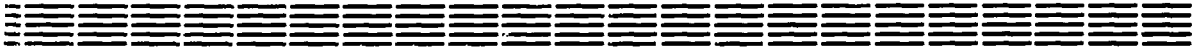


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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
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THE PULSARS AND POSSIBLE LOCAL
COSMIC RAY ORIGIN

ЦНИИАтоминформ
ЕРЕВАН — 1987

Գ.Ս. ՄԱՐՏԻՐՈՍՅԱՆ

ՊՈՒԼՄԱՐՆԵՐԸ ԵՎ ՏԻԵԶԵՐԱԿԱՆ ՃԱՌԱԳԱՅԹՆԵՐԻ
ՀՆԱՐԱՎՈՐ ՏԵՂԱՅԻՆ ԾԱԳՈՒՄԸ

Ենթադրելով, որ պուլսարները ցույց են տալիս գերնորերի պայթյունների ժամանակը և տեղը, որոնք միևնույն ժամանակ հանդիսանում են տիեզերական մառազայթների աղբյուրներ, և հենվելով միջաստղային տարածության մեջ տիեզերական մառազայթների տարածման դիֆուզիոն մոդելի վրա, հաշվված է տիեզերական մառազայթների էներգիայի խտությունը մերձերկրյա տարածությունում: Վերլուծությունը ցույց է տվել, որ տիեզերական մառազայթների էներգիայի դիտարկվող խտության մեջ հիմնական ավանդ ներմուծող աղբյուրները արեգակնային համակարգի շուրջ տեղադրված են $\tau = 0,9$ կպս շառավղի ներսում:

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THE PULSARS AND POSSIBLE LOCAL
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On the basis of the diffusion model of cosmic ray propagation in interstellar space, the density of cosmic ray energy in the circumterrestrial space is calculated under assumption that the pulsars are indicators of place and time of supernovae explosions which in turn are sources of cosmic rays. The analysis has shown that the sources making the basic contribution to the observed energy density of cosmic rays are distributed within the radius $\tau = 0.9$ kpc around the Solar system.

Yerevan Physics Institute

Yerevan 1987

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Г.С.МАРТИРОСЯН

ПУЛЬСАРЫ И ВОЗМОЖНОЕ ЛОКАЛЬНОЕ ПРОИСХОЖДЕНИЕ
КОСМИЧЕСКИХ ЛУЧЕЙ

Предполагая, что пульсары являются указателями места и времени взрывов сверхновых, которые в свою очередь являются источниками космических лучей, и основываясь на диффузионной модели распространения космических лучей в межзвездном пространстве, рассчитана плотность энергии космических лучей в околоземном пространстве. Анализ показал, что источники, вносящие основной вклад в наблюдаемую плотность энергии космических лучей, вокруг Солнечной системы распределены внутри радиуса $r = 0,9$ кпс.

Ереванский физический институт

Ереван 1987

1. Introduction

In the modern models of cosmic ray (CR) origin it is assumed that the particles may accelerate both at the supernova explosion itself and in the supernova shell or in the magnetospheres of young pulsars [1] .

At present, it is established that the pulsars are originated owing to supernovae explosions [2] . We assume in this work that the pulsars are indicators of place and time of supernovae explosions which in turn are sources of cosmic rays. Under this assumption and based on the diffusion model of particle propagation in turbulent magnetic fields of interstellar medium, we have calculated the CR energy density in the circumterrestrial space from these sources as well as determined the distribution region of those sources which make the basic contribution to the observed energy density. The calculations are based on the well-known space-time coordinates for 293 pulsars [3] .

In Ref.[4] , on the basis of such model, an attempt was

made as to explain the observed energy density and restore the CR prehistory using 12 pulsars known by that time.

2. Simulations

It is experimentally established that the CR spectrum extends up to energy $\sim 10^{20}$ eV. There is a number of arguments in favour of the fact that up to $\sim 10^{15}$ eV the cosmic rays are of galactic origin. In the circumterrestrial space the energy density of galactic cosmic rays is $W_{ex} \sim \sim 10^{-12}$ erg.cm⁻³ for particles with $E \geq 10^9$ eV, whereas for the particles with $E > 10^{15}$ eV $W_{ex} \sim 10^{-16}$ erg.cm⁻³ [1]. Following these and the fact that in the range 10^9 eV $\leq E \leq 10^{15}$ eV there are no sharp peculiarities in the energy spectrum, chemical composition and anisotropy, we shall imply under galactic cosmic rays the particles with the energy 10^9 eV $\leq E \leq 10^{15}$ eV for which the diffusion model is a good approximation when describing the motion of cosmic rays in the interstellar medium.

