Nuclear Abundances and Fluxes inside the magnetosphere

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***Abstract*— At 1 AU and outside the Earth's magnetosphere, the abundances of He, C and Fe nuclei, relative to protons were calculated using the measurements of AMS-01 (for p and He) and HEAO-3 (for C and Fe). We applied the back-tracing method to obtain allowed and forbidden trajectories inside the magnetosphere using the IGRF and T96 models. In this way we have evaluated the transmission function for the GCR propagation inside the magnetosphere for several geomagnetic regions. Then we derived the primary GCR fluxes in the same geomagnetic regions. These fluxes were found in good agreement with the observation data. Furthermore inside the magnetosphere we obtain the relative abundances of He, C and Fe nuclei to protons. The relative isotopic abundances were found to depend on the mass number and range from a factor ~ 2.3 up to ~ 3.3 larger than those outside the magnetosphere.**

I. Introduction

Galactic Cosmic Rays (GCR) are the dominant component of the charged particles present in space above few hundreds MeV of kinetic energy. Among the GCR components protons are largely the most abundant, but also the amount of Helium nuclei and electrons is relevant. A not negligible abundance of heavier nuclei, like Carbon, Nitrogen, Oxygen and Iron is also found. The knowledge of their relative abundances is based on measurements performed by several satellites, most of them operating outside the magnetosphere, and by stratospheric balloons during the last 30-40 years. Due to the different experimental apparatus, to the long time interval, and to the different places and conditions, the several measurements can not represent a uniform sample.

Above several GeV/nucleon the energy spectra exhibit a power law behavior as a function of the kinetic energy per nucleon, E, e.g., GCR's intensities are $\propto E^{-\gamma}$, where γ is the differential spectral index (see [1], [2], [3], [4], [5], [6]). The spectral index depends on the element, thus the relative abundance may depend on energy. In addition at these energies the solar modulation slightly affects the energy spectra.

The knowledge of the GCR's abundances can be relevant in determining, for example, the expected radiation effects on human beings and electronics in a space environment. In fact the energy deposition depends on Z^2 [7] and the most abundant nuclei up to nickel largely contribute to the overall energy-deposition process inside matter. Therefore the amount of nuclei have to be taken into account also in qualification procedures of VLSI components and circuits for space missions (see [8], [9], [10], [11], [12], [13], [14]). Moreover, taking into account the biological effectiveness, elements like Fe, Si, Mg and O make even larger contribution to the dose equivalent. Therefore, a realistic evaluation of these effects is needed for long duration space missions, like interplanetary journeys or those for the International Space Station (ISS), in particular for manned missions.

Furthermore, for near-Earth orbits, the local intensities and, thus, relative abundances of GCR's are expected to be affected by the Earth's magnetosphere, where the propagation of CR's is determined by their rigidities. Nuclei with the same kinetic energy per nucleon can have different rigidities, since they are related to the I/Z ratio, where I is the number of nucleons of the nuclide. Thus, also the abundances of nuclei relative to protons, inside the magnetosphere, are expected to be different with respect to the abundances outside the magnetosphere.

In the present contribution we used a Transmission Function (TF) approach [15], [16], [17], to evaluate the primary fluxes of He-nuclei in the same geomagnetic regions of AMS-01 observations, thus allowing a comparison with experimental data. In addition, the local abundances inside the Earth's magnetosphere are determined for p, He, C and Fe exploiting AMS-01 and HEAO-3-C2 data.

II. Cosmic Spectra and Abundances

AMS-01 has collected data in June 1998 on board of the Space shuttle Discovery (flight STS-91) at an altitude of ~ 380 km, using a large collecting area (~ 1 m^2) [18] (see also [19], [20], [21]). Its orbit had an inclination of 51.7 deg from the equatorial plane; the angular acceptance was a cone large ~ 32 deg from the detector axis, which was aimed, in most of the time of data taking, at the local zenith.

