ISOTOPES IN GALACTIC COSMIC RAYS

Hubert Reeves,
Section d'Astrophysique, Saclay
Institut d'Astrophysique, Paris

The data on isotopic ratios of elements in Galactic Cosmic Rays (GCR) is steadily improving and has recently reached the point where some information can be extracted, which has bearing on the problem of the origin of the cosmic rays. By and large, these data have generally confirmed the similarity between solar-type matter and GCR source, when spallation effects and selective acceleration are taken into account. The silicon and iron isotopic ratios, for

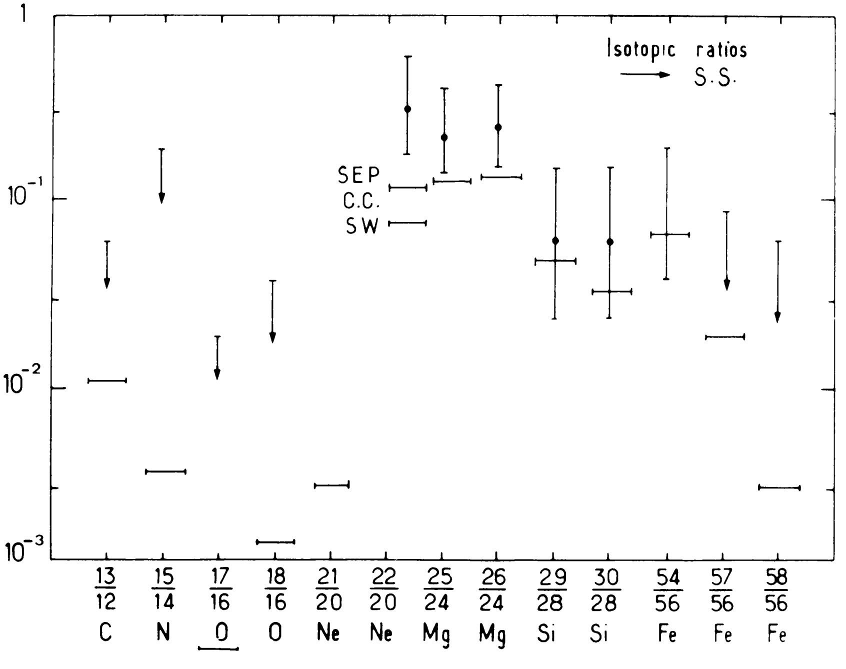

Fig. 1. Isotopic ratios in GCR (or their upper limits) compared to the same ratios in the solar system (horizontal bars). SEP is solar energetic particles, C.C is carbonaceous chondrites and SW is solar wind.

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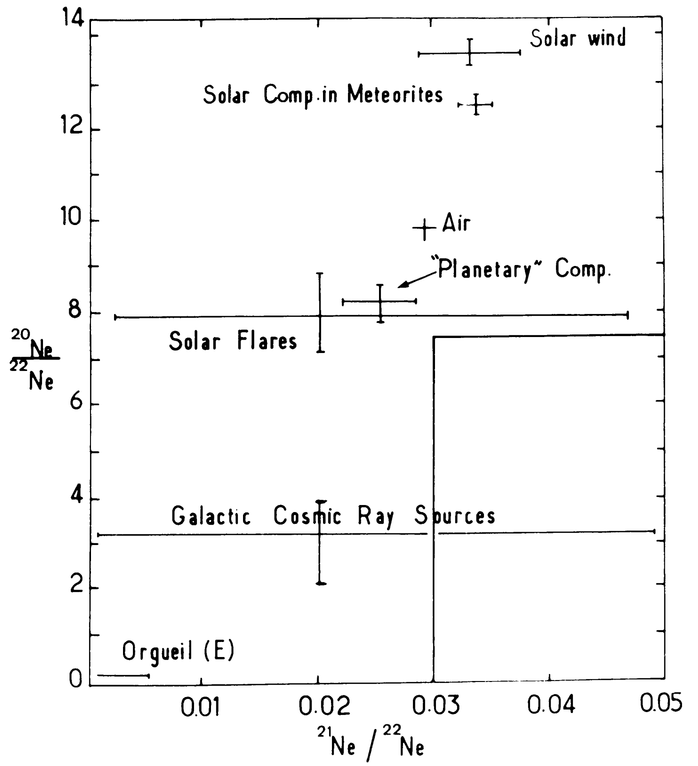

Fig. 2 Neon isotopic composition, Ne^{20}/Ne^{22} and Ne^{21}/Ne^{22}.

instance, are consistent with meteoritic ratios (Mewaldt et al. 1980a, 1980b). For iron, this is particularly important since two or perhaps even three different nucleosynthesis mechanisms are required to account for the species ^{54}Fe, ^{56}Fe, ^{58}Fe. For carbon, nitrogen and oxygen the problem is that the spallation corrections are large compared to the solar system ratios but nevertheless the present upper limits are not in contradiction with the solar system ratios (fig. 1).

