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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

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ON THE ORIGIN OF ULTRAHIGH-ENERGY GAMMA RAYS
FROM CYG X-3

ЦНИИатоминформ

ЕРЕВАН-1986

Ֆ.Ա. ԱՀԱՐՄԵԱՆ

**Ըյց X-3 ՌԵՆՏԳԵՆՅԱՆ ԱՂԹՈՒԻՒՑ ԱՌԱՔՎՈՂ ԳԵՐԲԱՐՁԸ
ԷՆԵՐԳԻԱՆՆԵՐԻ ԳԱՄՄԱ - ԲՎԱՆՏՆԵՐԻ ԵԱԳՄԱՆ ՄԱՍԻՆ**

Քննարկվում են Ըյց X-3 ռենտգենյան աղբյուրում զամմա-մտազայթման ծնման հարավոր եղանակները: Ցույց է տրված, որ զերբադր էներգիաների զամմա-քվանտների սպեկտրում դիտվող առանձնահատկությունները բավարար կերպով բացատրվում են առաջարկվող մոդելի սահմաններում, որի համաձայն զամմա-քվանտները հանդիսանում են \mathcal{N} -մեզոնների տրոհման աղբյուրնք՝ ծնվող արագացված մասնիկների /միջուկների և պրոտոնների/ և շրջապատի ցածրհամախային մտազայթման փոխազդեցության ժամանակ:

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ON THE ORIGIN OF ULTRAHIGH-ENERGY GAMMA RAYS
FROM CYG X-3

The gamma-ray production mechanisms in Cyg X-3 are discussed. It is shown that the observed features of gamma-ray spectra can be satisfactorily explained by a model in the framework of which gamma-rays are produced due to photomeson processes at interactions of accelerated protons with ambient low-frequency radiation.

Yerevan Physics Institute

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О ПРОИСХОЖДЕНИИ ГАММА-КВАНТОВ СВЕРХВЫСОКИХ
ЭНЕРГИЙ ОТ РЕНТГЕНОВСКОГО ИСТОЧНИКА ЛЕБЕДЬ X-3

Обсуждаются механизмы генерации гамма-излучения в рентгеновском источнике Лебедь X-3. Показано, что наблюдаемые особенности в спектре гамма-квантов сверхвысоких энергий удовлетворительно объясняются в рамках модели, предполагающей образование гамма-квантов в результате фоторождения π - мезонов при столкновениях ускоренных частиц (протонов и ядер) с окружающим полем низкочастотного излучения.

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1. Introduction

The X-ray source Cyg X-3 is of particular interest among other astrophysical objects. We can say without exaggeration that Cyg X-3 is the most popular object in the 80-ies, particularly for specialists dealing with the problem of the cosmic-ray origin. This is the only known source emitting electromagnetic radiation in the range from radiowaves to gamma-rays of ultrahigh energies. The source luminosity in the range 10^{12} - 10^{16} eV exceeds 10^{37} erg/s, which is comparable to that of the Galaxy in cosmic rays in the same energy range. Hence Cyg X-3 can explain an appreciable portion of ultrahigh-energy cosmic rays flux.

The radiation periodicity, 4.8 hr, revealed in various ranges of the spectrum of Cyg X-3 undoubtedly indicates that the observed radiation has a unique nature and is produced in close binary system, one of the components of which is a neutron star. At present, there are developed two models of particle acceleration up to ultrahigh energies in Cyg X-3. In the model of Vestrand and Eichler [1] it is assumed that the particles are accelerated by a young pulsar. Meanwhile, in the model of Chanmugam and Brecher [2] the particles are assumed to accelerate in the accretion disk which is formed when matter falls

onto the neutron star from its normal companion star.

Both models are far from describing the real situation in Cyg X-3. The available data are presumably insufficient to construct a more realistic model of particle acceleration in Cyg X-3. Meanwhile, the set of data in various energy ranges enables one to investigate the production process of gamma-rays, being secondary products of interactions of accelerated particles.

