A Possible Mechanism to Form the Source Composition of Galactic Cosmic Rays as Viewed from the Fractionation of Heavy Elements in Carbonaceous Chondrites

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Abstract: Referring to the observed data in the depletions of elements, refractory and siderophile, in the interstellar clouds, the chemical composition of dust grains has been deduced, though it is highly variable among these clouds. This variability seems to reflect upon the place where such dust grains are formed inside these clouds. Deep inside the clouds, the chemical composition of dust grains is well coincident with that of carbonaceous chondrites as classified as CI. Since the source composition of galactic cosmic rays in much more abundant in refractory and siderophile elements, being classified as heavy and ultra-heavy ones, as compared with those as contained in carbonaceous CI chondrites, the most of volatile elements must have been lost during the process which took place in forming the matter as identified to be 'seed mass' which is to be later accelerated to cosmic ray every this process seems necessarily to be associated with the heating and ionization of dust grains formed within interstellar clouds. Volatile elements must have effectively been lost from chondrites though that process, which become process, and then form the seed mass, which becomes the source matter from which cosmic rays are generated afterward.

Introduction

Even now, it has not been resolved in whether galactic cosmic rays (GCRs) are mainly accelerated in some localized regions as the sites of supernova explosions or in the interstellar space as a whole. In order to search for the regions where the most of GCRs are accelerated, it is necessary to determine the source composition of GCRs and its dependence on the physical proportions of various nuclei contained in GCRs. At present, two competitive ideas have been proposed on the formation of the source composition of GCRs; the one is concerned with the first ionization potentials (FIPs) in atomic states of nuclei as observed in GCRs (e.g., Cassé and Goret (1978)), while the other emphasizes the important role of volatility of each element which is the component of GCRs (Sakurai, 1989). Both of these ideas suggest that the most of GCRs are generated from the interaction of the source material of GCRs with shock waves associated with supernova explosions in the interstellar space (e.g., Ellison et al. (1997)).

The FIP oriented idea assumed that partially ionized particles while drifting in the interstellar space are preferentially accelerated to high energy as GCRs. However, the other one which considers the importance of the volatility of elements consisting of GCRs proposes that the source material of GCRs should be formed in some giant molecular clouds in the interstellar space, though these clouds are initially originated from supernova explosions within OB associations (Higdon and Lingenfelter, 2003). The physical nature of this material may be causally related to the condensation temperature of each element in those clouds, since the source material of GCRs seems to have been formed due to the fractionation of elements as dependent on this temperature (Sakurai, 1989, 1998). If this is the case, the higher is this temperature to each of various elements, the more abundant are the elements in the source material of GCRs (e.g., Hasebe et al. (2005)). This expectation has been confirmed through the comparison of the chemical abundance of the source material of GCRs with that of the solar atmosphere, which is thought of as

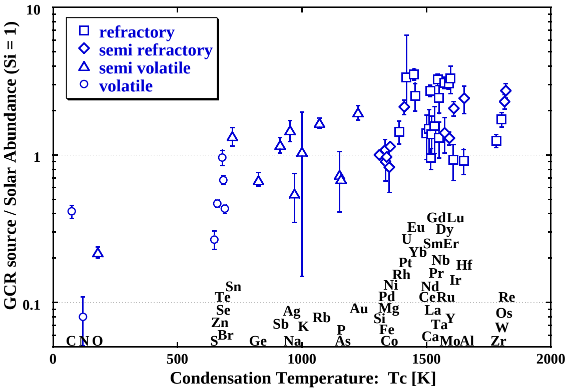

Figure 1: The source composition of galactic cosmic rays as a function of the elemental condensation temperature, being normalized with the element Si for the chemical abundances of galactic cosmic rays in their sources and the solar atmosphere (Hasebe et al., 2005).

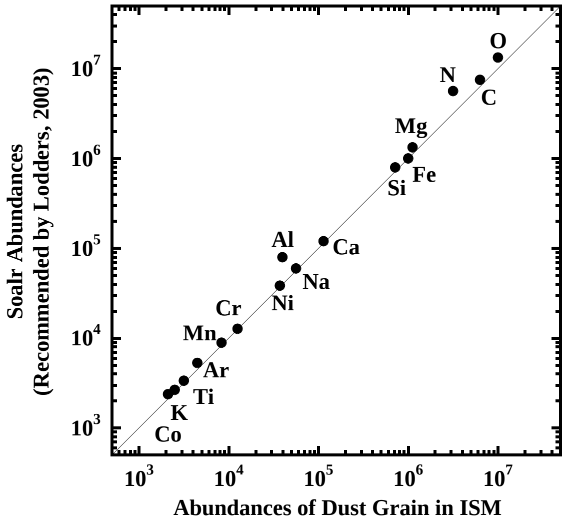

Figure 2: The chemical abundance of the interstellar dust grains versus that of the solar atmosphere.

the standard of the universal abundance (e.g., Lodders (2003)).

The Chemical Composition of Galactic Cosmic Rays in Their Sources as Compared with Those of Carbonaceous Chondrites

It has been shown in Fig.1 that both of refractory and siderophile (i.e., semi refractory) elements are overabundant in the chemical composition of the source material of GCRs as compared with that of the solar atmosphere, which is almost the same as that of carbonaceous chondrites classified as CI (Hasebe et al., 2005). This figure clearly indicates that, as a function of the condensation temperature of elements, the most of the elements, refractory and siderophile, have a tendency to become overabundant in the source composition of GCRs than the chemical composition of the solar atmosphere (Sakurai, 1989). This result may suggest that the source material of GCRs is identified as the dust grains formed gradually as somehow effectively losing volatile elements during the processes of elemental condensation inside giant molecular clouds.