The one isotopic ratio which definitely appears to differ is the neon ratio (Garcia Munoz et al. 1979a, Mewaldt et al. 1980a). Ironically, this is also the only element whose isotopic ratio is not known with certainty in the solar system. The situation is shown in figure 2. The solar wind ratio of $^{20}Ne/^{22}Ne$ is $\simeq$ 12-13 (Geiss and Bochsler 1979) while the value in the gas trapped in chondrites is about 8 (Black and Pepin 1969) not very different from the earth atmospheric value and the recently measured solar flare values (Mewaldt 1980). The GCR source value ($\simeq$3) certainly differs from both of these values, whichever is representative of the solar value. (The low $^{20}Ne/^{22}Ne<10^{-2}$ found in Orgueil (Eberhardt et al. 1979) probably originates from decay of ^{22}Na and may not have any bearing on the present discussion (fig. 2)).

There is also a fair probability that the magnesium ratios (Garcia-Munoz et al. 1979b) (both $^{25}Mg/^{24}Mg$ and $^{26}Mg/^{24}Mg$) are larger than the meteoritic ratios, although better data are needed to ascertain this question.

What do those ratios (Ne and perhaps Mg) teach us about the origin of the GCR? I can think of four possible scenarios by which these "anomalies" could have come about. I shall discuss them in turn, giving "pros" and "cons".

I - SELECTIVE ACCELERATION OF ISOTOPES

There is the possibility that we are not dealing with real compositional effects but with biases in the acceleration, just as is the case for elements in solar and galactic cosmic rays (Cassé and Goret 1978). In other words, is nature fooling us again? There are already some important examples of selective acceleration of isotopes. The $^3He/^4He$ ratio shows extreme variations (up to 10^4.) in solar flares and more modest variations (up to about 4) in solar wind. The $^{20}Ne/^{22}Ne$ shows selective acceleration effects in the solar wind (if the solar value is $\sim$8) or in the solar flares (if the solar value is $\sim$ 13). It is worth noticing that the Galileo mission to Jupiter is planned to measure this ratio there. The value obtained is likely to be extendable to the sun (Jupiter appears to have a solar composition in many other respects). The data will decide which, of the solar wind or the solar flares, is experiencing isotopic selective acceleration.

Are there other isotopic anomalies in the solar flares? There is a slight indication that magnesium may be such a case (Mewaldt 1980). If this is confirmed, we shall have to consider seriously this first scenario.

II - GALACTIC ENRICHMENT EFFECT

The GCR particles have ages of $\sim 10^7$ years (Garcia-Munoz et al. 1977, Wiedenbeck and Greiner 1980). If they represent a sample of ordinary galactic gas matter, they could differ from the solar system material (dating back to 4.5×10^9 years ago) simply because of gradual nucleosynthetic enrichment. More specifically this scenario requires that the abundance of ^{22}Ne should have increased by a factor from three to five during this period. It is fair to say that such large increments are not observed for other elements in stellar material of corresponding ages, even for secondary products like ^{13}C or N. This scenario would imply that ^{22}Ne is a product of small star nucleosynthesis (which are only becoming "ripe" in the last few billion years). The natural nucleosynthetic process would be:

a) CNO cycle which transform ^{12}C and ^{16}O in ^{14}N

b) The onset of helium burning with

$$^{14}N(\alpha,\gamma)\ ^{18}F(\beta^+,\nu)\ ^{18}O(\alpha,\gamma)\ ^{22}Ne \begin{array}{l} \rightarrow (\alpha,\gamma)^{26}Mg \\ \rightarrow (\alpha,n)^{25}Mg \end{array}$$

Thus, ^{22}Ne would be a secondary product and would be expected to increase at a slower rate than ^{20}Ne (which is a primary product of carbon burning). This process is advantageous in the sense that it would also explain the magnesium isotopic anomalies if confirmed. But the absence of N increase, between the birth of the sun and now, may be a difficulty for this scenario.

III - SUPERNOVA INJECTION OF RECENTLY GENERATED MATERIAL

There is very little support for the idea that supernovae are contributing freshly brewed material to the GCR. The evidence for transuranic nuclei is vanishing with the new data of HEAO-C (Waddington 1980) and Ariel-5 (Fowler 1980). The long-sought r-process peaks are still to be established. Quite generally, from Fe to Pb the GCR source are hardly distinguishable from solar material (there is not even the selective acceleration bias). Thus the neon (and perhaps magnesium) anomaly would be the only remaining effect of the supernova! Invoking a supernova to account for this effect is like using a sledge hammer to kill a fly ... And one would be left with the problem of explaining why we do not get other anomalies.

