ON THE ORIGIN OF ANNIHILATION EMISSION FROM THE GALACTIC CENTER

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ABSTRACT

Both diffuse high energy gamma-rays and an extended electron-positron annihilation line emission have been observed in the Galactic Center (GC) region. Although X-ray observations indicate that the galactic black hole Sgr A* is inactive now, we suggest that Sgr A* can become active when a captured star is tidally disrupted and matter is accreted into the black hole. As a consequence the galactic black hole could be a powerful source of relativistic protons. We are able to explain the current observed diffuse gamma-rays and the very detailed 511 keV annihilation line of secondary positrons by $p-p$ collisions of such protons, with appropriate injection times and energy. Relativistic protons could have been injected into the ambient material if the black hole captured a 50M$_\odot$ star at several tens million years ago. An alternative possibility is that the black hole continues to capture stars with $\sim$1M$_\odot$ every hundred thousand years. Secondary positrons produced by $p-p$ collisions at energies $\geq$ 30 MeV are cooled down to thermal energies by Coulomb collisions, and annihilate in the warm neutral and ionized phases of the interstellar medium with temperatures about several eV, because the annihilation cross-section reaches its maximum at these temperatures. It takes about ten million years for the positrons to cool down to thermal temperatures so they can diffuse into a very large extended region around the Galactic center. A much more recent star capture may be also able to account for recent TeV observations within 10 pc of the galactic center as well as for the unidentified GeV gamma-ray sources found by EGRET at GC. The spectral difference between the GeV flux and the TeV flux could be explained naturally in this model as well.

Key words: comic rays : general - Galaxy : center - Galaxies : gamma-rays - black hole - radiation mechanisms : nonthermal.

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1. INTRODUCTION

The annihilation of cosmic ray positrons produced as a result of cosmic ray proton collisions with the ambient plasma was discussed in a number of papers [see, e.g., 39, 45, 75, 16, etc.]. A typical cosmic ray positron resulting from secondary π-meson decay may undergo one of three fates: 1) escape from the Galaxy, 2) annihilate with an electron while at relativistic energy (*in-flight annihilation*), or 3) lose almost all its energy before annihilation. One can consider that annihilation may occur either between free electrons and positrons (*free annihilation*), or through the formation of the intermediate bound state of positronium. Positronium can form in either a singlet state, which annihilate into two 511 keV photons, or in a triplet state which decays by three photon annihilation producing a continuum emission below 511 keV [see 68]. From the ratio between line and continuum intensities near and below 511 keV it was concluded that positrons annihilate via positronium formation. The fraction of positronium was estimated to be in the region of 92-97% [83, 49]. From the observed width of the annihilation line it was concluded [see 23, 49] that the annihilation of thermal positrons takes place in a relatively warm (several eV) and lowly ionized (~ 0.1) interstellar medium.

The origin of such positrons is still poorly understood. A large variety of positron sources have been proposed. Among them novae and supernovae stars [19, 27]. However, as follows from Weidenspointner et al. [82] the annihilation of positrons appears to be even more concentrated in the bulge than are old stellar populations such as Type Ia supernovae, novae, or low-mass X-ray binaries. New, speculative, physics such as positron production from hypernovae stars [17], light dark matter [see 11] etc. has begun to be discussed as a possible solution. A supermassive black hole of $2.45 \times 10^6\ M_\odot$ is another candidate as a source of positrons.

Secondary positrons generated as a result of cosmic ray collisions with the ambient plasma is another alternative model. Melia et al. [65], Fatuzzo et al. [34] and Fatuzzo and Melia [35] suggested a supernova coinciding with the central radio source Sgr A East as an emitter of protons which can produce gamma-rays as well as high energy secondary positrons. However, they showed from simplified equations that Sgr A East could not be the source of annihilation radiation from the Galactic center because, based on their estimates, the thermalization time was too long. Besides, the annihilation emission appears to be diffuse. So far, there is no evidence for emission from point-like sources [54, 12]. On the other hand, the EGRET telescope found a flux of gamma-rays from the Galactic center at energies > 500 MeV [64] which was seen as a strong excess of gamma-rays peaking in an error circle of 0.2^o radius surrounded by a strong emission maximum within $\sim 5-8^o$ degrees from the Galactic center.