The HEAO-3-C2 experiment, on board of the HEAO-3 satellite, has measured the isotopic composition of the most abundant components of the CR flux with atomic mass between $I = 7$ and $I = 56$ and the flux of the several nuclei with charge between $Z = 4$ and $Z = 50$ [2]. HEAO-3 has been launched in September 1979; its altitude was ~ 500 km; the inclination of the orbit was ~ 43.6 deg from the equatorial plane; the angular acceptance of the detector HEAO-3-C2 was large ~ 28 deg from the axis, which was spinning around an axis pointing in direction of the Sun.

We have considered the data of protons and Helium from the AMS-01 detector. During the 5-6 days of data taking, AMS-

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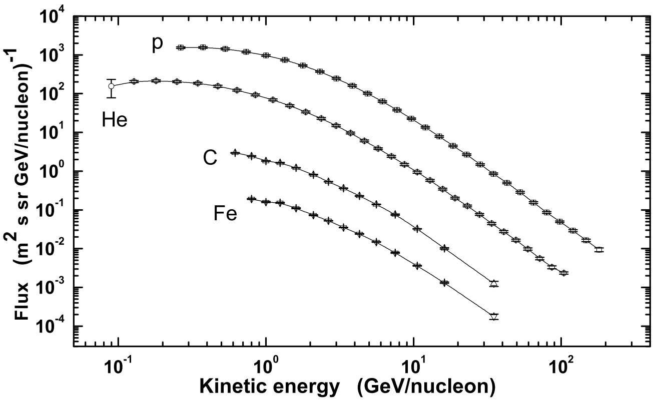

Fig. 1. Differential Cosmic Flux of p, He, C, Fe.

01 has detected $\sim 10^7$ protons in the range of kinetic energy $0.22 < E < 200$ GeV, and $\sim 10^6$ α particles in the energy range $0.074 < E < 114$ GeV/nucleon. In addition we used the data of Carbon and Iron from the HEAO-3-C2 experiment taken during the time period from October 1979 to June 1980. HEAO-3-C2 detected Carbon and Iron nuclei in the range of kinetic energy $0.6 < E < 35$ GeV/nucleon.

Data have been collected by the two detectors during periods of similar solar activity and polarity. HEAO has operated during 1980, at the beginning of the solar cycle 21. During this period the solar activity was raising from the minimum to the subsequent maximum and the magnetic field polarity was positive ($A > 0$). AMS-01 was in orbit in June 1998, at the beginning of the solar cycle 23, with rising solar activity and $A > 0$. The experimental conditions was comparable for the two experiments: altitude and inclination of the orbit, angular acceptance of the detectors. The differential energy spectrum of protons, Helium, Carbon, and Iron, as measured by these experiments is shown in Figure 1.

In Figure 2, the relative abundances to protons for He (He/p), C (C/p) and Fe (Fe/p) nuclei with the same kinetic energy per nucleon, E, are shown as function of E: for a kinetic energy of ~ 0.8 GeV/nucleon, the value of He/p is ~ 0.084, but ranges between $0.047 - 0.054$ above 4.5 GeV/nucleon, while the values of C/p range from ~ 0.0021 down to ~ 0.0016, and finally the values of Fe/p range from ~ 0.00017 up to ~ 0.00021. These relative abundances at 1 AU may be affected by the solar modulation, in particular at low energy, and then differ from those expected in the interstellar space.

III. Propagation of GCR in the Magnetosphere

In the space region surrounding the Earth the Geomagnetic field provides a partial shield against the penetration of CR down to the Earth surface. The transport of CR through the magnetosphere is determined by the rigidity P, the ratio between the momentum of the particle (p) and its charge (Ze): $P = pc/Ze$, where c is the speed of light. In this way we can calculate for every point in the space a limit called rigidity cut-off P_{cut} (see [22], [23]). Below this limit primary CR will never reach the Earth surface or any detector in orbit.

