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QUASISTATIONARY ASYMMETRY OF THE GALACTIC COSMIC RAY DENSITY DISTRIBUTION IN THE HELIOSPHERE[1])

КВАЗИСТАЦИОНАРНАЯ АСИММЕТРИЯ ПЛОТНОСТИ РАСПРЕДЕЛЕНИЯ ГАЛАКТИЧЕСКИХ КОСМИЧЕСКИХ ЛУЧЕЙ В ГЕЛИОСФЕРЕ

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As known from stratospheric data [1] (as well as from satellite and neutron monitor data) in 1971—1972 a breach of the inverse correlation between the galactic cosmic ray intensity and the level of solar activity was observed. As expected, the minimum of the 20th solar cycle was to take place in 1975—1976. However, already at the end of 1971 the galactic cosmic ray intensity had reached its maximum value and remained at the level up to 1976. On the average, during the period of the 8 years before the 20th cycle minimum in 1976 the galactic cosmic ray intensity with a rigidity of $R > 0.5$ GV was 1.2 times higher than that during the period of the 8 years before the 19th cycle minimum in 1965. Therefore, one may assume that at the beginning of the 20th solar cycle, in spite of a high solar activity, a breach of the solar modulation mechanism had taken place, so that, apparently, additional possibilities for the galactic cosmic ray penetration into the heliosphere had arisen.

The meteorite data [2] yield an invaluable information and thanks to them the picture of distribution and variation of galactic cosmic rays in the heliosphere in 1955—1976, i.e., practically, for two solar cycles, has been fixed. The fact that the meteorites, in particular, those fallen in the first half of the 20th solar cycle, had the orbits of a different extent and orientation was especially valuable. It has enabled us to compare the behaviour of galactic cosmic rays at both the southern and the northern latitudes and to estimate the dependence of the galactic cosmic ray gradients on heliocentric distance and heliolatitude. For example, in Fig. 1 the obtained spatial distribution of transverse gradients in the heliosphere at the beginning of the 20th solar cycle is presented. It is seen that at the northern latitudes the transverse gradients did not really exceed ~1 % per degree of latitude in accordance with the Pioneer 10 and 11 data [3]. However, at the southern latitudes they were considerably higher totalling 3—5 % per degree of latitude as during the years of maximum solar activity of the 19th cycle. Thus, the meteorite data evidence the existence of a considerable north-south asymmetry in the galactic cosmic ray distribution in the heliosphere at the beginning of the 20th solar cycle.

On the eve of the 20th solar cycle the reversal of polarity of the general solar magnetic field had taken place that resulted in numerous anomalous phenomena during the following years. Therefore, it was natural, first of all, to search for the cause of the north-south asymmetry especially in that inversion. To elucidate the question, we have analysed Howard's data [4] on the solar magnetic field observation in

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1967—1971. In Fig. 2 the field lines of the regular magnetic field of the sun at different stages of the reversal period are shown. It is seen that in 1967 the solar magnetic field was a completely dipole one: the northern hemisphere was negative and southern hemisphere was positive, so that the picture was symmetrical with respect to the north-south direction. First the inversion began to develop in March 1968 at 40—50° of the southern hemisphere and then advanced slowly towards the pole to reach it in September 1969. In the northern hemisphere the inversion in the zone of 40—50° began to develop only

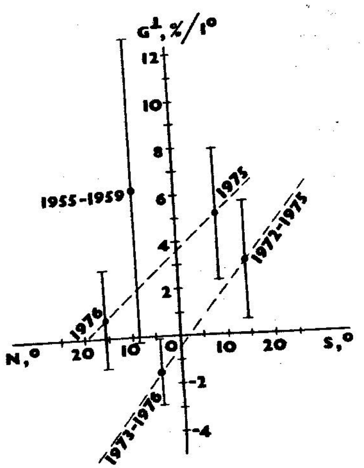


Fig. 1. Distribution of the transverse galactic cosmic ray gradients ($R > 0.5$ GV) in the heliosphere at the beginning of the 20th solar cycle according to meteorite data.