In the present paper we give arguments favouring that the observed radiation from Cyg X-3 is the result of the decay of mesons produced under collisions of accelerated protons both with ambient gas and low-frequency radiation.

2. Spectrum of Gamma Radiation from Cyg X-3

A drawback for gamma-ray observations of Cyg X-3 is, that they were carried out with different detectors and methods at different times and without separation of periodical and stationary components of radiation [3]. Therefore we can speak only about "mean" gamma-ray spectrum of Cyg X-3. The gamma-ray observations of Cyg X-3 were performed in 4 spectral ranges: $10^8 - 10^9$ eV, $10^{11} - 10^{13}$ eV, $\sim 10^{14}$ eV and $\geq 10^{15}$ eV.

In contrast with ultrahigh energy region, at low energies ($10^8 - 10^9$ eV) there takes place an obvious discrepancy between results obtained by various groups, in particular, the balloon-borne measurements of the Moscow Engineering-Physical Institute the SAS-2 and COS B data. Possible reasons for the discrepancy are discussed in a recent review [3].

Fig.1 shows an integral gamma-ray spectrum of Cyg X-3 in

the energy range 10^{11} - 10^{16} eV. The set of data obtained in this energy range, even with account of available uncertainties, indicates a tendency of the spectrum flattening in the range 10^{13} - 10^{14} eV, as well as of a possible cutoff at $E_\gamma \gg 3 \times 10^{15}$ eV. These spectral peculiarities become more evident when taking into account gamma-ray absorption on cosmic microwave background radiation (MBR).

When gamma-rays traverse the isotropic photon field with a typical energy ϵ , the (e^+e^-) production cross section, averaged over all angles, depends only on parameter $z = E_\gamma \epsilon / m_e^2 c^4$; starting from the threshold value $z=1$ the cross section increases rapidly to the maximum at $z=3$, and then decreases slowly as $z^{-1} \ln z$. In the case of Planckian distribution of MBR (temperature $T_r = 2.7$ K) the free path λ is minimal at $E_\gamma \sim 10^{15}$ eV, being equal to $\lambda (\sim 10^{15} \text{ eV}) \simeq 8$ kpc. For gamma-rays of lower energies the free path sharply increases (reaching ~ 20 kpc and ~ 30 Mpc at gamma-ray energies $5 \cdot 10^{14}$ eV, and 10^{14} eV, respectively), due to the threshold nature of the reaction owing to which gamma-rays interact only with the Wien "tail" of the MBR. The free path increases also at $E_\gamma \gg 10^{15}$ eV, since in this case $\bar{z} \sim 3kT_r E_\gamma \gg 1$

In Fig.1 photon fluxes are shown with account of corrections for the absorption on MBR. As far as photons with $E_\gamma \gg 10^{15}$ eV are exposed to more intensive absorption (approximately by a factor of 3), the corrected spectrum (corresponding to the spectrum of the source) possesses more distinctly pronounced peculiarities than the observed one. The absorption on MBR not only makes the observed spectrum steeper in the range 10^{13} - 10^{15} eV,

but partially "masks" the cutoff at $E_\gamma \approx 3 \cdot 10^{15}$ eV.

The interactions of accelerated protons as well as of electrons may, in principle, lead to production of secondary gamma-rays in Cyg X-3. Under conditions of high density of low-frequency radiation and magnetic field, the most essential mechanism of gamma-ray production in Cyg X-3, associated with the electron component, is inverse Compton scattering. However, the gamma-ray spectrum formed as a result of this process does not agree with the observed spectrum of Cyg X-3. Besides, electron acceleration up to $E_e \sim 10^{15}$ eV seems rather problematic because of catastrophic energy losses ($\sim E^2$) in the source. So, a "proton" version for the origin of gamma-rays from Cyg X-3 is more probable.

