GALPROP: New Developments in CR Propagation Code

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Abstract

The numerical Galactic CR propagation code GALPROP has been shown to reproduce simultaneously observational data of many kinds related to CR origin and propagation. Its ability to propagate all CR species in a self-consistent way has led to new results and also revealed new puzzles. We report on the latest updates of GALPROP, development of a Web-based user interface to facilitate the access to the results of our models, and a library of evaluated isotopic production cross sections. Using an updated version of GALPROP we study effects of wave-particle interactions in the interstellar medium (ISM).

1. Evaluated Nuclear Production Cross Sections

Nuclear production cross sections have for a long time been the Achilles' heel of CR propagation models. Accurate evaluation of the isotopic production cross sections is important also for studies of Galactic chemical evolution and cosmology. Fitting the B/C ratio in CR is a standard procedure to derive the propagation parameters, while other isotopes can give information about CR (re-)acceleration mechanisms [1], large-scale Galactic properties, and our local neigbourhood [7]. However, the experimental spallation cross section data are scarce and often unavailable to the CR community, while semi-empirical systematics are frequently wrong by a significant factor. We use all means at our disposal, such as the LANL nuclear database and modern nuclear codes [3], to produce evaluated production cross sections. Some evaluated cross sections have been published in [5] and used to improve estimates of the Galactic halo size. The major production cross sections of isotopes of LiBeB are presented in [4], while their propagation in the Galaxy is studied in [8]. We aim at the development of publicly available evaluated libraries of the cross sections.

pp. 1925–1928

2. Web-Based Interface

While the full information from a GALPROP run is contained in the output FITS files, this may not be convenient for all users. To facilitate the access to our published models, we are developing a Web-based user interface, supporting various formats. In the first step we will make avalable spectra of all CR species (isotopes of H through Ni, antiprotons, electrons, positrons) in the solar neighbourhood as calculated in our best published models (e.g., [6-8]). The interface will include a simple form in the Web browser while the output results will be provided as computer readable tables and graphics files. For every posted model, a user may require any of the following: spectra of any particular isotope or arbitrary combination of isotopes or elements in the requested units and scale, isotopic ratios vs. energy, which may include arbitrary isotopes in numerator and denominator, isotopic distribution of an arbitrary element, relative elemental and isotopic abundances at arbitrary energy, and electron/positron spectra and their ratio. Both interstellar and heliospheric (modulated) values will be provided. For current information and status of the Web-based interface check the following Web page: `http://lhea.gsfc.nasa.gov/∼imos/galprop.html`

3. Effect of Wave-Particle Interactions in the ISM

The mechanism of CR propagation in the ISM depends on the spectrum of interstellar turbulence. In turn, because of the high energy density of CR, they may affect the turbulence by damping the waves on a small scale. Therefore, a study of the propagation of CR in the ISM requires a self-consistent approach.

A self-consistent formalism of resonant wave-particle interactions in the ISM and dissipation of the MHD cascade has been developed [9], which can be applied to both Kolmogorov and Iroshnikov-Krainchnan forms of the cascade. Here we report preliminary results of our study of the effect of wave-particle interactions using the GALPROP code [6,10]. In our calculations, we use the following iterative procedure. In the first step, CR propagation is calculated using the undisturbed diffusion coefficient (see Table 1) and power-law CR injection spectrum. In the second step, we use the propagated proton spectrum at every spatial grid point to re-calculate the diffusion coefficient ([9], Eqs. [4,5]). In the third step, CR propagation is calculated using the new diffusion coefficient. Steps 2 and 3 are repeated until convergence is obtained. In this way, using the B/C ratio, one can derive the Alfvén speed and the damping constant. The CR proton spectrum has been simultaneously tuned to the data. The derived parameters are given in Table 1, where the damping constant g in each case combines all terms in the constant expression before the integral in [9] (Eqs. [4,5]).

