been measured in cosmic rays, and includes greatly-improved measurements of Cu and Zn measurements previously reported from early ACE-CRIS data[5,6]. The red lines are Solar System abundances taken from Lodders[7]. To obtain the numbers of nuclei detected for each isotope, simple cuts were taken at the valleys between the peaks of the isotopes shown in Figure 2. For the cases of Cu and Ga, only two stable isotopes exist. For zinc, in addition to those isotopes clearly resolved in Figure 2, ^{67}Zn and ^{70}Zn are low abundance stable isotopes with solar system abundances [7] of 4.1% and 0.6% respectively. To account for ^{67}Zn we have assumed that it has solar system composition and subtracted half of that fraction from the adjacent isotopes (i.e. 2% of the total number of zinc nuclei, which corresponds to 6.6 particles, were subtracted from the number of ^{66}Zn and ^{68}Zn obtained by cutting at the valley in Figure 2). The single particle at ~Z=30.5 was assumed to be ^{70}Zn and was included in the total number of zinc. For germanium, ^{73}Ge and ^{76}Ge are stable isotopes with solar system abundances of 7.7% and 7.4% respectively that are not resolved. In like manner as for the zinc, we assumed that ^{73}Ge had solar system abundance and 1.5 particles were subtracted from its adjacent isotopes of ^{72}Ge and ^{74}Ge. In addition, a first order leaky-box propagation back to the source is included.

Figure 5 shows these UH isotopes plotted in the context of our earlier isotopic ratios presented in Binns et al, 2005[8]. The results are generally consistent with a model in which the cosmic ray source is a mix of 20% massive star outflow and 80% normal interstellar medium composition (i.e. assumed to have solar system abundances). The likely astrophysical site where such a mix could occur is in associations of massive stars called OB associations[8].

References

1. M.H. Israel, et al. (2011) Proc. of 32nd International Cosmic Ray Conference (Beijing), Paper OG1.1- 0655
2. W.R. Binns et al. (2011) Proc. of 32nd International Cosmic Ray Conference (Beijing), Paper OG1.1- 0649
3. B.F. Rauch, et al., (2009) ApJ 697, 2083
4. B. Byrnak, et al. (1983) Proc. of 18th International Cosmic Ray Conference (Bangalore), 2, 29
5. J.S. George et al. (1999) Proc. of 26th International Cosmic Ray Conference (Salt Lake City) 3, 13
6. M.E. Wiedenbeck et al.(2001) Space Sci. Rev. 99, 15
7. K. Lodders, (2003) ApJ 591, 1220
8. W.R. Binns et al., (2005) ApJ 634, 351

NOTE: Figures are included on the pages below. They are also available as separate jpeg plots via the links in the text.

