Annihilation Emission from the Galactic Black Hole

K.-S. Cheng[1], D.O. Chernyshev[2], V.A. Dogiel[3], A.Y.L. Wong[1]

[1]*Department of Physics, University of Hong Kong, China*
[2]*Moscow Institute of Physics and Technology, Russia*
[3]*I.E.Tamm Theoretical Physics Division, P.N.Lebedev Institute of Physics, Moscow, Russia*

Both diffuse high energy gamma-rays and extended electron-positron annihilation emission have been observed in the Galactic Center region. Though the Galactic black hole is in inactive phase, we suppose that it was active in the past. We argue that the Galactic black hole could be a powerful source of relativistic protons when the captured star is tidally disrupted. We assume that the relativistic protons are injected into the ambient material from the Galactic black hole that produces secondary gamma-rays and positrons there. After Coulomb thermolization of secondary positrons they annihilate in the surrounding space that naturally explain the origin of annihilation emission from the galactic center.

§1. Introduction

The rate at which a massive black hole in a dense star cluster tidally disrupts and swallows stars has been studied extensively. 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. The average period between time captures $\sim 10^5$ years for non-AGN galaxies.1)

It was argued in2) 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}. In addition to the accretion power if the transient accretion disk can generate a sufficiently strong magnetic field, due to the instability of the disk, it can initiate the Blandford-Znajek process3) to extract rotation energy from the black hole, and the maximum energy that can be extracted from a black hole is given by4)

$$\Delta E_{max} \sim 6\times 10^{52}(\eta_p/10^{-1})(M_*/M_\odot)\mathrm{erg} \sim 3\times 10^{52}M_6^2\mathrm{erg}. \qquad (1\cdot1)$$

where M_6 is the black hole mass in units of 10^6 $M_\odot$. The maximum energy in relativistic protons can be estimated from Eq.(1·1). If a star with the mass about $M_* \sim 50 M_\odot$ is captured by a black hole, it gives an energy in relativistic protons as high as $\sim 10^{54}$ erg.

This process of energy output is accompanied by proton and electron acceleration at peripherical shocks whose synchrotron emission is seen as an extended time-variable non-thermal X-ray source that nicely describes observations as shown in Fig. 1.

According to5) the nuclear bulge of a radius 230 pc contains $10^7 M_\odot$ of hydrogen gas 90% of which 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.,6),7)). From the EGRET observations it is known that GeV cosmic ray protons freely

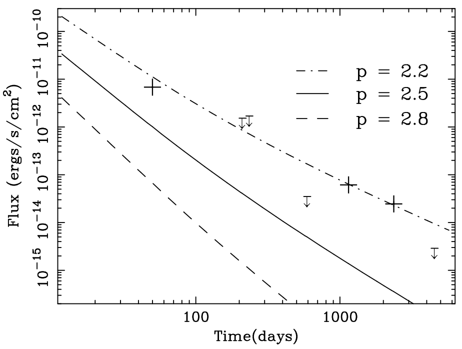

Fig. 1. Observed (0.1 - 2.4 keV) X-ray flux in NGC 5905[14),15)] together with the simulation results. In our theoretical calculation, we have taken $E_{0,\rm jet} = 3 \times 10^{51}$ ergs, Γ=5, $\epsilon_B = 0.001$ and $\epsilon_e = 0.06$.

penetrate into molecular clouds.[8)]

In our case (see[9)]) it means that relativistic protons propagate in the medium with the average gas density about $n \sim 1000$ cm^{-3} 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}.

Further propagation of relativistic protons through the dense ($n \sim 10^3$ cm^{-3}) medium surrounding the black hole ($L \sim 45 - 100$ pc) brings to production of secondary particles in the form of gamma-rays, electrons and positrons whose production rate decreases rapidly with the characteristic time of $p-p$ collision ($\sim (1-3) \cdot 10^4$ years). This is the characteristic time of variations of the gamma-ray flux from the Galactic center which at present equals $\sim 10^{37}$ erg s^{-1} at energies ≥ 100 MeV but it may be two orders of magnitude higher after the moment of eruption, i.e. $\sim 10^5$ years ago.

