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Neutrino induced nucleosynthesis

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Abstract. The detection of neutrinos from SN1987a has revived the interest in neutrino induced nucleosynthesis. In this work various results on the neutrino produced abundances of several isotopes are summarised and compared with the observations in the solar neighbourhood. It is suggested that there is a possibility of finding unusual correlated isotopic anomalies, which may serve as unmistakable signatures of neutrino induced nucleosynthetic processes.

Key words : neutrino physics—nucleosynthesis

1. Introduction

The detection (Bionta *et al.* 1987; Hirata *et al.* 1987) of neutrino signals from SN1987A, has revived interest in the neutrino induced nucleosynthesis. (Domogadskii & Nadyozhin 1977, 1978, 1980b; Domogadskii *et al.* 1978; Domogadskii & Imshennik, 1982; Woosley 1977; Epstein *et al.* 1988; Woosley & Haxton, 1988; Woosley *et al.* 1990). In this work, we want to alert the meteoritic community about the possibility of finding unusual correlated isotopic anomalies, which may serve as unmistakable signatures of neutrino induced nucleosynthetic processes. The light isotopes ^{7}Li and ^{11}B have been shown to be underproduced in the standard cosmic ray spallation processes (Reeves *et al.* 1970), leading to a suggestion (Audouze & Reeves 1982) of a peculiar second component of low energy cosmic rays to produce these. While ^{7}Li can possibly be produced in AGB stars by the Cameron-Folwer (1971) mechanism, ^{11}B is still a problem. The nucleosynthetic processes, producing the nature's rarest shielded isotopes, ^{138}La, ^{176}Lu and ^{180}Ta, are not known. Other shielded isotopes, which are not produced in mainline *r* and *s* process chains are attributed to, as yet little understood, *p* process. In the case of ^{176}Lu, a weak branch of the *s* process chain may lead to its production (Audouze *et al.* 1978). While the neutrino induced nucleosynthesis is capable of producing all these isotopes, it is shown in this work that the overabundance factors of these isotopes, produced by ν induced processes, single out ^{11}B, ^{138}La and ^{180}Ta as the dominant products of the ν induced nucleosynthesis. Hence it is suggested that a positive correlated study of isotopic anomalies of ^{11}B, ^{138}La and ^{180}Ta, is the best signature of the operation of ν processes.

2. Calculations

Basically the neutrino interactions of interest are inelastic neutral current scattering, which leaves the target in an excited state. The deexcitation may occur through one of the four channels, namely n, p, α or γ emission. In addition charged current scattering is also dominant in certain cases. The excitations are mainly to isobaric analog states or giant Gamow-Teller Resonance states. Shell-model calculations to determine the excited states, coupled with full Hauser-Feshbach optical model techniques to determine the branching ratios, are the standard techniques used in calculating cross-sections for the production of any nuclide. These have been reviewed by several authors (Haxton 1991; Woosley *et al.* 1990) and will not be repeated here.

The neutrino flux in a standard supernova explosion is of the order of about 10^{58} neutrinos emitted within about ten seconds (Arnett *et al.* 1989; Schramm & Truran 1990). The mean energy of the neutrinos is about 10 MeV. The muon and taon neutrinos have high mean energies, whereas electron neutrinos have mean energy of about 5 MeV. The cross-sections are of the order of 10^{-42} cm^2 per nucleon. The calculations in general use solar metallicity, though reduced metal abundances have been used in some of the calculations.

In order to decide the capability of any process to produce certain isotopes, in order to affect the solar abundances, the following procedure is adopted. First the overabundance of a particular isotope compared to the solar value is calculated for any particular shell undergoing nuclear burning. Then the mass fraction of that particular shell is found out. The ratio of this mass fraction to the mass of the ejecta multiplied by the overabundance factor will give the overabundance factor for that particular shell. When all the contributions are added together, we obtain the overall overproduction compared to the sun. Essentially, in this manner, the production ratios for particular supernova is obtained. If this ratio is much larger than unity, then the neutrino induced process is giving substantial contribution. This ratio may be calculated for stars of various masses and with the assumption of an 'initial mass function', one can determine the 'galactic chemical evolution'. Since our purpose is to alert the meteoritic community to look for specific anomalies, we are just presenting below in table 1, the average overabundance ratio in the ejected mass fraction of a 20 M_0 star, as inferred from the calculations of Woosley *et al.* (1990).

Table 1. Isotope-overabundance

^{7}Li	17
^{11}B	60
^{19}F	22
^{138}La	25
^{180}Ta	25

The value shown above for ^{138}La has been modified from the value quoted by Woosley *et al.* (1990) to take into account the charged current scattering off ^{138}Ba. In this case, the charged current interaction gives the dominant contribution due to the fact that the abundance of ^{138}Ba is an order of magnitude more than the abundance of ^{139}La (Cameron 1982). Further the charged current cross-section is large due to the Coulomb enhancement in the case of this high Z nuclei. In the case of ^{180}Ta, it is produced mainly by the neutrino excited ^{181}Ta, followed by neutron emission.

3. Discussion and conclusion

From an examination of the above table, it comes to our mind that the enigmatic Boron is produced by the neutrino process very efficiently. Further ^{19}F is also produced in the supernova models. In addition rare isotopes of La and Ta are also produced in large overabundances. This immediately brings to our mind the possibility of experimental confirmation of the neutrino produced nucleosynthesis. Though the chemistry of grain formation with such diverse elements like the volatile Boron and highly refractive Tantalum is highly complex, the recent isolation of interstellar diamonds trapping anomalous Xenon, makes us ask the question, if Xenon can be tapped in diamonds, why not B, La, F or Ta. It will be a great confirmation of the neutrino processes in supernova, if such correlated anomalies can be found.

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