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X-RAY AND GAMMA-RAY EMISSION OF SAGITTARIUS A* AS A WIND-ACCRETING BLACK HOLE

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ABSTRACT

If, as many believe, Sgr A* is a massive black hole at the Galactic center, one should expect it to be a source of X-ray and gamma-ray activity, behaving basically as a scaled-down active galactic nucleus. An unavoidable source of accretion is the wind from IRS 16, a nearby group of hot, massive stars. Since the density and velocity of the accreting matter are known from observations, the accretion rate is basically a function of the putative black hole mass, M_h, only; this value represents a reliable lower limit to a real rate, given the other possible sources of accreting matter. Based on this and on the theories about shock acceleration in active galactic nuclei, we have estimated the expected production of relativistic particles and their hard radiation. These values turn out to be a function of M_h as well. Comparing our results with available X-ray and γ-ray observations which show Sgr A* to have a relatively low activity level, we conclude tentatively that the putative black hole in the Galactic center cannot have a mass greater than $\sim 6 \times 10^3\ M_\odot$. This conclusion is consistent with the upper limits to the black hole mass found by different methods earlier, although much more work is needed to make calculations of shock acceleration around black holes more reliable.

Subject headings: X-rays: general — Galaxy: center — gamma rays: theory

1. INTRODUCTION

The idea that the Galactic center harbors a supermassive black hole (BH) is controversial (for recent reviews, see Genzel & Townes 1987; Phinney 1989; Ozernoy 1989). The main line of debate concerns the mass of a putative BH: is it as large as $10^6\ M_\odot$ or is it much less (for a review of recent estimates of the mass, see Ozernoy 1993)?

The wide-spread belief in a $\sim 10^6\ M_\odot$ mass for putative BH at the Galactic center is largely based on the *nonlocal* approaches which employ the gravitational field of a point mass at such large distances that the contribution of distributed matter and non-gravitational forces is not negligible. Although stars as a tracer of the gravitational field are not susceptible to magnetic and other nongravitational forces, a $\sim 10^6\ M_\odot$ BH is consistent but not demanded by kinematics of stars in the central parsec or so (McGinn et al. 1989). More recently, two attempts to employ a *local* approach trying to find the mass of Sgr A* from its radiation spectrum assuming that the latter is due to accretion onto a BH have been implemented (Melia 1992; Ozernoy 1992b, c); these were based on an earlier suggestion (Ozernoy 1989) that Sgr A* is fed by the wind from a nearby group of hot massive stars (IRS 16) and that this accretion can be approximated by a Bondi type. As the boundary conditions for this accretion can be set up from the observational data on the wind, the BH mass can be derived from a consistent accretion theory. Unfortunately there is no agreement yet between the results of the above papers, and further efforts to determine or constrain the Sgr A* mass are badly needed.

On another level, the recent *EGRET* detection of excess emission which is consistent in position with the Galactic center and the instrumental point spread function (Mattox et al. 1993; Mayer-Hasselwander et al. 1993) brings new interest in that region. The indications of time variations reported by the above authors might favor a single compact source over alternative explanations such as emission of unresolved objects or enhanced diffuse emission. In what follows we adopt the view that these gamma rays are produced due to a single compact source, namely a black hole; we connect this activity with theories of shock acceleration proposed some time ago to explain the activity observed in active galactic nuclei (AGNs) (Protheroe & Kazanas 1983; Kazanas & Ellison 1986). Therefore high-energy observations from the Galactic center can, in principle, give us useful insights of the mechanisms operating in the vicinity of black holes.

Thus the aim of the present paper is two-fold. It attempts to show that the high-energy observations of the Galactic center are indeed compatible with theories according to which ultrarelativistic hadrons exist in the vicinity of accreting black holes. It suggests also a new and potentially promising way of deriving/constraining the mass of the putative black hole at the Galactic center—the nearest massive BH assumed to exist as an "engine" in AGNs. The specific upper limit we derive in the present paper should be considered as a current illustration of this method rather than its final result.

The present paper is structured as follows: assuming that the BH mass is large enough and therefore the (inavoidable) Bondi accretion rate is sufficiently high (§ 2), we estimate the parameters of the shock related to this accretion and then evaluate

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the X-ray and gamma-ray emission associated with the relativistic particles accelerated by the shock (§ 3). Confrontation with available observational data on high-energy emission from the Galactic center makes potentially possible to derive new constraints to the BH mass (§ 4).

