Preprint ЕФИ-929(60)-86

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

F.A. AHARONIAN

MODEL-INDEPENDENT REQUIREMENTS TO THE SOURCE OF POSITRONS IN THE GALACTIC CENTRE

ЦНИИатоминформ

ЕРЕВАН-1986

Նախնատիպ ԵՖԻ-929(60)-86

Ֆ. Ա. ԱՀԱՐՈՆՅԱՆ

ԳԱԼԱԿՏԻԿԱՅԻ ԿԵՆՏՐՈՆՈՒՄ ԳՏՆՎՈՂ ՊՈԶԻՏՐՈՆՆԵՐԻ ԱՂԲՅՈՒՐԻՆ ՆԵՐԿԱՅԱՑՎՈՂ ՄՈԴԵԼԻՑ ԱՆԿԱԽ ՊԱՀԱՆՋՆԵՐ

Գալակտիկայի կենտրոնի ուղղությամբ դիտվող անիհիլացիայի գծի առաջացմանը պատասխանատու պոզիտրոնների աղբյուրի համար ձևակերպված են մոդելից անկախ պահանջներ: Ցույց է տրված, որ ամենահավանական մեխանիզմը, որն ի վիճակի է ապահովել պոզիտրոնների առաջացումը 10% արդյունավետությամբ, հանդիսանում է e^+e^- զույգերի ծնումը ֆոտոն-ֆոտոնային բախումների ժամանակ: Այդ մեխանիզմը կարող է իրականանալ երկու դեպքում. ա/ e^+e^- զույգերով գերակշռված ջերմային, թույլ ռելյատիվիստական պլազմայում, բ/ ռենտգենյան ճառագայթման դաշտում ռելյատիվիստական մասնիկների կողմից հրահրվող էլեկտրոն-ֆոտոնային հեղեղների ոչ ջերմային սահանքի /կասկադի/ զարգացման ժամանակ:

Գերբարձր էներգիաների / $E_\gamma \geqslant 10^{11}$ էվ./ գամմա-քվանտների պարզ դիտումները կարող են վճռական դեր խաղալ մոդելի ընտրման հարցում:

Երևանի ֆիզիկայի ինստիտուտ

ԵՐԵՎԱՆ 1986

Preprint ЕФИ-929(60)-86

F.A. AHARONIAN

MODEL-INDEPENDENT REQUIREMENTS TO THE SOURCE OF POSITRONS IN THE GALACTIC CENTRE

The main requirements, following from the observational data in a wide range of electromagnetic waves, to positron source in the Galactic Centre are formulated. The most probable mechanism providing an efficiency of positron production of 10% is the pair production at photon-photon collisions. This mechanism can be realized a) in a thermal pair-dominated mildly relativistic plasma and b) at the development of a nonthermal electromagnetic cascade initiated by relativistic particles in the field of X-rays. The future gamma-astronomical observations in the region of $E_\gamma \geqslant 10^{11}$ eV can be crucial in the choice of the model.

Yerevan Physics Institute

Yerevan 1986

Препринт ЕФИ-929(80)-86

Ф.А.АГАРОНЯН

МОДЕЛЬНО-НЕЗАВИСИМЫЕ ТРЕБОВАНИЯ К ИСТОЧНИКУ ПОЗИТРОНОВ В ЦЕНТРЕ ГАЛАКТИКИ

Сформулированы основные требования к источнику позитронов, ответственных за обнаруженную в направлении галактического центра аннигиляционную линию. Показано, что наиболее вероятным механизмом, способным обеспечить КПД образования позитронов $\sim 10\%$, является рождение пар при фотон-фотонных столкновениях. Этот механизм может быть реализован в двух случаях: а) в тепловой слаборелятивистской плазме, доминированной e^+-e^- парами и б) при развитии нетеплового каскада электронно-фотонных ливней, инициируемых релятивистскими частицами в поле рентгеновского излучения. Будущие наблюдения гамма-квантов сверхвысоких энергий ($E_\gamma \geqslant 10^{11}$ эВ) могут оказаться решающими для выбора между этими моделями.

