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Galactic Cosmic Rays Production at the Equator and Magnetic Poles at the Minimum and Maximum Solar Activity

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Authors' contributions

This work was done in collaboration among all the authors. Author NR designed the study, performed the analysis and wrote the first draft of the manuscript. Authors SG, KM and NE supervised the study and analyzed the data. All the authors managed the literature search writing of the final manuscript.

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Original Research Article

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ABSTRACT

Cosmic rays is composed of charged particles, created and possibly accelerated in the remains of supernovas. The measurement of cosmic ray fluxes allows to put constraints on their sources and their transport, but also to consider the problem of these radiations in the terrestrial environment. It is to answer these questions, that a numerical simulation code is established through the equations of HEAPS (1978) to evaluate this galactic flux in the upper atmosphere. The work proposed in this article is to estimate the production of galactic radiation at the equator and magnetic poles at the minimum and maximum of solar activity.

On the other hand, the Sun emits a plasma which interacts with the particles of the cosmic radiation, modifying the fluxes resulting from the propagation in the galaxy. This modification evolves in time following the solar activity cycle and is called solar modulation.

From this work, it appears that the magnetospheric geoefficiency depends on the geomagnetic latitude, and a high production at the magnetic poles. Since the cosmic ray intensity is affected by the interplanetary magnetic field, the galactic production is small during maximum solar activity and large at minimum solar activity.

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1. INTRODUCTION

Life on Earth was made possible by the atmosphere and the Earth's magnetic field. Indeed, without these two, the earth's soil would be bombarded by an enormous quantity of high-energy particles and radiation, making any form of life impossible [1-8]. Irradiance can nevertheless be detected at ground level where the contribution to population exposure is small [9]. On the other hand, astronauts going into space are exposed to a higher dose of radiation. Airplanes and their occupants are also exposed [10-17]. Cosmic radiation is one of the major health hazards during space flight. The strength and turbulence of the interplanetary magnetic field vary with the solar activity cycle [18-22]. The cosmic radiation intensity has a minimum during periods of high solar activity and a maximum around the minimum of solar cycle [23]. The variations of the solar magnetic field are certainly a major factor in the perturbations affecting the Earth, but they also constitute a screen against the charged particles coming from outside the solar system [24-29]. The present work consists in assessing the Galactic cosmic irradiance at the magnetic equator and poles during the minimum and maximum of solar activity in the Earth's environment. This raises important questions that are still open about these effects on the atmosphere and also on human health. Since solar activity is known to follow an average cycle of eleven years, it is possible to predict the exposure to galactic radiation in the atmosphere over several years.

2. MATERIALS AND METHODOLOGY

Parameterized relations for the calculation of the Galactic cosmic ray production given by HEAPS were used to characterize the non-solar radiation [30-31]. Before determining the Galactic production in the atmosphere, we have defined a key parameter to translate the magnetospheric geo-efficiency. This parameter is called the geomagnetic cutoff strength and is given by equation 1 [30].

$$R_c = 14.9\cos^4\varphi \qquad 1$$

This parameter reflects the state of the Earth's geomagnetic field lines where Rc is the magnetic stiffness expressed in GeV and phi is the geomagnetic latitude expressed in degrees.

For the production of radiation, a numerical calculation through some equations of HEAPS (1978) allowed quantifying this radiation in the lower ionosphere. Equation 2 allows for the calculation of the cosmic radiation as a function of the solar activity, the density of the air, and the magnetic latitude [30].

$$\begin{cases} P_{gcr} = (A + B\sin^4\varphi)3\exp[17(1 - C)]\,M^C \\ \qquad \text{for } M > 3exp\ (17) \end{cases} \qquad 2$$

With

$A = 1.74\exp(-18)$

$B = 2.84\exp(-17)$ (Minimum solar activity)

$B = 1.93\exp(-17)$ (Maximum solar activity)

$C = 0.6 + 0.8|\cos\varphi|$

M is the air density expressed at (1/cm^3); phi is the geomagnetic latitude and P_{gcr} expressed by $(cm^{-3}.s^{-1})$.

The relation allowing the calculation of the production of cosmic radiation in the polar zones is given by equation 3 [30].

$$P_{gcr} = (A + B\sin^4\varphi)M \qquad 3$$

Through these equations, a program was established that we simulated in the software for data acquisition.

3. RESULTS AND DISCUSSION

3.1 Geomagnetic cut-off rigidity

The Fig. 3.a shows the progression of stiffness as a function of geomagnetic latitude.

