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INTERSTELLAR ^{22}Na AS A POSSIBLE SOURCE OF THE EXCESS ^{22}Ne IN THE GALACTIC COSMIC RAY

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ABSTRACT

We propose a selective injection mechanism of cosmic ray seed nuclei due to nuclear decay effects. It is shown that ^{22}Na ejected by novae explosion can explain the excess ^{22}Ne in the galactic cosmic ray source by invoking energization and ionization during its beta-decay process in interstellar space.

1. Introduction.

Recent investigations on the cosmic ray charge and isotopic composition have revealed many remarkable features to understand the origin of the galactic cosmic ray (GCR). Among of these are;the organization by the first ionization potential(FIP) of the elemental abundance in GCR source relative to the local galactic abundance(1,2); the excess abundance of several neutron rich isotopes at GCR source(1,3). The most significant and well-established fact is that ^{22}Ne is overabundant in GCR source by a factor of ~3.5 with respect to the solar system value(1).

In this contribution, we want to propose a new mechanism to explain this peculiar imprint bearing the nature of GCR source, and also want to discuss the origin of the source material relating with the recent observational result of galactic gamma-ray lines(4,5).

2. Mechanism producing the excess ^{22}Ne in GCR source.

It has been suggested that the elemental abundance pattern of GCR source relative to the local galactic abundance is well organized by FIP and that this pattern is reproduced by an exponential distribution of temperature at GCR source, with an average temperature $T_0 \simeq 7000$ K(6). Accordingly, a dramatic increase in the relative abundance might be expected for species which attain a significantly higher speed than that of thermal particles, if the particles are injected and accelerated from the tail of a Maxwellian distribution. An example of this kind of preferential heating is proposed to explain ^{3}He-rich solar flare events(7).

Along the similar lines of thought, we want to propose here a new mechanism of selective heating and subsequent preferential injection due to nuclear decay effects which is applicable in principle to any isotopes which have radioactive progenitors. Specificall, we consider here the case of ^{22}Na. This isotope decays to ^{22}Ne via beta-decay with a half life of ~2.6 yr and with a maximum beta-decay energy of

~0.55 MeV. The ^{22}Ne produced by this decay will attain an energy $E_r \simeq 10$ eV owing to the nuclear recoil effect. The temperature corresponding to this energy is ~$1.2\mathrm{x}10^5$K and is significantly higher than the average temperature at GCR source, ~7000 K(6). In addition to this heating, ^{22}Ne will be ionized by the "shakeoff" process during the beta-decay(8), even if the parent ^{22}Na is neutral. This ionization effect might be significant, because neon is virtually neutral at a temperature of ~7000 K. Because of these energization and ionization effects, it is expected that the ^{22}Ne population originated from ^{22}Na may be selectively picked up as cosmic ray seeds and be subjected to subsequent acceleration processes. Certainly, to show this mechanism actually does work, we must investigate if the thermalization and recombination timescales of recoiled ^{22}Ne are long enough so that the nucleus has a chance to be accelerated. But, here, we want to restrict our discussion only to pointing out the possibility of the preferential injection mechanism due to the nuclear decay effects as shown above. Instead, in following, we want to compare quantitatively the rate of ^{22}Na supply into interstellar medium(ISM) with the production rate of ^{22}Ne in GCRs.

3. Estimation of production rates. The excess isotopic abundance of ^{22}Ne in GCR source to be explained is

$$\Delta n_{22} = (^{22}\mathrm{Ne}/^{20}\mathrm{Ne})_{GCR} - 1.6\mathrm{x}(^{22}\mathrm{Ne}/^{20}\mathrm{Ne}) \simeq 0.2$$

where $(^{22}\mathrm{Ne}/^{20}\mathrm{Ne})_{GCR}$ and $(^{22}\mathrm{Ne}/^{20}\mathrm{Ne})$ are the neon isotopic ratios in GCR source (~0.4) and in the solar system (~0.12), respectively(1,3).Here we assume the excess ^{22}Ne up to ~1.6 times of the solar system value is explained by the super metalicity hypothesis(9)(although our conclusion is not affected whether the factor of 1.6 is taken into account or not). Then the production rate of the excess ^{22}Ne in the whole galaxy is estimated as follows,

$$\Delta \dot{N}_{22} \simeq \dot{N}_{CR} \mathrm{x} (n_{20}/n_{CR}) \mathrm{x} \Delta n_{22} \simeq 3\mathrm{x}10^{38} \text{particles/sec}$$