2. WIND ACCRETION ONTO SGR A*

In accordance with the numerous data (e.g., Geballe et al. 1991; Krabbe et al. 1991), we adopt the following values for the parameters of the IRS 16 wind: $n_\infty \simeq 10^4$ cm^{-3}, $v_\infty \simeq 700$ km s^{-1}, $\dot{M}_{\rm ej} \simeq 2 \times 10^{-3}$ $M_\odot$ yr^{-1}, where n_∞ is gas number density in the wind far from Sgr A*, v_∞ is velocity of the wind, and $\dot{M}_{\rm ej}$ is the resulting power of the wind.

The BH intercepts a fraction of $\dot{M}_{\rm ej}$ that depends on the BH mass M_h and also on n_∞ and v_∞ but does not depend on the distance from the source of the wind provided that this is large enough. The Bondi accretion rate can be written as

$$\dot{M}_a \simeq 10^{-4} \frac{M_\odot}{\rm yr} M_6^2 n_4 v_{700}^{-3} \equiv 10^{-4} A M_6^2 \frac{M_\odot}{\rm yr} , \quad (1)$$

where $M_h \equiv M_6 \times 10^6$ $M_\odot$, $n_\infty \equiv n_4 \times 10^4$ cm^{-3}, and $v_\infty \equiv v_{700} \times 700$ km s^{-1}. Since there may exist, besides the IRS 16 wind, some additional sources of accreting matter, the true value of the accretion parameter $A \equiv n_4 v_{700}^{-3}$ might well exceed its lower limit $A \simeq 1$.

In Bondi accretion onto a BH, once n_∞ and v_∞ are known, the accretion rate, $\dot{M}_a \propto M_h^2 n_\infty v_\infty^{-3}$, is determined solely by the BH mass M_h. We employ the standard theory of spherical accretion (e.g., Ipser & Price 1982) modified by taking into account the decoupling of electrons and ions at small distances from the BH where the energy exchange time between them, $t_{ei} \propto T_e^{3/2}/n$, exceeds the inflow time, $t \sim r/v$. Since the density in the flow varies as

$$n \simeq 2.5 \times 10^{12} \beta_v^{-1} \dot{m} M_6^{-1} \left(\frac{r}{r_g}\right)^{-3/2} {\rm cm}^{-3} , \quad (2)$$

where $r_g = 2GM_h/c^2$ is the gravitational radius, $\beta_v \equiv v/v_{\rm ff} \sim 1$, $v_{\rm ff} = c(r/r_g)^{-1/2}$ being the free-fall velocity, and $\dot{m} \equiv \dot{M}_a c^2/L_{\rm Edd}$, the decoupling happens at distances $r \lesssim r_{\rm dec}$. Here $r_{\rm dec} \simeq 2.6 \times 10^3$ $\dot{m}^{-2/3} r_g \simeq 2.1 \times 10^4 M_6^{-2/3} A^{-2/3} r_g$ and the Coulomb logarithm $\Lambda = 20$ is adopted.

The magnetic field in the accretion flow can be evaluated by assuming equipartition of the magnetic density either with electron energy density or with kinetic energy density. Here we will consider the latter case by following similar approaches for the case of accretion onto black holes in AGNs (see, for example, Mastichiadis & Protheroe 1990). Assuming therefore that $B^2/8\pi = \beta_B \rho v^2/2 (\beta_B \sim 1)$ and substituting ρ and v as given above, one gets

$$B \simeq 4.6 \times 10^4 G (\beta_v \beta_B)^{1/2} 2 A^{1/2} \left(\frac{r}{r_g}\right)^{-5/4} . \quad (3)$$

One can show that unless $r \leq r_{\rm dec}$ the value of the magnetic field in the accretion flow is quite insensitive to various equipartition models.

3. CONSEQUENCES OF RELATIVISTIC PROTON INTERACTIONS

Although it was proposed a while ago that protons can be accelerated to very high energies in the vicinity of an accreting black hole by the first-order Fermi process (Protheroe & Kazanas 1983; Kazanas & Ellison 1986), it has only recently been proven that a strong shock can be formed in the close vicinity of a BH (Chakrabatri 1990). However, a self-consistent solution that would include the feedback of the particles generated by the shock is lacking so far. Therefore, in the present paper we will not deal with the specifics of proton acceleration. Instead, we will assume a priori the existence of relativistic protons in the vicinity of the BH; we consider them as having a power-law distribution

