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Supernova induced star formation*

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Abstract. The evidence for the triggering of star formation by shocks from expanding supernova shells is examined with special emphasis on the solar system. It is shown that the recently discovered isotopic anomalies, mainly in Ti, can serve as the best signature for this purpose. It is suggested that the discovery of correlated anomalies in Ti, Fe, and Ca will give important clues to the nucleosynthetic origin, as well as chemical history.

Key words : star formation—supernova—explosive nucleosynthesis

1. Introduction

The idea that supernova explosions can trigger star formation in dense interstellar clouds was suggested by Opik (1953). It was based on the general phenomena of expanding shells of supernovae, giant rings of Orion, and Large Magellanic Clouds—appearing to represent advanced stages of expansion in supernova shells—and stellar associations. But the real thrust for this idea came from the discovery of isotopic anomalies in meteorites in several elements like oxygen magnesium, rare gases, etc. (Cameron & Truran 1977; Manuel & Sabu 1975; Reeves 1978; Wasserburg, Papanastassiou & Lee 1980). These anomalies indicated the presence in the primitive solar nebula of nucleosynthetic products from supernovae. Since, to postulate that only our solar system has received nucleosynthetic products directly from a supernova, is preposterous, it was suggested that in general, star formation is triggered by a supernova explosion. This was further supported by the interpretation of dense shell of gas near Canis Major R1 region as due to a supernova explosion (Herbst & Assousa 1977). Further, numerical simulation of star formation also indicated that supernovae can induce star formation in

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interstellar clouds in several ways, including Kelvin-Helmoholtz and Rayleigh-Taylor instabilities (Woodward 1976, 1980). But at present, the situation remains unclear, as other interpretations of the observations of isotopic anomalies as well as Canis Major Rl region are possible.

In this brief review, new observational evidences on the possible supernovae associated star formating regions as well as isotopic anomalies are summarized. Further new advances in numerical simulation are also mentioned. The nucleosynthetic products from supernovae may retain their identity during the star formation stage, inspite of the chemical history of condensation to form solid material (Clayton 1982; Lattimer, Schramm & Grossman 1978). The possibility of getting information about nucleosynthetic origin and chemical history using the isotopic anomalies is investigated with special reference to the formation of solar system. Finally, the predicted isotopic anomalies are summarized.

2. Recent new results

2.1. *Supernovae associated star forming regions*

The far-infrared and molecular cloud sources such as in W44, W28, and G357.7–0.1 have been examined with respect to their associations with supernova remnants. A systematic study of this type using the IRAS point source catalogue was done by Rengarajan, Verma & Iyengar (1985). With a total sample of 117 supernova remnants, they find an excess of IRAS sources associated with supernova remnants with a significance of more than 4σ. These sources are likely to be young contracting protostars.

2.2. *Isotopic anomalies in meteorites*

The primitive meteorites of carbonaceous chondrite type are believed to be coeval with the formation of the solar system. Hence an understanding of the isotopic composition of the meteoritic material will give information about the primordial solar nebula. The earlier studies on the extinct radioactivities in meteorites—seen as isotopic anomalies in magnesium-26 (parent-26 Al with half-life of 0.7×10^6 yr), neon-22 (parent-22 Na with half-life of 2.2 yr), potassium-41 (parent-41 Ca with a half-life of 1.3 10^5 yr), and silver-107 (parent-107 Pd with a half-life of 6.5×10^6 yr)—indicated that the time difference between the last nucleosynthetic event adding their products to the primitive solar nebula and the formation of solar system was less than 3×10^6 yr. Further the anomalies in oxygen indicated that nearly 5% of pure ^{16}O was added to the primitive solar nebula. The ideal source for all these materials is a supernova and it was believed that the supernova triggered the formation of the solar system dumping some of its nucleosynthetic products in the nebula during the formation stage.

Since then, several new developments have taken place. The oxygen anomaly, which was the cleanest of all the isotopic anomalies, could be due to mass fractionation process due to the chemistry taking place in the process of UV irradiation in the primitive solar nebula. The other isotopic anomalies of the extinct radioactivities-type could have reached the solar system in the form of carrier grains from the interstellar medium (Clayton 1982).

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The latest experimental discovery is the unambiguous determination of isotopic anomalies in titanium (Fahey *et al.* 1985; Niederer, Papanastassiou & Wasserburg 1985). Analysing the individual hibonite and pyroxene grains from the two primitive carbonaceous chondrites, namely Murchison and Murray, and using ion probe technique Fahey *et al.* (1985) concluded that the grains have a 10% excess of ^{50}Ti compared to the solar system values. This is 25 times more than the earlier reported values. It was also found that the ratio of excess 50/excess 49 is 26 ± 10, which is very different from other measurements Earlier the Swiss-Caltech group had analysed Allende and Leoville meteorites and found evidence for some isotopic fractionation effects in ^{50}Ti, but no such correction for the isotopic fractionation effects in Ca and Mg (Niederer, Papanastassiou & Wasserburg 1985). It should be mentioned that the anomaly in ^{50}Ti has a large spread from very negative values (Hutcheon *et al.* 1983) to the extreme excesses reported by Fahey *et al.* (1985).

The interpretation of the above startling results leads one to the effects of the chemistry of the formation of the grains as well as the nucleosynthetic processes. As emphasized by Fahey *et al.* (1985), the excess ^{50}Ti clearly points to the nucleosynthetic process of neutron-rich nuclear statistical equilibrium processes (Cameron 1979; Hartmann, Woosley & El-Eid 1985). It is necessary to find out the correlated anomalies especially in Ni. For an enrichment of the order observed by Fahey *et al.* one expects an enrichment ^{60}Ni (produced as ^{60}Fe) by a factor of 60. If such an enrichment is observed, but no isotopic anomalies in Ca, then it is clear that the nucleosynthetic products from supernovae were present in the primitive solar nebula. This is because the condensation temperatures of Ti, Fe, Ni, and Ca are 1660, 1535, 1453, and 839 K respectively. As we have argued (Ramadurai 1985) it is clear that the twin problems of condensation chemistry and nucleosynthetic processes can be solved by the study of correlated anomalies.

2.3. *Numerical simulations*

In addition to the early work of Woodward (1976), recently detailed numerical work by Krebs & Hillebrandt (1983) has shown that isothermal compression from the exploding star can lead to the collapse of the whole interstellar cloud provided separation is less than 20 pc. This was extended to the magnetic cloud too and it was shown by the same group (Oettl, Hillebrandt & Muller 1985) that, provided the magnetic field is less than 10 microgauss, the collapse still proceeds.

3. Conclusions

Marginal evidence for the dynamical association of star forming regions near supernova remnants is available. The numerical simulations lend support to such a view. The isotopic anomalies in meteorites too lend support to the supernova trigger for the solar system. A study of correlated anomalies in Ti, Ni, Ca, Fe, etc. is likely to give clues to both chemistry and nucleosynthetic processes responsible for the formation of solar system.

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