Ереванский физический институт
Ереван 1986

1. Introduction

The presence of a compact nonthermal radio source in the Galactic Centre (GC) as well as peculiar motion of gas clouds within the inner 1 pc region undoubtedly testify the activity of the Galactic nucleus. Is the observed activity of GC associated with the nonthermal radio source, and if it is, then is the latter a weak analogue of AGNs and QSOs ? The available observational data unfortunately do not unambiguously answer these questions touching the fundamental problems on the nature and evolution of galactic nuclei. Investigation of GC in a wide range of electromagnetic waves, including X- and gamma-rays, may be crucial for the development of a self-consistent theory on activity of galaxies. Gamma-ray observations, in particular the discovery of E_γ=511 keV annihilation line from GC, have already significantly contributed to revealing of unusual properties of GC. The first reliable evidence for an emission feature at 0.5MeV in the radiation spectrum, observed from the direction of GC has been obtained by means of baloon-borne Ge detectors in November 1977 [1]. The exact measurement of a narrow emission line energy of 510.7 $\pm$ 0.5keV makes one sure that it has an annihilation origin. Observations on HEAO-3 confirmed the existence of narrow annihilation line (FWHM $<$

$\lessdot$2.5keV) and also showed a strong variability of the line intensity [2]. The threefold change of intensity during six months (from $\Phi = (1.85 \pm 0.2) \cdot 10^{-3}$ photons/cm^2 sec in Autumn 1979 to $\Phi = (0.65 \pm 0.27) \cdot 10^{-3}$ photons/cm^2 sec in Spring 1980) indicates that the annihilation radiation is produced in the GC region of size less than 0.1 pc.

In this paper model-independent requirements to the positron source in GC are formulated, and a critical analysis of the current models of the compact source in GC is made.

Since the source of positrons and their annihilation region may not generally coincide, we shall begin with the limitation of parameters characterizing the annihilation line production region.

2. The Annihilation Line Production Region

It follows from the small width ($\leqslant$ 2.5keV) of the observed annihilation line that if the annihilation takes place in a gas, the latter's temperature must be less than $5 \cdot 10^4$K, and the degree of ionization $n_e/n_H \geqslant 0.1$ [3]. At such conditions the main portion of particles annihilates after the formation of a bound state of positronium and, consequently, a 3γ-continuum should be observed together with the annihilation line. In Ref. [1], on the basis of the observed excess at energies less than 511keV, a conclusion has been made that about 90% of annihilations take place via positronium. This ratio of positronium annihilation to the direct annihilation leads to the yield of 511keV photons per annihilation act $K = 0.65$.

However, HEAO-3 observations show that no more than 40% of positrons annihilate via ^{3}Ps [4], i.e. $K > 1.2$. Annihilation via an intermediate state of positronium can be suppressed in a dense medium ($n_H > 10^{15}$ cm^{-3}) [5], and also in a low-density medium at the presence of an intense ionizing UV-radiation [6]. Annihilation on dust takes place through intermediate state of positronium. However, in this case 2γ-decays dominate, since most of positronium atoms before the annihilation via ^{3}Ps pass into parapositronium state ^{1}Ps. Hence, as in the case of direct annihilation, $K \sim 2$. Taking this into account, Zurek [7] discussed the possibility that the HEAO-3 observations can be explained by positron annihilation on the interstellar dust grains. The question if the different values of K obtained in different observations are due to experimental errors or reflect the changes in conditions in the annihilation region, is very important for the future investigations. At present the ambiguity of the value of K by a factor of 4 ($K = 0.5$ if all positrons annihilate via Ps and $K = 2$ if all positrons annihilate directly) leads to the same ambiguity in the positron annihilation rate:

$$\dot{N}_+ = 4\pi d^2 \bar{\Phi}(511\,\mathrm{keV})\,K^{-1}\ \mathrm{sec}^{-1}, \qquad (1)$$

where $d \simeq 10$ kpc is the distance to GC, and $\bar{\Phi}$ (511keV) = $= 10^{-3}$ photons/cm^2 sec is the mean line intensity. When estimating $\dot{N}_+$ we assume that the radiation of the source is an isotropic one which directly follows from the unshifted value of the energy of the observed annihilation line. Note, that at a quasistationary mode of positron injection into production region of the annihilation line, $\dot{N}_+$ corresponds to the injection rate. At interactions with the environment electrons the protons annihilate both, before and after thermalization. The annihilation of thermalized positrons leads to the formation of the 511keV line, and possibly, to the 3 -continuum radiation, whereas the annihilation of nonthermalized positrons in flight leads to continuous spectrum in the range of $mc^2/2 \leq E_\gamma \leq E_o + mc^2$ (m is the electron rest mass, E_o is the total energy of the annihilated positron) with two maxima located symmetrically relative to the point of the spectrum minimum $E_\gamma = (E_o + mc^2)/2$ [8]. This allows to connect the flux in γ-continuum with the annihilation line intensity [9]

$$\Phi(E_\gamma) = \bar{\Phi}(511\,\text{keV}) \frac{\ln(2E_\gamma/mc^2 - 1)}{2\kappa E_\gamma (C_i + C_b E_\gamma/mc^2)} f(\geq E_\gamma), \qquad (2)$$

where $f(>E_\gamma) \equiv I_o(E_o > E_\gamma)/I_o(E_o \geq mc^2)$ is the share of positrons injected into the annihilation region with energies $E_o > E_\gamma$; C_i and C_b are coefficients characterizing the ionization and bremsstrahlung losses(for neutral hydrogen ($C_i \simeq 20.2 + 3\ln(E/mc^2)$; $C_b \simeq 0.13$).

