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THE COSMIC RAY COMPOSITION AS VIEWED FROM THE CHEMICAL ABUNDANCES OF THE SOLAR SYSTEM

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ABSTRACT

It is shown that the chemical composition of cosmic rays at their sources for the elements up to the atomic number as 80 is quite similar to that of the carbonaceous chondrites, which have been keeping the properties of the proto-solar nebula. In particular, the similarity between these two compositions is significant to the elements classified as refractory and siderphile, in addition to the elements, Ca and Al. These results as cited above suggest that cosmic rays, being currently observed near the earth, may have been accelerated from the matter with the composition similar to that which is found of these chondrites as Allende.

1. Introduction. For many years since 1950's, it has been thought that the sources of cosmic rays are identified with supernova explosions, which seem to happen every ten years or so. However, some questions have recently arisen to the idea on the supernova origin of cosmic rays on the basis of the observations on the chemical composition. Really speaking, the chemical composition of cosmic rays at their sources is different from that which has been theoretically deduced from the r-process associated with supernova explosions, but similar to that of the solar system(1). This difference becomes larger as the charge numbers of nuclei increase, and become more significant to the nuclear species heavier than the medium nuclei as C, N and O(2). This tendency is known as the overabundances of heavy nuclei in the cosmic ray composition as compared to the chemical composition of the solar atmosphere. It is, therefore, urgently necessary to investigate whether the source composition of cosmic rays is similar to the composition of the solar atmosphere and the proto-solar nebula or not. Then, it would become possible to estimate the physical state on the birth place of cosmic rays in the galactic space.

2. Comparison of the Chemical Composition of Cosmic Rays at Their Sources with That of the Solar System. As well known, the chemical composition of the solar system has been mainly derived from the chemical analyses of the earth's crust and meteorites and also from the spectroscopic analysis of the solar atmosphere. Based on these analyses, it is now thought that the chemical composition of carbonaceous chondrites is representative as that of the primordial solar nebula, from which the solar system, both of the sun and its own planets,

may have been originated about 4.6 billion years ago(3).

In order to examine whether the chemical composition of the solar system can be considered as typical to that of cosmic rays at their sources, it is convenient to compare the characteristics of these two compositions. Using the chemical compositions of the solar system and of cosmic rays at their sources currently available(4), the relative abundances have been examined of the elements up to Pb (Z = 82) for these two compositions. The result thus obtained as shown in Fig. 1 clearly shows that the cosmic ray source abundances tend to become relatively higher with the increase of the charge numbers of the elements under consideration.

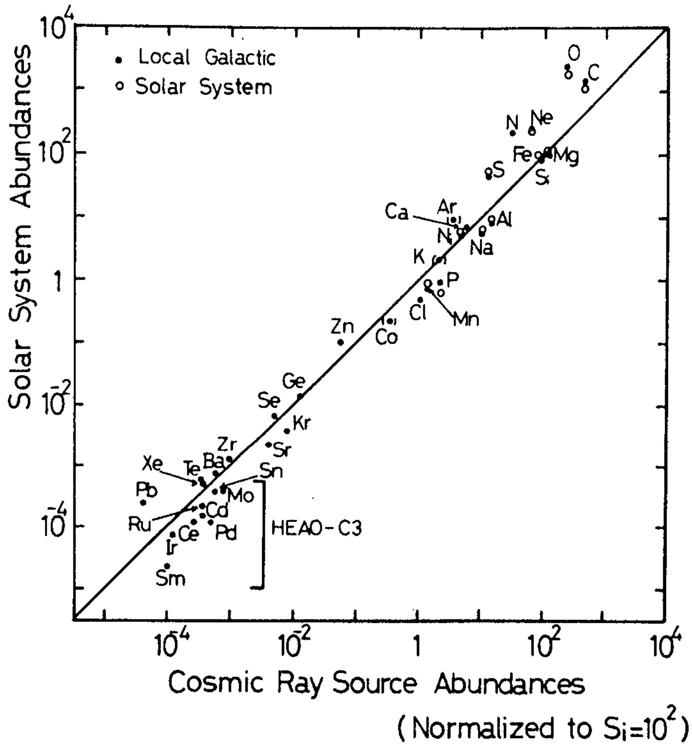

Fig. 1 Comparison between the relative abundances of the solar system and of cosmic ray sources.

Although it is thus clear that, with the increase of the charge numbers of the elements, the chemical composition of the solar atmosphere is relatively less abundant when compared to that of carbonaceous chondrites as the Allende meteorite, Fig. 1 suggests that the chemical composition of cosmic rays at their sources is quite similar to that of the primordial solar nebula. Thus, it can be said that the birth place of cosmic rays in the galactic space may be found in the interstellar clouds whose chemical composition is almost the same as that of the primordial solar nebula.

<u>3. Chemical Composition of Cosmic Rays as Viewed from Their FIP's.</u> In order to see the distinction between the relative abundances of the cosmic ray sources and the solar atmosphere in more detail, the ratio of these abundances for the cosmic ray sources to those of the solar atmosphere have been examined with respect to each element and compared with the first ionization potentials (FIP) of these elements. The relation between the ratios and the potentials for these elements is shown in Fig. 2 without error bars, since we are only interested to see if there is any systematic tendency between these two. Overall relations between these ratios and the FIP's are shown in Fig. 3 as a function of the charge