In our model we assume the black hole is a source of high energy protons generated by star accretion. They produce secondary gamma-rays and relativistic positrons as a result of $p-p$ collisions. The secondary positrons requires over 10 million years to cool down before annihilation. Hence they are able to propagate far away from the central source during their lifetime and to fill a sphere with the radius about several hundred pc. Therefore the annihilation emission can be seen as diffuse if these protons were ejected a relatively long time ago. From kinetic equations we shall show that processes of Coulomb collisions are effective enough to cool down these relativistic positrons and to thermalize them before their annihilation, which can explain the origin of the annihilation emission from the Galactic center.

2. ENERGY RELEASE SUPPLIED BY A BLACK HOLE

The rate at which a massive black hole in a dense star cluster tidally disrupts and swallows stars has been studied extensively [e.g. 48, 8, 61]. Basically when a star trajectory happens to be sufficiently close to a massive black hole, the star would be captured and eventually disrupted by tidal forces. After a dynamical time-scale (orbital time-scale), the debris of a tidally disrupted star will form a transient accretion disk around the massive black hole, with a radius typically comparable to the tidal capture radius [71]. Rees has also argued that most of the debris material will be swallowed by a black hole with a mass $\sim 10^6 M_\odot$ on a time scale of ~ 1 yr for a thick hot ring, or $\sim 10^2$ yrs for a thin cool disk, respectively. The capture rate is essentially a problem of loss-cone diffusion-diffusion in angular momentum rather than energy. By assuming a Salpeter mass function for the stars, Syer and Ulmer [78] have estimated the capture rate in our Galaxy as $\sim 4.8\times10^{-5} yr^{-1}$ for main sequence stars and $\sim 8.5\times10^{-6} yr^{-1}$ for red giant stars, respectively. However, the actual capture rate depends sensitively on the assumed mass function of stars, the stellar evolution model used, the radius and mass of the captured star, the black hole mass and the internal dispersion velocity of stars (v_s) around the black hole. For example, Cheng and Lu [20] obtained a longer capture time $\sim 10^6$ years, by taking $v_s = 10^2 \mathrm{km/s}$ and $M_{bh} = 2.45\times10^6 M_\odot$. Therefore the capture time for a main sequence star with mass $\sim 1 M_\odot$ could range from several ten thousand years to several hundred thousand years. The capture time for the more massive stars is expected to be even longer. For t$>t_{peak}$, the accretion rate evolves as, Rees [71], Phinney [70]

$$\dot{M} \sim \frac{1}{3}\frac{M_*}{t_{min}}\left(\frac{t}{t_{min}}\right)^{-5/3} \qquad (1)$$

where M_* and R_* are the mass and the radius of the captured star, respectively and $t_{peak} \sim 1.59 t_{min}$, where

$$t_{min} \approx 0.2\left(\frac{M_\odot}{M_*}\right)\left(\frac{R_*}{R_\odot}\right)^{3/2}\left(\frac{M_{bh}}{10^6 M_\odot}\right)^{1/2} \text{ yr} \qquad (2)$$

is the characteristic time for the debris to return to the pericenter [63]. The recent *Chandra* observations of three large amplitude, high-luminosity soft X-ray flares in AGNs provide strong evidence for the tidal capture events, and the decrease of X-ray luminosity indeed follows closely the above theoretical predictions (e.g. Halpern, Gezari and Komossa 2004).

It is very important to know how much of the accretion power will be converted into the out-flow of relativistic protons. Processes of particle acceleration near black holes are not well known though several models of particle acceleration in accretion disks and jets of black holes have been developed [see, e.g., 52, 46, 58, 5]. For our aims we estimate roughly from Eq.(1) the energy of disruption which can be transferred to protons. In the case of star capture, it is very natural to assume that the resulting jet contains mainly protons simply because of the dominance of hydrogen in stars.

Falcke and Biermann [33] have argued that the conversion efficiency (η_p) from accretion power ($\dot{M}c^2$) into the the energy of jet motion ranges from 10^{-1} to 10^{-3}. Integrating the Eq.(3) and using typical values of the parameters, the energy carried away by relativistic protons is estimated as

$$\Delta E_p \sim 6\times10^{52}(\eta_p/10^{-1})(M_*/M_\odot)\text{erg.} \qquad (3)$$

In addition to the accretion power, Cheng and Lu [20] have argued that if the transient accretion disk can generate a sufficiently strong magnetic field, due to the instability of the disk, this strong magnetic field can initiate the Blandford-Znajek process [10] to extract rotation energy from the black hole. They estimate that the maximum energy that can be extracted from a black hole is given by

$$\Delta E_{max} \sim 3\times10^{52} A^2 f(A) M_6^2 \text{erg.} \qquad (4)$$

where A is the dimensionless angular momentum of the black hole, $f(A)$ is a constant for given A and M_6 is the black hole mass in units of 10^6 $M_\odot$. If the black hole is rotating in maximum angular velocity, $A = 1$, then $f(A)$=1.14.

