GALACTIC COSMIC RAY INTENSITY IN PERIODS OF THE HELIOSPHERIC MAGNETIC FIELD INVERSION

Krainev M.B.[1,3], Bazilevskaya G.A.[1], Kalinin M.S.[1], Mikhailov V.V.[2], Svirzhevskaya A.K.[1], Svirzhevsky N.S.[1], Luo X.[3], Potgieter M.S.[3]

[1]Lebedev Physical Institute (LPI), RAS, Moscow, Russia
[2]Moscow Engineering-Physical Institute, Moscow, Russia
[3]Shandong Institute of Advanced Technology (SDIAT), Jinan, Shandong, China

ИНТЕНСИВНОСТЬ ГАЛАКТИЧЕСКИХ КОСМИЧЕСКИХ ЛУЧЕЙ В ПЕРИОД ИНВЕРСИИ ГЕЛИОСФЕРНОГО МАГНИТНОГО ПОЛЯ

Крайнев М.Б.[1,3], Базилевская Г.А.[1], Калинин М.С.[1], Михайлов В.В.[2], Свиржевская А.К.[1], Свиржевский Н.С.[1], Луо С.[3], Потгитер М.С.[3]

[1]Физический институт им. П.Н. Лебедева РАН, Москва, Россия
[2]Московский инженерно-физический институт, Москва, Россия
[3]Шаньдунский институт передовых технологий, Цзинан, Шаньдун, Китай

https://doi.org/10.31725/0552-5829-2023-187-190

Кратко формулируются наблюдаемые явления, результаты моделирования и представления об инверсии гелиосферного магнитного поля (ГМП) и связанных с ним эффектах в интенсивности галактических космических лучей (ГКЛ). Основное внимание уделено обсуждению моделей ГМП в периоды его инверсии и сравнению ожидаемого из этих моделей поведения ГКЛ с наблюдаемым. Обсуждаются также пути дальнейшего численного исследования эффектов.

Introduction

The heliospheric magnetic field (HMF) is rooted in the solar poloidal fields that, due to its large size, has an advantage when entering the heliosphere. For the larger part of the solar cycle the HMF consists of two unipolar “hemispheres” divided by the wavy heliospheric current sheet (HCS). During the periods of high sunspot activity around the poloidal field’s inversion such a simple picture is inadequate with no generally accepted model of this phenomenon (see [1] and references therein).

Since the first mentioning of the effect in galactic cosmic ray (GCR) intensity connected with the HMF inversion by the LPI group in 1973 [2], the study of the 22-y variations in GCR intensity has continued for 50 years. However, for most studies the periods around sunspot minima, not maxima, have been studied, while the LPI group has tried to consider attentively GCR effects due to both “two unipolar hemispheres” and the change of the polarities in these “hemispheres”.

The main results of our analysis of GCR effects during periods of the HMF inversion are published in ~~details~~ in [1]. Here we discuss them, considering models of the HMF inversion, the description of GCR intensity in these periods and ways to proceed with minimum of references (as in the extended abstract).

GCR intensity effects connected with the HMF inversion

In [1] we considered GCR intensity around the HMF inversion during the last 5 sunspot maxima and isolated two effects:

- Dependence of the rate of intensity recovery after the HMF inversion on the sign of *qdA/dt*, where *q* is the particle's charge and by *dA/dt* > 0 we mean the transition from *A* < 0 to *A* > 0 and vice versa;
- A sharp change in the GCR intensity and in the energy dependence of its variation associated with the Gnevyshev Gap effect in the HMF strength due to the HMF inversion.

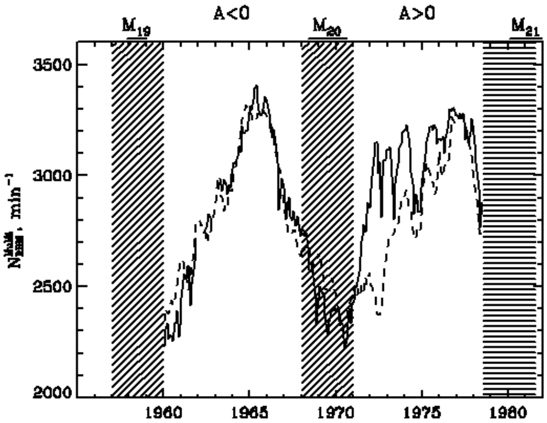

Fig. 1.

