



Large Scale Observation Program of Ultra Heavy Nuclei in Galactic Cosmic Rays

N. HASEBE¹, T. DOKE¹, M. HAREYAMA¹, S. KODAIRA¹, T. MIYACHI¹, M. MIYAJIMA¹, O. OKUDAIRA¹, K. SAKURAI¹, S. OTA¹, M. SATO¹, Y. SHIMIZU¹, M. TAKANO¹, S. TORII¹, N. YAMASHITA¹, N. YASUDA², S. NAKAMURA³, T. KAMEI³, H. TAWARA⁴, K. OGURA⁵, S. MIKADO⁵, H. SHIBUYA⁶, K. NAKAZAWA⁷, AND A.J. WESTPHAL⁸

¹Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, Japan

²Fundamental Technology Center, National Institute of Radiological Sciences, Chiba 263-8555, Japan

³Department of Physics, Yokohama National University, Kanagawa 240-8501, Japan

⁴Radiation Science Center, High Energy Accelerator Organization, Ibaraki 305-0801, Japan

⁵College of Industrial Technology, Nihon University, Chiba 275-8576, Japan

⁶Department of Physics, Toho University, Chiba 274-8501, Japan

⁷Department of Physics, Gifu University, Gifu 501-1193, Japan

⁸Space Sciences Laboratory, University of California at Berkeley, CA 94720, USA

nhasebe@waseda.jp

Abstract: Our galaxy is filled with relativistic nuclei and electrons, being called galactic cosmic rays (GCRs). The origin of GCRs nuclei is still unknown. The precise observation of ultra heavy (UH) GCRs ($Z \geq 30$) is important to resolve the remaining problems in cosmic ray astrophysics. Observation program of UH nuclei in GCRs is proposed with the use of high performance solid-state track detector (SSTD) on board long-duration balloon. The program focuses to measure the isotopic abundance above iron-peak elements and the composition of the rare ultra heavy nuclei up to actinide elements with relativistic energy. The observation of nuclear composition covers a wide range of scientific themes including studies of nucleosynthesis of cosmic ray sources, chemical evolution of galactic material, the characteristic time of cosmic rays, heating and acceleration mechanism of cosmic ray particles. In order to achieve the objectives, the super-ressure balloon capable of carrying very large scientific payloads for long extended period is best suited. The possible approach based on a large telescope array consisting of modularized SSTD stacks is described.

Introduction

Our galaxy is filled with various relativistic nuclei and electrons, being called galactic cosmic rays (GCRs). The source of GCR nuclei is still unknown. However, GCRs are thought to be accelerated by supernova (SN) shocks in the interstellar medium (ISM). The location of SNs are not distributed randomly in the Galaxy, but explode preferentially in OB-associations which have been the site of massive star formation and in which hot and young stars are abundant [1, 2]. An SN explosion in an OB association forms a shock into a local ISM which is enriched in freshly synthesized material from previous SNe. Recently, the Cosmic Ray Isotope Spectrometer (CRIS) measurement of

Fe-Co-Ni isotopes by the Advanced Composition Explorer (ACE) tells us that the average time delay between nucleosynthesis and acceleration is greater than about 10^5 years [3].

Elemental abundance in GCRs above $Z \geq 30$ has been measured by experiments of ARIEL-6 [4], HEAO-3 [5], and recent experiments of TREK [6] and TIGER [7]. Even with these observations, the chemical separation of even- Z and its neighboring odd- Z nuclei in the range of $Z = 30$ to 60 has not been individually resolved. For $Z > 60$, since the statistics are very low and the charge resolution is broadened in the Ariel-6 [4] and HEAO-3 [5] data, the grouping of charges is necessary for meaningful abundance measurements. Those results for $Z > 60$ are likely enhanced in r -process

elements at the source. However, such an enhancement among elements with $Z > 60$ is complicated by elemental fractionation process. The isotopic measurement provides a distinct advantage in determining the mixing ratios of the s - to r -process products, because those ratios are immune to elemental fractionation processes. And we still lack definitive data for elements $Z > 30$ that could provide further understanding of the origin and history of galactic matter. The precise measurements of GCR composition beyond the iron peak are of special interest because of their information about neutron-capture nucleosynthesis processes and because of a number of stable and radioactive species contained in them. The next step beyond ACE/CRIS [8] is to measure individual isotopes with an excellent mass resolution and a high statistics for elements with $30 \leq Z \leq 58$, and to measure Pt-Pb group nuclides and actinides with an excellent charge resolution and a high statistics by the use of particle spectrometers with at least two orders of magnitude increase in collecting power.