The maximum energy in relativistic protons can be estimated from Eq.(5) or (4). If a star with the mass about

$50\ M_\odot$ is captured by a black hole, it gives an energy in relativistic protons as high as $\sim 10^{54}$ erg.

Thus, we conclude that when eventually a massive star is captured, a huge amount of energy can be released in the form of relativistic protons during a very short time. Below we assume that such primary protons interact with the medium gas in the region, its intensity derived from the gamma-ray data, and produce there secondary gamma-rays and positrons.

3. NONSTATIONARY MODEL OF POSITRON PRODUCTION

If we calculate from the kinetic equation the number of thermal positrons annihilating in the eV temperature medium on the assumption that they are produced by the same relativistic protons which are responsible for the observed gamma-ray flux of $2 \cdot 10^{37}$ erg s^{-1} then we obtain the value $2 \cdot 10^{41}$e^{+}s^{-1}, which is two orders of magnitude less than necessary to explain the annihilation flux from the Galactic center. Therefore the stationary model fails to explain the data. One of the solutions to this problem might be that in the past the positron production rate was much higher than follows from the current gamma-ray flux from the GC. Under this condition the production function of positrons is an essential function of time.

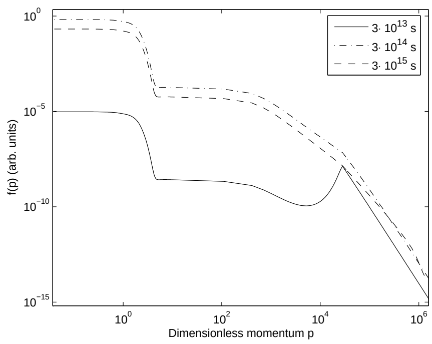

Figure 1. Time variation of the positron distribution function $f(p)$ for a gas temperature $T = 2.5$ eV. The dimensionless momentum is defined as $p/\sqrt{m_e kT}$ so the dimensionless momentum at unity corresponds to a positron with energy $\sim kT$.

In Fig.1 the evolution of the positron spectrum is shown for the parameters of the interstellar medium: the density $n = 1$ cm^{-3}, the temperature $T = 2.5$ eV, the magnetic field strength $H = 5 \times 10^{-6}$G and the energy density of background photons $U_{cmb} = 1$ eV cm^{-3}.

The distribution function of the positrons injected at the initial stage at $\bar{p} > \bar{p}_0$ is shifted to the momentum region $\bar{p} < \bar{p}_0$ under the influence of Coulomb collisions that can be seen in Fig. 1 as a "bunch" of positrons propagating into the region of small momenta. Later Coulomb collisions start to form the equilibrium Maxwellian distribution in the range $\bar{E} \leq 10^{-2}$ keV . At a subsequent point of time Coulomb collisions continue to form the equilibrium distribution and accumulate positrons in the thermal energy range, as can be seen in Fig. 1 as the increasing Maxwellian distribution. At the final stage when the source ceases to work the number of thermal positrons decreases because of annihilation (see Fig. 2).

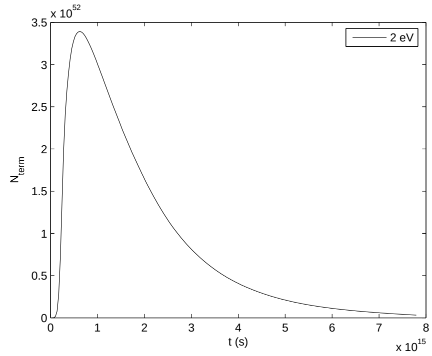

Figure 2. Time variation of the amount of thermal positrons produced by relativistic protons injected 4×10^{15} s ago in the gas with a temperature $T = 2.5$ eV and a density $n = 1$ cm^{-3}.

We notice that the positron evolution and the number of thermal positrons depend on the background gas temperature, e.g. in the plasma with the temperature 100 eV we can produce a much larger amount of positrons because the annihilation cross-section in this medium is several orders of magnitude smaller than in a neutral gas.