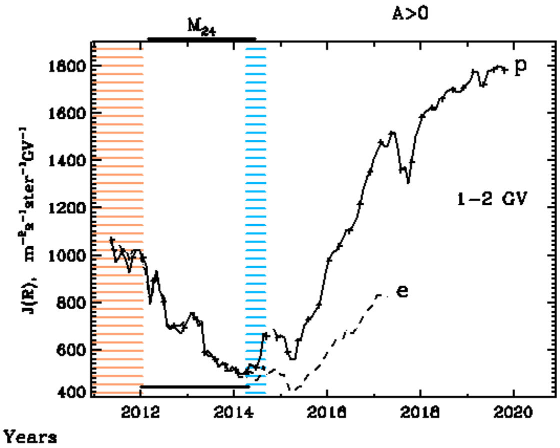

Fig. 2.

The first of these effects was actually reported in [2] as the break of correlation between the observed GCR intensity (solid line in Fig. 1) and its approximation in the 1960s dependent on the number and heliolatitude of the sunspot groups (dashed line) after the inversion of the poloidal solar magnetic fields in 1969-1971. Different rate of intensity recovery for protons (*q* > 0, solid line) and electrons (*q* < 0, dashed line) regressed to protons can be seen in Fig. 2.

The manifestation of the Gnevyshev Gap in GCR intensity that was associated in [1] with the HMF inversion, as the second of the effects, can be seen in Fig. 2 as a sharp variation in both proton and electron intensities during the period of the HMF inversion in 2012-2013. It follows that during this period there were absolutely no dependence in the GCR intensity on the sign of the particle's charge. A much detailed discussion of both effects can be found in [1].

The Models of the HMF inversion

The first qualitative picture of the structure of the HMF inversion was formulated as the change in the types of the HMF polarity distribution: from the two unipolar "hemispheres" divided by a single global HCS corresponding to a general polarity (A_1) to the break of this global HCS and then again to the formation of single global HCS with an opposite general polarity (A_2 = -A_1). In Fig. 3b the structure of the four last HMF inversions is coded through different types of HMF polarity distribution. To quantify this, we found the HMF polarity *F* averaged over ~~the~~ longitude for each latitude and each Carrington Rotation

(CR). Then it is averaged for the previous 13 CRs to account for the time (≈ 1 year) that the SW travels from the Sun to the outer border of heliosphere.

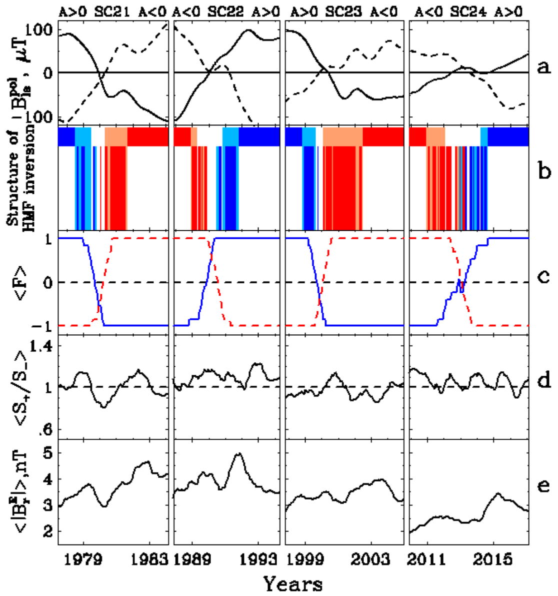

Fig. 3.

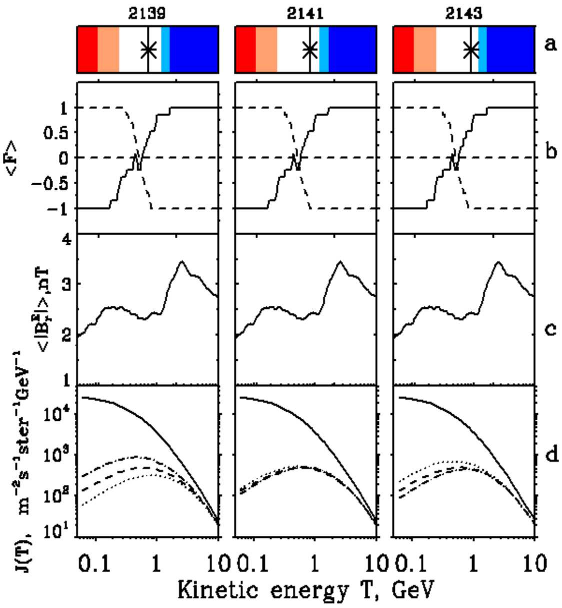

Fig. 4.