$$n_p(E_p) = n_0 E_p^{-\alpha} \quad (4)$$

for $E_p \leq E_{p,\rm max}$. Relativistic protons lose energy mainly through three channels: inelastic proton-proton collisions, photomeson production, and proton-photon pair production. Sikora et al. (1987) compared the efficiencies of these three processes for AGN conditions and found that *p-p* cooling dominates the other processes as long as the proton energies do not exceed 10^4–10^5 GeV. Following the same line of arguments as the above authors, one can easily show that because of the low luminosity of the Galactic center putative BH, the loss processes related to ambient photons cannot be important. It is therefore the collisions between relativistic and ambient protons which will always dominate the proton cooling.

3.1. *Production of γ-Rays*

Inelastic proton-proton collisions give γ-rays, relativistic electrons, and neutrinos resulting from the decay of the produced neutral and charged pions. While one can calculate in detail their production spectrum once the relativistic proton distribution is given (see, for example, Dermer 1986 and Mastichiadis & Protheroe 1990), we feel that for the present calculation it suffices to use the δ-functional approximation to the differential cross section for production of energetic pions $d\sigma(E_\pi)/dE_\pi = \sigma_{pp} \delta(E_\pi - 0.15 E_p)$ with $\sigma_{pp} \simeq 4 \times 10^{-26}$ cm^2 being the proton-proton cross section (e.g., Atoyan 1992). Since the mean energy per gamma-photon produced at the decay of the π^0-meson is $0.5 E_\pi = 0.075 E_p$, the photon-production spectrum, in this approximation, can be taken as

$$Q_\gamma(E_\gamma) = 2 \nu_{\rm coll} \frac{n_p(E_\gamma/0.075)}{0.075} , \quad (5)$$

where $\nu_{\rm coll}$ is the *p-p* collision rate given by

$$\nu_{\rm coll} = n(r) \sigma_{pp} c \simeq 3 \times 10^{-3} \dot{m} M_6^{-1} x^{-3/2} \ {\rm s}^{-1} . \quad (6)$$

Here $n(r)$, the ambient proton number density, is given by equation (2) and $x \equiv r/r_g$. The limits in which equation (5) is valid are given by 100 MeV $\leq E_\gamma \leq 0.075 E_{p,\rm max}$. For $E_\gamma < 100$ MeV the δ-functional approximation breaks down and the photon spectrum becomes flatter than that given by equation (5). In this case, in order to calculate the photon spectrum, one has to resort to the detailed treatment of Dermer (1986). However, this is not of practical interest as *EGRET* cannot detect a point source above the diffuse background level at energies of less than 100 MeV (J. R. Mattox & D. L. Bertch, personal communication). From equations (4) and (5) it follows that the slope of the π^0-produced γ-rays reflects directly the slope of the parent proton distribution, provided that the γ-rays are optically thin against photon-photon pair attenuation on the existing ambient photons.

Therefore for the GCBH the following scenario suggests itself: If protons are indeed accelerated by a shock front close enough to the black hole, then the γ-rays observed by *EGRET* (Mattox et al. 1993; Mayer-Hasselwander et al. 1993) coming from the direction of Sgr A* can be the π^0-produced γ-rays from p-p collisions. In this case the reported index $\alpha = 1.7 \pm 0.15$ reflects the slope of the accelerated proton distribution. Furthermore, the spectrum seems to steepen at the very last bin of the *EGRET* energy band (4–30 GeV). This apparent cutoff can be attributed to either a steepening due to photon-photon pair production or a cutoff of the proton spectrum at energies $E_{p,\max} \simeq 400\epsilon_{\gamma,30}$ GeV (protons of these energies will give γ-rays of energy $\epsilon_\gamma \simeq 30$ GeV; cf. eq. [5]). Here we assume that the observed steepening is due to a cutoff in the proton spectrum, and we will show that it cannot be due to photon-photon production in the next section. (This is a major difference from AGN environments, where the soft photon compactnesses can be high leading to substantial absorption and reprocessing of the injected primary photons—see, e.g., Svensson 1987.) Thus, in the absence of photon-photon attenuation one can assume that the total amount of γ-radiation produced in the source is equal to the observed luminosity:

$$L_{\gamma,\text{tot}} \simeq L_{\gamma,\text{obs}} \simeq 6 \times 10^{36} \text{ ergs s}^{-1} . \tag{7}$$

3.2. *Production of X-Rays*

We turn next to the radiating electrons. The electron injection spectrum resulting from the decay of charged pions is given by

$$Q_e(E_e) = 2\nu_{\text{coll}} \frac{n_p(E_e/0.039)}{0.039} , \tag{8}$$

since the electron (positron) carries on the average 26% of the initial pion energy $E_\pi \approx 0.15E_p$, i.e.$\langle E_e \rangle \approx 0.039E_p$ (Atoyan 1992).