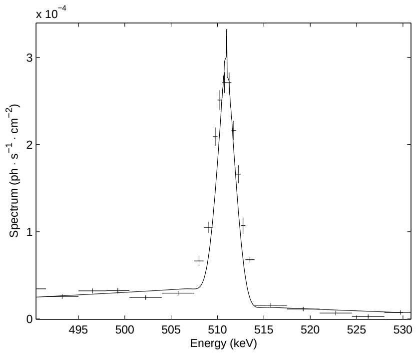

Figure 3. The total annihilation spectrum from a plasma with a temperatures 2.5 eV, together with the INTEGRAL data

To fit the INTEGRAL data [23], shown at Fig. 3, we used the following medium parameters: plasma temperature 2.5 eV, plasma density 1 cm^{-3}, degree of ionization 5% [see, e.g., 51]. The plasma temperature affects the width of the annihilation line. In order to fit the INTEGRAL data for energies at and below 511 keV we need a temperature in the region 2-5 eV.

The line emission at these temperatures is due to the two photon decay of the charge-exchange process. The emission below 511 keV is generated by three photon decay of positronium. The process of in-flight annihilation in a low temperature medium is negligible because the time for thermalization in this medium is smaller than the characteristic time of the in-flight annihilation. This process is essential in the hot component of the interstellar medium, about 20% of which is filled by a hot plasma with the parameters $T = 100$ eV and $n = 3 \times 10^{-3}$ cm^{-3}. However the flux of the annihilation line produced in the hot interstellar plasma by in-flight annihilation is negligible in comparison with emission in a cold plasma.

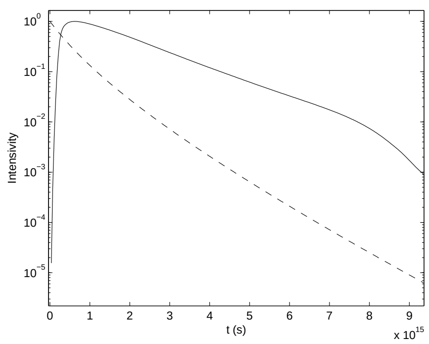

Figure 4. Time variation of the gamma-ray (dashed line) and annihilation (solid line) fluxes for a gas density $n = 1$ cm^{-3}

The temporal variations of the gamma-ray and the annihilation fluxes are shown in Fig. 4. The maximum of the fluxes are taken as unity. We see that the gamma-ray flux is always decreasing with time, while the annihilation flux reaches its maximum a long time after the proton eruption ($\sim 3 \times 10^{14}$ s) and then gradually decreases. We can estimate the necessary input proton energy without going into the technical calculation details. The current observed energy flux of gamma-rays is 2×10^{37}erg s^{-1} and the current annihilation rate of thermal positrons is 10^{43} positron s^{-1}, corresponds to a higher proton collision rate in the past. From Fig. 4, one can see that this situation is realized if we are observing these fluxes at a time $t > \tau_p$ when the current gamma-ray intensity is at least three order of magnitude less than its maximum, while the current annihilation flux falls from its maximum value by less than one order of magnitude (just because of the delay effect). In this case, the necessary input proton energy is at least $\sim 10^{55}$erg. Of course, this estimate sensitively depends on the number density. Even if we take the average density of the gas in the bulge as high as $n = 100$ cm^{-3} we get a value of the energy necessary to produce the gamma-ray and annihilation fluxes about $W_p \sim 10^{53}$ erg. This amount of energy may be able to be supplied by a very massive star accreting onto the black hole (see Eq.(4)) or by extracting the rotation energy of the black hole (see Eq. 6). However, we may not be able to obtain a distribution of the annihilation line extending to several hundred pc from the GC because the characteristic length of diffusion propagation is about 100 pc for this high gas density. Thus, in the framework of this model we have problems with the conditions 2) or 4) from Section 2. Nevertheless, we conclude that this model is marginally acceptable if a 50 $M_\odot$ massive star was captured by the black hole about hundred million years ago.