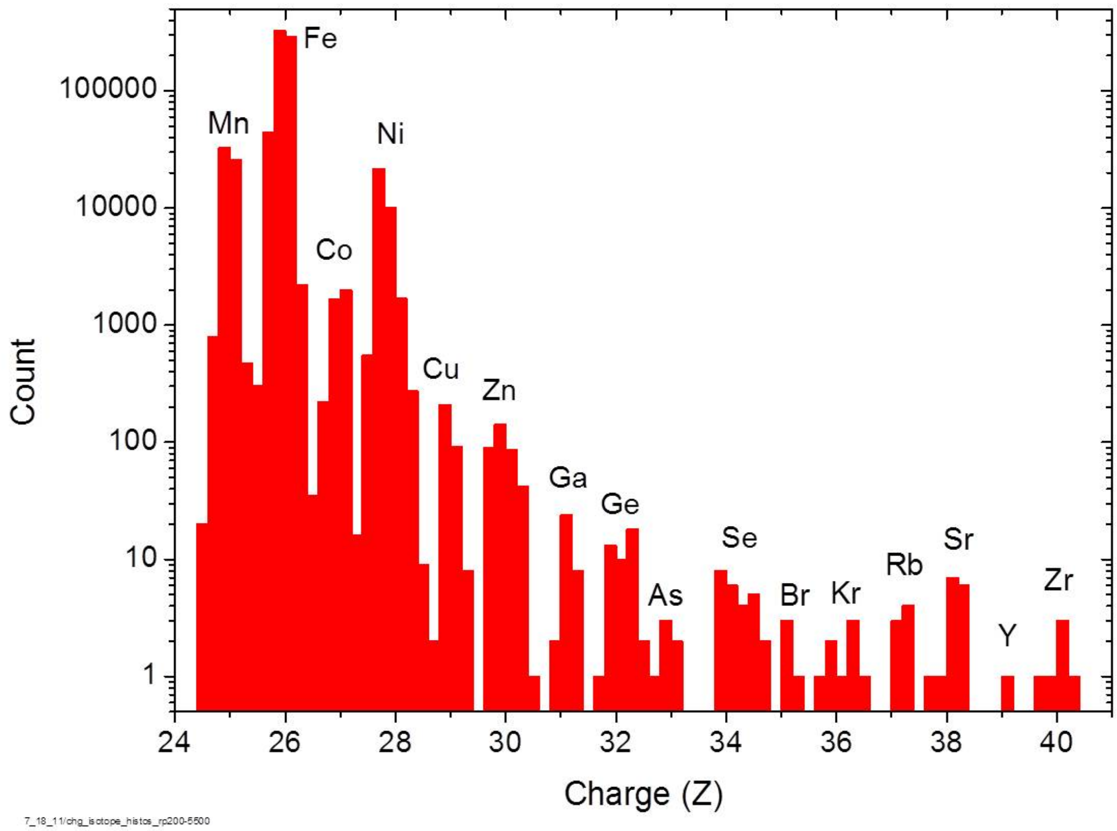

Figure 1: Elemental histogram. Data collected by the ACE/CRIS instrument from 4 December 1997 to 2 April 2011 excluding only intervals when the CRIS instrument was not in operation due to large fluxes of solar energetic particles.

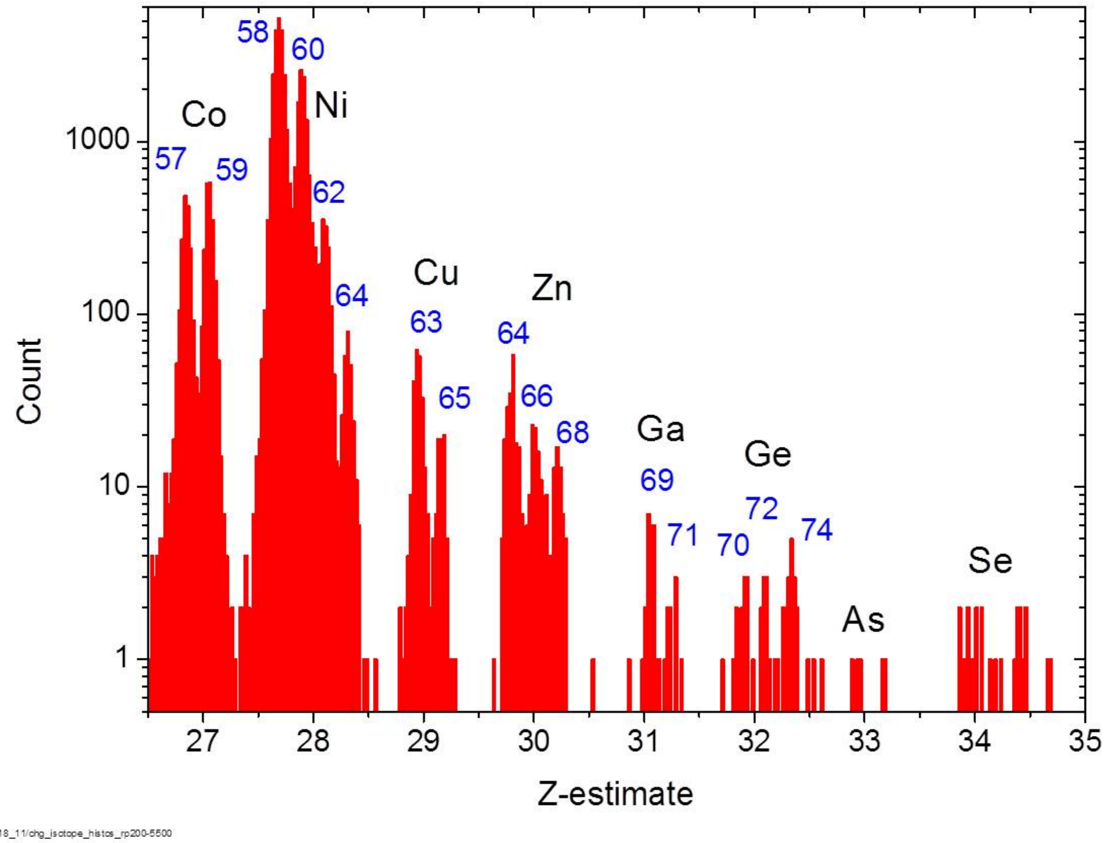

Figure 2: Isotopic histogram. Data collected by the ACE/CRIS instrument from 4 December 1997 to 2 April 2011 excluding only intervals when the CRIS instrument was not in operation due to large fluxes of solar energetic particles.