The limits of the electron spectrum are 100 MeV $\leq E_e \leq 0.039E_{p,\max}$. The injected relativistic electrons (which are also produced with the proton index α) lose their energy by inverse Compton scattering or synchrotron radiation. In either case, the standard solution of the electron kinetic equation (e.g., Blumenthal & Gould 1970) yields a steady state electron distribution with index $p = \alpha + 1$ and, consequently, a radiated photon spectrum of slope $s = (p + 1)/2 = (\alpha + 2)/2$.

By comparing the photon energy density (u_{ph}) to the magnetic one (u_B) for the Galactic center BH environment, we find that electron synchrotron losses dominate over inverse Compton scattering when

$$L_{\text{bol}} < 2.8 \times 10^{42} A M_6^{-1} x_{\text{sh}}^{-1/2} \text{ ergs s}^{-1} , \tag{9}$$

where $x_{\text{sh}} = r_{\text{sh}}/r_g$ is the dimensionless distance to the shock. It is therefore evident that the relativistic electrons will cool predominantly by synchrotron radiation. Note that by attributing the *EGRET* γ-rays to π^0 decays, the proton spectrum given by equation (4) is completely specified. Therefore, the electron injection is also specified, and in order to calculate the radiated synchrotron spectrum one needs the value of the magnetic field at the site of electron production. Since the pions are produced essentially at the shock located at the distance r_{sh} from the black hole, and since the decay time for the charged pions is very short (of the order of 10^{-15} s), we can safely assume that the electrons are produced at radius r_{sh}. Furthermore, since the magnetic field in our model is determined uniquely by the radius r (see § 2), in order to calculate $B(r_{\text{sh}})$, it suffices to determine r_{sh}. The latter value could be treated as a more or less free parameter; however, our model is further constrained by available observations of the Galactic center region. According to these observations (Pavlinski et al. 1992; Churazov et al. 1993), Sgr A* was detected as a weak source by ART-P (energy range 4–20 keV) with a rather flat spectrum of slope $s = 1.6$ but it was not detected at harder X-rays (35–1000 keV) by *SIGMA*. Furthermore the slope observed by ART-P was not seen to break (E. Churazov, private communication). Since continuation of the same power-law slope between the two regimes would have made the source very bright at high energies and thus easily observable with *SIGMA*, one has to assume that there is either a sharp break or a cutoff at some energy not very far above 20 keV. Here for concreteness we assume that the cutoff occurs at $\epsilon_{s,\max} = 30\epsilon_{s,30}$ keV (the subscript "s" denotes photons created by the synchrotron mechanism). Attributing this turnover to the upper cutoff of the proton distribution (which would result in a cutoff in the injected electron and, consequently, in the radiated synchrotron spectrum), taking the magnetic field from equation (3) and using the standard relation for the critical synchrotron frequency (see, e.g., Rybicki & Lightman 1970) which corresponds to the maximum electron Lorentz factor $\gamma_{\max}$, i.e.,

$$\epsilon_{s,\max} \simeq 1.2 \times 10^{-8} B(x_{\text{sh}}) \gamma_{\max}^2 \text{ eV} , \tag{10}$$

we find

$$x_{\text{sh}} = r_{\text{sh}}/r_g \simeq 10\epsilon_{s,30}^{-4/5} \epsilon_{\gamma,30}^{8/5} . \tag{11}$$

This value is consistent both with a detailed analysis of standing shock formation in the Bondi accretion (Chakrabatri 1990) and with shock acceleration theories which usually place x_{sh} between 10 and 100. Furthermore, the radiated synchrotron spectrum will have a slope of $s = 1.85 \pm 0.15$ which is rather close (although somewhat steeper) than that observed by ART-P. If the above scenario is correct, the synchrotron spectrum should extend down to energies of

$$\epsilon_{s,\min} \simeq 1.2 \times 10^{-8} B(x_{\text{sh}}) \gamma_{\min}^2 \text{ eV} \simeq 1.3 A^{1/2} \epsilon_{s,30} \epsilon_{\gamma,30}^{-2} \text{ eV} , \tag{12}$$

where $\gamma_{\min} \simeq 2 \times 10^4$ is the lower limit of the electron spectrum as given by equation (8). The photon spectrum should flatten below $\epsilon_{s,\min}$ reflecting the flattening in the electron spectrum.

