The size of collecting regions in the galactic disk for proton, Beryllium, Carbon and Iron cosmic rays

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Abstract

Using the length and the shape of the trajectories of cosmic rays the physical dimensions of the collecting regions in the galactic disk are determined. Each ion has a particular collecting region with a size dominated by the atomic number and the position of the observer. Trajectory lengths are mainly determined by the galactic magnetic field and gas density in the disk which are embodied by appropriate algorithms in the calculation. It is found that protons have, by far, the largest collecting basins because a consistent fraction of cosmic protons are secondary protons, a characteristic that enlarges the size of the collecting regions.

1. Introduction

Observational evidence indicates that most cosmic rays reaching the Earth are generated in the Galaxy, most likely in the disk and not in the halo. At very high energy, above 10^{16} eV a tiny fraction of the cosmic-ray flux is believed to come from the exterior of the Milky Way [1].

Since cosmic rays come from the interior of the Galaxy, two simple questions may be formulated regarding the propagation of cosmic rays from region to region in the Galaxy: (I) What distance cosmic rays travel before reaching the solar cavity, the Earth ? (II) How this distance depends on the nuclear species, on the atomic number of the cosmic rays ? The present calculation intends to answer these two questions.

The distribution in space of the sources feeding cosmic rays to the local galactic zone defines a volume called in this paper collecting region or basin. The last term is vaguely reminiscent of the zone of a country drained by a river. Traditionally, by source is meant the location, the site in the Galaxy where cosmic rays are accelerated. A number of galactic sites have been suggested as source candidates, primarily the circumstellar space around a supernovae. In this calculation the sources are taken with a uniform distribution in the disk volume and only pointlike sources are considered.

The structure of the galactic magnetic field basically determines the extension of cosmic-ray basins. The galactic magnetic field characterized by its shape

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(spiral), intensity (3 μG) and the characteristic time variation, called chaotic component, is the dominant parameter governing the length of cosmic-ray trajectories. Besides the dominant role of the galactic magnetic field [2,3], the gas density (1 hydrogen atom per cm^3 [4]) and the dimensions of the Milky Way come into play in the evaluation of the distance of the cosmic-ray sources from the solar cavity. The dimension of the disk, the position of the local galactic zone and spiral field line intercepting the solar cavity are shown in figure 1.

The propagation of a cosmic ray from the acceleration site to another arbitrary location takes place by a diffusive motion. The algorithms for the propagation are concisely described in another contribution to this conference and a detailed description can be found in other papers [5,6]. In figure 2 are displayed the source distribution in space of Iron arriving to the local galactic zone. The source distribution of those iron nuclides intercepting the local zone is an image of the iron basin. The basins for Carbon, Aluminium are similar in shape but they have dimensions larger than those of Iron. Nuclear species arriving to the local galactic zone are disseminated along the principal field line of the spiral magnetic field, shown in figure 1 by a solid line.

2. The distance of cosmic-ray sources from the solar cavity

A quantitative characterization of the galactic basins is the average length of the trajectories, L_D, forming a given basin. In figure 3 are reported the mean length of cosmic-ray trajectories generated and contained in the galactic disk for a variety of nuclides. The curve is a smooth interpolation of the mean trajectory lengths at the energy of 10 GeV/u for Helium, Beryllium, Carbon, Neon, Aluminum, Calcium and Iron, as indicated in the figure. There is no strong dependence of L_D on the energy below eV/u. The mean trajectory length clearly decreases with increasing atomic mass and, at the atomic mass of about 30, initiates to level off to the value of about 150 kpc.

3. Conclusions

A notable aspect of this study is that different cosmic ions have very different collecting regions. The existence of the galactic magnetic field and the rates of nuclear collision for different ions causes trajectory lengths to vary with A, the atomic mass of the ion, and as a consequence, a very different grammage is sensed by different nuclear species. This conclusion is opposite to that inferred by a variety of propagation models, called leaky box models, where all nuclear species with the same rigidity encounter the same amount of interstellar matter [7,8].

The present results confirm those of a similar study regarding proton and beryllium trajectories in the Galactic disk [9, 10] which unambiguously indicated

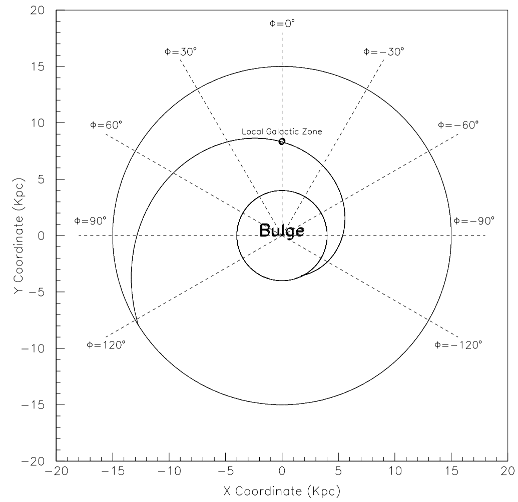

Fig. 1. Dimension of the galactic disk, radius 15 kpc and half thickness of 250 pc, the position of the solar cavity, and the principal field line in galactocentric cylindrical coordinates.

that proton sources are placed, on average, at greater distance from the solar cavity than beryllium sources.

4. References

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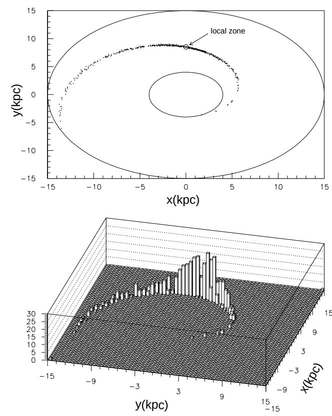

Fig. 2. Iron source distribution in the galactic disk with constant energy of 1 GeV/u feeding the local galactic zone. Sources are predominantly located around the principal field line.

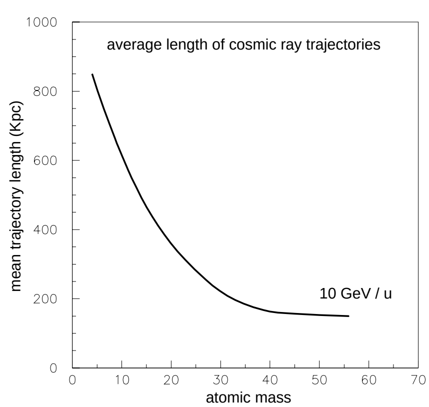

Fig. 3. Mean trajectory length of cosmic rays reaching the solar cavity versus atomic mass at the energy of 10 GeV/u.