where $\dot{N}_{CR}$,~$3\mathrm{x}10^{42}$ particles/sec, is the production rate of GCR in the whole galaxy and is estimated from the localcosmic ray density ~$10^{-10}/\mathrm{cm}^3$, the volume of the galaxy ~$10^{67}\mathrm{cm}^3$ and the life time of GCRs, ~10^7yr(10). (n_{20}/n_{CR}) is the relative abundance of ^{20}Ne in the cosmic ray, ~$5\mathrm{x}10^{-4}$(2). From our point of view, it is necessary that sufficient amount of ^{22}Na exists in interstellar space to maintain ^{22}Ne abundance in GCR. In other words, the rate of ^{22}Na supply should be higher than the production rate of the excess ^{22}Ne in GCR. Explosive nucleosynthesis in novae is expected to produce ^{22}Na and ^{26}Al (11). The gamma-ray spectroscopy experiment has detected the line with an energy of 1.8 MeV, consistent with the decay of ~3 $M_\odot$ of ^{26}Al in the interstellar space(5). The source of the observed ^{26}Al has been attributed to galactic novae, not supernovae(5). We can estimate the total amount of ^{22}Na of novae origin, M_{22}, from the observed amount of ^{26}Al, $M_{26} \simeq 3\ M_\odot$, by using the simple model for the chemical evolution of the galaxy(12) as following,

$$M_{22} = M_{26} \times (X_{22}/X_{26})$$

$$\simeq M_{26} \times (P_{22}/P_{26}) \times (T_{22}/T_{26})$$

where, (X_{22}/X_{26}) is the abundance ratio of ^{22}Na and ^{26}Al in the present interstellar space; (P_{22}/P_{26}) is the average isotopic production ratio of ^{22}Na and ^{26}Al for explosive process in novae and is $\sim 10^{-3}$ (13); (T_{22}/T_{26}) is the ratio of half lives, $\sim 3.6 \times 10^{-6}$. From this analysis the amount of ^{22}Na in the interstellar space is estimated as $\sim 2.2 \times 10^{25}$g or 5.9×10^{47} atoms. If the decay and production are in equilibrium, the rate of supply of ^{22}Na is estimated as $\sim 5 \times 10^{39}$ atoms/sec (approximately the same value is also obtained from the occurance of novae in the galaxy $\sim$40/yr (14), the average mass of matter ejected by a nova explosion $\sim 10^{-4} M_\odot$ and the concentration of ^{22}Na in the ejecta $(2 \sim 10) \times 10^{-7}$ g/g (13)). This value of the production rate (or the decay rate) of ^{22}Na, Q_{22}, is not inconsistent with the upper limit $\sim 4.4 \times 10^{42}$ atoms/sec obtained by HEAO3 observation of the diffuse galactic gamma-ray lines(4) and is higher than $\Delta \dot{N}_{22} \simeq 3 \times 10^{38}$ atoms/sec, the production rate of the excess ^{22}Ne in GCR source. The ratio of $\Delta \dot{N}_{22}$ to Q_{22} is $\sim$6%. This means that the probability of ^{22}Na ejected by novae to become a cosmic ray ^{22}Ne is 6%. Therefore, novae can supply the seeds of excess ^{22}Ne in GCRs, in principle. ^{22}Na ejected by novae explosion might be preferentially injected as cosmic ray seeds owing to the effects shown above.

4. Discussion and conclusion.

Although the amount of ^{22}Na ejected by novae explosion is enough to account the excess ^{22}Ne, the probability of 6% seems to be rather high. So it is interesting here to estimate the probability for the bulk GCRs and enhancement factor of ^{22}Ne to be realized by our selective injection model. It has been suggested by the shock acceleration model for cosmic ray production that energetic particles are drawn directly from a thermal pool (15). If this view is correct, we can estimate the average efficiency of interstellar medium (ISM) to become cosmic rays. The ISM is undergoing continual change on a time scale of $\sim$Gyr (16). If our galaxy is in a steady state (or if the amount of ISM is constant) during the last several Gyr, the rate of supply of ISM from stars is estimated as $\sim 3 \times 10^{51}$ atoms/sec by dividing the amount of ISM with 10^9yr. So the efficiency of ISM is $\dot{N}_{CR}/(3 \times 10^{51}) = 10^{-9}$. Consequently, the efficiency of ^{22}Na is $\sim 6 \times 10^7$ times higher than that of the general ISM. On the other hand, the enhancement factor of $\exp(E_r/kT_0) = 2.8 \times 10^7$ is expected by our selective injection mechanism for ^{22}Ne due to the nuclear decay effects if the average temperature of the thermal pool of GCR source is $\sim$7000 K as suggested by the ionic model for GCR source(6).

This value is not different so much to the required enhancement factor ~6x10^7. Furthermore, the requirement may be weekened if there is any source of ^{22}Na other than novae.

Finally, we should comment on a question, that is, why the excess is seen only for ^{22}Ne. The answer is that the selective injection mechanism due to the nuclear decay effects does not work fully for isotopes other than ^{22}Na, because they are either too short-lived or have been locked up into grains. Only ^{22}Na has an appropriate half life and remains in gas phase because Na is expected to behave as a volatile in space.

In conclusion, it may be possible to explain the origin of the observed ^{22}Ne excess in GCR source as due to interstellar ^{22}Na selectively injected by the nuclear recoil and shakeoff effects.

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