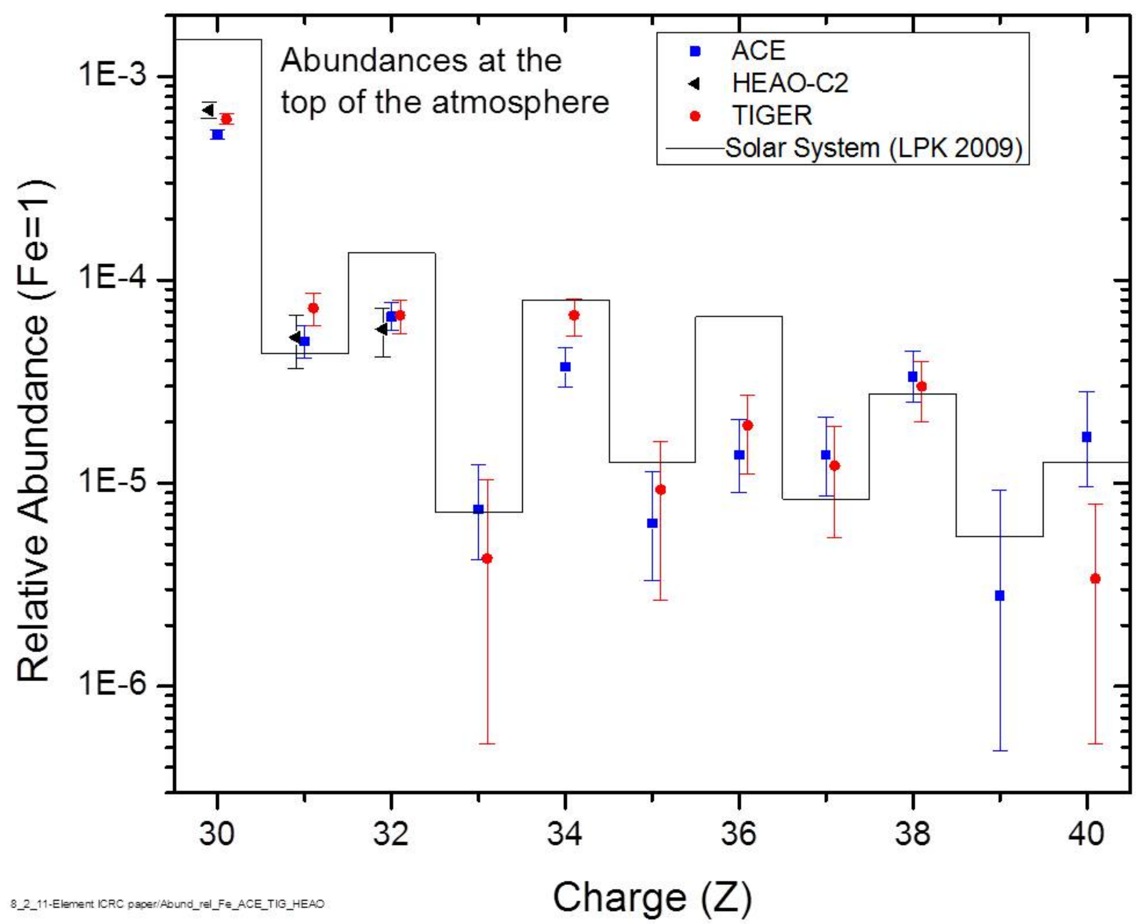

Figure 3: The measured abundances at the top of the detector compared with corresponding TIGER and HEAO3-C2 results.

