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On supernova explosion in the nearby interstellar space

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Abstract

The data obtained in the long-term stratospheric measurements and on the ground level (neutron monitor and ionization chamber data) during 4 consecutive solar activity minima (1964-65, 1976-77, 1987, and 1996-97) show the long-term negative trend $\delta=-(0.01\text{-}0.09)$ % /year. The data on cosmogenic radioactive isotopes of ^{10}Be and ^{14}C also show the gradual decrease of their concentrations on the time-scale of more than $\sim 10^4$ years. The effect could be explained if supernova explosion took place in the nearby interstellar space about 5×10^4-5×10^5 years ago at the distance 30-150 parsec from the solar system.

1 Introduction:

The long-term observations of cosmic ray fluxes in the atmosphere and on the ground performed during several 11-year solar activity cycles allow getting the information on cosmic rays in the nearby interstellar space. When the processes of cosmic ray modulation in the heliomagnetosphere are studied the flux of cosmic rays falling on the modulation region boundary from the nearby interstellar space is suggested to be constant. It is very important to verify this suggestion. Let us consider the fluxes obtained on the Earth during several solar activity minimum periods. Long-term measurements of cosmic ray flux are performed in the atmosphere from 1957, on the ground level by ionization chamber from 1937, and by neutron monitors from 1953 to the present time.

If any trend of these fluxes (increase or decrease from one solar minimum to another one) is observed then it could be arisen from the respective changes of solar activity level during periods under considerations or from the changes of cosmic ray flux falling on the modulation region boundary from the nearby interstellar space.

2 Long-term negative trend in cosmic ray flux:

From 1957 till now cosmic ray fluxes in the atmosphere are measured at the polar, middle and low latitudes with the standard radiosondes [Charakhchyan et al., 1976; Bazilevskaya et al., 1991]. In this long-term experiment the Geiger tubes are used as detectors of charged particles. We shall consider the data obtained at polar latitude where R_c is low and its possible changes will not disturb cosmic ray flux. Also we shall compare cosmic ray fluxes N_m measured at Pfotzer maximum to avoid the possible errors which could be due to the atmospheric pressure sensors.

In Fig. 1 the monthly values of N_m smoothed with the period T=3 months are presented in the four successive solar activity minima: 1964-1966, 1975-1978, 1986-1987, and 1994-1998. The maximum values of N_m were observed in April-June 1965, in September-October 1976, in January-March 1987, and in April-June 1997. The straight line in this figure calculated by the least square method passes through the maximum values of N_m. It is seen that the value of cosmic ray flux decreases gradually from 1965 to 1997 with the rate $\delta=-(0.08\pm0.01)$ %/year (the values of N_m in January 1965 were taken as 100%). The same effect is observed if we analyze the data obtained at the different latitudes on the ground level and in the atmosphere (see Table 1). The ^{10}Be and ^{14}C concentration data given by Beer et al. (1990) and Dergachev (1999) show the decrease of cosmic ray fluxes on the time scale about 20 000 years. The negative trend in the ^{10}Be data equals $\delta\approx-0.05$ %/year and $\delta\approx-0.005$%/year is in the ^{14}C data.