In all at present existing theoretical models it is assumed that gamma-rays are produced due to production and decay of π -mesons occurring in interactions of accelerated protons with the surrounding matter (see, e.g. [4]). However, to explain the above-quoted peculiarities in radiation spectrum of Cyg X-3 by (p-p) interactions, rather hard and artificial assumptions on the spectrum of accelerated protons are required. Indeed, if accelerated protons distributed by a "standard" power law

$$J_p(E) = AE^{-\Gamma} \quad (1)$$

interact with hydrogen medium of density n_H , then the gamma-ray spectrum in the range $E_\gamma \gg 100$ MeV can be approximated in the form [5]:

$$q_{\gamma}^{PP}(E_\gamma) = \psi(\Gamma) \delta_{in}^{PP}(E_\gamma/f) n_H \cdot AE_\gamma^{-\Gamma} \quad (2)$$

where σ_{in}^{pp} is the cross section of inelastic p-p interactions at the proton energy $E = E_\gamma / f$ ($f \sim 0.2$); function $\varphi(\Gamma)$ weakly depends on Γ and at variation of Γ from 2.2 to 2.7, varies within limits 0.01-0.05 [5].

From the comparison of Eq.(2) with the observed spectrum there follows that in order to explain the gamma-ray spectrum of Cyg X-3 by (p-p) interactions, the corresponding peculiarities in the accelerated proton spectrum are needed. However, such peculiarities, first, contradict to the observed power-law spectrum of ultrahigh-energy cosmic rays, and ,second, cannot be provided by any reasonable acceleration mechanism.

The assumption on ultrahigh-energy gamma-ray production in Cyg X-3 due to (p-p) interactions may be explained partly by the fact that in the low-energy range ($E_\gamma \sim 100$ MeV) p-p interactions, as shown by COS B observations, play a very important role in gamma-ray production. However, at ultrahigh energies, protons efficiently interact not only with matter, but also with low-frequency radiation, the most important process in the latter case being the inverse photoproduction of π mesons ($p\gamma \rightarrow \pi^0 \rightarrow \gamma$). So long as in the proton rest frame the threshold energy of gamma-rays is about 100 MeV, then at a given energy of low-frequency photons \bar{E} the pions will be produced at proton energy $E \geq 10^{16} (\bar{E} / 10eV)^{-1}$ eV. If accelerated protons are distributed by the power law (1), then the spectrum of gamma-rays and neutrino from secondary π meson decays has the form [6]:

$$q_{\gamma\nu}^{p\gamma} = \begin{cases} Q_{\gamma\nu} & E_{\gamma\nu} \leq E_1 \\ Q_{\gamma\nu} (E_{\gamma\nu} / E_1)^{-(\Gamma+1)} & E_{\gamma\nu} > E_1 \end{cases} \quad (3)$$

where $Q_{\gamma\nu} = 20\pi\sigma_0 \cdot A \cdot n_{ph} \cdot E_0^{-\Gamma} / 2^{\Gamma}(\Gamma+1)\eta$; $\sigma_0 = 2 \cdot 10^{-28} \text{ cm}^2$;
 $E_1 = \eta E_0 / 5$; $E_0 \approx 0.35 (m_p c^2)^2 / \bar{\epsilon}$. Parameter η characterizes a
kinematics of $\pi \rightarrow \gamma\nu$ decays being equal to $\eta_\gamma \sim 0.5$ and
 $\eta_\nu \sim 0.2$, respectively; n_{ph} and $\bar{\epsilon}$ are density and mean
energy of low-frequency photons in the source.