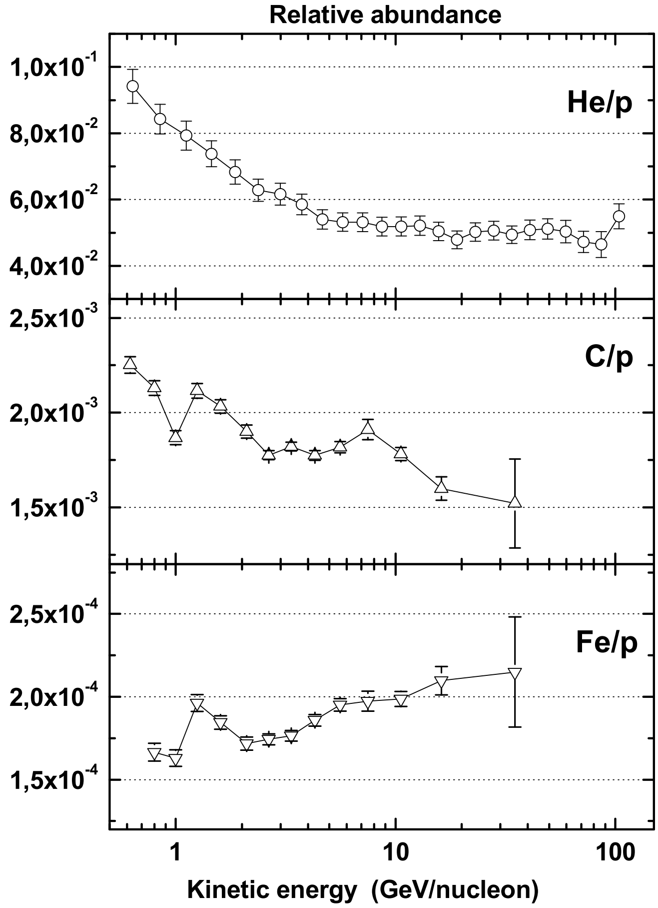

Fig. 2. Abundance of cosmic He, C and Fe nuclei relative to protons.

P_{cut} changes with the geographical location, as it is larger in sites at lower geomagnetic latitude. Besides, all the nuclei are positively charged, therefore due to the charge drift western incoming directions are preferred (this effect is known as the East-West anisotropy).

Since the proton and neutron masses are approximately equal, the rigidity of an ion with kinetic energy per nucleon E is given by

$$P_{ion} \approx \frac{I}{Z} P_H \tag{1}$$

where P_H is the proton rigidity with the same kinetic energy E, Z and I are the atomic number and the number of nucleons (i.e., the mass number) of the ion, respectively. The ratio I/Z for the most abundant stable isotopes ranges from 2.0 up to $\sim$ 2.3 with the exception of ^{3}He for which it is $I/Z \simeq 1.5$, while for protons $I/Z \simeq 1$. As a consequence less energetic (but heavier than proton) GCR can penetrate deeply the magnetosphere: in any location, the associated geomagnetic rigidity cut-off, P_{cut}, requires a kinetic energy of the isotope lower than that of a proton and, thus, the isotopic abundances relative to protons are expected to be larger inside the magnetosphere than those outside it (see [24]).

Trajectories calculations in the geomagnetic field are usually performed to estimate the particles approaching to a ground station or an orbiting satellite. The reconstruction of the particle trajectory inside the magnetosphere is necessary especially in the so called penumbra region, i.e. around the rigidity cut-off. We have developed a code to reconstruct the Cosmic Rays trajectory in the Earth magnetosphere (see [15], [17]). This code solves the Lorentz equation and propagates a particle backward in time. The total magnetic field is evaluated by using the International Geomagnetic Reference Field (IGRF) [25], representing the main contribution due to the inner Earth, and the external magnetic field Tsyganenko-96 (see [26], [27]), representing all the other contributions, like particle currents in the magnetosphere.

The code is time dependent: it must take into account both the long term variation (running over years) of the inner Earth magnetic field and the short term variation (changing in few days) of the external field. Besides most of the long term variation is related to the solar activity through the solar wind effect and its interaction with the Earth magnetic field. The Earth magnetopause is calculated using the Sibeck equation [28] modified by Tsyganenko [26] for the solar wind effect. We have introduced an empirical magnetosphere boundary large 25 Earth radii in the night-side region to avoid long calculations in the far tail. Access for primary cosmic ray to some place is supposed to be allowed when the back-traced particle trajectory reaches the magnetopause or the magnetospheric boundary. As internal boundary we have considered a sphere at an altitude of 40 km, corresponding to the surface containing the 99% of the Earth atmosphere.