4. SPATIALLY NON-UNIFORM MODEL

To solve the possible problem of energy excess we take into account that the background gas is heterogeneously distributed in the bulge. According to Jean et al. [49] hydrogen gas in the nuclear bulge is trapped in small high density molecular clouds. Penetration of cosmic rays into molecular clouds was analyzed in a number of papers [see, e.g., 18, 31, 69]. From the EGRET observations it is known that GeV cosmic ray protons freely penetrate into molecular clouds [28] while it is almost unknown how MeV electrons interact with the clouds. However, Skilling and Strong [73] showed that the flux of cosmic rays below a few hundred MeV might be completely excluded from molecular clouds.

In our case it means that relativistic protons propagate in the medium with the average gas density about n=30 - 1000 cm^{-3} (depending on their propagation distance from the bulge center) while the secondary positrons ejected from the clouds propagate in the intercloud medium only, where the average gas density is about $n \simeq 1 - 10\ cm^{-3}$.

For protons it means that they fill the region of a radius $<$ 100 pc (if the diffusion coefficient equals the average in the Disk, $D \sim 10^{27}$ cm^{2}s^{-1}) during their lifetime $\tau_p \sim (1-5) \times 10^{13}$ s while electrons can fill a sphere of radius ~ 400 pc over the period of time of their Coulomb cooling ($\sim 3 \times 10^{14}$ s for $n = 1$ cm^{-3}).

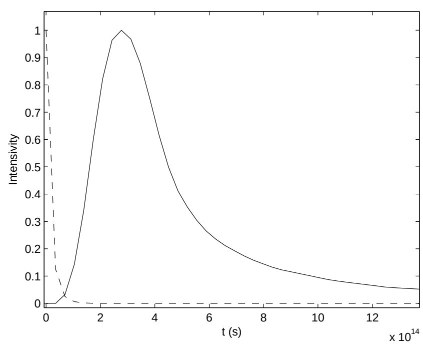

Figure 5. Time variation of the gamma-ray (dashed line) and annihilation (solid line) fluxes for a gas density $n = 30$ cm^{-3} for protons

The time variations of the gamma-ray and annihilation emission are shown in Fig. 5 for an average density for protons $n = 30$ cm^{-3}. As is to be expected the gamma-ray flux drops rapidly from its initial value while the annihilation flux reaches its maximum $\sim 3 \times 10^{14}$ s after the eruption. The energy of relativistic protons necessary to get the peak production of thermal positrons of about

10^{43} e$^+$s^{-1} is about $7 \cdot 10^{53}$ erg. The energy in relativistic protons changes weakly if we increase further the gas density. Thus, for a density $n = 100$ cm^{-3} the necessary energy of the protons is $5 \cdot 10^{53}$ erg. These injected proton energies are compatible with the estimates in Eq.5 or Eq.6 for a massive star capture.

Besides, if the average density of the gas in the medium traversed by positrons is a little bit higher than 1 cm^{-3} (e.g, 3 cm^{-3}) than we obtain slightly smaller values for the thermolization time ($\sim 10^{14}$s) as well as the necessary energy output of protons ($\sim 10^{53}$ erg) that makes our estimates even more acceptable.

Then, we can assume that the gamma-ray and the annihilation fluxes from the Galactic center belong to different accretion events. Gamma-rays were generated relatively recently ($\sim 10^{13}$ s ago) when a one solar mass star was captured by the black hole. Indeed the necessary amount of energy in injected protons is about $\geq 10^{51} - 10^{52}$ erg (see Section 5). In this respect it is clear why this emission was observed by EGRET as point-like. The average length of proton propagation is ≤ 100 pc for the diffusion coefficient $D = 10^{27}$ cm^{2}s^{-1}. If the annihilation line emission was produced $\sim 10^{14}$ s ago by a previous event of a 30 M$_\odot$ star capture, with an energy release of $\geq 10^{53}$ erg in protons, then it appears as an extended source long after the time when the gamma-ray emission produced by this capture died out. Thus, this model satisfies the conditions formulated in Section 2 though the annihilation and gamma-ray fluxes observed from the GC are not connected with each other in this case.

5. CONTINUOUS STELLAR CAPTURES

In the framework of the non-uniform model we can estimate the minimum energy at relativistic protons in order to produce in the current time the thermal positron rate of about 10^{43}e$^+$s^{-1} and not contradict the gamma-ray observations. We remember that the present gamma-ray flux from GC is about $2 \cdot 10^{37}$ erg $^{-1}$ and it is seen as a point-like object. We remember also that the gas distribution is unknown but that the main part of the gas is concentrated inside the central region of the bulge where the its density is as high as ~ 1000 cm^{-3} [see 49]. If relativistic protons freely penetrate into the clouds the average density $n \sim 1000$ cm^{-3}. We define this density as n_{pp}.