Thus, if in the production region of gamma-rays besides
the gas component also low-frequency radiation takes place,
then the gamma-ray spectrum will consist of two (pp- and p γ)
components. Fig.2 shows a differential spectrum of total gamma-
radiation. The spectrum is characterized by three features:
a) the first low-energy part is due mostly to p-p interactions
and has a power-law behaviour with an index $\Gamma_\gamma = \Gamma$; b) in the
energy range $E_\gamma \sim E^*$, when contributions from pp and p γ photons
equalize, the total spectrum of gamma-rays flattens:

$$E^* \sim 5E_1 \left[\frac{(\Gamma+1)^{\Gamma}(\Gamma)}{40\pi} \frac{n_0}{n_{ph}} \frac{\sigma_{in}^{pp}}{\sigma_0} \right]^{1/\Gamma} . \quad (4)$$

An essential flattening takes place when $\xi \equiv \frac{E^*}{E_1} \leq 0.3$.
The value of E^* does not depend on the coefficient A and
is determined only by the ratio n_H / n_{ph} and the values of $\bar{\epsilon}$
and Γ ; c) in the energy range $E_\gamma \gg E_1$ the gamma-ray spec-
trum is already entirely due to p γ - photons. The spectrum has
a power-law behaviour with an index $\Gamma_\gamma \approx \Gamma + 1$.

Thus, the spectrum of gamma-radiation due to superposition
of pp- and p γ - photons has two peculiarities - flattening at
 $E_\gamma \sim E^*$ and cutoff at $E_\gamma \sim E_1$, which depend only on parameters
characterizing the production region of gamma-rays, namely on
 n_H / n_{ph} and $\bar{\epsilon}$.

Fig.3 shows integral spectra of total gamma-radiation

$$q_{\gamma}(>E_{\gamma}) = \begin{cases} \frac{A}{\Gamma-1} E_1^{-\Gamma+1} (E_{\gamma}/E_1)^{-\Gamma+1} + Q_{\gamma} E_1 (1+1/\Gamma - E_{\gamma}/E_1), & E_{\gamma} \leq E_1 \\ \frac{A}{\Gamma-1} E_1^{-\Gamma+1} (E_{\gamma}/E_1)^{-\Gamma+1} + \frac{Q_{\gamma} E_1}{\Gamma} (E_{\gamma}/E_1)^{-\Gamma}, & E_{\gamma} > E_1 \end{cases} \quad (5)$$

Since at the given value of Γ the relation between A and Q is determined from the condition $q_{\gamma}^{PP}(E_{\gamma}^*) = q_{\gamma}^{P\gamma}(E_{\gamma}^*)$, where $E^* = \xi E_1$, then, expressing the photon energy in terms of E_1 , one can unambiguously determine the shape of spectrum (5) versus parameter $\xi \equiv F(n_H/n_{ph}, \bar{E}, \Gamma)$. From the comparison of Fig.3 and Fig.1 follows that for Cyg X-3 parameter ξ approximately equals to 0.1.

Thus, having known the peculiarities of gamma-ray spectrum in a wide energy range, one can obtain an important information concerning the conditions of acceleration and interaction of ultrahigh-energy particles in Cyg X-3: by cutoff in the gamma-ray spectrum at energy E_1 one can estimate the mean energy of low-frequency photons: $\bar{E} = 10(E_1/3 \cdot 10^{15} \text{ eV})^{-1} \text{ eV}$, while by the spectrum slope above E_1 one can determine the value of index of the accelerated proton spectrum ($\Gamma \approx \Gamma_{\gamma} (E_{\gamma} > E_1) - 1 \approx 2.1+2.5$). Note, that in the energy range $E_{\gamma} \ll E^* \sim 10^{14} \text{ eV}$ the photon spectrum must have a power-law behaviour with an index $\Gamma_{\gamma} (E_{\gamma} \ll E^*) \sim \Gamma \sim 2.1+2.5$, which is in agreement with the data of Cyg X-3 (see Fig.1). At given values of ξ and Γ one can obtain the ratio

$$\frac{n_{ph}}{n_H} \sim 5^{\Gamma} \frac{(\Gamma+1) \psi(\Gamma)}{40\pi} \frac{6_{in}^{PP}}{6_0} \xi^{-\Gamma} \quad (6)$$

At $\xi \sim 0.1$ and $\Gamma \approx 2.3$ we get $n_{ph}/n_H \sim 10^3$. If the low-frequency radiation is in thermodynamic equilibrium with the medium,

then the radiation temperature is $kT_r \sim 3$ eV, and photon density $n_{ph} \sim 10^{15}$ photons/cm³. Hence we obtain $n_H \sim 10^{-3} n_{ph} \sim 10^{12}$ cm⁻³.