In this paper, we focus the observation program of isotopic and elemental compositions of ultra heavy galactic cosmic rays (UH-GCRs) for $Z \geq 30$ with the energy above several 100 MeV/nucleon by means of an extremely large exposure array made of solid-state track detectors (SSTD) onboard long duration super-pressure balloon over Antarctica or Southern hemisphere.

Scientific objectives and goal

Observation of elemental and isotopic compositions of UH-GCRs

Our observation program is designed to resolve the individual elemental and isotopic compositions in UH-GCRs using high performance solid-state track detector with extremely large collecting power. The precise measurements of chemical compositions in UH-GCRs will provide us rich information for understanding the origin, the stellar nucleosynthesis, the chemical evolution of the galaxy and the history of an interstellar material, and offer new possibilities for the study of the cosmic ray acceleration and propagation mechanisms in interstellar space.

Origin of GCRs

The element ^{22}Ne in the GCR source (GCRS) abundance is enhanced relatively as compared with the solar system (SS) abundance from the previous observations of isotopic compositions for $Z < 30$ based on most recent experiment ACE/CRIS [9]. This is thought as due to the contribution from Wolf-Rayet stars which usually exist in superbubble (SB) [9, 10]. The measurement of the abundances of ^{59}Ni and ^{59}Co gives the average delay time greater than about 10^5 yr between nucleosynthesis and acceleration, and suggests that the SN does not instantly accelerate their own ejecta [3].

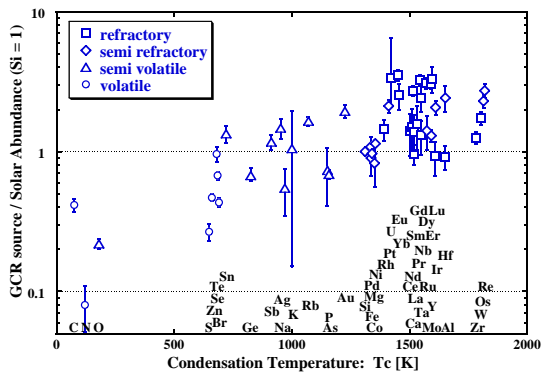


Figure 1: The source composition of GCRs relative to the SS abundance for their condensation temperatures [11].

Comparison of GCRS abundance with SS abundance indicates that ultra heavy composition in GCRs with high condensation temperature is relatively enhanced to the SS abundance, as shown in Fig. 1 [12, 11]. This tendency is explained by assuming that the multiple supernova (SN) shocks in OB-association can accelerate the GCRs from seed nuclei originated from dust-grains drifting in interstellar medium which condensed rapidly after an SN explosion [11, 13]. Since a typical SN explodes within several ten Myr in SB, the interstellar, circumstellar gases or dust-grains in SB are thought of relatively overabundant with fresh materials as compared with normal old interstellar material. Therefore, a part of these fresh materials should be accelerated as cosmic rays by SN shocks in SB. A signature of GCR origin in SB is an enhancement in r -process material of UH-

GCRs. Our cosmic ray detector telescope will detect the actinide elements (Th, U, Pu, Cm) and the isotopes mainly synthesized r -process (e.g. ^{82}Se , ^{100}Mo , ^{129}I). There is a distinct advantage to determining the s -process to r -process mixture by measuring isotopic ratios, since these ratios are immune to elemental fractionation effects.

Furthermore, the precise measurements of unstable isotopes, ^{93}Zr (1.53 Myr), ^{129}I (15.7 Myr), ^{135}Cs (2.3 Myr) with β decay mode, ^{247}Cm (15.6 Myr) with α decay mode, and short life time elements with electron capture decay mode, ^{81}Kr (0.229 Myr), will tell us the nearby source and life-time (confinement time, delay time between nucleosynthesis and acceleration) of GCRs.

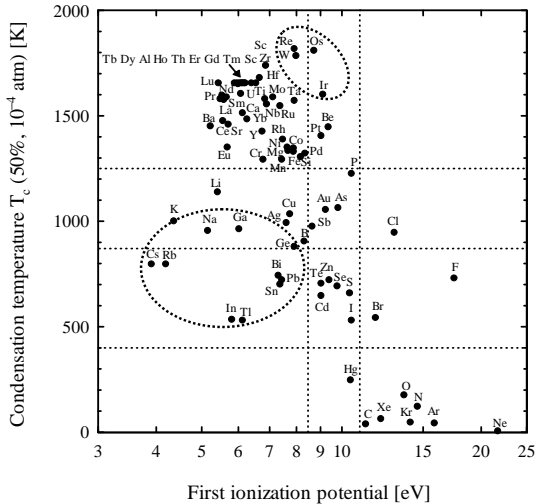


Figure 2: Correlation between FIP and Volatility (revised figure [14] using new SS abundance by Lodders [15]).