Continuous gamma-ray emission from the direction of GC in the range $5 \div 20$ MeV has been investigated in baloon-borne experiments [10] , and above 100 MeV - by COS B satellite [11]. Since the angular resolution of the detectors being used is not high ($\Delta\psi < 2^o$), one can judge about only the upper limit of the intensity of photons irradiated from the central region of GC of the size ≤ 0.1 pc: $\Phi(\sim 5\text{MeV}) \simeq 10^{-6}$, $\Phi(\sim 20\text{MeV}) \simeq 3\ 10^{-7}$, and $\Phi(\sim 100\text{MeV}) \simeq 10^{-8}$ (photons/cm^2

sec MeV). Using these fluxes one may find the upper limit of the share of positrons $f(E \geq E_0)$, injected into the annihilation region with energies greater than E_0:

$$f(E \geq E_0) \leq \begin{cases} 0.02K & E_0 = 100 \text{ MeV} \\ 0.07K & E_0 = 20 \text{ MeV} \\ 0.1K & E_0 = 5 \text{ MeV} \end{cases} \qquad (3)$$

So, it follows from the comparison of the observed photon fluxes of the annihilation line and γ-ray continuum that the main portion of positrons ($> 90\%$) injected into the annihilation line formation region must have energy of $E_0 \lesssim 5$MeV. It should be pointed out that the obtained constraint (3) is independent of the medium density and depends only on the mode of annihilation of thermalized positrons. Restriction to the density of the annihilation region can be obtained from the observed variability $\Delta t \leq 10^7$ sec [2]:

$$\max(t_A, t_{th}) \leq \Delta t, \qquad (4)$$

where t_A and t_{th} are annihilation and thermalization times. Since in the energy range of $E \leq 10\ mc^2$ ionization losses dominate, the thermalization time would be equal to

$$t_{th} = (2\pi r_0^2 cnC_i)^{-1} \frac{E_0}{mc^2} \simeq 3\cdot 10^{12} n^{-1} (E_0/mc^2) \text{ sec.} \qquad (5)$$

The mean annihilation time for thermalized positrons is

$$t_A = (\pi r_0^2 cn)^{-1} g_A \simeq 10^{14} g_A n^{-1} \text{ sec}, \qquad (6)$$

where the factor g_A in the most probable gas temperature range $T \sim 10^4 \div 10^5$K varies between 10^{-4} and 10^{-3} [3,6]. Comparison of Eqs. (5) and (6) shows that at any reasonable values of g and E the thermalization time exceeds the annihilation time and, consequently, the Eq.(4) can be rewritten as:

$$n \geqslant \frac{3\cdot 10^{12}}{\Delta t} \frac{E_o}{mc^2} \simeq 2\cdot 10^5 \frac{E_o}{mc^2}\ cm^{-3} \qquad (7)$$

So, even in the case with positrons penetrating into the annihilation region with nonrelativistic velocities ($E_o - mc^2 \ll mc^2$), the density must be $n \geqslant 2\cdot 10^5$ cm^{-3}

Let us estimate now the positron number density in the annihilation region. In case of quasistationary (in the timescale of t_A) mode of injection of positrons

$$n_+ \sim \dot{N}_+ t_A / \bar{R}^3 , \qquad (8)$$

where $\bar{R}$ is the characteristic size of the annihilation region. The obvious condition $n_+ \ll n$ (otherwise nonthermal positrons would heat the annihilation region up to temperatures contradictory to the observed small width of the annihilation line) imposes a very strong restriction to the size of the annihilation region:

$$\bar{R} \gg 3\cdot 10^{14} (g/10^{-3})^{1/3} (n/2\cdot 10^5 cm^{-3})^{-2/3} K^{-1/3}\ cm. \qquad (9)$$