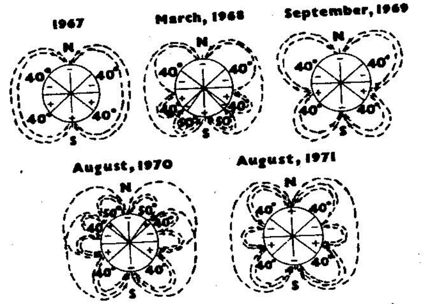
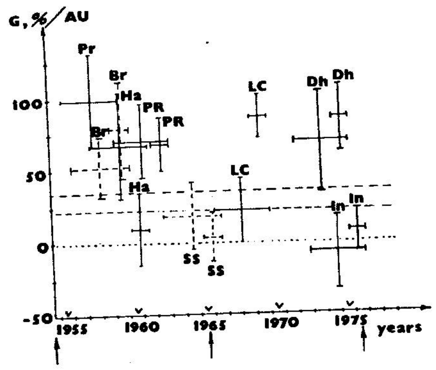


Fig. 2. Evolution of the solar magnetic fields in 1967—1971 according to the data of Howard [4].

in August 1970, but it was stronger and had reached the pole within a year. In the course of the whole period in the equatorial zone of ±40° there was no inversion at all. It is well seen in Fig. 2 that the north-south asymmetry caused by the polarity reversal of the general solar magnetic field existed from March 1968 up to August 1971 with the most pronounced manifestation from September 1969 up to August 1970 when the field inversion near the southern pole was at its end but near the northern one had not begun yet. Due to the absence of the inversion in the equatorial zone of ±40°, in 1969 at southern latitudes charged particles had already received an opportunity to penetrate into the heliosphere along the field lines of the magnetic field not only near the pole, but also in the equatorial zone of ≤40° S. At the northern latitudes charged particles had received such an opportunity from August 1970 on and especially in 1971 when the polarity of the magnetic field near the northern pole had also changed. From that moment on the solar magnetic field symmetry with respect to the north-south direction had been restored. However, the comparison of the first and the last schemes in Fig. 2 is clearly illustrated that due to the inversion the heliosphere had opened not only near the poles, as in 1967, but, in part, also at the equatorial zone of ±40°. This additional opportunity of charged particle penetration into the heliosphere through some sort of "holes" in its magnetosphere explains, most probably, the sharp increase of the galactic cosmic ray intensity at the end of 1971 and, on the whole, the higher level of their intensity in the 20th solar cycle than that in the 19th one.

The completed analysis shows that the effect of the reversal of the general solar magnetic field on the magnitude of the north-south asymmetry in the heliosphere was of a short duration and cannot be observed, for instance, in 1975—1976 when, as it follows from the meteorite data, the north-south asymmetry was being considerable. In that connection, one may suppose that a quasistationary asymmetry conditioned by the heliolatitude asymmetry of solar activity is a dominant factor of the asymmetrical distribution of the galactic cosmic ray intensity in the heliosphere; on the average, the

Fig. 3. Variation of galactic cosmic ray radial gradients ($R > 0.5$ GV) in 1955—1976 according to the meteorite data: Př — Příbram, Br — Bruderheim, Ha — Harleton, PR — Peace River, SS — St. Severin, LC — Lost City, Dh — Dhajala and In — Innisfree (dashed crosses are the gradients in the ecliptic plane; dashed horizontals are average values of the gradients over ~1 My).



northern hemisphere of the sun was more active than the southern one over the 19th and 20th solar cycle. If it is so, the north-south asymmetry should also have existed before the inversion, i.e., in the 19th solar cycle as well. To ascertain it the data on radioactivity of the Peace River chondrite fallen on March 31, 1963 have been analysed. The Peace River orbit had a longitudinal inclination over the ecliptic plane, i.e., the aphelion as well as the perihelion were near the ecliptic, so that half the orbit lay above the ecliptic, and half the orbit lay below it. Therefore, ^{54}Mn has recorded the average galactic cosmic ray intensity over a year before the Peace River fall to the earth at southern latitudes, and ^{22}Na has recorded it for ~4 years before its fall averaging it also for both the northern and southern latitudes. The obtained values of galactic cosmic ray radial gradients are presented in Fig. 3 together with the earlier obtained data for the different years of the 19th and 20th solar cycle according to the radioactivity of the meteorites. It is seen that during the years of high solar activity (1959—1962) the high average value of the radial gradient derived from the ^{22}Na radioactivity in the Peace River chondrite corresponds to the data on the Příbram, Bruderheim and Harleton chondrites. However, according to the ^{54}Mn radioactivity in the Peace River chondrite, at southern latitudes the gradient remained high at the decrease of the solar activity in 1962—1963 when at northern latitudes, according to the ^{54} Mn radioactivity in the Harleton chondrite, it was already ≤10 %/AU. Therefore, indeed, the north-south asymmetry existed before the field inversion on the sun and, apparently, was determined mainly by the quasistationary asymmetry of the solar activity distribution.