Cosmic rays that have not been deviated from their trajectory by the solar wind must now penetrate the Earth's magnetosphere in order to reach the upper layers the Earth's atmosphere. For any point of the magnetosphere and for any direction of arrival at this point, there is a value of magnetic stiffness below which the cosmic particle will not reach this point called the geomagnetic stiffness cutoff. The figure shows a total decrease in the magnetic cutoff. The level of rigidity is very important at the magnetic equator

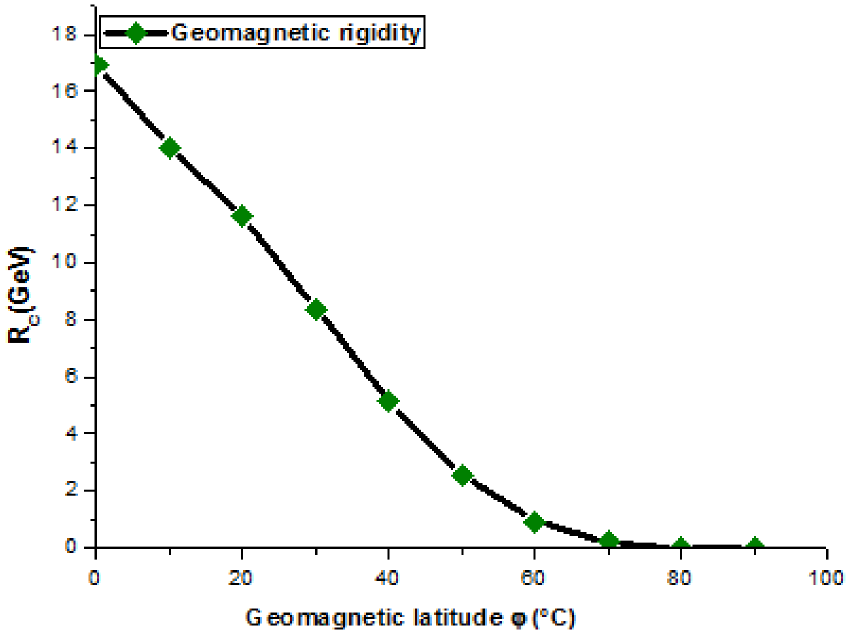


Fig. 3.a. Geomagnetic stiffness as a function of magnetic latitude

than at the magnetic poles. At the magnetic equator, the geomagnetic cutoff stiffness reaches its maximum. This means that in this part the magnetic field lines are resistant. At the Earth's poles, the geomagnetic cutoff strength decreases, resulting in weak magnetic field lines. The geomagnetic cutoff stiffnesses for particles with a non-vertical arrival direction depend the angle incidence of these particles.

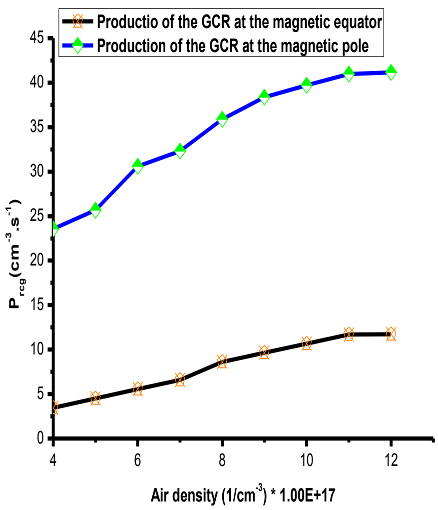
3.2 Influence the Solar Activity (SA) on Galactic Radiation Production

Fig. 3.b illustrates the progression of galactic cosmic ray (GCR) production during the minimum and maximum of solar activity as a function of air density at the equator and magnetic poles.

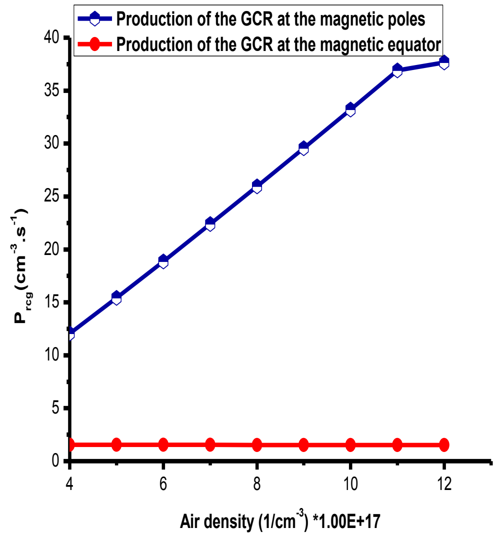
During the minimum of solar activity, the magnetic field and the solar wind become weak, and therefore the extension of the Earth's magnetic field is reduced. In this case, galactic cosmic rays with medium and high energy can pass through the atmosphere without energetically degrading, reaching an altitude of about 50 km. During the maximum of the SA, the atmosphere of the Sun lets escape permanently a flow of particles that fills all the interplanetary medium, which is called the solar wind. The characteristics, especially magnetic, of the solar wind vary with the solar activity and induce a field that keeps the cosmic rays away from the Earth. For this reason, cosmic rays of galactic origin have more difficulty propagating in the solar system. At the magnetic equator, the magnetic field lines are parallel to the surface of the Earth and reflect the incident particles vertically. Because of the state of the magnetic field lines at this level, the particles that can cross the magnetosphere are fewer. At the level of the poles, the state of the field lines weakens or even disappears and these field lines are practically vertical and let the maximum number of cosmic particles through, which explains the high production of the GCR at this level. Other particles then tend to follow the magnetic field lines of force, with all the more "ease" as they have less energy and thus reach the poles. This is why the areas near the poles (zero stiffness cut-off) are more irradiated than the Equator, which is better protected by the Earth's magnetic field.

