ARE STELLAR FLARES AND THE GALACTIC COSMIC RAYS RELATED?

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It has been suggested that the Galactic cosmic rays may be accelerated by a two stage process in which one process, such as stellar flares, inject non-relativistic, super-thermal particles which are subsequently boosted to cosmic ray energies by some other mechanism, perhaps related to supernovae (eg. Cassé and Goret, 1978). Two-stage models in which the injection and re-acceleration processes are uncorrelated are apparently untenable because they cannot fit the observed energy dependence of the LiBeBN/CNO ratio (Fransson and Epstein, 1980). Here it is shown that additional contraints derived by considering the energy losses and nuclear reactions suffered by the super-thermal particles prior to their re-acceleration severely restrict other types of two-stage models.

Two-stage models can be characterized by two important parameters: E_i, the mean energy of the super-thermal particles which ultimately become cosmic rays, and $n\Delta t$, where n is the ambient nucleon density and Δt is the typical time between the injection of the super-thermal particles and their re-acceleration to relativistic energies.

<u>IONIZATION LOSSES</u>. There is an energy, E_t, such that a proton which initially has an energy less than this loses all its excess energy and is thermalized in a time less than Δt.

$$E_t = 50\ (n\Delta t/5\text{x}10^6\ \text{cm}^{-3}\ \text{yr})^{2/3}\ \text{MeV} \tag{1}$$

The first point to be made is that for plausible two-stage models

$$E_i \gtrsim E_t \tag{2}$$

There are three lines of reasoning which support this contention. (a) <u>Composition</u>: Since ionization losses increase with the charge of the ion, if $E_i < E_t$, the higher Z elements would be strongly depleted before re-acceleration. The resulting abundance distribution of the Galactic cosmic rays would then decrease with increasing Z, contrary to observations. This is an important constraint to keep in mind, since

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one of the major motivations for appealing to two-stage models is the hope that flaring stars could produce the correct cosmic ray source composition. (b) Energy requirements: If $E_i < E_t$, flaring stars must inject additional super-thermal particles to compensate for those which are degraded; the minimum power which must be emitted in super-thermal particles is $P_{min} \approx \dot{N} E_i (E_t/E_i)^{3/2}$ where $\dot{N}$ is the rate at which the cosmic ray nuclei must be replenished. This requirement is less severe when $E_i \approx E_t$, but even in this case it is likely to be several per cent of the total power supplied to the cosmic rays. (c) Depletion of lower energy particles: If the mean energy spectrum averaged over many flares is less steep than $dN/dE \propto E^{-5/2}$ at energies below E_t, then after a time Δt, the lower energy particles would be largely thermalized. The mean energy of the remaining super-thermal particles would then be greater than $\sim E_t$.

NUCLEAR SPALLATIONS. Super-thermal or cosmic ray CNO nuclei which have energies above the spallation threshold, $E_s \approx 50$ MeV/n, produce light secondary nuclei. The relative abundances of the secondary and primary nuclei in the cosmic rays indicate that the CNO nuclei have traversed only about 5 g cm^{-2} of matter. Since viable two-stage models must not over-produce secondary nuclei, at least one of two conditions must be satisfied: either (a) $m_p n \Delta t v \lesssim 5$ g cm^{-2}, where $m_p v^2/2 \approx E_i$ or (b) $E_i < E_s$. If eq. 2 is valid, then condition (a) is the less stringent one, and it is satisfied only if

$$n\Delta t \lesssim 6\text{x}10^6 \text{ cm}^{-3} \text{ yr}. \tag{3}$$

This condition severely restricts possible two-stage models; acceptable models must have the source of the supra-thermal particles and the agency for their final acceleration very closely related. For example, even models in which the flaring stars and the supernovae which re-accelerate the supra-thermal particles are in the same OB association (Montmerle, 1979) appear to violate eq. 3. If one follows Montmerle and takes the density in the OB association to be $\sim$100 cm^{-3} and the time before re-acceleration to be of the order of the association lifetime $\sim 10^7$ yr, then $n\Delta t \sim 10^9$ cm^{-3} yr.

References

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