It is interesting that, according to the ^{26}Al radioacivity in meteorites, the average over a million years transverse gradients of galactic cosmic rays at the northern latitudes were higher than at the southern ones (see Fig. 4), i.e., apparently, on the average over a million years, the southern hemisphere of the sun was more active than the northern one. We can believe that the sign of the quasistationary asymmetry, possibly, changes periodically (perhaps, every ~ 22 years), but so that, on the average over a million years, the southern solar hemisphere turns out to be more active than the northern one. In connection with this, the preliminary data on cosmic ray variations observed by means of the Meteor satellite [5] are very interesting. According to them, at the beginning of the 21st solar cycle a higher activity of the southern solar hemisphere, in comparison with the northern one, had already been exhibited.

On the whole, the profiles of the dependence of the galactic cosmic ray intensity on the heliocentric distance, which are obtained due to the meteorite data, correspond to the results of the numerical solutions of the equations of the three-dimensional modulation models [6, 7]: ~85 % of the galactic

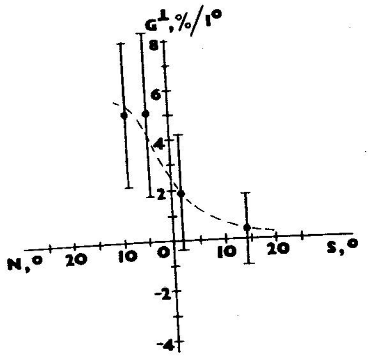


Fig. 4. Distribution of the transverse galactic cosmic ray gradients ($R > 0.5$ GV) averaged over a million years in the heliosphere according to the meteorite data.

cosmic ray intensity is restored up to ~3 AU from the sun. It follows from the totality of the experimental and theoretical data that the galactic cosmic ray modulation range in the heliosphere is not spherical, but it is compressed in the meridional plane, mainly within the heliolatitude region of ±40° [6]. Therefore, the meteorite orbits with a high inclination can transgress the limits of the modulation

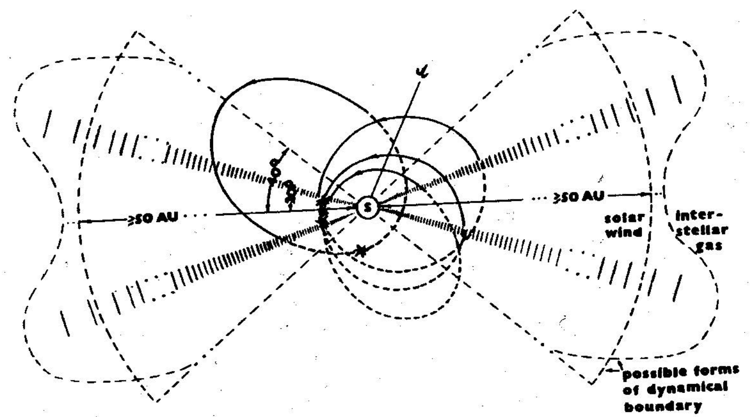


Fig. 5. A sketch of a meridian-section of the modulation range in the heliosphere (shades mark the direction of the highest modulation at ±(15—20)° heliolatitudes; solid parts of meteorite orbits are located above the ecliptic plane, illustrating the different kinds of orbital inclinations: both lateral and longitudinal ones).