IV. Transmission Function and Fluxes inside the Magnetosphere

Charged particles (protons and nuclei) are generated by the tracing code at a fixed altitude, in particular at the position of the space detectors AMS-01 and HEAO-3. They are back-traced in time until they reach one of the two boundaries: the magnetopause/magnetosphere boundary or the atmosphere. In the first case we get a trajectory allowing the penetration of GCR, otherwise a trajectory forbidden to GCR. The external field is evaluated taking into account the parameters changing with the solar activity. Those parameters are evaluated at the time of the data taking of the two experiments.

The TF has been calculated in the following way: for every position i_M in a certain geomagnetic region M, for a fixed rigidity P, we have evaluated the ratio $R^{i_M} = N_{all}^{i_M}/N_{total}^{i_M}$ between the number of allowed trajectories $N_{all}^{i_M}$ and the number of all the computed trajectories $N_{total}^{i_M} = N_{all}^{i_M} + N_{forb}^{i_M}$. This ratio represents the probability for particles with rigidity P to reach this geographic position coming from outside the magnetosphere. Then, for every geomagnetic region M, we have averaged the ratio R^{i_M} over all the positions i_M. This average ratio $TF_M(P) = \langle R^{i_M} \rangle$ represents the transmission function for a particle with rigidity P to reach that geomagnetic region M, at the altitude of AMS or HEAO-3. We have considered the AMS geomagnetic regions (see [18], [17]), defined as a function of the geomagnetic latitude, from $M1$, around the magnetic equator, to $M10$, near the magnetic poles. These are indeed very wide regions with a complex structure of penumbra changing from position to position.

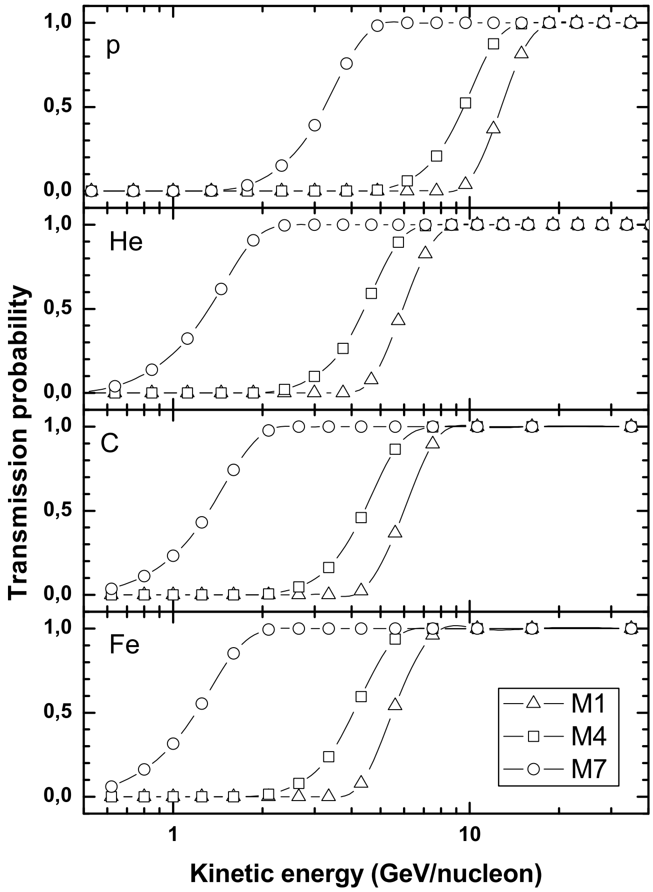

Fig. 3. Transmission Function of p, He, C and Fe, in the geomagnetic regions $M1$, $M4$, $M7$.