The diffuse gas is distributed in the intercloud medium with an average density of 10 cm^{-3} and it may reach at the central regions the value of $30-60$ cm^{-3}. If positrons do not penetrate into the cloud then the gas density of the medium in which positrons are cooled down by the Coulomb collisions is determined by these values. Below, we define this gas density as n_{cc}. Let us estimate the minimum energy of primary protons necessary to produce the annihilation flux as a function of n_{pp} and n_{cc}.

In the framework of the nonuniform model the initial energy of protons necessary to produce the annihilation emission depending on n_{pp} and n_{cc} is varying in the following way: It is clearly seen that when we increase the value of n_{pp} the output energy of protons decreases because the production rate of relativistic positrons is proportional to the gas density

Table 1. Injected Proton Energy

n_{pp}(cm^{-3})	n_{cc}(cm^{-3})	W (erg)
1	1	10^{55}
30	1	$7 \cdot 10^{53}$
100	1	$5 \cdot 10^{53}$
100	10	$2 \cdot 10^{53}$
1000	1	$2 \cdot 10^{53}$
1000	10	$1.5 \cdot 10^{53}$
1000	30	$4.5 \cdot 10^{52}$
1000	60	$3 \cdot 10^{52}$

$$F_{e^+} = \int N_p(E_p)\sigma_{pp} n_{pp} dE_p \quad (5)$$

However as follows from Table 1 the proportionality between W_p and n_{pp} is not linear as it would seem from Eq.(5). From Eq.(5) one can see that the higher the density n_{pp} the shorter is the injection impulse of positrons which is determined by the lifetime of protons $\tau_p = n_{pp}\sigma_{pp}c$. The necessary energy output of protons as a function of the ratio n_{pp}/n_{cc} is shown in Fig. 6.

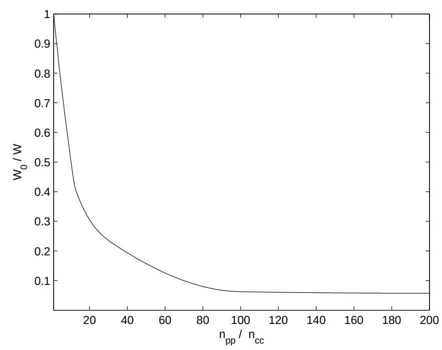

Figure 6. Variation of the proton energy output as a function of the ratio n_{pp}/n_{cc}. The output energy W_0 corresponds to $n_{pp}/n_{cc} = 1$

In the figure we take the density $n_{cc} = 1$ cm^{-3} and W_0 is the proton energy when $n_{pp}/n_{cc} = 1$. The variation of the proton injected energy W_p can easily be understood from the solution of the diffusion equation. When $n_{pp}/n_{cc} = 1$ we have $\tau_p \geq \tau_c$ and the energy W_p at this density for a fixed flux of thermal positrons at the level $F_{e^+} \sim 10^{43}$e$^+$s^{-1} is of the order of $W_p \propto \tau_p \cdot F_e^+$ i.e it decreases as $W \propto 1/n_{pp}$. However when $n_{pp} \gg n_{cc}$ the impulse of proton injection is very short $\tau_p \ll \tau_c$ (almost delta-function injection) and we obtain $W_p \propto \tau_c \cdot F_e^+$, i.e W_p is independent of n_{pp} as one clearly sees in Fig. 6.

The time τ_c cannot be too short otherwise the gamma-ray flux would not drop down below the observed gamma-ray flux from the GC (see Fig. 5). Variations of the gamma-ray flux for a fixed annihilation flux of thermal positrons of 10^{43} ph s^{-1} as a function of the ratio n_{pp}/n_{cc} is shown in Fig. 7. From this figure we see that this ratio cannot be below $n_{pp}/n_{cc} = 17$ otherwise the peaks of gamma-rays and the annihilation emission are so close to each other that the flux of gamma-rays does not have enough time to drop below the observed limit.