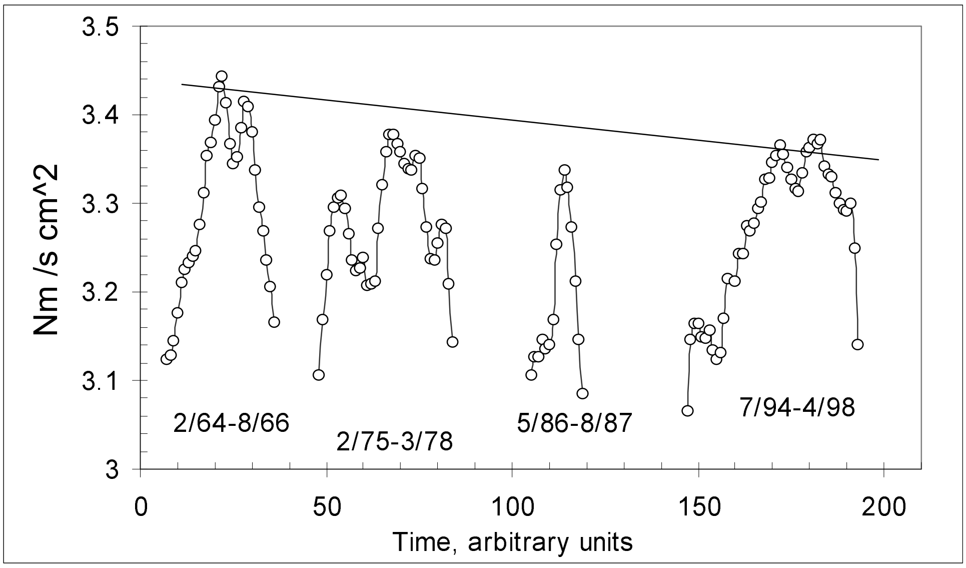

Fig. 1. The 3 monthly running values of N_m correspond to Pfotzer maximum measured in the northern polar atmosphere (R_c=0.6 GV) during four periods of minimum solar activity are depicted. The start and the end of each period are given under the curves. The straight line calculated from the 4 maximal values on N_m by the least square method shows the decrease of N_m with the rate $\delta=-(0.08\pm0.01)$ %/year.

Table 1. The value of trend in cosmic ray flux (δ) according to neutron monitor data, ionization chamber data, and stratospheric measurements in Pfotzer maximum (str.)

Site	R_c, GV	δ, %/year	Site	R_c, GV	δ, %/year
Thule	0.0	-0.08±0.01	Climax*	3.0	-0.04±0.01
Goose Bay	0.6	-0.06±0.01	Jungfraujoch	4.6	-0.08±0.01
Apatity	0.6	-0.09±0.01	Hermanus	4.6	-0.05±0.01
Ouly	0.8	-0.05±0.01	Huancayo	12.8	-0.03±0.01
Washington	1.5	-0.02±0.01	Ioniz. chamber	1.8	-0.010±0.003
Yakutsk	1.6	-0.09±0.01	Murmansk, str.	0.6	-0.08±0.01
Kiel	2.3	-0.08±0.01	Moscow, str.	2.4	-0.08±0.01
Moscow	2.4	-0.08±0.01			

*Climax neutron monitor data have been used without correction coefficient 1.0121 for the period after August 1981 [Pyle, 1997].

Using our long-term measurements of cosmic rays in the atmosphere at the polar and middle latitudes (R_c=0.6 GV and R_c=2.4 GV accordingly) we can define the changes of galactic cosmic ray spectrum in the energy range of E=0.1-1.5 GeV from one solar activity minimum to another one. Let us consider the values of $dN(x)=N_{0.6}(x)-N_{2.4}(x)$ where $N_{0.6}(x)$ and $N_{2.4}(x)$ are omnidirectional cosmic ray fluxes in the atmosphere at the atmospheric pressure level x and at the latitudes with R_c=0.6 GV and 2.4 GV. In the atmosphere the value of $dN(x)$ is absorbed as $dN(x) \propto \exp(-x/L)$, where L is the absorption length of charged particle flux. For the whole period of our measurements the yearly averaged values of L were calculated by the least square method and the results are given in Fig. 2. The periods of high solar activity when the values of *dN(x)* are small were omitted. The straight line demonstrates the decrease of *L* from 1960 to 1998. It means the softening of galactic cosmic ray spectrum in the energy range 0.1-1.5 GeV or the increase of nuclear component in total flux of primaries falling on the top of the atmosphere.

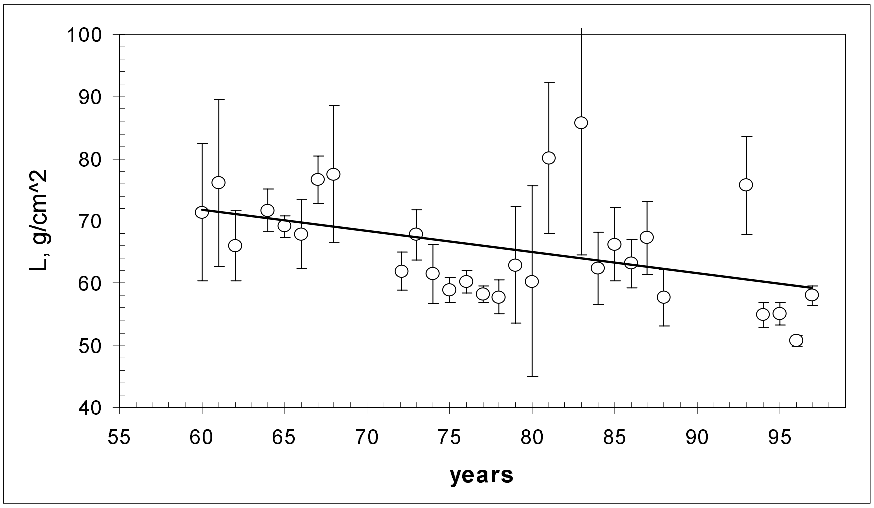

Fig. 2. The time dependence of *L* calculated from the absorption curves of the half-year averages of *dN(x)*. The straight line shows the gradual decrease of *L*. The vertical bars give the values of standard errors.

