Mass to Charge Dependence of Particle Injection into DSA

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The high precision spectrometry of galactic cosmic rays (CR), e.g., the Pamela experiment [1], accurately determined an ≈0.1 difference between the rigidity spectral indices of protons and helium ions. Similar deviations have been indicated earlier by other experiments [2] and were confirmed by the recent high-fidelity AMS-02 measurements [3]. These findings may shed light on the long standing problem of CR origin. While the CR particles are believed to be accelerated in supernova remnant (SNR) shocks via diffusive shock acceleration (DSA), it is still not understood how different CR elements are extracted from the supernova environments and injected into the DSA. Comparing the spectra of accelerated particles with different mass-to-charge ratios is a powerful tool for studying the physics of particle injection. Moreover, the similarity of He/p, C/p, and O/p rigidity spectra demonstrated by AMS-02 has provided new evidence that injection is a mass-to-charge dependent process. In oder to investigate the elemental selectivity of the injection mechanism and to determine the injection efficiency of ion species with different mass-to-charge (A/Z) ratio, we performed fully self-consistent hybrid simulations. Our results confirm the earlier theoretical predictions: the efficiency of injection depends on the shock Mach number (M) and its increase with A/Z saturates at a level that grows with M. Moreover, our results show that for high A/Z the injection efficiency decreases. By convolving the time-dependent injection rates of p and He, obtained from the simulations, with a decreasing shock strength over the active life of SNRs, we generate the integrated SNR spectra for p and He. These spectra are consistent with the AMS-02 and Pamela data. In particular they correctly predict the decrease in p/He ratio with increasing rigidity at exactly the rate measured in the experiments for $\mathcal{R} > 10$ GV. Only at lower rigidities, $\mathcal{R} \lesssim 10$ GV, the difference between the data and our predictions becomes noticeable. Except for this deviation, which might be due to propagation effects or solar modulation, the suggested mechanism for A/Z-dependence of the injection fully explains the measured p/He ratio.

References

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