For that regions we have computed the transmission function $TF_M(P)$ [29]. We have selected a grid of 3600 positions and from every point we have generated particles in 1800 directions outwards. Each starting position and direction has been chosen in order to have a uniformly distributed sample. In every region M a particle with a rigidity (P) lower than a threshold value (usually called rigidity cut-off, P_{cut}) can not enter the magnetosphere. For $P << P_{cut}$ we obtain $TF_M = 0$, while for $P >> P_{cut}$ we have $TF_M = 1$. This threshold value is decreasing going towards the magnetic poles, but is nearly independent from the considered ion. Besides, looking at the TF_M vs kinetic energy, instead of rigidity, we can find a shift in the cut-off region for the nuclei respect to protons, as expected. This effect can be observed in the Figure 3, where TF_M is shown for the regions $M1$, $M4$, $M7$, as a function of the kinetic energy.

Then we have computed the flux of primary CR ($\Phi_M^{pri}(E_i)$) entering each geomagnetic region M, relative to the energy bin i^{th}, using the TF calculated as described above ($TF_M(E_i)$) (see [30]). We also used the AMS-01 cosmic flux ($\Phi^{cos}(E_i)$) for p and He and the HEAO-3-C2 cosmic flux for C and Fe,

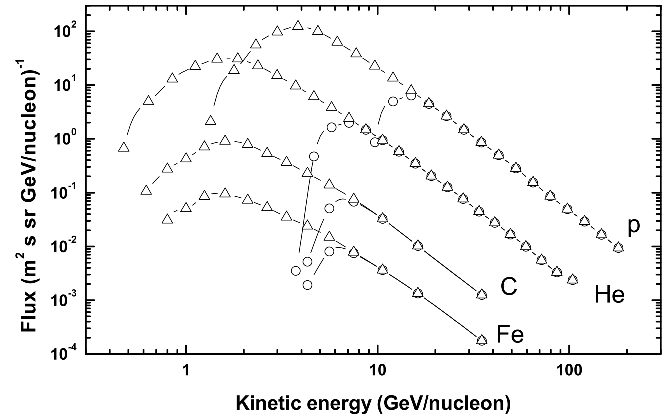

Fig. 4. Flux of primaries p, He, C and Fe, in the geomagnetic regions $M1$ (circles), and $M7$ (triangles).

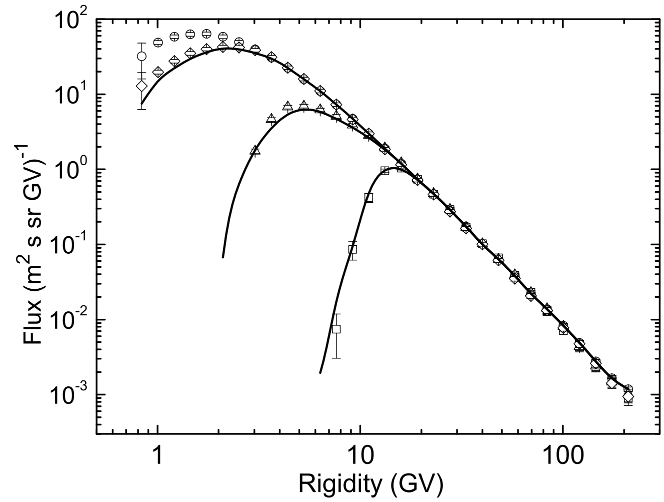

Fig. 5. Flux of He, C and Fe, in three geomagnetic super-regions. Symbols are experimental data, while calculations are solid lines.

as shown in Figure 1:

$$\Phi_M^{pri}(E_i) = \Phi^{cos}(E_i) \cdot TF_M(E_i) \tag{2}$$

In Figure 4 we present the flux of p, He, C, and Fe for the geomagnetic regions $M1$ (higher value of the energy cut-off) and $M7$ (lower value of the energy cut-off). As for the Transmission Function, the cut-off in the same geomagnetic region occurs at the same value of rigidity, but at different values of kinetic energy, as shown in Figure 4.

Finally, using the same procedure, we computed the flux of He CR extended to the geomagnetic super-regions (SM) considered in [21], in order to compare our calculation with the experimental data and validate the results. The He fluxes in these SM regions are reported in Figure 5.