3. The Source of Positrons

There are various nuclear and electromagnetic processes of positron production in astrophysical objects. There is no shortage in theoretical models for sources of positron production too. However, the observational data allow one to unambiguously exclude most of the proposed models for GC. By Lingenfelter and Ramaty [12], in particular, strong arguments have been brought against the model based on the production of positrons due to interactions of cosmic rays with the ambient gas (via decays of secondary $\pi^{\pm}$-mesons or radioactive nuclei) as well as against the model of positron production in explosive nucleosynthesis. It should be noted, that these arguments, based on the COS B and HEAO-1 data, are valid for the case of quasi-continuous production of positrons. If the burst accompanied by production of π-mesons or radioactive nuclei took place in the past, then contradictions with the observations are removed in the high energy region. However, positron production as a result of single burst appears to be impossible, since we could have expected a monotonically decreasing dependence of the annihilation line intensity on time ($\Phi(0.511\,\mathrm{keV}) \propto \exp(-t/t_A)$), where t_A is the annihilation time). But, such a dependence is never observed. The comparison of 1970 - 1980 data shows that the intensity of 511keV line does not decrease monotonically, but varies around the value $\sim 10^{-3}$ photons/cm^2 sec. This allows one to claim that the annihilation line originates at quasicontinuous mode of positron injection into the annihilation region with timescale $\Delta t \leq t_A$, where t_A is determined by the Eq.(6). Taking into account that the medium density $n \geq 2\cdot10^5\,\mathrm{cm}^{-3}$, one obtains that $\Delta t \leq 10^5$sec. The given restriction excludes the possibility of positron production due to supernova explosions.

Does the quasicontinuous production of positrons take place directly in the annihilation region or do the positrons enter that region from outside? The only model based on the first assumption has been proposed by Kardashev et al. [13]. According to this model electron-positron pairs are produced due to irradiation of gaseous cloud-target by a directed beam of gamma-rays. Despite its seeming simplicity, this hypothesis includes a number of severe requirements both to gamma-ray source ("gamma-gun"- a supermassive rotating black hole) and to the cloud-target: almost a monoenergetic ($E_\gamma \sim 100MeV$) gamma-ray beam of diameter $d \geqslant 10^{14}$ cm, a prolonged target with an amount of matter along the beam $\sim 20-30$ gram/cm^2, etc. To avoid a contradiction with the observed flux of gamma-rays at $E_\gamma \sim 10MeV$, it is assumed in this model that e^+e^- pairs, produced by the interaction of gamma-ray beam with the cloud, are not deflected by chaotic magnetic field and penetrate in the initial beam direction due to "self-focusing" effect. In In Ref. [13], unfortunately, no estimations have been presented to show the possibility of such crucial assumption. Besides, due to small efficiency of positron production, it is automatically admitted in this model (as well as in any other one suggesting interactions of gamma-rays and/or electrons with matter) that the compact source in GC must be responsible for ionization of the clouds by a radiation with luminosity $\sim 10^{41}$erg/sec. However, the ionizing radiation most probably is associated with the intensive process of star formation within 1 pc of GC [14].

From the known physical processes of positron production the most efficient seems to be the (e^+e^-) pair creation at photon-photon collisions [12]. When certain conditions are satisfied, the effeciency of positron production in the source can reach the value $\eta \gtrsim 10\%$, which is comparable with the observed ratio of the annihilation line luminosity to the continuum one at $E_\gamma > 511$keV. Such a situation can be realized when: a) gamma-rays of comparable energies $E_{\gamma 1} \sim E_{\gamma 2} \sim mc^2$ collide, and b) high-energy photons ($E_{\gamma 1} \gg mc^2$) collide with the field low-energy photons ($E_{\gamma 2} \ll mc^2$). The first case corresponds to mildly relativistic plasma and the second one - to nonthermal cascade processes initiated by relativistic particles in a nonrelativistic thermal plasma.

i). Production and Escape of Positrons in Thermal Plasma

It follows from the observed break in the gamma-ray spectrum at $E_\gamma \gtrsim 2$MeV and from the ratio $L_{0.511}/L_\gamma\ (>0.511) \gtrsim 0.05$, that the plasma temperature can not essentially exceed $kT_e \sim mc^2$. It has been suggested by Lingenfelter and Ramaty [12] that positrons are produced at $\gamma - \gamma$ collisions in an optically thin plasma ($\tau_T \lessdot 1$) with temperature $kT_e \sim mc^2$. It is easy to show that this hypothesis is internally inconsistent. Really, the rate of positron production at $\gamma - \gamma$ collisions in a plasma cloud of radius R is

$$\dot{N}_+ = \frac{4}{3}\pi R^3 n_\gamma^2 \vartheta_{\gamma\gamma} , \tag{10}$$