The main reason for my lack of sympathy for this model is a question of strategy. This model is not vulnerable, in the sense that it can hardly be shown to be wrong. Too much freedom is left in the choice of the free parameters (zone mixing, etc ...). This is an unfortunate situation but one we have to live with. Personally, I would try any other solution before I fall back on this one, although it may still be the correct one.

IV - OB ASSOCIATIONS AND RELATED OBJECTS

To develop this scenario we take advantage of some recent developments in UV, X-ray and gamma-ray astronomy.

Because cosmic rays are charged particles, they are isotropized by galactic magnetic fields and loose the memory of their birthplace. But photons keep their original direction. For this reason gamma-ray observations are potentially highly informative in telling us where the cosmic rays originate (provided γ ray photons are produced by cosmic rays interactions).

The recent data of COS-B (Wills et al. 1980; Hermsen 1980) on photons with energies $\geqslant$ 100 MeV have revealed the presence of "gamma ray sources" which could well fulfill this hope. The one important piece of information is that those sources are all well within the galactic plane. The scale height is about 100 pc. This corresponds to the scale height of very young objects in the Galaxy: molecular clouds, OB associations, HII regions, etc. Hence the hint that the origin of the cosmic rays may well be related to these places of stellar births. Detailed analyses of the celestial coordinates of these sources gives in fact some correlation with the position of the OB associations with supernova remnants (Montmerle 1979).

Before this point is established however, one would have to convincingly establish that these gamma-ray enhancements do not simply reflect the concentration of matter in clouds. In other words, can they be quantitatively accounted for without invoking a local increase in the proton flux itself (the gamma ray source function is proportional to the product of the flux times the matter density)? Wolfendale (this Conference) has defended this view and has contested the presence of enhanced cosmic ray emissivities. It seems that for at least one source (ρ Ophiuchi)an enhanced emissivity is required. More work is needed to clear this very important issue ...

Blaauw (1964) has studied in detail the structure of OB associations. Their dispersion times is $\simeq 15 \times 10^6$ years, longer than the whole lifetime of stars more massive than 16 $M_\odot$. Stellar statistics indicate that in a typical OB association, from ten to twency stars will have time to undergo their evolution and die before dispersion. Upon dying, these stars generate a supernova remnant which disturbs the whole association (Reeves 1978, 1979). Such events appear to have played a role in the origin of the solar system and to be responsible for some of the meteoritic anomalies recently observed (Wasserbug 1978, Clayton 1976).

UV data from the Copernicus satellite have shown that O and B stars have very strong supersonic winds (2000 km/sec, $\dot{M} = 10^{-7}$ to 10^{-5} $M_\odot yr^{-1}$) giving rise to P Cygni profiles. Occasionally, among these O stars, a few Wolf-Rayet stars are present with rather unusual chemical composition: very low H/He ratio ($\leqslant 0.1$), enhanced N or C. Because of the high frequency of binaries in this population, it is believed that WR stars have lost their original atmosphere through Roche lobe overflow and are showing shells with freshly made nucleosynthetic products (of H or He burning) (see e.g. Van beveren and Packet 1979).

Thus, the following scenario, developed in detail later on this Conference by Cassé, Paul, Montmerle and Meyer. Acceleration takes place as a result of Fermi mechanism combined with Alfven scattering (Blandford and Ostriker 1978) either at the boundary of the stellar wind cavity (Cassé and Paul 1980) or in relation with shock-waves induced by the supernovae of the OB associations (Montmerle 1979).

The O stars have solar abundances. Energetically they meet the requirements of GCR. But how do we account for the ^{22}Ne anomaly?

We take advantage of the fact that ^{22}Ne is a normal product of

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He burning after the CNO phase (same as described previously), to speculate that WR atmospheres could be enriched in ^{22}Ne with respect to ^{20}Ne. It is further known that these stars have extremely strong stellar winds ($\sim 10^{-4} M_{\odot}\, yr^{-1}$). Thus the sum of O stars and WR stars could inject a solar type sample of material with additional ^{22}Ne (and perhaps ^{25}Mg, ^{26}Mg). Observations of neon overabundances (if possible) in WR would help to promote this scenario.

No matter whether this specific ^{22}Ne enriching mechanism is the correct one or not, it seems fair to say that OB associations are likely to play an increasingly important role in the origin of cosmic rays. We are looking forward to the observations of gamma-ray lines (the 4.4. MeV line of ^{12}C in particular) in these regions to give us more information on this question.

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