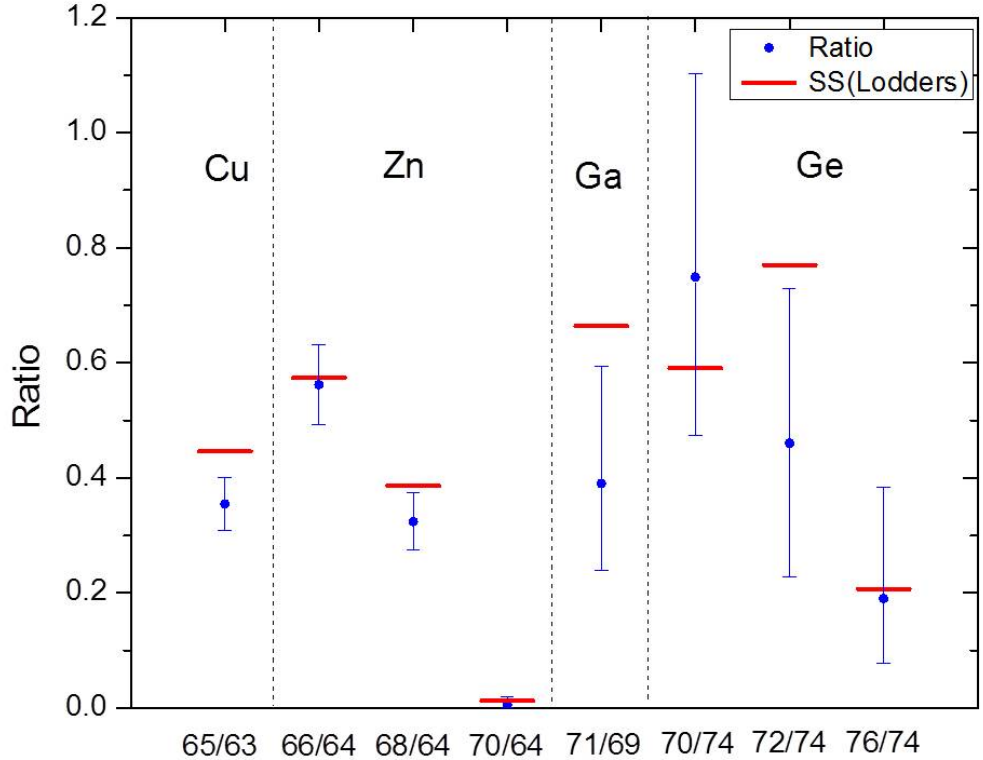

Figure 4: The measured abundances of the $_{29}$Cu, $_{30}$Zn, $_{31}$Ga, and $_{32}$Ge isotopes.

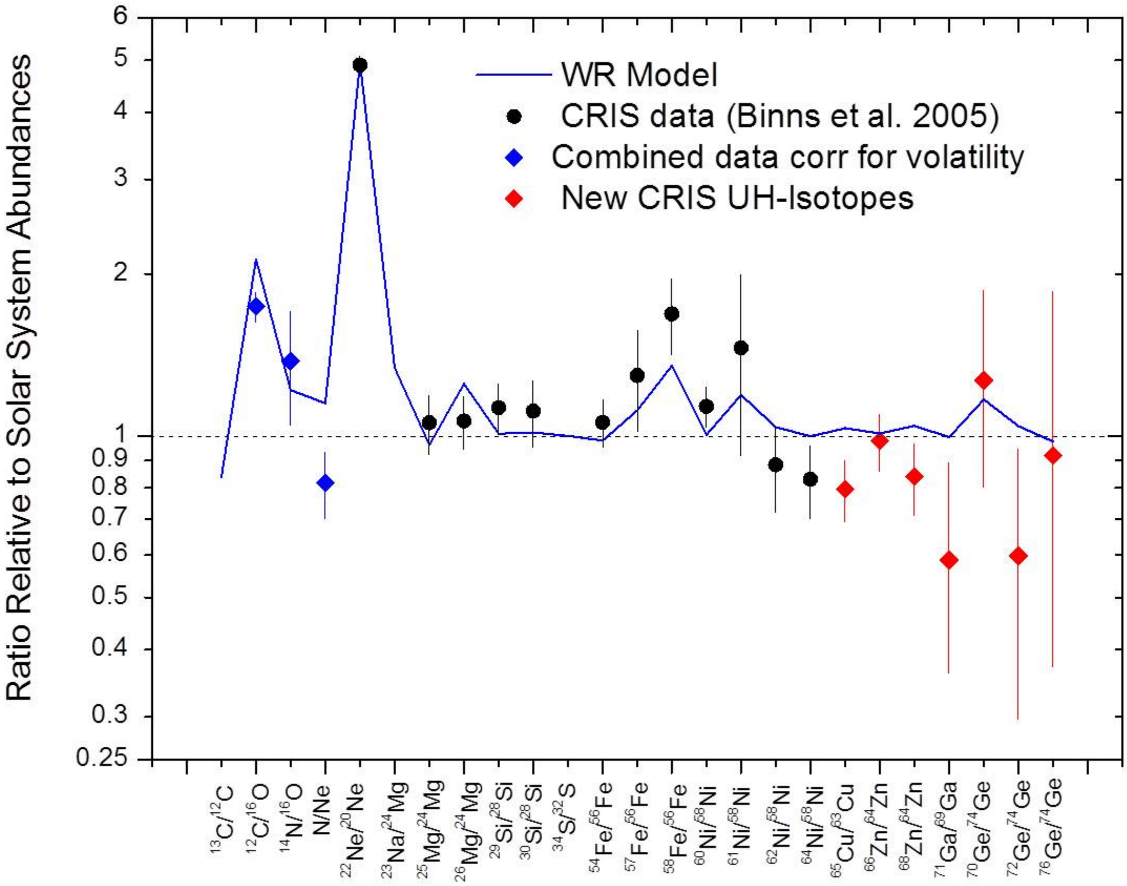

Figure 5: New CRIS UH isotopes plotted in the context of our earlier isotopic ratios presented in Binns et al, 2005.