where $\vartheta_{\gamma\gamma} \sim \sigma_T c/5$; n_γ is the number density of gamma-rays of energy greater than mc^2:

$$n_\gamma \leqslant \frac{L_\gamma(>mc^2)}{4\pi R^2 mc^3} = \frac{\ell_\gamma}{4\pi}\ \frac{n_e}{\tau_T} , \tag{11}$$

where $\ell_\gamma = L_\gamma \sigma_T / Rmc^3$ is the dimensionless luminosity, and $\tau_T = n_e \sigma_T \cdot R$ is the Thomson scattering optical depth. In an optically thin plasma [15]

$$\ell_\gamma = \tau_T^2 F(\theta_e) ; \qquad (12)$$

$$F(\theta_e) = 18\alpha\theta_e [\ln(2\eta_E \theta_e + 0{,}14] ; \quad \theta_e \equiv \kappa T_e / mc^2 .$$

Substituting Eq.(11) and Eq.(12) into Eq.(10) one finds

$$\dot{N}_+ \leqslant \frac{\tau_T^4 F^2(\theta_e) c}{60\pi\sigma_T} R . \qquad (13)$$

Using Eq.(1) one obtains

$$R \geqslant 4 \cdot 10^{10} \kappa^{-1} / F^2(\theta_e) \tau_T^4 \quad \text{cm} . \qquad (14)$$

(the equality sign corresponds to the case with 100 % escape of positrons from the source).

The observed X- and γ-ray luminosities of GC do not exceed $\sim 3\ 10^{38}$ erg/sec. Hence, one obtaines a restriction to the dimension of the cloud of optically thin plasma

$$R \lessdot \frac{L\sigma_T}{F(\theta)\tau_T^2} \simeq 8 \cdot 10^9 / F(\theta_e) \tau_T^2 \quad \text{cm} . \qquad (15)$$

The inequalities (14) and (15) are simultaneously satisfied at

$$\tau_T \simeq \sqrt{5}\, F^{-1/2}(\theta_e) \kappa^{-1/2} . \qquad (16)$$

At $\theta_e \sim 1$ the function $F(\theta_e) \sim 0.2$, hence, even at $\kappa = 2$ the optical depth τ_T is noticeably more than unity and is in evident contradiction with the former assumption of its being small ($\tau_T \ll 1$). At $\theta_e \geqslant 1$ and $\tau_T \gg 1$ the plasma can be pair-dominated, i.e. $z \equiv n_e / n_p \gg 1$ [15,16]. The luminosity of pair-dominated plasma essentially exceeds the bremsstrahlung luminosity. In this state the ratio of photon and pair densities approximately is

$$\frac{n_\gamma}{n_e} \sim \frac{\dot{N}_\gamma}{\dot{N}_e} \frac{\tau_T}{a} , \qquad (17)$$

where $\dot{N}_\gamma$ and $\dot{N}_e$ are the photon and pair escape rates, a is the ratio of the pair escape timescale to the light travel time across the source.

The annihilation and escape times are determined as:

$$t_{esc} = a \frac{R}{c} ; \qquad (18)$$

$$t_A = \frac{16}{3} \frac{R}{c} \frac{1}{\tau_T g_A(\theta e)} , \qquad (19)$$

where $g_A(\theta_e \sim 1) \sim 0.3$. Comparing these times one finds the condition when e^+e^- pair escape dominates over the annihilation

$$a \lesssim a^* \sim \frac{16}{3} \frac{1}{g_A(\theta e)\tau_T} \lesssim 10 \; (\tau_T > 1) . \qquad (20)$$

Generally the parameter a depends on many factors, e.g. on the character of magnetic inhomogenieties. Assuming that the positron source in GC has a thermal origin, one can estimate the possible value of a based on the observational data. When in the pair-dominated plasma the pair escape dominates over the annihilation, $n_\gamma / n_e \sim a^{-1/2}$ [16]. Hence,

$$a \simeq \left(\frac{\dot{N}_\gamma}{\dot{N}_e} \tau_T \right)^{1/2} . \qquad (21)$$

Substituting here the observed luminosities $\dot{N}_\gamma\,(> mc^2) \sim 10^{44}$ phot./sec and $\dot{N}_+ \sim 10^{43}\ K^{-1}$ pos./sec, we obtain $a \sim 3(\tau_T K)^{1/2}$.