Secondary positrons are generated at energies ≥ 30 MeV because of the threshold of p-p reaction. The annihilation cross-section is high (in several orders of magnitude) for annihilation of thermolized positrons if the temperature of background plasma is about several eV. Therefore for effective annihilation positrons have to lose their energy by Coulomb collisions and reach the regions of neutral and ionized gas with temperatures $\sim$ eVs which are situated at relatively large distances from the Galactic center (several hundred pc). This time ($\sim 10^6 - 10^7$ years) is much longer than the time of $p - p$ collisions. Therefore, the peak of annihilation emission occurs long after the peak of gamma-ray emission (see Fig. 2). The total energy of relativistic protons ejected from the black hole should be of the order of 10^{52} erg in oder to produce the observed annihilation flux from the bulge.

Such eruption processes should happen rather often in galaxies with the characteristic time about $\tau_c \sim 10^5$ years which is much shorter then the thermolization time of secondary positrons. Then many eruption events are expected during the thermalization time of positrons, and we expected accumulation of positron in thermal energy range which are generated by several eruption processes. As we see from our numerical calculation in order to produce the annihilation flux the proton energy output in each of the multi ejection case is almost 20 times less than in the case of

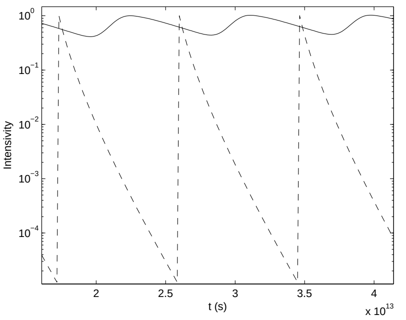

Fig. 2. Gamma-ray and annihilation emission from several successive eruption of protons by the black hole. The peak values of these fluxes are normalized to unity.

single eruption, i.e. only $\sim 5 \cdot 10^{50}$ erg in each star capture event should be released in the form of relativistic protons.

With these parameters we can obtain the intensity and the profile of the line emission in the eV temperature plasma as it was obtained with INTEGRAL.[10)] Here we include the two-photon annihilation of the 511 keV emission as well as the three-photon annihilation continuum below 511 keV.

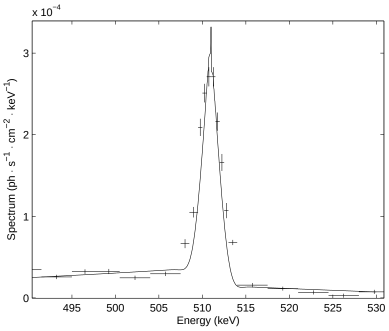

Fig. 3. The total annihilation spectrum from, together with the INTEGRAL data.

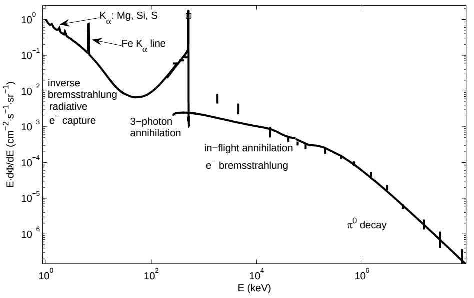

Fig. 4. The total emission from the 5^0 region around the Galactic center.

The process of annihilation emission is accompanied by production of continuous emission in the range below 511 keV due to the three-photon decay and the inverse bremsstrahlung emission of primary subrelativistic protons and the diffuse emission in MeV region due to the in-flight annihilation of secondary positrons and the spectrum due to π^0-decay due to $p - p$ collisions. We calculated also the X-ray line emission generated by subrelativistic protons in surrounding plasma using the method of.[11)] The expected spectrum together with the COMPTEL and EGRET data for the central part of the Galaxy is shown in Fig. 4. One can see that our model nicely describe the emission spectrum from the central Galaxy except the region 1-50 MeV where the calculated flux is below the observation data. Therefore, the criticism of our model following from[12),13)] who predicted that our results had to be above the observational data are inessential.

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