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Origin of Spectral Hardening of Secondary Cosmic-Ray Nuclei

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We discuss the acceleration and escape of secondary cosmic-ray (CR) nuclei, such as lithium, beryllium, and boron, produced by spallation of primary CR nuclei like carbon, nitrogen, and oxygen accelerated at the shock in supernova remnants (SNRs) surrounded by the interstellar medium (ISM) or a circumstellar medium (CSM). We take into account the energy-dependent escape of CR particles from the SNR shocks, which is supported by gamma-ray observations of SNRs, to calculate the spectra of primary and secondary CR nuclei running away into the ambient medium. We find that if the SNR is surrounded by a CSM with a wind-like density distribution, the spectra of the escaping secondary nuclei are harder than those of the escaping primary nuclei, while if the SNR is surrounded by a uniform ISM, the spectra of the escaping secondaries are always softer than those of the escaping primaries. Using this result, we show that if there was a past supernova surrounded by a dense wind-like CSM with $\dot{M} \sim 2.5 \times 10^{-3} M_\odot\ \mathrm{yr}^{-1}$), which happened $\sim 1.6 \times 10^5$ yr ago at a distance of ~ 1.6 kpc, we can simultaneously reproduce the spectral hardening of primary and secondary CRs above 200 GV that have recently been reported by AMS-02.

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