Table 1

Maximum Date	h	Proton energy MeV	Flux J_m $cm^{-2}s^{-1}sr^{-1}$	γ	A %	Duration Δt h	Flare in H_α Beginning Date	Flare in H_α Beginning UT	Coordinates $\varphi°$	Coordinates $\lambda°$	Importance	SC Date	SC UT	Solar wind velocity km s^{-1} V_{af}	V_{bf}	IMF nT B_{af}	B_{bf}
29.IX.69	05	>10	$1.1.10^1$	4.6	—	7	27.IX	0343	10N	01E	3B	27.IX	2124				
	05	>30	0.07									29.IX	0453	452	700	—	—
25.VII.70	00	>5	$5.4.10^2$	5.4	+40	8	23.VII	1831	09N	09E	1B	24.VII	1125	463	879	5.3	21.9
	01	>10	$2.0.10^2$	5.5									2350				
	01	>30	0.33														
6.XI.70	02	>10	$2.7.10^1$	4.5		8	5.XI	0308	12S	36E	3B	7.XI	0046	377	394	4.4	8.9
	02	>30	0.19										0630				
17.VI.72	19	>10	5.1	4.2		9	15.VI	0951	10S	11E	1N	17.VI	1311	—	—	8.3	23.6
	18	>30	0.05														
5.VIII.72	05	>10	$5.3.10^3$	1.4		7	4.VII	0617	14N	08E	3B	4.VIII	2054	620	1120	41	18.1
	05	>30	$1.8.10^3$									5.VIII	2344			20	40
	05	>60	$4.2.10^2$														
9.IX.73	11	>5	$3.1.10^1$	3.5	−7	4	7.IX	1141	18S	46W	2B	9.IX	0906	—	—		
	11	>15	0.66										1529				
3.V.76	12	>5	$1.3.10^1$	3.0	+25	5	30.IV	2047	08S	46W	1B	2.V	1829	595	784		
	12	>15	0.50														
	12	>25	0.17									1.VI	2143	—	—		
2.VI.78	09	>5	$2.7.10^2$	8.9	−20	9	31.V	1006	20N	43W	3B	2.VI	0913				
	09	>15	0.13														
	09	>25	0.05														

–Proton fluxes with $E_p > 5$, 15, 25 MeV were measured on Meteor, those with $E_p >$ 10, 30, 60 MeV — on Explorer range at such small distances from the sun as 1.5—3 AU, in spite of the boundary of the modulation range, i.e., the dynamical boundary between the solar wind and the interstellar gas lies farther than ~50 AU from the sun (see Fig. 5). Similar models of the modulation range were offered earlier too [8]. We believe there exists a fine structure of the modulation range with the maximum galactic cosmic ray gradients at ±(20—25)°, which can be resolved by means of a further investigation of radioactivity of the meteorites with orbits of a high extent and inclination. As it follows from the conformity of the data on radioactivity of cosmogenic radionuclides with different half-lives, such a from of the modulation range has been existing, at least, over the last million years.

REFERENCES

[1] Vernov, S. N., Charakhchyan, A. N., Stojkov, Yu. I., Charakhchyan, T. N.: *Preprint No. 107 Phys. Inst. Acad. Sci*, USSR, Moscow 1974.
[2] Lavrukhina, A. K., Ustinova, G. K.: Adv. Space Res. *1* (1981), 143.
[3] McKibben, R. B., O'Gallagher, J. J., Pyle, K. R., Simpson, J. A.: *Proc. 15th Int. Cosm. Ray Conf.* Plovdiv *3* (1977), 240.
[4] Howard, R.: Solar Phys. *38* (1974), 283.
[5] Avdyushin, S. I., Pereyaslova, N. K.: *Report Int. Symp. CAPG*, Smolenice 1982 (this issue).
[6] Lavrukhina, A. K., Ustinova, G. K., Alania, M. V., Dorman, L. I.: *Proc. 17th Int. Cosm. Ray Conf.*, Paris *3* (1981), 238.
[7] Kóta, J.: *Report Int. Symp. CAPG*, Smolenice 1982 (this issue).
[8] Miroshnichenko, L. I.: *Cosmic Rays in the Interplanetary Space.* Nauka, Moscow 1973.

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