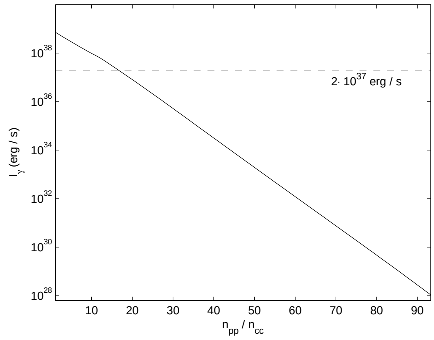

Figure 7. The expected gamma-ray flux at the moment when the production of thermal positrons reaches a value of 10^{43} $e^{+}s^{-1}$ as a function of the ratio n_{pp}/n_{cc}

From this restriction we conclude that the injected proton energy cannot be less than $\sim 3 \times 10^{52}$ erg even for $n_{pp} = 1000$ cm^{-3} while $n_{cc} = 60$ cm^{-3}. This gives the average distance of proton propagation by diffusion of about 20 pc and about 100 pc for positrons during their lifetime, which is less than necessary, but the diffusion coefficient may be spatially dependent such that it gives a more extended positron spatial distribution. Under this assumption even the capture of 1 $M_{\odot}$ star can give the necessary energy in protons as follows from Eq.(5) or Eq.(4), and the process of annihilation emission is not an exceptional event as we had in the previous models when a massive star capture was needed to supply the necessary energy in relativistic protons.

Since there are so many stars at the GC, there is very good reason to believe that the capture of stars can continuously take place from time to time. If there are several successive eruptions near the black hole then the annihilation flux is fluctuating near a certain level of emission as is shown in Fig. 8. In the calculations we take $n_{cc} = 60$ cm^{-3} and $n_{pp} = 1000$ cm^{-3} which give $\tau_c \sim 5 \times 10^{12}$ s and $\tau_p \sim 7 \times 10^{11}$ s respectively. The time between two successive eruption equals $\sim 8 \times 10^{12}$ s. When the variations of the energy fluxes of gamma-rays and the photon flux of the annihilation emission are normalized relative to their maximum their values, which for gamma-rays is 3×10^{39} erg s^{-1} and for the annihilation flux is 10^{43} ph s^{-1}, the average injected proton energy is $\sim 8 \times 10^{52}$ erg.

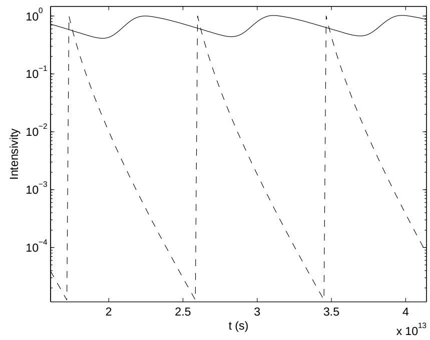

Figure 8. Gamma-ray and annihilation emission from several successive eruption of protons by the black hole. The parameters are presented in the text

6. DISCUSSION

We suggest that the capture of stars by the Galactic black hole is a natural energy mechanism for providing relativistic protons with a typical energy of $\sim 10^{52-53}$erg. An essential point of our analysis is the non-stationary processes and the non-uniform density conditions of emission regions.

Our calculations show that it is marginally possible that the gamma-rays coming from the GC and the annihilation emission belong to the same eruption process provided the injected proton energy is $\sim 10^{54}$ erg, this might be possible theoretically if we take model parameters to their extreme values. An alternative assumption that the currently observed gamma-rays from the GC and the currently observed annihilation emission belong to at least two different injections seems to be more attractive. The first one belong to a recent capture of a one solar mass star with the injected energy of about 3×10^{51} erg while the second one is a consequence of a previous capture of a much more massive star with an energy release as high as 10^{53} erg. This does not contradict estimations from theoretical models if we assume capture of a massive star.

Furthermore, if processes of secondary particle production occur very close to the GC where the gas density is about 1000 cm^{-3} then even a 1 $M_{\odot}$ star capture can provide the necessary energy of protons, which is in this case $\sim 3 \cdot 10^{52}$ erg. The GC is a region with a high concentration of stars, the capture of a star should continue to take place from time to time. Although the characteristic capture time scale is not known, TeV emission from the GC suggests that it should be $> 10^{5}$yr. If this is true, assuming the positrons cannot penetrate the cloud, so that the cooling time is longer than the $p - p$ collision time, our calculations indicate that the positron annihilation rate is more or less constant whereas the current gamma-ray flux is measured somewhere between two proton injection events. This naturally explains why the annihilation rate is about two orders of magnitude higher than follows from the current emission rate of gamma-ray photons.

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