By knowing the total radiated γ-ray luminosity (cf. eq. [7]), one can immediately derive the total synchrotron luminosity (i.e., the luminosity radiated between $\epsilon_{s,\min}$ and $\epsilon_{s,\max}$). This will be given by $L_{s,\text{tot}} \simeq 0.55 L_{\gamma,\text{tot}} \simeq 3.3 \times 10^{36}$ ergs s^{-1}, while the expected synchrotron luminosity in the 4–20 keV (the ART-P energy band) will be $L_{s,4-20\text{ keV}} \simeq 0.9 \times 10^{36}$ ergs s^{-1}. This is consistent with the reported 4–20 keV Sgr A* luminosity which was found to vary within the range $(0.76–1.66) \times 10^{36}$ ergs s^{-1} in a year (Churazov et al. 1992).

3.3. *Photon-Photon Attenuation*

As we claimed in § 3.1, the spectral break observed by *EGRET* at energies around 30 GeV should be due to a break in the proton distribution and not due to photon-photon pair production. We proceed now to show that 30 GeV γ-rays can escape freely from the shock site as long as the mass of the black hole is not too small.

The optical depth to photon-photon pair production can be calculated in an approximate analytical way by following the method proposed by Bassani & Dean (1981). (Although an exact numerical calculation is possible, we feel that for the purposes of the present paper an approximate analytical approach is more appropriate). The photon-photon pair production cross section is approximated by a rectangular function of height $\sigma_{\gamma\gamma}^0 \simeq 1.7 \times 10^{-25}$ cm^2 at $\epsilon = 2\epsilon_*$ and width $2.5\epsilon_*$, where $\epsilon_* = 4(m_e c^2)^2/\epsilon_\gamma$. Here ϵ_γ is the energy of the γ-ray photon. Assuming that the target photon distribution is a power law [$n_s(\epsilon) = n_{s,0}\,\epsilon^{-\alpha}$], the optical depth for the photons of energy ϵ_γ against photon-photon pair production is

$$\tau_{\gamma\gamma}(\epsilon\gamma) \simeq R\sigma_{\gamma\gamma}^0 n(\epsilon_*)2.5\,\frac{\epsilon_*}{2}\,. \qquad (13)$$

Here R is the size of the source. Normalizing $n_{s,0}$ to the luminosity L we get from (13)

$$\tau_{\gamma\gamma}(\epsilon_\gamma) = \frac{2.5}{8\pi c}\,\frac{2-\alpha}{\epsilon_{\rm max}^{2-\alpha} - \epsilon_{\rm min}^{2-\alpha}}\,\frac{L\sigma_{\gamma\gamma}^0}{r_{\rm sh}}\,\epsilon_*^{-\alpha+1}\,, \qquad (14)$$

where $\epsilon_{\rm min}$ and $\epsilon_{\rm max}$ are the lower and upper cutoffs of the soft photon distribution. A primary target for absorption of γ-rays are the soft synchrotron photons produced in the same region as the γ-rays. Therefore we can use in equation (14) the parameters derived in § 3.1. Thus we get (by setting $R \equiv r_{\rm sh} = 3 \times 10^{11} M_6\, x_{\rm sh}$ cm)

$$\tau_{\gamma\gamma}(\epsilon_\gamma = 30\ {\rm GeV}) \simeq 6.7 \times 10^{-4} \epsilon_{\gamma,30}^{-8/5}\,\epsilon_{s,30}^{4/5}\,M_6^{-1}\,. \qquad (15)$$

Therefore as long as M_h is larger than $6.7 \times 10^2\ M_\odot$, γ-rays of energy 30 GeV can escape the shock site without attenuation. Here we would like to emphasize the fact that these calculations are based on the assumption that the background field is isotropic. Anisotropic considerations relax the constraint imposed by equation (15) even more (Protheroe, Mastichiadis, & Dermer 1992).