In order to estimate the chemical composition of dust grains formed deep within giant molecular clouds, the observed data on the depletion degrees of various elements in these clouds have been analyzed (Sakurai et al., 2007). The result thus obtained is shown in Fig.2, which indicates that, except for volatile elements, this composition is almost the same as that of the solar atmosphere recommended by Lodders (2003). It is thus necessary to consider some possible mechanism in which volatile elements must be efficiently taken away from dust grains, because these elements are deficient in the source material of GCRs as clearly seen in Fig.1. This mechanism must interpret how volatile elements have been efficiently lost from duet grain. So, a possible mechanism is proposed here as that which is schematically, shown in Fig.3.

As described in Fig.3, the initial composition of dust grains is the same as or similar to the chemical composition of CI chondrites, and these dust grains seem to be heated and then partially ionized as a result of their encounters with shock waves of nearby supernova explosions. Due to this heating and ionization, volatile elements may be taken away effectively from the gases formed in the outer regions composite of partially ionized dusts and gases (the middle and right figures in Fig.3). These dust and

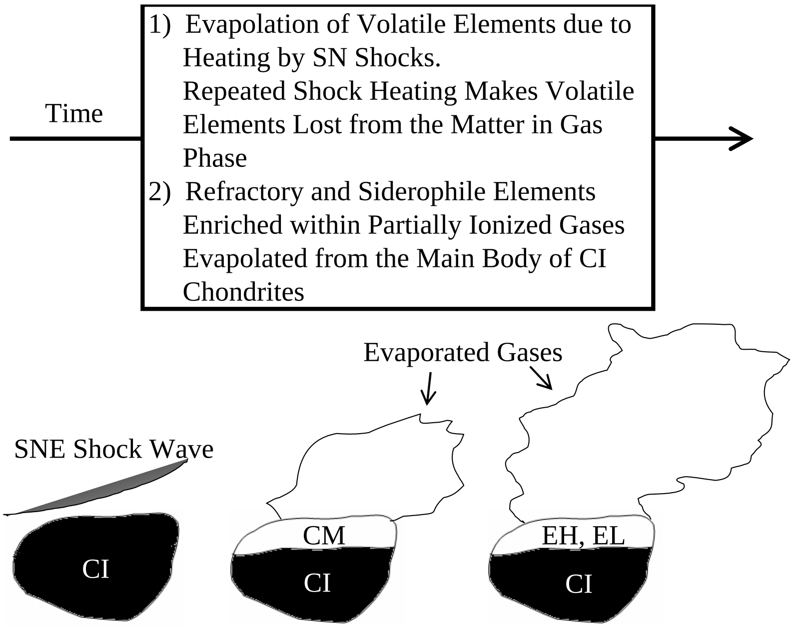

Figure 3: A possible time sequence for the source composition of galactic cosmic rays to be formed as the result of the interaction of dust grains with SNE shock waves in the interstellar space (Sears, 2004).

gases being partially ionized, are, of course, deficient of volatile elements.

Acceleration of Cosmic Rays as Resulted from Their Interaction with Supernova Shocks

As inferred from Fig.3, the chemical composition of the source material of GCRs is somewhat similar to that of chondrites classified as CM or C2 and C3 in the classical term. This source material, being partially ionized, is then accelerated as results of its interaction with shock waves from supernova explosions after released from dust grains into the interstellar space.

These processes as outlined earlier in this paper are highly suggestive for the source composition of GCRs to be introduced from an efficient loss of volatile elements from the source material of GCRs as described in Fig.3. So, both of refractory and siderophile (semi-refractory) elements necessarily become relatively more abundant in source material. These processes thus emphasize that the volatility of elements must have worked more efficiently as compared with the ionization of elements as being reflected upon their first ionization potentials (FIPs). It is noted, however, that the ionization of dust grains and their dissolved components is a factor important for them to be effectively accelerated to high energy as cosmic rays.

While drifting in the interstellar space after released from dust grains, being partially ionized, as described in Fig.3, these dust grains and their dissolved components repeatedly encounter with shock waves associated with supernova explosions and accelerated into higher energy. Finally, these dissolved components must be broken up into ionized gases. These accelerated ionized gases could be identified as GCRs. Thus, the chemical composition of these gases is necessarily similar to that which is shown in Fig.1. The formation of the source material of GCRs must have been initiated with the process being possibly identified as fractionation of elements in carbonaceous chondrites.

Concluding Remarks

As shown in Fig.2, the chemical composition of dust grains formed inside giant molecular clouds is almost the same as that of the solar atmosphere, except for such volatile elements as O, C and N. Since the chemical composition of the source material of GCRs is enriched in both refractory and siderophile (semi refractory) elements more efficiently as compared with those of the solar atmosphere and CI chondrite, such mechanism as fractionation of elements as shown in Fig.3 must take place to effectively lose volatile elements from CI chondrite inside giant molecular clouds. It should be remarked that heating and ionization of dust grains and their dissolved components play a role important to form the source material of GCRs in association with the repeated interactions between these grains and shock waves from supernova explosions in giant molecular clouds. Many of such explosions and SNE remnants have been observed in the OB associations in the Orion arm in the interstellar space.

In order to grasp some clue to resolve in which region cosmic rays are accelerated in the interstellar space, it is essential to search for the chemical composition of ultra heavy nuclei in cosmic rays, since the observations of these nuclei using large telescope array modularized solid state track detector stacks onboard super-pressure balloons or the International Space Station may give some clue to their origin.

Although it seems difficult to precisely identify the species of those ultra heavy nuclei, since most of them are minor components as compared with iron group nuclei in cosmic rays, the stacks developed by our group have proven excellent merit and capability in the test experiments done in our laboratory. Our plan on the observation of those nuclei is described in Hasebe et al. (2007a) and a paper to be presented to this conference (Hasebe et al., 2007b).

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