It should be noted that the luminosity of a mildly relativistic pair-dominated plasma is proportional to R (since $\ell \equiv \ell(R) \sim const \sim 10$ [15]), therefore

$$R = \frac{L_\gamma \sigma_T}{\ell m c^3} \simeq 8 \cdot 10^8 \text{ cm}, \qquad (22)$$

At present only one model of a compact quasicontinuous source is discussed which permits, the formation of a mildly relativistic thermal plasma. That is an accreting-black-hole model. In the gravitational field of black hole electrons become relativstic ones only due to energy exchange between electrons and protons, the temperature of which can reach $10^{11} - 10^{12}$ K in the main zone of energy release ($R \lesssim 10 R_g$). The energy exchange rate between protons and electrons due to elastic Coulomb interactions is [17]:

$$Q_{ep} \simeq \frac{3}{2} \frac{m_e}{m_p} \sigma_T c \kappa T_p \frac{1 + \theta_e^{1/2}}{\theta_e^{3/2}} \Lambda_{ep} n_e n_p , \qquad (23)$$

where $\Lambda_{ep} \sim 20$ is the Coulomb logarithm;

The equilibrium temperature of electrons is determined from the thermal balance $L_\gamma = Q_{ep} \cdot \frac{4}{3} \pi R^3$:

$$\ell = 2\pi \Lambda_{ep} \tau_N \tau_T \theta_p \frac{1 + \theta_e^{1/2}}{\theta_e^{3/2}} , \qquad (24)$$

where

$$\tau_N = n_p \sigma_T \cdot R ; \quad \theta_p \equiv \kappa T_p / m_p c^2 .$$

Taking into account, that in the main zone of energy release ($R \lesssim 10 R_g$) $\theta_p \lesssim 0.05$, and taking the characteristic values $\ell \sim 10$ and $\tau_T \sim 2$ [15] for pair dominated plasma, one obtains the needed value for optical depth $\tau_T^{(0)} = \tau_N \sim 0.4$. The obtained qualitative estimations show that the assumption of production of positrons responsible for the annihilation radiation of GC in the thermal mildly relativistic plasma do not contradict to the observed values of integral characteristics.

ii) Positron Production at Development of Relativistic Electromagnetic Cascade Initiated by Nonthermal Particles

Effective production of positrons is possible at development of an electromagnetic cascade initiated by relativistic electrons and/or gamma-rays in the field of X-rays.

It is hard to approximate the X-ray emission from GC by any single law because of high variability of radiation in the hard X-ray range ($\gtrsim 50$ keV), indefiniteness of the coefficient of photon absorption in the region of $\lesssim 10$ keV, and also of the contribution of other sources situated in the central region of the Galaxy. Taking these ambiguities into account one can approximate the observed data by the power law with the index varying in the range of $\alpha_x \sim 1-2$. The spectrum can be explained to be both, a synchrotron self-Compton mechanism and a comptonization of low-frequency radiation in a thermal plasma with $\kappa T_e \sim 25$-30 and $\tau_T \sim 2$-5.

The main parameter characterizing the development of linear cascade in the field of X-rays is [18]

$$\text{æ}_x = \frac{L_x}{L_{Edd}} \frac{R_g}{R}, \qquad (25)$$

where $R_g = 2GM/c^2 \simeq 3 \cdot 10^5 (M/M_\odot)$ cm and $L_{Edd} = 2\pi R_g m_p c^3/\sigma_T \simeq 10^{38} (M/M_\odot)$ erg/sec are the gravitation radius and the

Eddington luminosity of gravitation centre with mass M, respectively. Two conditions determine the value of $\varkappa_x$ for GC: 1) the break of spectrum at $E_x \geqslant$ 2MeV and 2) the observed relation $\dot{N}_+/L_\gamma(>mc^2) \simeq 5\cdot10^4 K^{-1}$ e^+/erg. Calculations show that the values $\varkappa_x \geqslant 2\cdot10^{-3}$ do satisfy these conditions. The number of positrons produced at the cascade development is

~ 0.06 per $2\ mc^2$ energy of the injected relativistic particles at $\varkappa_x = 2\ 10^{-3}$. Hence, one obtains the value of the needed power of injection to provide the rate of positron delivery into the region of annihilation: $\dot{W}_0 \sim 3\cdot10^{38}\ K^{-1}$ erg/sec. Taking into account that at $\varkappa_x = 2\cdot10^{-3}$ about 30% of initial power is wasted on the luminosity of gamma-rays in the region of $E_\gamma \geqslant mc^2$, the value of $K = 0.5$ is needed to explain the observed luminosity $L_\gamma(\geqslant mc^2) \simeq 2\cdot10^{38}$erg/sec. However, values of $K \geqslant 1$ are also possible if a considerable number of positrons annihilate before escaping from the source.

