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DO SUPERNOVAE OF TYPE I PLAY A ROLE IN COSMIC-RAY PRODUCTION?

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ABSTRACT

A model of cosmic-ray origin is suggested which aims to account for some salient features of the composition. Relative to solar abundances, the Galactic cosmic rays (GCR) are deficient in hydrogen and helim (H and He) by an order of magnitude when the two compositions are normalized at iron. Our conjectural model implicates supernovae of Type I (SN-I) as sources of <u>some</u> of the GCR. SN-I occur approximately as often as SN-II, though their genesis is thought to be different. Recent studies of nucleosynthesis in SN-I based on accreting white dwarfs, find that the elements from Si to Fe are produced copiously (1). On the other hand, SN-I are virtually devoid of hydrogen, and upper limits deduced for He are low. If SN-I contribute significantly to the pool of GCR by injecting energetic particles into the interstellar medium (ISM), then this could explain why the resulting GCR is relatively deficient in H and He. A test of the model is proposed, and difficulties are discussed.

<u>1. Introduction.</u> A puzzling feature of cosmic-ray composition is the enhancement of many heavy primary nuclei (HPN) among the particles arriving in the vicinity of the earth (2). Compared to solar composition or the local galactic abundances, this ten-fold enrichment in peak elements like Mg, Si, and Fe can also be described as a relative deficiency of H and He. However it may be characterized, this order-of-magnitude discrepancy, unlike other anomalies in composition, cannot be explained by fragmentation in the interstellar medium or by selection effects that depend on the first ionization potential. Any viable theory of cosmic-ray genesis must account for this anomaly.

It is noteworthy that the source energy spectra of H and He also differ from those of the HPN; the latter are somewhat steeper (3). Taken together, the dearth of H and He, and the difference in their energy spectra from those of the HPN, raise the question whether these two components have had different histories. On the other hand, the fact that their production spectra are not very different suggests that a common acceleration mechanism may be working for both.

<u>2. Supernovae and Cosmic Rays.</u> Some three decades ago, supernovae and their remnants were invoked as self-contained sites of cosmic-ray

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origin, i.e., as energy sources, material sources, and regions of acceleration. In trying to explain the source composition, the massive precursors of Type II supernovae (SN-II) were favored as sites of nucleosynthesis for the material destined to become cosmic rays. Recent calculations of SN-II explosions show, however, that it would be difficult to eject sufficient Fe, since the iron is left in the core of the residual neutron star. Moreover, it is doubtful that a sufficient flux of heavy nuclei could escape from the SN-II explosion through the surrounding red-giant envelope.

3. Supernovae of Type I as Injectors of HPN. We propose a conjectural model for the genesis of GCR in which the pool of cosmic-ray nuclei is a mixture of two components:

(A) the bulk of cosmic-ray hydrogen and helium, and a minor portion of HPN, with an overall composition resembling that of the solar system or the ISM; and
(B) the bulk of the HPN (some 90 per cent?) originating predominantly in supernova outbursts of Type I.

With this model we hope to account for the relative deficit of H and He in the cosmic rays.

First we recall some distinguishing features of SN-I and SN-II. While the two types of explosions occur with comparable frequency, their precursors are quite different according to currently favored theories. A Type II supernova results from the evolution of a single massive star; an SN-I, on the other hand, evolves from an accreting white dwarf in a binary system. Among the observational differences are the following. An SN-II has a thick hydrogen envelope, whereas in SN-I light spectra, the lack of H lines implies the absence of a substantial hydrogen envelope. The same SN-I spectra have been used to deduce very low upper limits to the He abundance. The precursors of SN-I are old stars of low mass. The two types of supernovae have different light curves. SN-I are considered to have steep density gradients and to generate strong shocks.

Referring to the two components (A and B) of the GCR postulated above, we envisage the following scenarios for their injection and acceleration: (A) The arriving ("primary") H and He nuclei, and a small fraction of the HPN are injected, e.g., from flares in main-sequence F-to-M stars; other source-injectors are not excluded. They are then accelerated at expanding shock fronts in the ISM, energized mainly by supernova outbursts. (B) Nearly all of the HPN are injected--with modest energies-- from SN-I explosions, and then accelerated in the ISM by the same shock waves as component (A).

4. Nucleosynthesis in SN-I. Since the SN-II seem incapable, by themselves, of yielding a solar-type composition, attention has turned to SN-I models that might produce a plausible mix of metals, especially to carbon-deflagration models (1, 4, 5). These involve a rapidly accreting white dwarf in a close binary system. The evolution of the progenitor system is calculated from the start of accretion to the complete disruption of the white dwarf. From this outburst one gets ~ 0.5 M of ^{56}Ni which decays to cobalt, then to iron. The radioactivities generate the

observed light curves. From a sequence of nuclear burnings in the white dwarf, one obtains a copious supply of the intermediate elements, from Co to Ca. Based on this calculated output, it has been possible to construct synthetic profiles of line spectra; these are consistent with the spectra observed near maximum brightness (6). Certain of the carbon deflagration models seem to work well. There is a whole class of such models which depend on the choice of certain parameters. The products of these modeled SN-I events are complementary to those of nucleosynthesis in SN-II, giving an ISM composition in reasonable accord with observations.

5. Test of the Cosmic-Ray Model. Our prescription for a critical test, dealing mainly with component (B), starts with the calculated output of nuclides from SN-I using a promising model of nucleosynthesis, e.g., one like "W7" of Nomoto, Thielemann and Yokoi. A fraction of the ejected material is assumed to be boosted in energy to, say, tens of MeV or higher, and injected into the ISM. The initial ensemble of sub-relativistic nuclei is then "propagated" through the ISM with an appropriate distribution of path lengths. This can be done with available computational programs utilizing the latest cross sections for fragmentation. The calculated residual distribution of nuclides arriving locally can be compared with observations of metal abundances in the solar system (taking account of solar modulation at sub-GeV energies). Finally, one tries to construct a plausible mix of components (A) and (B) so as to get a reasonable fit to the observed, arriving composition.

6. Discussion. It would be fortuitous if the initial attempts at fitting were to succeed in accounting for the cosmic-ray composition as well as the composition of (thermal) solar material. In the SN-I models, the main uncertainties at the burning fronts reside in the hydrodynamics rather than in the nuclear physics (7). The quasi-convective mixing length is unknown, and must be selected rather arbitrarily (8). Yet the final deflagration yields depend decisively on this choice.

Apart from uncertainties in models of nucleosynthesis, one may ask whether particle injection by SN-I will work. A conceivable obstacle is the energy loss during the adiabatic expansion. It seems, however, that while such loss may prevent acceleration at or near the source up to relativistic energies, it would not preclude injection into the ISM at modest energies. The steep density gradients and strong shocks occurring in SN-I could provide the limited boost in energy that is required.

It should be emphasized that we are concerned here mainly with particle energies $\lesssim 10^{12}$ eV/amu, a domain comprising, by far, most of the cosmic rays, and for which the composition is rather well known.

A different explanation of HPN enhancement has been proposed by D. Eichler et al. (9,10). They argue that shocks in the ISM preferentially accelerate partially ionized heavy elements over protons. Their model may provide an attractive alternative to the one presented here.

7. Conclusions. If SN-I contribute significantly to the Galactic pool of cosmic rays by injecting enough HPN into the ISM, then this would

solve a major cosmic-ray problem--we would understand why the GCR is relatively deficient in H and He. From our model one could expect some difference in the energy spectra of components (A) and (B). On the other hand, because the main acceleration of the HPN is accomplished by the same mechanism that energizes the H and He, it is understandable that the spectral difference between the two components is not great.

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