The free path of gamma rays in the field of black-body radiation with $kT_r \sim 3$ eV is $\lambda_{\gamma r} \sim 5 \cdot 10^{12}$ cm at $E_\gamma \sim 10^{15}$ eV. Precisely of the same order turns out the value of free path of protons relative to the π -meson photoproduction: $\lambda_{p\gamma} = (n_{ph} \sigma_0)^{-1} \approx 5 \cdot 10^{12}$ cm. Hence, even in case of rectilinear leakage of protons from the source $\lambda_{p\gamma} \sim \lambda_{\gamma r}$, i.e. an appreciable portion of photons will freely leave the source.

A more probable region of gamma-ray production seems to be the normal star atmosphere irradiated by high-energy protons accelerated near the relativistic object. However, we do not exclude a possibility of gamma-ray production in the vicinity of relativistic object either, e.g. in the accretion disk around the neutron star.

The luminosity of Cyg X-3 in ultrahigh-energy gamma-rays, if the source radiates isotropically, is $L_\gamma (10^{12} - 10^{16} \text{ eV}) \sim 10^{37}$ erg/s. Hence, at the efficiency of transformation of accelerated particles energy into gamma rays, $\alpha \sim 0.1$, Cyg X-3 can, in principle, maintain the observed luminosity of the Galaxy in cosmic rays (CR) of ultrahigh energies: $L_{CR} (\geq 10^{16} \text{ eV}) \sim 5 \cdot 10^{37}$ erg/s. But besides Cyg X-3, at least two discrete sources of gamma-rays with $E_\gamma \geq 10^{15}$ eV are discovered at present: X-ray pulsars Vela X-1 [7] and Her X-1 [8]. So, to avoid contradictions with the observed fluxes of ultrahigh-energy CR, we have to presume that Cyg X-3 radiation has a highly directed nature (this reduces nearly by an order the energy requirements)

or $\mathcal{X} \sim 1$. The latter assumption is favoured by a "diffuse" gamma radiation of ultrahigh energies discovered at the Tien Shan EAS array [9]. One can be readily be convinced that the observed radiation can be called "diffuse" only conventionally, since it is most probably due to superposition of the unresolved discrete sources, and not to interactions of CR with interstellar medium. Indeed, assuming that the CR responsible for the observed "diffuse" flux of gamma-rays are captured to the region with a characteristic size ℓ , for the ratio of luminosities in gamma-rays and in CR we have:

$$\mathcal{X} = \frac{\dot{W}_\gamma}{\dot{W}_{CR}} \sim \frac{J_\gamma}{J_{CR}} \cdot \frac{\ell}{\lambda}, \quad (7)$$

where λ is the scale of magnetic inhomogenieties in the Galaxy (the free path of gamma-rays with $E_\gamma \gtrsim 10^{15}$ eV on the MBR directly indicates that gamma-rays are produced within the Galaxy); $J_\gamma/J_{CR} \sim 10^{-3}$ is the relative content of gamma-rays in CR at $E_\gamma \gtrsim 5 \cdot 10^{14}$ eV. Substituting the characteristic values $\ell \sim 1$ kpc (the Galaxy disk thickness), $\lambda \sim 1$ pc we obtain $\mathcal{X} \sim 1$! The strikingness of this result is that if the gamma-rays are secondary products of CR interactions, then there must take place an exceptionally efficient mechanism for the transformation of the CR energy into gamma-rays of ultrahigh energies.

Evidently, the interactions responsible for gamma-ray production cannot proceed in the interstellar medium, since the grammage traversed by CR in the interstellar medium is much less than 100 g/cm^2 - the proton free path with respect to nuclear interactions. In the energy region of interest the contribution from inverse Compton scattering of electrons on

low-frequency photon field is negligible too. Hence, the "diffuse" component of gamma-rays should, in fact, be the superposition of contributions of unresolved discrete sources in which the transformation of accelerated particles energy into gamma-rays proceeds more efficiently.