V. Magnetospheric Abundances

In order to evaluate the relative abundance of He, C and Fe, respect to the protons, inside the several geomagnetic regions, the integral flux above the geomagnetic cut-off has been computed. In this way inside the magnetosphere we get the contribution of all the penetrated particles. Therefore the relative abundance has been defined as the ratio $\Re$ of the integral flux of Helium, Carbon, Iron, respect to the flux of protons. We have computed $\Re$ using the primary flux Φ^{pri}, shown in Figure 4, integrated above the full spectrum of kinetic energy (E):

$$\Re_{He/p}(M) = \frac{\int \Phi_{M,He}^{pri}(E')\ dE'}{\int \Phi_{M,p}^{pri}(E')\ dE'} \tag{3}$$

$$\Re_{C/p}(M) = \frac{\int \Phi_{M,C}^{pri}(E')\ dE'}{\int \Phi_{M,p}^{pri}(E')\ dE'} \tag{4}$$

$$\Re_{Fe/p}(M) = \frac{\int \Phi_{M,Fe}^{pri}(E')\ dE'}{\int \Phi_{M,p}^{pri}(E')\ dE'} \tag{5}$$

In this calculation the contribution of the high energy tail in most cases is negligible. The correction increases up a to few percent only for the region $M1$ for C and Fe. The ratios $\Re(M)$ are shown in Table I for the geomagnetic regions $M1$, $M4$, $M7$ (see also [31]). We have also computed the enhancement factors Æ(M) for the several regions:

$$\text{Æ}(M) = \frac{\Re(M)}{\Re^{cos}} \tag{6}$$

The values of $\Re^{cos}$ are the cosmic abundances relative to protons for He, C and Fe. These values are computed from the data reported in Figure 2 using the equations 3 - 5 extended from $E \simeq 0.8$ Gev/nucleon to ∞. The enhancement factors account for the increase of isotopic abundances inside the magnetosphere with respect to the modulated values outside it. Values of Æ for the geomagnetic regions $M1$, $M4$, $M7$ are shown in Table I. From an inspection of Table I, it is possible to note that the ratios Æ: i) depend on the mass number I; ii) range from ~ 2.1 up to ~ 3.7 in the investigated geomagnetic regions; iii) exhibit a slight dependence on the geomagnetic latitude. Æ varies from the average by less than ± 5, 7 and 13% for He/p, C/p and Fe/p, respectively. On average the enhancements factors are ~ 2.3, ~ 2.7 and ~ 3.3 for He/p, C/p and Fe/p, respectively. These factors also account for the variation of the ratio I/Z and the overall behavior of the spectral indexes with the kinetic energy for the modulated spectra.

VI. Conclusions

At 1 AU and outside the Earth's magnetosphere, the relative abundances to protons for He (He/p), C (C/p) and Fe (Fe/p) nuclei were calculated using the observation-data of AMS-01 (for p and He) and HEAO-3 (for C and Fe). The relative abundances account for the modulation of GCR's inside the heliosphere and are $\Re^{cos}_{He/p} \simeq 6.7 \times 10^{-2}$, $\Re^{cos}_{C/p} \simeq 1.9 \times 10^{-3}$ and $\Re^{cos}_{Fe/p} \simeq 1.8 \times 10^{-4}$ for He/p, C/p and Fe/p, respectively.

We have computed the transmission probability for protons, Helium, Carbon and Iron nuclei inside several geomagnetic regions. Combining the TF with the cosmic flux we are able

TABLE I

RELATIVE ABUNDANCE RATIOS, $\Re$ AND ABUNDANCE ENHANCEMENTS, Æ, FOR THE GEOMAGNETIC REGIONS $M1$, $M4$, $M7$.