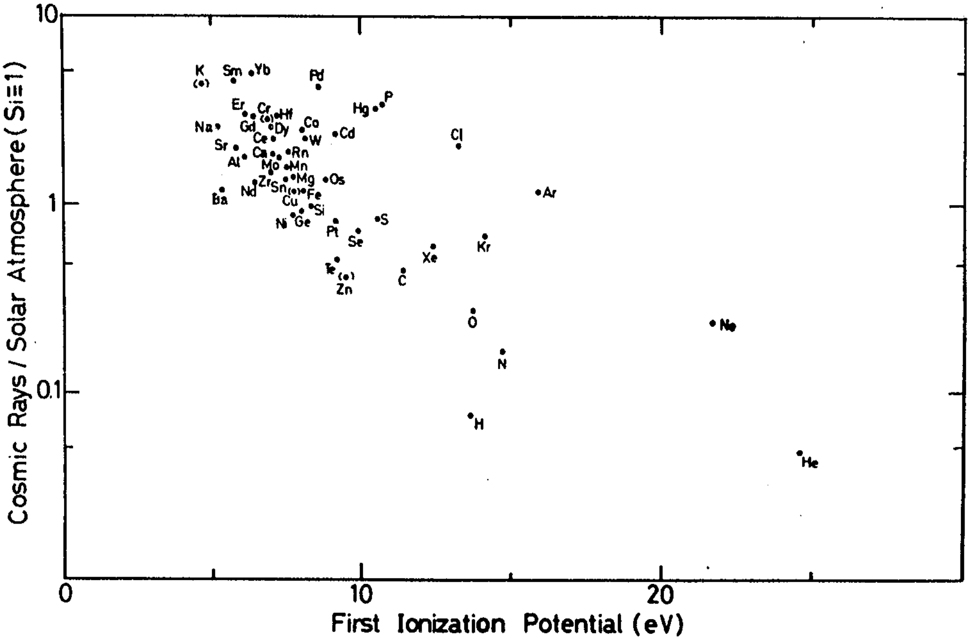

Fig. 2 Relation of the ratios of the chemical composition of cosmic ray sources to that of the solar atmosphere with the first ionization potentials of the nuclei in their atomic states.

number of elements.

The result shown in Fig. 2 indicates that, in addition to the enrichement of Ca and Al nuclei, both refractory and siderophile elements are well overabundant in the source composition of cosmic rays as compared to the chemical composition of the solar atmosphere. This tendency is also clearly seen on the mean chemical composition of the white inclusions, CAI(I) and CAI(II), of the Allende meteorite, a typical example of carbonaceous chondrites(5). As regards lanthanides, their relative abundances in the cosmic ray sources are also similar to those of these inclusions, since the overabundant nature of these elements is very similar between the cosmic ray source composition and the mean composition of these inclusions.

These results as mentioned above seem to indicate that cosmic rays have been accelerated initially from particles in a matter, whose composition is almost the same as that of the primordial solar nebula. Such matters seem to be distributed almost everywhere throughout the galactic space, since they must have been born from the expanding gases associated with supernova explosion. While drifting in this space after cooled down, a part of them may have been later accelerated to cosmic rays by interstellar shocks originated from super-

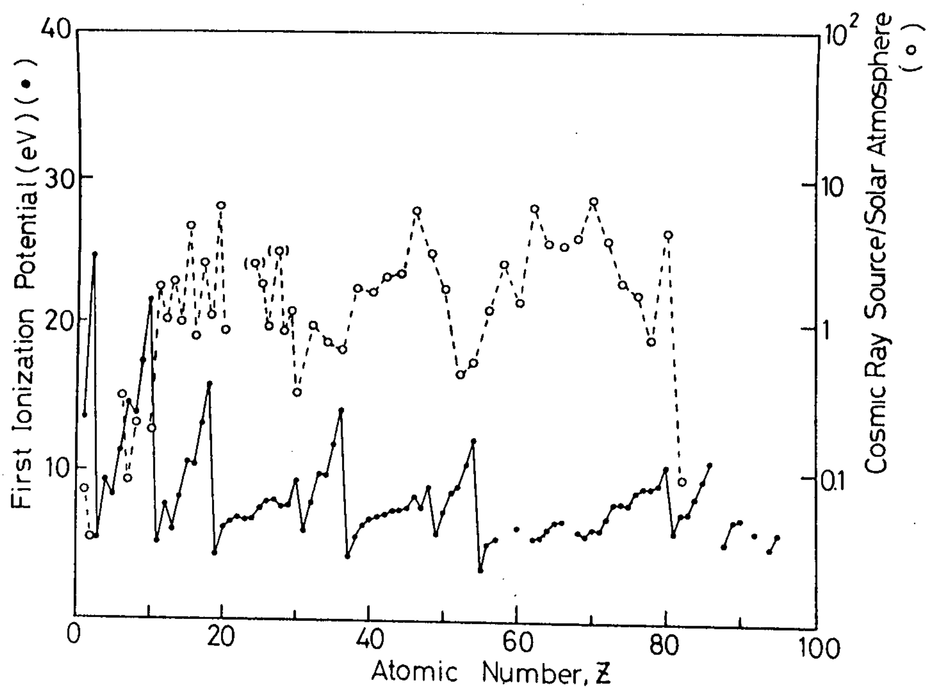

Fig. 3 The same ratios as in Fig. 2 and FIP's as plotted as a function of the nuclear charge numbers.

novae occurred later in the nearby space.

4. Cocluding Remarks. The chemical compositin of cosmic rays at their sources is very similar to that of carbonaceous chondrites which may have been still keeping the properties of the primordial solar nebula or alike. This similarity between these two compositions is clearly seen on the overabundant nature of refractory and siderophile elements as observed in cosmic rays and those chondrites. These results strongly suggest that cosmic rays must have been accelerated from particles ambient in the matter, drifting in the galactic space, whose chemical composition is almost the same as that of carbonaceous chondrites. Furthermore, Fig. 2 suggests that cosmic rays must have been generated in the matter whose temperature is not so high, but is 10^6 K at most as once proposed earlier(2,6).

References

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