Thus, from the limited size of the production region of ultrahigh-energy gamma-rays (≤ 10 kpc), from incapability of cosmic rays to provide the observed flux of gamma-rays in the interstellar medium and, finally, from the large value of the parameter \mathcal{E} (~ 1), we can conclude that the main portion of cosmic rays (at least in the range 10^{15} - 10^{17} eV) is accelerated in the galactic sources.

If gamma-rays are produced at interactions of accelerated protons with matter, then, as mentioned above, they must travel ~ 100 g/cm² prior to their leaving the source. However, in this case the accelerated nuclei would not be able to escape from the source due to a practically complete spallation in ~ 100 g/cm² of matter. On the other hand, the hypothesis on generation of ultrahigh-energy gamma-rays in p-p collisions leads to fluxes at $E_{\gamma} \sim 100$ MeV, exceeding the intensities of COS B sources. In principle, the photon intensity at $E_{\gamma} \sim 100$ MeV might be "suppressed" assuming very hard spectra of accelerated particles in the sources, but such spectra do not agree with the observations. Therefore, it seems more likely, that gamma-rays are produced due to π -meson photoproduction in collisions of accelerated protons with a surrounding field of low-frequency radiation. In addition to the above-stated argument, based on spectral peculiarities of Cyg X-3 radiation, this assumption

agrees with the hypothesis that the observed cutoff in the CR energy spectrum at $E \sim 10^{15}$ eV as well as the chemical composition of CR are the result of π -meson photoproduction and nuclei photodisintegration directly in the CR sources [10-12].

The future complex investigations of ultrahigh-energy gamma-rays as well as of chemical composition and energy spectrum of CR will undoubtedly provide very important information on the sources of acceleration of ultrahigh-energy particles.