	$\Re_{\mathrm{He/p}}$	$Æ_{\mathrm{He/p}}$
$Cosmic$	6.7×10^{-2}	
$M1$	1.6×10^{-1}	2.4
$M4$	1.5×10^{-1}	2.2
$M7$	1.4×10^{-1}	2.1
	$\Re_{\mathrm{C/p}}$	$Æ_{\mathrm{C/p}}$
$Cosmic$	1.9×10^{-3}	
$M1$	5.6×10^{-3}	3.0
$M4$	5.1×10^{-3}	2.7
$M7$	4.1×10^{-3}	2.2
	$\Re_{\mathrm{Fe/p}}$	$Æ_{\mathrm{Fe/p}}$
$Cosmic$	1.8×10^{-4}	
$M1$	6.5×10^{-4}	3.7
$M4$	6.0×10^{-4}	3.4
$M7$	4.3×10^{-4}	2.4

to obtain the primary CR flux inside the magnetosphere for the several geomagnetic regions. These primary CR fluxes result truncated, as expected, at energy lower than the local effective cut-off. While the rigidity cut-off occurs at the same value for the different nuclei, inside the same geomagnetic region, the cut-off in terms of kinetic energy is changing, due to the different ratio between elementary charges (Z) and atomic mass (I). The effect is particularly important when protons, for which we have $I/Z \simeq 1$, are compared with other nuclei like Helim, Carbon and Iron, for which $I/Z \simeq 2$.

The abundance of the several nuclei inside the magnetosphere are then compared with the cosmic abundance. We have found that the abundance of nuclei inside the magnetosphere is larger than the cosmic abundance, related to the protons, by a factor $\sim 2.3 - 3.3$. These results must be taken into account when the effects of radiation on orbiting satellites are evaluated.