3.3 Comparaison of the Galactic Production According to the Solar Activity (SA)

The Fig. 3, we present a comparative study of the production of Galactic cosmic-rays at the equator and at the magnetic poles during the minimum and maximum of the SA.



Production of the GCR at minimum SA



Production of the GCR at maximum SA

Fig. 3.b. Galactic cosmic-ray production at the equator and magnetic poles

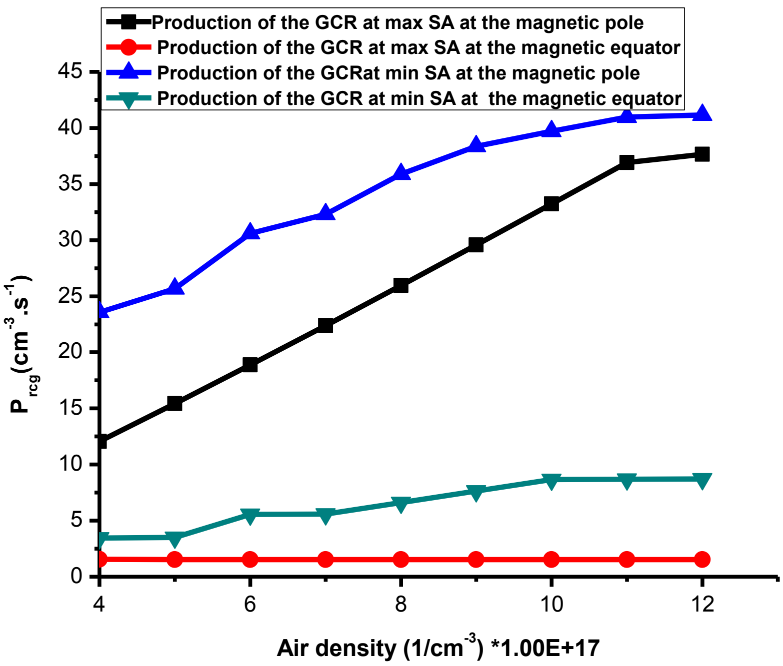


Fig. 3.c. Profiles of cosmic-ray production during the two phases

We observe a higher production of the GCR at the minimum of the solar activity than at the maximum of the solar activity. It should be noted that at the maximum of the solar activity, the sun induces a magnetic field carried by the solar wind whose intensity varies with the solar activity. The strength and turbulence of the interplanetary magnetic field vary with the solar activity cycle. The intensity of the cosmic radiation has a minimum during the period of strong solar activity and a maximum during the minimum of the cycle. This is why we have a higher production at a minimum than at a maximum. The variations of the solar magnetic field are certainly a major factor in the disturbances affecting the Earth, but they also constitute a screen against the charged particles coming from outside the solar system. So the solar activity cycle disturbs the global flux of cosmic rays. At solar minimum due to a weaker solar magnetic field shielding, the cosmic radiation fluence is significantly higher than at solar maximum.

The results found in this part of our study are consistent with those found by Reitz et al, 1993 using an AMS-02 detector located on the International Space Station since May 2011 and allows to measure the cosmic rays fluxes [32, 33]. The work carried out by J. Marc et al, 1977 also showed that this extrasolar radiation is responsible for the electronic and ionic production in the lower ionosphere (D layer) below 70 Km [34]. Cosmic rays with a very high energy can pass through the atmosphere without energetically degrading to an altitude of about 50 km. Therefore the ionization rate can be considered as being proportional to the atmospheric density. The intensity of galactic cosmic rays depends on the geomagnetic latitude, so the ionization rate also depends on the geomagnetic latitude.

4. CONCLUSION

More than a century after the discovery of cosmic rays, many questions remain open about their nature, their origins, and their propagation in the interstellar medium. To try to answer these questions, particle fluxes have been measured since the 1950s. The detectors are inside the solar cavity, the zone of influence of the Sun, which modifies the fluxes coming from the sources and from the galactic propagation. The understanding of this phenomenon, variable in time, is thus a necessary step to putting constraints on the galactic propagation models of the CR. This part of my work consisted in contributing to the estimation of the Galactic radiation flux through a numerical code executed under MATLAB. This allowed me to quantify the cosmic ray production at the equator and at the magnetic poles at the minimum and at the maximum of the solar activity. It appears from this study that the production is maximum at the magnetic poles whatever the nature of the solar activity. The cosmic-rays galactic production has a maximum at the minimum of the solar activity and a minimum at the maximum of the solar activity. It should also be noted that the production depends on the geomagnetic latitude, air density, and also on solar activity. We can conclude by saying that the transpolar routes are more exposed than the transequatorial routes.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper

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