3 The possible mechanism of the long-term negative trend

The fact that the instruments of the different types are observed very small value of cosmic ray flux decrease gives the assurance that this effect is real one. There are several natural causes, which could produce this trend. One of them is solar activity increase for the period under consideration. However the analysis of changes of solar activity indexes, parameters of interplanetary space, and some indexes of the Earth's magnetic field in the solar activity minimum periods of 1964-1966, 1975-1978, 1986-1987, and 1995-1997 does not show their growth [Solar Geophys. Data, 1964-1998]. Also there is not the positive trend in the number of sunspots in the periods of solar activity minima from 1900 to 1997: $\delta(R_z)=-(0.001\pm0.002)$ %/year. Thus, it is unlikely that our Sun or interplanetary space or the Earth's magnetosphere were responsible for the long-term negative trend observed in cosmic rays (the first time the long-term negative trend in cosmic rays was discussed by Stozhkov et al. (1997) but the explanation of this effect was wrong).

The decrease of cosmic ray particles in the nearby interstellar space (the decrease of the flux on the modulation region boundary) may be a reason of the negative trend. The trend could be arisen as a result of supernova explosion in the nearby interstellar space [Amosov et al., 1991; Johnson, 1993; Sonett et al., 1997].

Let cosmic rays be produced by the point-like source during a short time after explosion. The accelerated particles propagate in the interstellar space by diffusion-convection process. If the maximum of diffusion wave of charged particle flux passed away from the solar system then the decrease of the particle flux has to be observed and the spectrum of particles has to be softening. From the solution of the spherical symmetric diffusion equation with convection one can get the value of trend [Dorman and Miroshnichenko, 1983]: $\delta = \frac{1}{n}\frac{dn}{dt} = -\frac{3}{2}\times\frac{1}{t} + \frac{r^2-(ut)^2}{4Dt^2}$, where *n*-charged particle concentration, *t*-time elapsed after supernova explosion, *r*-distance to supernova, *u*-average shock wave velocity, *D*-diffusion coefficient.

Let us consider two cases when the value of trend equals δ=-0.01 %/year and δ=-0.07 %/year. In our case the energy of primaries detected is 1-10 GeV and we can take $D=10^{27}$ cm^2/s and $u=3\times10^3$ km/s [Berezhko and Krymsky, 1988]. The calculated values of t and r are given in Table 2. As one can conclude it is possible to find values of r and t to explain the negative trend in cosmic rays via the supernova explosion in the nearby interstellar space.

In the energy range of primaries $E=10^{11}$-10^{14} eV a sidereal anisotropy was measured by several instruments [see e.g., Clay et al., 1996; Morishita et al., 1997]. Its experimental value is about (1-8)$\times10^{-4}$. For the spherical symmetric model of the supernova explosion discussed above the value of sidereal

Table 2. The time and the distance of the possible supernova explosion if $D=10^{27}$ cm^2/s and $u=3\times10^3$ km/s; the value of sidereal anisotropy A.

δ=-0.01 %/year			δ=-0.07 %/year		
t, years	*r*, pc	*A*	*t*, years	*r*, pc	*A*
2×10^4	60	1.5×10^{-2}	2×10^4	21	5.2×10^{-3}
5×10^4	146	1.4×10^{-2}	5×10^4	36	3.5×10^{-3}
10^5	288	1.4×10^{-2}	10^5	57	2.8×10^{-3}
3.5×10^5	1000	1.4×10^{-2}	3.5×10^5	149	2.1×10^{-3}

anisotropy $A = \frac{3r}{2ct}$, where c is velocity of particles [Johnson, 1993]. In the Table 2 the calculated values of A for relativistic particles and for values of r and t taken from this Table are shown.

Thus, experimental data on the long-term negative trend in cosmic rays presented above can be explained if the supernova explosion took place at the distance 30-150 parsec from the solar system about 5×10^4-5×10^5 years ago. Such celestial objects could be Loop-1 ($r\approx170$ pc, $t\approx2.0\times10^5$ yr.), Geminga ($r<100$ pc, $t\approx3.4\times10^5$ yr.), or Spur ($r\leq30$ pc, $t\approx5.0\times10^4$ yr.) [Shklovsky, 1966; Bignami et al., 1993. The analysis of cosmogenic isotope concentrations of ^{14}C in rings of trees and ^{10}Be in ice cores also demonstrates that supernova explosion could take place in the vicinity of the solar system [Beer, 1988; Amosov et al., 1991].

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