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REFERENCES

[1] J.J. Engelmann et al., Source energy spectra of heavy cosmic ray nuclei as derived from the French-Danish experiment on HEAO-3, *Astron. and Astrophys.*, **148**, 12 (1985).
[2] J.J. Engelmann et al., Charge composition and energy spectra of cosmic-ray nuclei for elements from Be to NI - Results from HEAO-3-C2, *Astron. and Astrophys.*, **233**, 96 (1990).
[3] R.A. Mewaldt, Galactic cosmic ray composition and energy spectra, *Adv. Space Res.*, **14**, 737 (1994).
[4] P.K.F. Grieder, (2001). *Cosmic Rays at Earth*, Elsevier, Amsterdam (2001).
[5] ISO-19390, *Space Environment (Natural and Artificial)–Galactic Cosmic Ray Model*, Ref. no. ISO 15390:2004(E) (2004).
[6] T. Stanev, *High Energy Cosmic Rays*, Springer-Praxis, Berlin (2004).
[7] C. Leroy, and P.-G. Rancoita, *Principles of Radiation Interaction in Matter and Detection* (*2nd Edition*), World Scientific, Singapore, ISBN 978-981-281-827-0 (2008).
[8] A. Colder et al., Study of Radiation Effects on Bipolar Transistors, *Nucl. Instr. and Meth. in Phys. Res.*, **B 179**, 397 (2001), doi:10.1016/S0168-583X(01)00582-1.
[9] A. Colder et al., *Proc. of the* 7^{th} *ICPPAT*, Como 15-19 October 2001, World Scientific (Singapore) 780 (2002).
[10] A. Colder et al., *Proc. of the European Space Component Conference* (Toulouse 24-27 September 2002), ESA **SP-507**, 377 (2002).
[11] D. Codegoni et al., Radiation Effects on Bipolar and MOS Transistors Made in BiCMOS Technology, *Proc. of the 8th ICATPP* (6–10 October 2003, Como, Italy), ISBN 981-238-860-5, World Scientific, Singapore, 622 (2004).
[12] D. Codegoni et al., *Nucl. Instr. and Meth. in Phys. Res.* **B 217**, 65 (2004).
[13] C. Consolandi et al., Systematic investigation of monolithic bipolar transistors irradiated with neutrons, heavy ions and electrons for space applications, *Nucl. Instr. and Meth. in Phys. Res.* **B 252**, 276, *doi:10.1016/j.nimb.2006.08.018* (2006).
[14] C. Leroy, and P.-G. Rancoita, Particle Interaction and Displacement Damage in Silicon Devices operated in Radiation Environments, *Rep. Prog. in Phys.*, **70**, no. 4, 403–625, doi:10.1088/0034-4885/70/4/R01 (2007).
[15] P. Bobik, M.J. Boschini, M. Gervasi, D. Grandi, E. Micelotta, and P.G. Rancoita, A Back-Tracing Code To Study The Evolution of the Magnetosphere Transmission Function for Primary Cosmic Rays in The Inner Magnetosphere: Physics and Modeling, *Proc. of the CHAPMAN Conference* (25-29 August 2003, Helsinki, Finland), Editors T.I., Pulkkinen, N.A., Tsyganenko and R.H.W., Friedel, American Geophysical Union (AGU), Washington D.C., *Geophysical Monograph Series*, **155**, ISBN 0-87590-420-3, 301 (2005).
[16] P. Bobik, M.J. Boschini, M. Gervasi, D. Grandi, E. Micelotta, and P.G. Rancoita, Magnetospheric transmission function to separate near earth primary and secondary cosmic rays, *Int. J. of Modern Phys.* **A 20**, 6678, doi:10.1142/S0217751X05029782 (2005).
[17] P. Bobik, G. Boella, M.J. Boschini, M. Gervasi, D. Grandi, K. Kudela, S. Pensotti, and P.G. Rancoita, Magnetospheric transmission function approach to disentangle primary from secondary cosmic ray fluxes in the penumbra region, *J. Geophys. Res.*, **111**, A05205, doi:10.1029/2005JA011235 (2006).
[18] AMS collaboration - M. Aguilar et al., *Phys. Rep.*, **366**, 331 (2002).
[19] AMS Collaboration - J. Alcaraz et al., Protons in Near Earth Orbit, *Phys. Lett. B*, **472**, 215 (2000).
[20] AMS Collaboration - J. Alcaraz et al., Cosmic Protons, *Phys. Lett. B*, **490**, 27 (2000).
[21] AMS Collaboration - J. Alcaraz, et al., Helium in Near Earth Orbit, *Phys. Lett. B*, **494**, 193 (2000).
[22] K. Stoermer, *Z. Astroph.*, **1**, 237 (1930).
[23] E. Fermi, *Nuclear Physics*, The University Of Chicago press (1950).
[24] P. Bobik, M.J. Boschini, M. Gervasi, D. Grandi, and P.G. Rancoita, Ions abundance close to the earth surface: the role of the magnetosphere, *Proc. of the 9th Conference Astroparticle, Particle and Space Physics, Detectors and Medical applications* (17–21 October 2005, Como, Italy), ISBN 981-256-798-4, World Scientific, Singapore, 928 (2006).
[25] C.E. Barton, International Geomagnetic Reference Field: The Seventh Generation, *J. Geomag. Geoelectr.*, **49**, 123 (1997).
[26] N.A. Tsyganenko, *J. Geophys. Res.*, **100**, 5599 (1995).
[27] N.A. Tsyganenko, and D.P. Stern, *J. Geophys. Res.*, **101**, 27187 (1996).
[28] D.G. Sibeck et al., *J. Geophys. Res.*, **96**, 5489 (1991).
[29] P. Bobik, G. Boella, M.J. Boschini, M. Gervasi, D. Grandi, K. Kudela, S. Pensotti, and P.G. Rancoita, The transmission function of Helium, Carbon and Iron and their flux inside the magnetosphere, *Proc. of the 20th ECRS - European Cosmic Ray Symposium*, 5–8 September 2006, Lisbon, Portugal.
[30] G. Boella, M.J. Boschini, M. Gervasi, D. Grandi, S. Pensotti, P.G. Rancoita, P. Bobik, and K. Kudela, Evaluation of the flux of CR nuclei inside the magnetosphere, *Proc. of the 10th Conference Astroparticle, Particle and Space Physics, Detectors and Medical Physics applications* (8–12 October 2007, Como, Italy), ISBN-10 981-281-908-8, World Scientific, Singapore, 875 (2008).
[31] P. Bobik, G. Boella, M.J. Boschini, M. Gervasi, D. Grandi, K. Kudela, S. Pensotti, and P.G. Rancoita, Fluxes and Nuclear Abundances of Cosmic Rays inside the Magnetosphere using a Transmission Function Approach, *Adv. Space Res.*, in press (2008).