Further we shall assume that the supernovae are the sources for the cosmic rays and that the latter may accelerate both directly at supernova explosion and in its young shell. So long as the lifetime of supernovae young shells, where the cosmic rays may be accelerated, is appreciably less than their age, we shall consider the CR acceleration instantaneous in this case. The supernova age is determined by the pulsar age according to data on deceleration of pulsar's rotation. If there occurs an instantaneous point-like explo-

sion of the supernova at a distance z from the Earth, and the propagation of produced particles in the interstellar medium obeys the diffusion equation, then in time t the observed energy density of cosmic rays from the given source will be:

$$W_i(z,t) = W_{Sn} [4\pi Dt_i]^{-3/2} \exp[-z_i^2/4Dt_i] \exp[-t_i/\tau_e], \quad (1)$$

where W_{Sn} is total energy release during the outburst in the form of cosmic rays, $D=1/3\lambda v$ is the diffusion coefficient, λ is the mean distance between magnetic inhomogeneities, $v \approx c$ is the particle velocity, $\tau_e = 3d^2/2\lambda c$ is the cosmic ray lifetime relative to the escape from the capture region with linear dimension d . The total energy density from n sources will be $W = \sum_{i=1}^n W_i$. In expression (1) we have neglected the contribution of CR nuclear interactions with interstellar matter, since the CR lifetime relative to nuclear interactions is substantially larger than τ_e .

The value of the free path length λ was chosen following Refs. [1,5,6].

In Ref. [1], after a detailed discussion of the available experimental data, it is mentioned that in the galactic disk the diffusion coefficient must be $\sim 10^{27} \text{ cm}^2 \text{ c}^{-1}$ ($\lambda \sim 3.2 \cdot 10^{-2} \text{ pc}$). In Ref. [5] the authors, assuming that the supernovae, being the CR sources, have random spatial distribution inside the galactic disk with the frequency of appearance $10^{-2} \text{ year}^{-1}$, and using the diffusion model, have calculated the energy density, anisotropy and the ratio of L to M of CR nuclei. From these calculations the authors con-

cluded that λ - the free path length of diffused particles - must vary within $10^{-2} \text{ pc} \leq \lambda \leq 10^{-1} \text{ pc}$.

From experimentally observed abundance of ^{10}Be isotope in CR in Ref. [6] for τ_e in the galactic disk there was obtained the value $\tau_e = 1.7 \cdot 10^7$ years, which at $d=500\text{pc}$ corresponds to $\lambda \sim 7 \cdot 10^{-2} \text{ pc}$.

In this work the calculations were carried out at the following parameters: $W_{\text{sn}} = 10^{51}$ erg, $d=500 \text{ pc}$ and $\lambda = 5 \cdot 10^{-2} \text{ pc}$. At these values of λ and d the time of CR confinement is $\tau_e = 2.45 \cdot 10^7$ years.

In order to reveal sources with coordinates (z, t) which at the present epoch make the basic contribution to the observed energy density of CR, the equation $\partial W(z, t) / \partial t = 0$ was solved. For expression (1) the solution of this equation with respect to t has the form:

$$T = 0,25 \tau_e (-3 + \sqrt{9 + 4z^2 / \tau_e D}) \quad (2)$$

Expression (2) at definite values of τ_e and D points out the time T in which the CR energy density from the given source attains maximum at a distance z .

In Fig.1 the dashed area points out $T=T(z)$ dependence corresponding to the interval $10^{-1} \text{ pc} \leq \lambda \leq 10^{-2} \text{ pc}$.

3. Discussion of Results

From the number of supernovae mentioned above, the selection of the CR sources which make a substantial contribution to the observed energy density in the present epoch was carried out by two criteria.

1. Only those sources were considered for which

$$W_{\max} \geq 10^{-15} \text{ erg.cm}^{-3} = 0.1\% W_{\text{ex}}(E \geq 10^9 \text{ eV}) \text{ at } \lambda = 5 \cdot 10^{-2} \text{ pc.}$$

2. From the number of sources satisfying the first condition there were selected ones in which the lifetime t (the time passed after the moment of supernova explosion) satisfied the condition $T_1 \leq t \leq T_2$, where T_1 and T_2 were calculated according to expression (2) respectively for $\lambda = 10^{-1}$ pc and $\lambda = 10^{-2}$ pc at the given distance z from the source.

The calculations have shown that from 293 supervovae the parameters of only 39 supernovae satisfy the above-cited two conditions. In Fig.1 the black points refer to the space-time coordinates of these 39 supernovae. As seen from the figure, all the sources are distributed by distance inside the band $0.2 \text{ kpc} \leq z \leq 0.9 \text{ kpc}$, and the characteristic age of these sources amounts to $\sim 1.04 \cdot 10^7$ years. The calculated total density of CR energy from these supernovae near the Earth is $\sim 6.6 \cdot 10^{-13} \text{ erg.cm}^{-3} = 0.4 \text{ eV.cm}^{-3}$. Experimentally observed density of CR energy near the Earth is 0.5 eV.cm^{-3} .

