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# Influence of Jupiter on the Interplanetary Magnetic Field and Cosmic-Ray

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**Abstract:** Analysis of experimental data on the variations in the intensities of 2 –12 MeV electrons and cosmic rays and the interplanetary magnetic field (IMF) magnitude has revealed "responses "to the influence of Jupiter in these parameters. Their amplitudes, in instrumental count units, are the following: 0.15 (71 %) in the electron intensity, 48 (0.8 %) in the cosmic-ray intensity, and 0.19 (2.8 %) in the IMF magnitude. The maximum of the response in the electron intensity and the minimum f the response in the IMF magnitude coincide and lie near the magnetic field line that runs along the Sun – Earth –Jupiter axis. The minimum of the response in the cosmic-ray intensity is shifted against the solar rotation by 75 days from the magnetic field line connecting Jupiter and the Earth. Jupiter has the strongest influence on the intensity of high-energy electrons (71 %of their total intensity).

## Introduction and formulation of the problem

Chenette et al. [1], McDonald and Trainor [2], and Skryabin et al. [3] point out that Jupiter is an intense source of low- and high-energy particles. On e might expect large fluxes of these particles to be able to affect noticeably the interplanetary magnetic field (IMF). Since the IMF modulates the cosmic-ray intensity, the influence of Jupiter can also manifest itself via magnetic-field variations in cosmic rays. The goals of this work are:
(1) finding the phase characteristics of the responses on a period of 399 d (399 d is the synodic period of the Jupiter);
(2) estimating the influence of Jupiter on the cosmic-ray diffusion.

## Experimental data processing and analysis

Figure 1a shows the time variations in the daily mean intensities of 2–12 MeV electrons as measured by the IMP-8 spacecraft from October 30, 1973, to January 14, 1997. The day numbers are along the horizontal axis; the first day is October 30, 1973. The electron intensity, in instrumental count units, is along the vertical axis. The vertical lines mark the oppositions of the Jupiter and the Earth from Astronomical Yearbooks [4]. The first line corresponds to the opposition of September 5, 1974.
As we see from Fig.1, a 399-day variation clearly manifests itself in the primary data on the intensity of 2–12 MeV electrons. In Fig. 1, the times of minimum (m) and maximum (M) solar activity are marked. No 399-day cyclicity is visually seen in the primary data on the IMF magnitude and cosmic rays (Oulu [4], OMNI database [5], for the same period. However, if these data are processed using a filter with the period passband 100–600 d, then the 399-d variation can be clearly seen. F or example, the dips show up in 14 of the 20 cases (≈70%) in Fig.1b and in 12 of the 20 cases (≈60%) in Fig.1c.

If the data are processed by the superposed-epoch technique (for the 399-d period) after such filtering, then we will obtain responses to Jupiter's influence (see Fig.2). In the superposition, we took the opposition days of the Earth and Jupiter as reference points. For clarity, Fig.2 shows two periods. The vertical solid lines correspond to the opposition times of the Earth and Jupiter; the dashed lines correspond to the times the Earth crosses the IMF line running along the Sun–Earth–Jupiter axis. The mean intensities and responses, in instrumental count units, are the following: the mean intensity and the response are, respectively, 0.214 and 0.15 (≈71%) for 2–12 MeV electrons, 6.85 and 0.19 (≈2.8%) for the IMF magnitude, and 6048 and 48 (≈0.8%) for the cosmic-ray intensity.

We see from Fig.2 that the maximum of the response in the electron intensity and the minimum of the response in the IMF magnitude coincide and lie near the magnetic field line running along the Sun–Earth–Jupiter axis. The minimum of the response in the cosmic-ray intensity is shifted against the solar rotation by 75 d from the magnetic field line connecting Jupiter and the Earth.

For our analysis, we will need the mean amplitudes of the responses. These are calculated as the root-mean-square values from the data shown in Fig.2. The mean response is ≈0.092 (43%) in the electron intensity, 0.1 (1.5%) in the IMF magnitude, and 32 (0.53%) in cosmic rays.

## Analysis of results

In this paper, we analyze only the relationship between the average effects in the IMF and cosmic rays. As we see from Fig.2, a decrease in the IMF strength, on average, by ≈1.5% corresponds to a decrease in the cosmic-ray intensity, on average, by ≈0.53%. A decrease in the IMF strength will cause the diffusion across the field ($D_\perp$) to increase. This follows from the formulas given by Toptygin [6], who specially considered the problems of diffusion for relativistic particles. It follows from Toptygin's work that the dependence of the diffusion coefficient on $\tau$ is $D_\| = v\tau/3$ and $D_\perp = D_\|{*}R_0^2/(R_0+\lambda^2)$ for the diffusion along and across the field, respectively, where $R_0$, $\lambda$, $\tau$ are the cyclotron radius, the mean free path, and the

mean momentum transfer time during the jump from one cyclotron orbit to another. Since the mean free path $\lambda$ is considerably larger than the cyclotron radius $R_0$, we find from these formulas that

$$D_\perp = R_0^2/3\tau \qquad (1)$$

Since any neutron monitor records mainly only a mean energy of ≈10 GeV, $\tau$ is taken to be constant for any specific monitor. Consequently, for the experimental data for one chosen monitor, $D_\perp$ is proportional to $R_0^2$. $R_0^2$ is known to be proportional to $B^{-2}$ (for constant $\tau$). Hence,

$$R_0^2/3\tau = kB^{-2} \qquad (2)$$

where k is the proportionality coefficient.