In Fig. 3 panels c, d, e show the averaged HMF polarity in the North (solid) and South (dased) poles (c), the ratio of areas of positive and negative HMF polarity (d) and the absolute value of the HMF radial component (e).

Although the change of the HMF polarity is shown in Fig. 3c only for the North and South poles, it behaves in a similar way for any latitude. The small deviation in Fig. 3d of the ratio of "positive" and "negative" areas from 1 means that the same $|B_r|$ can be used for both positive negative HMF polarities.
The main conclusions that can be drawn from Fig. 3c is that (1) the HMF inversion is rather similar to that of the poloidal high-latitude solar magnetic field (Fig. 3a), and (2) the HMF inversion is too fast to account for the absence of the GCR intensity dependence on the sign of the particle's charge for 2 years (see Fig. 2 and [4]).

Description of effects due to the HMF inversion in the long-term GCR intensity

The boundary-value problem and the specifics of the description of ~~the~~ particle drift are the same as in our accompanying paper in this Proceedings (Kalinin et al., On the influence of corotating interaction regions…).

In Fig. 4 the calculated proton spectra with three variants of drift velocity (multiplied by 1 (dotted), -1 (dash-dotted), 0 (dashed)) are shown for three every other rotations in panel (d). The relative position of three lines shows that the particles feel the change of the HMF polarity in 1 or 2 CRs and the HMF inversion is really very fast which contradicts to [4].

Recently another quantitative model of the HMF inversion appeared [3], that in some respects is rather similar to the described above and at first glance has both advantages and disadvantages.

On the other hand there are papers devoted to the behavior of GCR intensity during the period of the HMF inversion (e.g., [4]) with excellent description of the GCR observations through the use of a set of rigorously determined modulation parameters. Probably, to achieve a better understanding of both the HMF inversion and GCR behavior in these periods, we need to use the combination of different approaches.

Conclusions

1. The effects in the GCR intensity associated with the HMF inversions - dependence of the rate of intensity recovery after the HMF inversion and a sharp change in the GCR intensity and in the energy dependence – can be seen in any HMF inversion.
2. Recently, models of the HMF inversion were suggested based on the study of the polarity distributions calculated in the base of the heliosphere. However, the HMF inversion according to these models is too fast to account for the absence of the GCR intensity dependence on the sign of the particle's charge for 2 years.
3. Both the model for the HMF inversion and that for GCR modulation should be changed for the description of the effects in the GCR intensity associated with the HMF inversions.

Xi Luo is grateful for the support of the Taishan Scholar Project of Shandong Province (202103143) and a grant from the National Science Foundation of China (NSFC, U2106201). V.V. Mikhailov thanks the Ministry of Science and Higher Education of the Russian Federation for support (state assignment, project "Fundamental and Applied Research of Cosmic Rays" № FSWU-2023-0068).

References

1. *Krainev M.B., Bazilevskaya G.A., Kalinin M.S., et al.* Fifty years of studying the GCR intensity during the inversion of the heliospheric magnetic fields. I. Observations // Solar-Terrestrial Physics. 2023. Vol. 9. Iss. 4., in print.
2. *Charakhchyan A.N., Stozhkov Yu.I., Svirzhevsky N.S., Charakhchyan T.N.* Anomalous effect in the 11-year galactic cosmic ray modulation // Proc. the 13th International Cosmic Ray Conference. 1973, vol. 2, pp. 1159–1164.
3. *Kopp A., Raath J.L., Fichtner H., et al.* Cosmic-ray transport in heliospheric magnetic structures. III. Implications of solar magnetograms for the drifts of cosmic rays // Ap.J., 922:124 (13pp), 2021 1 https://doi.org/10.3847/1538-4357/ac23e0
4. *Aslam O.P.M., Luo X., Potgieter M.S., et al.* Unfolding Drift Effects for Cosmic Rays over the Period of the Sun's Magnetic Field Reversal // ApJ, 947:72 (17pp), 2023 April 20 https://doi.org/10.3847/1538-4357/acc24a