Injection mechanism of GCRs

The problem on whether GCRs are initially accelerated by FIP (First Ionization Potential) or Volatility one still remains as the injection mechanism. Casse et al. [16] suggested that the abundance of GCRs is highly dependent on the FIP of each element in atomic stable as compared with that of the solar system, and the elements with low FIP are easily accelerated than high ones. The environmental condition injected into GCRs should be hot enough to partially ionize atoms, so that seed

nuclei must be in gas phase. While, Sakurai [12] suggested that the seed nuclei such as refractory elements are relatively enhanced in GCRs (see Fig. 1) should be condensed in dust-grains. The temperature at injection site should be at 1000 K or less.

It is very difficult to distinguish injection mechanism because of good correlation between FIP and Volatility, as shown in Fig. 2 [14]. Meyer et al. [14] pointed out, however, that there are some elements (Ge, Rb, Sn, Cs, Pb, Bi) without the correlation between FIP and Volatility. Comparing their GCRS abundances with SS abundances in the broad range of chemical elements will resolve the injection mechanism.

Chemical evolution of galactic material

Recently, universality of elemental abundance of r -process nuclei has been indicated from the comparison of abundances between proto metal-poor stars and the solar system [17]. The proto-metal-poor stars are thought of the first or second generation stars born about 10 Gyr ago or less with the evolution of universe, while the solar system was born 4.5 Gyr ago. The cosmic ray abundance should be composed of relatively fresh materials synthesized in stars about several 10 Myr ago as estimated from their injection time to acceleration site and transportation time in the interstellar space. Therefore, the comparison among these abundances in different epoch will give the understanding of chemical evolution of galactic material.

In addition, we may find superheavy nuclei, namely trans-uranium nuclei, in GCRs by the extremely large collection power of our cosmic ray detector telescope. It is predicted that such extremely massive particles should exist in "island of stability" which corresponds to the region of predicted neutron magic number of $N = 184$ [18].

Observation program

Since the flux of UH-GCRs is extremely low, the cosmic ray detector with a large collecting power is required to observe such ultra heavy events. The high performance solid-state track detector (SSTD), CR-39 and/or BP-1, with large exposure

area is very promising for the large-scale observation of these nuclei in space. We plan to observe isotopic composition of $30 \leq Z \leq 58$ with the energy of < 500 MeV/n and elemental composition up to actinide elements in the relativistic energy region. The charge resolution for $30 \leq Z \leq 92$ and mass resolution for $30 \leq Z \leq 58$ are 0.1-0.2 cu (rms) and 0.1-0.3 amu (rms), respectively. Clear separation of nuclear charge and isotope of UH nuclei in GCRs would be expected. The details of performance of the SSTD and its measurement system are described elsewhere [19, 20].

Definitive measurements are almost available for long duration flight using super-pressure balloon over Antarctica or Southern hemisphere capable of carrying very large scientific payloads for a long extended period. The super-pressure balloon has some advantages of long duration flight for a few month or more, relatively small variation of air thickness and a stability of high altitude without ballast. The super-pressure balloon is currently under development in JAXA. We expect that our experiment by using super-pressure balloon will be realized a few years later.

The cut-off rigidities over the Antarctica and Southern hemisphere were calculated to estimate the expected number of particles by assuming the energy spectrum of iron nuclei observed by HEAO-3/C2 [21]. The number of particles to be observed has been estimated in 100-day of 4 m² and 16 m² over Antarctica and Southern hemisphere, respectively. The relative abundance of UH-GCRs was taken from HEAO-3/C3 [5] as references. The results based on the assumption for the number of particles expected for UH-GCRs are summarized in Table 1.

Table 1: Expected number of UH-GCR particle

Experiment	G.F(m ² sr)	Region	Expected number
Antartica ballon	~ 12	$30 \leq Z \leq 58$	~35,000
Southern hemisphere ballon	~ 63	$30 \leq Z \leq 92$	~55,000
HEAO-3[5]	5.9	$30 \leq Z \leq 92$	3,357

Summary

The observation of actinide elements and isotopic compositions of UH-GCRs is the next important step, because any data of those chemical compositions in UH-GCRs regions are not available yet. A large-scaled cosmic ray telescope made of high performance solid-state track detectors onboard the long duration super-pressure balloon over Antarctica or Southern hemisphere will make the first measurement of the elemental and isotopic compositions of UH-GCRs, and provide critical data to resolve residual problems in cosmic ray astrophysics.

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