A Possible Causal Relation of the Source Composition of Cosmic Rays with the Elemental Depletion in the Interstellar Space

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Abstract

Based on the observed results on the source composition of cosmic rays, a possible mechanism for the formation of this composition is considered by taking into account the fractionation of the elements in the interstellar molecular clouds, in which there may exist dusts and grains enriched with the elements whose condensation temperature is higher than about 1000K. Most of these nuclei enhanced in the source composition are identified as heavy and ultra-heavy ones, which must have been synthesized in the r-process initiated with the explosions of type II supernovae and/or supergiant stars. It seems that these nuclei in atomic states may have been relatively efficiently condensed into dusts and grains in the interstellar clouds, which are formed in supernova ejectae while being cooled off.

1. Introduction

It has been known that the source composition of cosmic rays is relatively overabundant of heavy and ultra-heavy nuclei, mostly siderophile and refractory, as compared with the solar abundance [1,2,3]. The condensation temperature of these nuclei in their atomic states is usually higher than about 1000K, so that their volatility is, of course, relatively lower in comparison with such volatile elements as carbon, oxygen and argon [4].

Since the properties as found in the source composition of cosmic rays seem to have been produced by some process which take place in the sites where cosmic rays are accelerated in order to form the source composition. This composition, therefore, seems to give a clue to find out the mechanism for its formation.

The relative overabundances of heavy and ultra-heavy nuclei in the source composition seem to have been produced either in the regions where they are accelerated or in the interstellar space, through which they propagate after ejected from their acceleration sites.

Referring to the observed data, currently available, on the source composition of cosmic rays, a possible mechanism for the formation of this composition will be considered by taking into account the observed data on the depletion of elements in the interstellar space, since these data could give some hint for rela-

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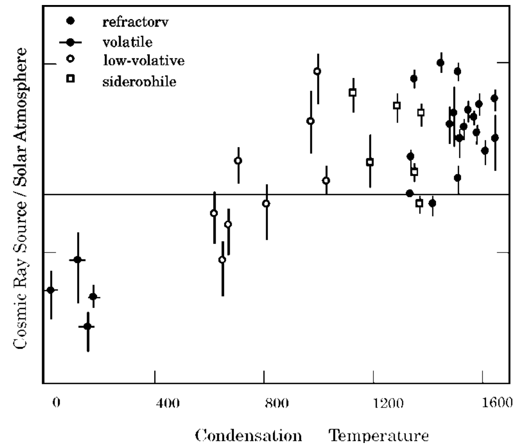

Fig. 1. The ratio of the source composition of cosmic rays to the solar abundance as a function of the depletion of the elements in the interstellar space.

tively efficient acceleration of the elements with the relatively higher temperature of condensation.

2. The source composition of cosmic rays and its possible causal relation to the interstellar depletion of elements

The heavy and ultra-heavy nuclei in the chemical composition of cosmic rays in their sources are relatively overabundant in comparison with the chemical composition of the solar atmosphere. Since these overabundant nuclei seem to be produced in the processes causally related to the mechanism for the formation of the matter, from which cosmic rays are accelerated, it seems necessary to search for this mechanism by taking into account the properties of nuclei either in the ionized or atomic states.

The observed results on the source composition of cosmic rays are shown in Fig. 1, in which it is seen that the source composition is relatively overabundant of heavy and ultra-heavy nuclei as compared with the solar abundance. In this figure, the condensation temperature of these nuclei in atomic states is made in use, because it is convenient in our later consideration to compare the source composition with the data on the depletion of elements in the interstellar space.

Since cosmic rays must have been accelerated somehow a couple of years later after the matter, identified as cosmic ray source, one is ejected into the space surrounding the explosion sites of type II supernovae, this matter seems to have been cooled off to condense efficiently siderophile and refractory elements. These elements are mostly heavy and ultra-heavy nuclei in atomic states in accordance with the terminology in cosmic ray physics.

In order to search for the regions where the matter identified as cosmic ray

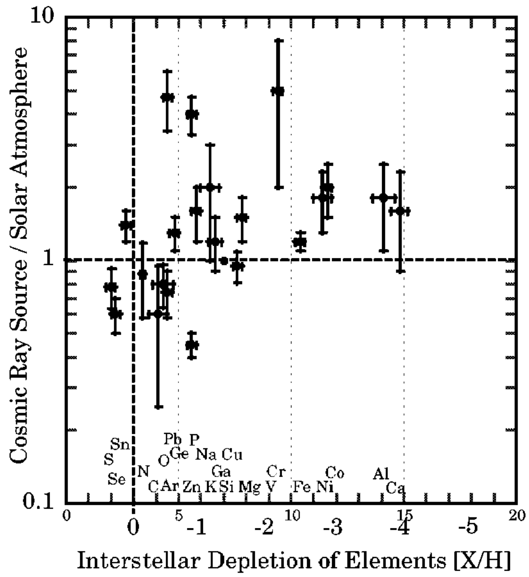

Fig. 2. The ratio of the source composition of cosmic rays to the solar abundance as a function of the depletion of the elements in the interstellar space.

source one is formed, the relative chemical abundance of the interstellar matter has been considered, because this abundance seems to be reflected upon the depletion of elements in this matter [4,5]. Fig. 2 indicates the relation between the source composition of cosmic rays and the depletion of nuclei in their atomic states in the interstellar space [5]. It is clear from this figure that the elements depleted comparatively well are relatively highly enhanced in the source composition of cosmic rays. However, it is noted that the elements highly depleted as Ca and Al are deficient as compared with siderophile elements as iron, cobalt and nickel. This deficiency may have been formed during the process producing the Ca-Al inclusions within chondrites.

As seen in Fig. 1, the condensation temperature of siderophile and refractory elements is higher than about 1000K. So, these elements are relatively enhanced as clearly seen in Fig. 2, though these enhancements tend to become lower with the increase of their depletion degrees, but this tendency is not so large. Except for the element, Pb, volatile elements in the source composition are mostly lower abundant as compared with the solar composition.

3. A possible mechanism for the formation of the source composition

While expanding after ejected from the explosions of type II supernovae, extremely hot gases tend to cool down to a few thousand K within a couple of years. Thus dusts and grains enriched with silicates, carbohydrates and other compounds are formed inside these cooled gases.

Since these gases of such low temperature as some thousand K must have excessively contained compounds concentrated highly as just mentioned, the elements contained in these compounds should be highly depleted in the interstellar clouds.

When these clouds, while drifting in the interstellar space, are eventually hit by shock waves from the explosions of nearly supernovae, various elements condensed inside dusts and grains are partly evaporated from these clouds and some of them are ionized and then accelerated to cosmic ray energy.

Since the elements of condensation temperature relatively lower than 1000K or so are easily ionized [4], they tend to be efficiently accelerated due to their interaction with these shock waves. These elements, therefore, tend to become overabundant in the source composition of cosmic rays as compared with the solar composition. This tendency is seen of the observed results shown in Fig. 2, except for volatile elements, which are found at the lower-left corner of this figure.

4. Concluding remarks

It is necessary to further investigate the mechanism on how these nuclei are accelerated to cosmic ray energy after they are released from interstellar clouds whose temperature is as low as 1000K. The results shown in Fig. 1 suggest that the main component of cosmic rays as being currently observed in the solar system is not identifiable with cosmic rays being accelerated in the envelopes expanding outward from the explosion sites of supernovae, though the observed evidence has been put forth on the acceleration of cosmic rays inside the expanding envelopes of supernovae [6,7].

5. References

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