Taking the differential of Eq. (2) and dividing it by $D_\perp$, we obtain the relation

$$\Delta D_\perp / D_\perp = -2(\Delta B/B) \qquad (3)$$

We see from Fig.2 that the amplitude of therelative IMF variations in the 399-day interval is, on average, ≈0.015.T he mean values of the diffusion coefficient for the cosmic-ray particles recorded by neutron monitors (E ≈ 210 GeV) are $\approx 10^{22}$ $cm^2$ $s^{-1}$ (Ginzburg and Syrovatskii [7]; Dorman and Miroshnichenko [8]; Bieber et al. [9]. According to Krymskii [10], the diffusion coefficients in the directions perpendicular to the IMF lines account for about 0.1 of the mean coefficient. Taking all of this into account, we find from Eq. (3) that the mean change in the diffusion coefficient for the relative mean IMF variations of ≈0.015 is ΔD = 2× 0.015 × 0.1 × 1022 = 3× 1019 cm2 s−1.

Let us now derive the diffusion coefficient (as an addition ΔD to the main, background diffusion coefficient D) from the response in cosmic rays .The cosmic-ray density n and intensity J are related by the formula n = J/c. Therefore, the equation for a constant (mean) diffusion coefficient is $\partial n/\partial t = \Delta D(\partial^2 n/\partial x^2)$, where x is the spatial coordinate along the Earth's orbit, in units of time, because the Earth moves uniformly along its orbit. This equation has an exact solution in the form of a normal law in which $\sigma = 2\Delta Dt$.I n Fig.2c, the shape of the curve after background subtraction is very close to the normal law. The mean value of σ along the Earth's orbit is $\sigma^2 \approx 55$ d ($1.44 \times 10^{13}$ cm) and the mean scattering time is t ≈ 55 d ($4.65 \times 10^6$ s). We estimate the mean variation of the diffusion coefficient from the formula $\sigma^2 = 2\Delta Dt \approx 2.3 \times 10^{19}$ $cm^2$ $s^{-1}$. As we see, the mean variations in the diffusion coefficient obtained independently from the responses to Jupiter's influence in the IMF and cosmic rays coincide to within ≈27%. This coincidence is quite satisfactory for theoretical estimates and for such small effects, since the coefficients themselves are measured with approximately the same accuracy. Therefore, it would be unreasonable to expect a close coincidence.

The results obtained prove that the particles injected by Jupiter can slightly rearrange the IMF. However, this rearrangement takes place in a large volume, at least in the entire space between the Earth and Jupiter.

The following brief conclusions can be drawn from our analysis:

(1) By injecting a large number of particles, Jupiter rearranges the IMF in a large volume (in the entire space between the Earth and Jupiter).

(2) The amplitudes of Jupiter's effects on the electron intensity, the IMF magnitude, and cosmic rays, in percent, are 71%, 2.8%, and 0.8% of the mean value, respectively.

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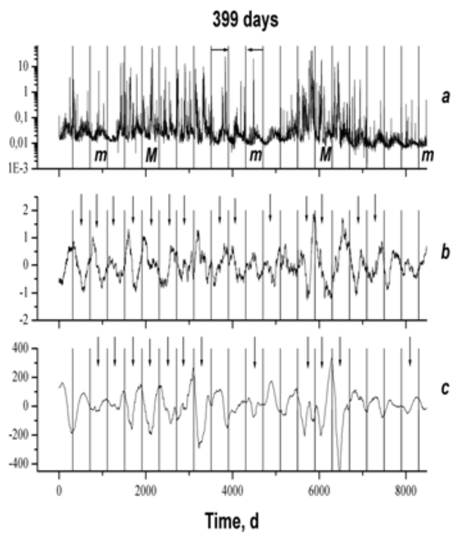


Figure 1: (a) Time variations in the primary intensity f high-energy (2–12 MeV) electrons (daily mean values) The IMF magnitude (b) and the cosmic-ray intensity (c) after filtering The arrows indicate the dips.

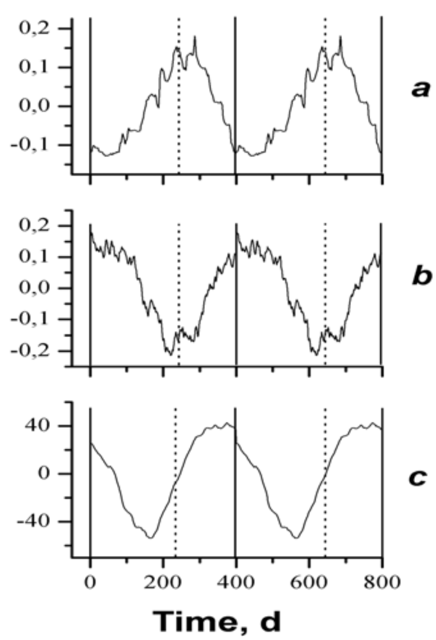


Figure 2: Superposition f the data after filtering: (a)the electron intensity,(b) the IMF magnitude, and (c) the Oulu neutron monitor data.Tw 399-d superposition periods are shown.