Fig. 1 shows the calculated B/C ratio and Fig. 2 shows the spectrum of carbon calculated in both models for two different modulation potentials. The

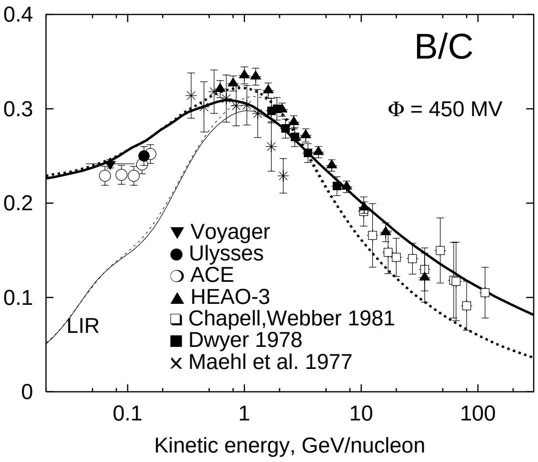

Fig. 1. B/C ratio. Calculations: ••• – Kraichnan cascade, solid line – Kolmogorov cascade. Thick lines – modulated, thin lines – interstellar (LIR). Data: for references see [7].

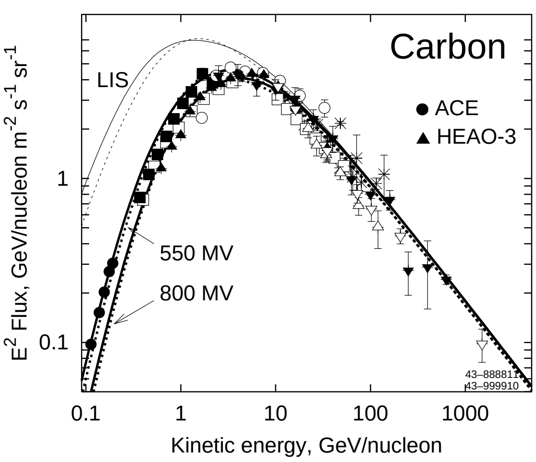

Fig. 2. Spectrum of carbon. Lines are coded as in Fig. 1. Thick lines – modulated ($\Phi = 550$, 800 MV), thin lines – interstellar (LIS). Data: for references see [7].

calculated secondary/primary nuclei ratios and CR nuclei spectra agree well with the data. Our numerical calculations confirm the qualitative result [9] that the Iroshnikov-Krainchnan type cascade is significantly affected by the CR damping, while the Kolmogorov type cascade is not very sensitive to the damping.

We should mention two important differences in the cases considered from standard reacceleration models. First, the damping allows us to obtain good agreement with the spectra of all CR nuclei using a unique power-law form of the injection spectrum. It thus removes the necessity for different injection spectra for protons and heavier nuclei invoked in standard reacceleration models [2]. Second, the calculations show a deficit of antiprotons compared to the antiproton flux measured in the heliosphere, as usual in reacceleration models (see discussions in [6,7]), but also a new feature appears – the calculated interstellar spectra have a strong dip below 0.5 GeV. This dip is even stronger in the Iroshnikov-Krainchnan case; however it is not visible in the heliosphere because of the solar modulation.

To summarize, inclusion of the effect of wave-particle interactions allows

Table 1. Propagation Parameter Sets

Cascade type	Injection index, γ	Diffusion coeff. at 3GV		Alfvén speed v_A, km s^{-1}	Damping const, g
		D_0, cm^2 s^{-1}	Index, δ		
Kolmogorov	2.43	4.4×10^{28}	0.33	27	5.6×10^{-3}
Kraichnan	2.25	4.3×10^{28}	0.50	40	4.5×10^{-2}

us to derive the energy dependence of the diffusion coefficient in a self-consistent way. The consequences for radioactive and K-capture isotopes in CR will be addressed in a future paper.

The contribution of Irina Malkova (UMBC) to the critical parts of the Web-based user interface is gladly acknowledged. This work was supported in part by NASA Astrophysics Theory Program grants, by the US Department of Energy, and a Russian Fund for Basic Research grant at IZMIRAN.

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