4. SUMMARY-DISCUSSION

In the present paper we have tried to explain the recently observed γ-rays and X-rays coming from the Galactic center region as a manifestation of the activity of a black hole there. The relative proximity of the Galactic center allows us to obtain the parameters of the IRS 16 wind and therefore to determine the parameters (such as the mass accretion rate and the magnetic field strength) of the accretion onto the central black hole. Following theories of first-order Fermi acceleration at accretion shocks, we can attribute the γ-rays to the π^0 decays produced in proton-proton collisions at the shock site. We find that a rather flat ($n_p \propto E^{-1.7}$) proton distribution up to $E_{p,\rm max} \simeq 400$ GeV can explain the *EGRET* observations. On the other hand, according to this scenario, the X-rays observed by ART-P are of nonthermal origin: they are due to synchrotron radiation from the electrons/positrons produced in the same proton-proton collisions. Thus the spectra in the two regimes are directly connected and, if such a picture is correct, one would expect γ-rays and X-rays to be strongly correlated. Since ART-P has detected Sgr A* to be a rather steady source (Pavlinski et al. 1992), we expect that the source should have rather modest variations in the γ-ray regime as well.

The above considerations can bring—albeit indirectly—an estimate to the mass of the black hole. Thus using the well-known relation $L_p = \eta \dot{M}_a c^2$, where η is the shock efficiency we obtain

$$M_h \lesssim 0.6 \times 10^4\ M_\odot\ L_{X,36}^{1/2}\,\eta_{0.1}^{-1/2} A^{-1/2}\,. \qquad (16)$$

Here we have adopted $\eta = 0.1\eta_{0.1}$ (which is consistent with the value of $x_{\rm sh}$ cf. eq. [11]) and we have derived the proton luminosity L_p from the relation (Atoyan 1992) $L_p = L_{s,\rm tot}/0.18 = 2 \times 10^{37} L_{X,36}$ ergs s^{-1}, where $L_{X,36}$ is the X-ray luminosity observed by ART-P in units of 10^{36} ergs s^{-1}. As long as only a part of the observed gamma-ray luminosity from the Galactic center given by equation (7) might be due to the point source, those of X-rays which are related to the underlying protons might be only a part of the observed X-ray luminosity entering equation (16). This is why the latter gives us, strictly speaking, an upper limit to, rather than evaluation of, the BH mass.

Although equation (16) is based on many assumptions and cannot be robust, it turns out to be in rough agreement with the results from four different methods which include (1) tidal distruption of stars by a BH; (2) displacement between Sgr A* and IRS 16; (3) electron-positron pair production by a BH via electromagnetic cascade; and (4) wind diagnostics of Sgr A*. These resulted in upper limits to the BH mass, which depending on the method employed range between ~30–100 $M_\odot$ and $2 \times 10^4\ M_\odot$ (see Ozernoy 1992a and references therein). Although these methods have some flaws, all of them might indicate for a putative BH at the Galactic center to have a mass $M_h \ll 10^6\ M_\odot$.

The fact that *EGRET* might have detected the Galactic center black hole but it has not detected any γ-rays coming directly from the black holes in the AGNs is not as puzzling as it might appear. The 20 or so AGNs detected by *EGRET* so far belong to the category of blazars (for a review, see Fichtel et al. 1993). The fact that *EGRET* has not detected thus far even one Seyfert may be pointing to the conjecture that γ-rays are produced in jets (Dermer & Schlickeiser 1992). Meanwhile, this does not necessarily mean that γ-rays cannot be produced close to the central object. In the AGN case, however, the photon compactnesses are high (10–100) and any energetic photon will be absorbed by the intense soft X-ray field which will also be produced in the same region. For the case of the Galactic center black hole the situation is different as the compactness is very low and the produced γ-rays will escape easily.

The present paper points some consequences of wind accretion and shock formation around black holes but it does not attempt to solve this problem self-consistently. As a matter of fact, we found that in order to explain the slope of γ-rays observed by *EGRET* one needs an index of 1.7 in accelerated protons (see § 3). This is flatter than the "canonical" value of 2 and it might imply the presence of a strong shock. (We note in passing that the strong shock approximation fails when M_h is not too large since equation (1) would give rather small $\dot{M}_a$ unless an additional source of accretion is operating). It is evident that in order to understand the physical conditions prevailing in such shocks more detailed calculations are needed. At the same time, however, we feel that the high-energy observations, especially in such optically thin conditions, can give us a valuable diagnostic for the physical environments around accreting black holes. A possibility to verify the present model that makes quite definite predictions concerning the interrelation between X-ray and γ-ray luminosity of Sgr A* as a putative wind accreting black hole seems to be an example of such diagnostics.

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