Table 1 lists parameters of 39 pulsars determining coordinates and time of explosions of these supernovae as well as the values W_{\max} at $\lambda = 5 \cdot 10^{-2}$ pc.

Fig.2 presents projections of 58 sources on the Galaxy plane, for which $W_{\max} \geq 10^{-15} \text{ erg.cm}^{-3}$. The black points refer to coordinates of above-mentioned 39 sources. The circles refer to coordinates of 10 sources from which W_{\max} for 10 sources near the Earth was observed in the past and for 9 ones in the future. For example, from the well-known supernova in

the Vela (PSR 0833-45; $z = 0.5$ kpc, $t = 1.12 \cdot 10^4$ years) the CR maximal flux ($W_{\max} = 3.5 \cdot 10^{-14}$ erg.cm $^{-3}$) will reach the Earth in $T = 6.88 \cdot 10^6$ years. In this connection, it is interesting to note that $1.74 \cdot 10^8$ and $3.09 \cdot 10^7$ years ago the CR energy density near the Earth must have increased respectively by a factor of 5-6 owing to explosions of supernovae producing pulsars PSR 0950 + 08 and PSR 1929 + 10. Such increase of CR energy density might have brought to biological consequences discussed in Ref.[7] .

As one can see from Fig.2, all the 39 sources around the Solar system are distributed isotropically with the consequence of observed low anisotropy of CR at $E \leq 10^{15}$ eV. From the given calculations there follows that if the diffusion approximation describes the CR motion in the interstellar space sufficiently correctly, then the observed CR are of local origin. So, we can make the following concrete conclusions.

1. The main contribution to the observed CR energy density comes from the sources located in the region with radius $z \leq 0.9$ kpc around the Solar system.

2. The confinement time for CR in this region is $\sim 2.45 \cdot 10^7$ years.

3. To ensure the observed CR energy density $W_{\text{ex}} \sim 10^{-12}$ erg.cm $^{-3}$, it is enough that the luminosity of the sources in CR was $L_{\text{CR}} \sim 10^{38}$ erg.sec $^{-1}$, which is by 2-3 orders of magnitude lower than the required luminosity of sources at the galactic model of CR origin.

Authors of some works have come to the same conclusion from other assumptions. E.g., the authors of Ref.[8], follow-

ing the reasons connected with the CR lifetime, L/M ratio, low anisotropy and high-energy electron spectrum, have come to the conclusion that low-energy particles ($R \geq 10$ Gv/c), while diffusing, may reach the Earth from the near sources ($z \leq 100 - 300$ pc), while high-energy particles ($R > 10^6$ Gv/c) from sources with distances $z \leq 1 - 10$ kpc. The authors of Ref.[9], on the basis of observation data connected with 44 OB stars inside the Gould's Belt which also are a powerful source of γ radiation, have come to the conclusion that CR observed near the Earth are of local nature (sphere with a radius ~ 1 kpc, confinement time $\sim 2 \cdot 10^7$ years).

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Table 1

No.	PSR	z [pc]	t [year]	$W_{\max}/10^{-14}$ [erg.cm $^{-3}$]
1.	0105 + 65	850	$1.55 \cdot 10^6$	0.18
2.	0149 - 16	440	$1.02 \cdot 10^7$	2.29
3.	0203 - 40	470	$8.32 \cdot 10^6$	1.82
4.	0301 + 19	560	$1.69 \cdot 10^7$	0.97
5.	0403 - 76	790	$5.62 \cdot 10^6$	0.25
6.	0450 + 55	450	$2.29 \cdot 10^6$	2.12
7.	0538 - 75	650	$3.47 \cdot 10^7$	0.55
8.	0656 + 14	400	$3.80 \cdot 10^6$	3.17
9.	0823 +26	710	$4.90 \cdot 10^6$	0.39
10.	0834 + 06	430	$2.95 \cdot 10^6$	2.48
11.	0844 - 35	610	$1.12 \cdot 10^7$	0.71
12.	0853 - 33	580	$3.09 \cdot 10^6$	0.85
13.	0905 - 51	860	$2.19 \cdot 10^6$	0.17
14.	0906 - 17	510	$9.55 \cdot 10^6$	1.36
15.	0940 + 16	750	$1.91 \cdot 10^7$	0.31
16.	0943 + 10	560	$4.90 \cdot 10^6$	0.97
17.	1112 + 50	320	$1.05 \cdot 10^7$	6.64
18.	1237 + 25	330	$2.29 \cdot 10^7$	5.99
19.	1508 + 55	730	$2.34 \cdot 10^6$	0.35
20.	1530 + 27	490	$2.19 \cdot 10^7$	1.57