Values of $\varkappa_x \geqslant 2\cdot10^{-3}$ correspond to the source dimentions $R \leqslant 10^8$ cm (at $L_x(1 \div 100\ \text{keV}) \simeq 7\cdot10^{37}$ erg/sec). If the source of energy is an accreting black hole, we get quite severe restrictions to the mass of the black hole.

Really, as the main energy release of the accreting fluid takes place in the internal zone with $R \lesssim 10R_g$, then $M \lesssim 30M_\odot$. The corresponding Eddington luminosity is $L_{Edd} \sim 3\cdot10^{39}$ erg/sec.

Is the production of relativistic electrons of power $\dot{W}_0 \sim$ $\sim 3\cdot10^{38}\ K^{-1}$ erg/sec, exceeding 10% of the Eddington luminosity, possible in the accreting plasma? Relativistic electrons, positrons and gamma-rays can be created during decays of

π- mesons formed at inelastic collisions of thermal protons in two-temperature accretion plasma. However, due to larger relaxation time of the Maxwellian "tail" with respect to the time scale of plasma falling onto black hole [19], this mechanism becomes effective at extremal temperatures of ions $T_i \sim 10^{12}$ K, possible only near an extremal Kerr black hole [20]. At lower temperatures the processes of excitation and destruction of nuclei make some contribution to the production of positrons and gamma-rays with $E_\gamma \sim 1$ MeV, however, the luminosity in nuclear gamma-lines and in positrons does not exceed the 10^{-4}-th part of the X-ray luminosity [21]. So, to explain the rate of delivery of positrons and also the observed excess in GC spectrum at $E_\gamma \sim 1$ MeV in the framework of the "cascade" model, appearently, a nonthermal source is needed. Though there have been suggested a number of machanisms of particles acceleration near black holes, unfortunately, their efficiency can not be quantitatively evaluated [22]. The gamma-ray emission formed at the development of electromagnetic cascade has a "standard" form with a maximum near $E_\gamma \sim 1$MeV weakly depending on the initial spectrum of accelerated particles. This is the reason why it is impossible to unambiguously choose between a thermal or nonthermal model from the spectrum of the observed gamma-rays. However, it is true for gamma-rays of moderate energies. Indeed, due to decreasing dependence of photoproduction cross section on the parameter $b = E_\gamma E_x/m^2c^4$ the compact X-ray source, being thick for low-energy gamma-rays, is transparent for high-energy ones. Taking into account that at $b \gg 1$ the photoproduction cross section is approximately

$\langle \sigma \rangle \simeq \frac{3}{2}\sigma_T[\ln 2\varepsilon - 1]/\varepsilon$, one obtains that the source is transparent (at $R \leq 10^8$ cm) for photons with $E_\gamma \geq 10^{11}$ eV. This radiation can be detected by modern detectors if the acceleration of particles with $E > 10^{11}$ eV is $\sim 10^{35}$ erg/sec, i.e. approximately 0.1% against the total nonthermal power of the source.

4. Conclusions

The observed variable annihilation radiation from GC indicates that there is a compact quasicontinuous source of positrons there.

Though the photons in the annihilation line contain no information on initial spectrum of the injected positrons, nevertheless, it follows from the comparison of fluxes in the 511keV line and in γ-continuum that the positrons leaving the source enter the region of annihilation with their typical energy being $E_+ \lesssim 5$ MeV. This condition and also the observed relation $\dot{N}_+/L_\gamma(\geq mc^2) \gtrsim 0.05$ positron/mc^2 considerably reduces the number of the proposed models requiring extremely effective mechanism of positron production as a result of $\gamma - \gamma$ collisions. This mechanism, providing positron production efficiency of $\gtrsim 10\%$, can be realized in two cases: a) in case of thermal mildly relativistic pair-dominated plasma and b) at the development of a nonthermal cascade of electron-photon showers initiated by relativistic particles in the field of X-ray radiation.

The future gamma-astronomical observations in the region of $E_\gamma \geq 10^{11}$ eV can be crucial in the choice of the model.