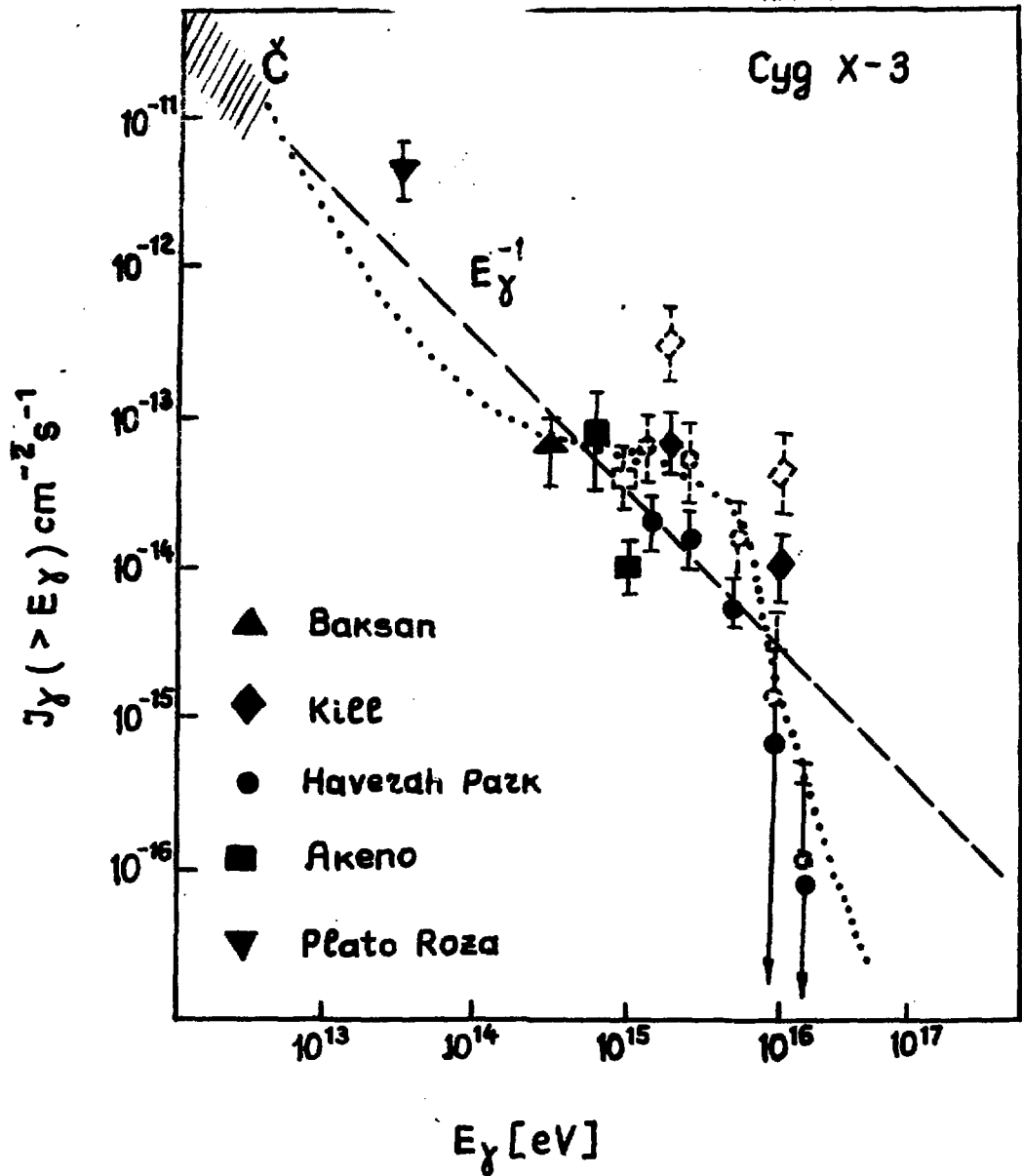


Fig.1 The spectrum of ultrahigh-energy gamma-rays, observed from Cyg X-3. The dotted symbols correspond to the fluxes after correction to absorption of gamma-rays on MBR.

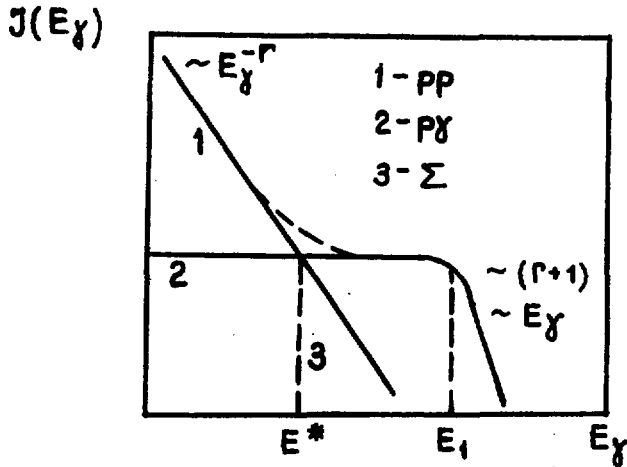


Fig. 2 The differential spectrum of total (pp- and p γ -) radiation $\ell_g J(>E_\gamma)$