Table 1 (continuation)

No.	PSR	z [pc]	t [year]	$W_{\max}/10^{-14}$ [erg.cm ⁻³]
21.	1530 - 53	650	$1.51 \cdot 10^7$	0.55
22.	1540 - 06	660	$1.26 \cdot 10^7$	0.52
23.	1601 - 52	800	$4.07 \cdot 10^7$	0.24
24.	1612 + 07	800	$8.13 \cdot 10^6$	0.24
25.	1702 - 18	740	$1.15 \cdot 10^6$	0.33
26.	1706 - 16	810	$1.62 \cdot 10^6$	0.22
27.	1747 - 46	660	$9.12 \cdot 10^6$	0.52
28.	1845 - 19	530	$2.95 \cdot 10^6$	1.19
29.	1919 + 21	330	$1.58 \cdot 10^6$	5.99
30.	1946 - 25	880	$4.47 \cdot 10^6$	0.16
31.	2021 + 51	680	$2.75 \cdot 10^6$	0.45
32.	2045 - 16	380	$2.82 \cdot 10^6$	3.77
33.	2048 - 72	640	$2.75 \cdot 10^7$	0.58
34.	2151 - 56	500	$5.13 \cdot 10^6$	1.46
35.	2152 31	600	$1.32 \cdot 10^7$	0.75
36.	2315 + 21	710	$2.19 \cdot 10^7$	0.39
37.	2321 - 61	580	$1.45 \cdot 10^7$	0.85
38.	2323 + 63	530	$7.94 \cdot 10^6$	1.19
39.	2327 - 20	290	$5.62 \cdot 10^6$	9.16

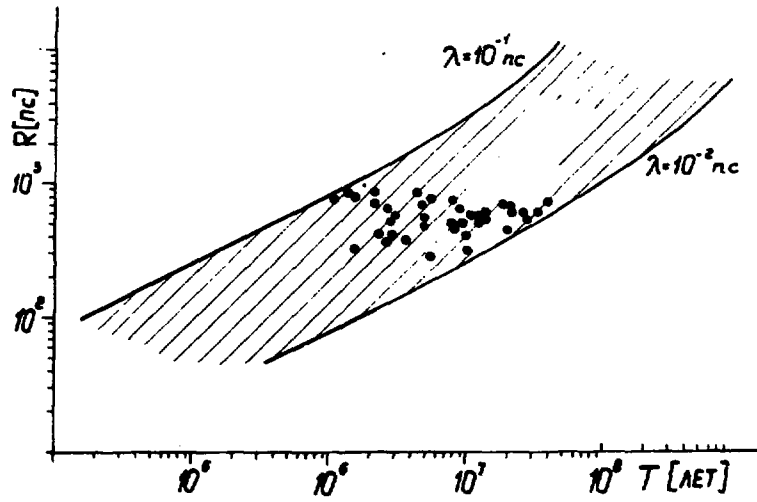


Рис. I

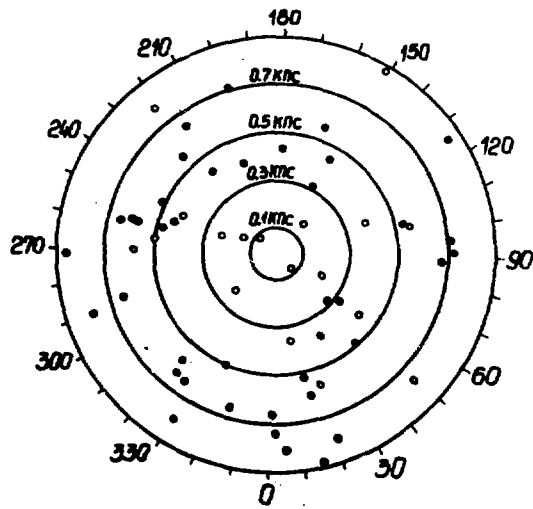


Рис.2

Figure Captions

Fig.1. The distance dependence of time T after which the maximal energy density is observed at a distance z . The dashed area refers to the interval 10^{-1} pc $\leq \lambda \leq 10^{-2}$ pc. Black points refer to the sources making the basic contribution to CR energy density at the present epoch.

Fig.2. Projections of sources with $W_{\max} \geq 10^{-15}$ erg.cm $^{-3}$ on the Galaxy plane. Black points refer to the sources making the basic contribution to CR energy density at the present epoch.

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...МАРТИРОСЯН

УЛЬСАРЫ И ВОЗМОЖНОЕ ЛОКАЛЬНОЕ ПРОИСХОЖДЕНИЕ КОСМИЧЕСКИХ ЛУЧЕ*
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