REFERENCES

1. Leventhal M., MacCallum C.J., Stang P.D. Detection of 511keV Positron Annihilation Radiation from the Galactic Centre Direction. Ap. J., 1978, vol.225, p.L 11 .
2. Riegler G.R., Ling J.C., Mahoney W.A. et al. Variable Positron Annihilation Radiation from the Galactic Centre Direction Ap.J., 1981, vol.248, p.L 13.
3. Bussard R.W., Ramaty R., Drachman R.J. The Annihilation of Galactic Positrons. Ap.J., 1979, vol.228, p.928.
4. Riegler G.R., Ling J.C., Mahoney W.A., Wheaton W.A., Jacobson A.S. The Gamma-Ray Spectrum of the Galactic Centre Region. in AIP Conf. Proc. No.101 ("Positron-Electron Pairs in Astrophysics"), 1983, p.230.
5. Leventhal M. Positron-Formation Redshift of the 511 keV Annihilation Line. Ap.J., 1973, vol.183, p.L 147.
6. Lingenfelter R.E., Ramaty R. The Origin of the Galactic Centre Annihilation Radiation. - in AIP Conf. Proc. No.101 ("Electron-Positron Pairs In Astrophysics"), 1983, p. 267.
7. Zurek W.H. Annihilation Radiation from the Galactic Centre: Positrons in Dust? Ap.J.,1985, vol.289, p.603.
8. Aharonian F.A., Atoyan A.M. Cosmic Gamma-Rays Associated with Annihilation of Relativistic e^+e^- Pairs. Phys. Lett., 1981, vol.99B, p.301.
9. Агаронян Ф.А., Атоян А.М. К вопросу о происхождении галактического аннигиляционного излучения. Письма в АЖ,1981, т.7, с.714.

10. Bacher K., Schonfelder V. The Bremsstrahlung Component of the Diffuse Galactic Gamma-Ray Emission at MeV Energies. Ap.J., 1984, vol.279, p.817.

11. Mayer-Hasselvander H.A., Bennet K., Bignami G.F. et al. Large-Scale Distribution of Galactic Gamma-Radiation Observed by COS B. Astron. Astrophys., 1982, vol.105, p.164.

12. Lingenfelter R.A., Ramaty R. On the Origin of the Positron Annihilation Radiation from the Direction of the Galactic Center. - in "The Galactic Center" (ed. G.R. Reigler, R.D. Blandford), 1982, p. 148.

13. Кардашев Н.С., Новиков Н.Д., Полнарев А.Г., Штерн Б.Н. "Гамма-пушка" в центре Галактики. АЖ, 1983, т.60, с.209.

14. Rieke G., Lebobsky M.J. Comparison of Galactic Center with other Galaxies. - in "The Galactic Center" (ed. G.R. Reigler, R.D. Blandford), 1982, p.194.

15. Svensson R. Steady Mildly Relativistic Thermal Plasmas: Processes and Properties. M.N.R.A.S., 1985, vol.212, p.525.

16. Zdziarski A.A. Power Law X- and γ-Ray Emission from Relativistic Thermal Plasmas. Ap.J., 1985, vol.289, p.514.

17. Guilbert P.W., Stepney S. Pair Production, Comptonization and Dynamics in Astrophysical Plasmas. M.N.R.A.S., 1985, vol.212, p.523 .

18. Aharonian F.A., Kirillov-Ugryumov V.G., Vardanian V.V. Formation of Relativistic Electron- Photon Showers in Compact X-Ray Sources. Ap.Sp. Sci., 1985, vol.115, p.201.

19. Агаронян Ф.А., Атоян А.М. К вопросу о временной эволюции функции распределения частиц в высокотемпературной плазме. ЖЭТФ, 1983, т.85, с.1857.

20. Eilek J.A., Kafatos M. The High-Energy Spectrum of Hot Accretion Disks. Ap.J., 1983, vol.271, p.804.

21. Aharonian F.A., Sunyaev R.A. Gamma-Ray Line Emission, Nuclear Destruction and Neutron Production in Hot Astrophysical Plasmas. The Deuterium Boiler as a Gamma-Ray Source. M.N.R.A.S., 1984, vol.210, p.257 .

22. Rees M.J. The Compact Source at the Galactic Center. – in "The Galactic Center" (ed. G.R. Riegler, R.D. Blandford), 1982, p. 166.

The manuscript was received 4 August 1986

Ф.А.АГАРОНЯН

МОДЕЛЬНО-НЕЗАВИСИМЫЕ ТРЕБОВАНИЯ К ИСТОЧНИКУ ПОЗИТРОНОВ В ЦЕНТРЕ ГАЛАКТИКИ

(на английском языке, перевод Г.А.Папяна)

Редактор Л.П.Мукаян

Технический редактор А.С.Абрамян

Подписано в печать 22/Х-86г. ВФ-05732 Формат 60х84/16
Офсетная печать.Уч.изд.л. 1,0 Тираж 299 экз. Ц.15 к.
Зак.тип.№ 566 Индекс 3624

Отпечатано в Ереванском физическом институте
Ереван 36, Маркаряна 2

индекс 3624

ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