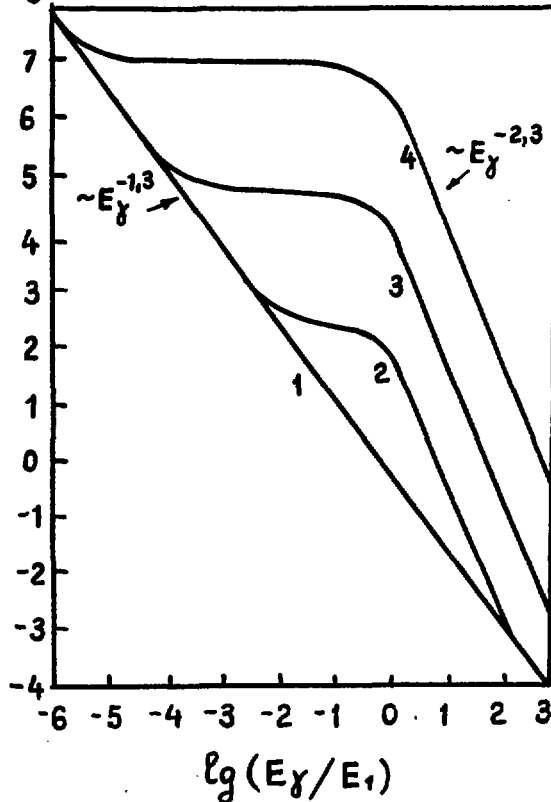


Fig. 3 The integral spectrum of total (pp- and p γ -) radiation. The spectrum of accelerated protons is taken in the form (1) with $\Gamma=2.3$ and $A=1$.

1. $\xi=1$; 2. $\xi=10^{-1}$; 3. $\xi=10^{-2}$; 4. $\xi=10^{-3}$.

REFERENCES

1. Vestrand W.T., Eichler D. On the Ultrahigh-Energy Gamma-Rays from Cyg X-3. *Ap. J.*, 1982, vol.261, p.251.
2. Channugan G., Brecher K. Ultrahigh-Energy Gamma-Rays and Cosmic Rays from Accreting Gegenerate Stars. *Nature*, 1985, vol. 313, p.767 .
3. Владимирский Б.М., Гальпер А.И., Лучков Б.И., Степанян А.А. Мощный галактический источник жесткого излучения Лебедь X-3. *УФН*, 1985, т.145, с.255.
4. Berezhinsky V.S. On Gamma and Neutrino Radiation from Cyg X-3. 19th ICRC, La Jolla, 1985, vol.1, p.75 .
5. Berezhinsky V.S., Volynsky V.V. Generation Function of High-Energy Cosmic Neutrinos. I PP-neutrino. 16th ICRC, Kyoto, 1979, vol.10, p.326 .
6. Stecker F.W. Diffuse Fluxes of Cosmic High-Energy Neutrinos. *Ap. J.*, 1979, vol.228, p.919 .
7. Protheroe R.J. Clay R.W., Gerhardy P.R. First Observation of Gamma-Rays from Vela X-1 at Energies Greater than $3 \cdot 10^{15}$ eV. *Ap. J.*, 1984, vol.280, p.L 47.
8. Baltrusaitis R.M., Cassiday G.L., Cooper R. et al. 500 TeV Gamma-Rays from Hercules X-1. 19th ICRC, La Jolla, 1985, vol.1, p.111 .
9. Aharonian F.A., Mamidjanian E.A., Nikolsky S.I., Tushish N.I. Primary Gamma-Rays with $E_{\gamma} \geq 10^{15}$ eV: Evidence for Ultrahigh-Energy Particle Acceleration in Galactic Sources. 19th ICRC, La Jolla, 1985, vol.1, p.255 .

10. Hillas A.M. The Knee of Cosmic Ray Spectrum: Not a Magnetic Trapping Effect? 16th ICRC, Kyoto, 1979, vol.8, p.7 .
11. Silberberg R., Tsao C.H., Letaw J.R., Shapiro M.M. Propagation and Origin of Energetic Cosmic Rays, 10^{14} - 10^{19} eV. 18th ICRC, Bangalore, 1983, vol.2, p.283 .
12. Nikolsky S.I., Stamenov J.N. Mass Composition of the Primary Cosmic Radiation in the Energy Interval 10^{16} - 10^{17} eV, Derived from the Akeno EAS Data. 18th ICRC, Bangalore, 1983, vol.2, p. 115 .

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О ПРОИСХОЖДЕНИИ ГАММА-КВАНТОВ СВЕРХВЫСОКИХ ЭНЕРГИЙ
ОТ РЕНТГЕНОВСКОГО ИСТОЧНИКА ЛЕБЕДЬ X-3

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