Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 42 (2008) 538–543
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

High energy radiation from the direction of the galactic black hole Sgr A*

K.S. Cheng [a,*], D.O. Chernyshov [b], V. Dogiel [c]

[a] Department of Physics, The University of Hong Kong, Hong Kong, China
[b] Moscow Institute of Physics and Technology, Institutskii lane, 141700 Moscow Region, Dolgoprudnii, Russia
[c] I.E.Tamm Theoretical Physics Division of P.N.Lebedev Institute, Leninskii pr, 53, 119991 Moscow, Russia

Received 27 October 2006; received in revised form 25 February 2007; accepted 26 April 2007

Abstract

X-ray observations indicate that the Galactic black hole Sgr A* is inactive now, however, we suggest that Sgr A* can become active when a captured star is tidally disrupted and matter is accreted into the black hole. Consequently the Galactic black hole could be a powerful source of relativistic protons with a characteristic energy $\sim 10^{52}$ erg per capture. The diffuse GeV and TeV γ-rays emitted in the direction of the Galactic Center (GC) are the direct consequences of p–p collisions of such relativistic protons ejected by very recent capture events occurred $\leqslant 10^5$ yr ago. On the other hand, the extended electron-positron annihilation line emission observed from GC is a phenomenon related to a large population of thermalized positrons, which are produced, cooled down and accumulated through hundreds of past capture events during a period of $\sim 10^7$ yr. In addition to explaining GeV, TeV and 511 keV annihilation emissions we also estimate the photon flux of several MeV resulting from in-flight annihilation process.

Keywords: Galactic black hole; γ-rays; Radiation processes

1. Introduction

A supermassive black hole known as Sgr A^*, with a mass of $2.6\times10^6 M_\odot$ (Schödel et al., 2002) is located at the Galactic center (GC). It is known that many remarkable high energy sources harbored in this region (Melia and Falcke, 2001). In particular, intense high energy radiation ranging from 511 keV annihilation lines detected by INTEGRAL (e.g., Churazov et al., 2005), 100 MeV–10 GeV photons by EGRET (e.g., Mayer-Hasselwander et al., 1998), and TeV photons detected by Whipple (Kosack et al., 2004), by CANGAROO (Tsuchiya et al., 2004), and by HESS (Aharonian et al., 2004) are observed from the direction of GC. Although TeV photons from the direction of the Galactic Center are detected by both CANGAROO-II and HESS, their spectral indexes are complete different. The observed spectrum by HESS is much flatter than that of CAGAROO-II. On the other hand, the observed TeV spectrum of CAGAROO-II appears close to that of EGRET, which has angular resolution of $\sim$0.5°. It should be noticed that the angular resolution of HESS is of order of arcmin and it is much better than that of CAGAROO-II. Therefore the spectrum of CAGAROO-II actually represents the average spectrum of a region over >10′, which is closer to the angular size of EGRET. It is very interesting to know in future observations by HESS, which can confirm that the TeV spectrum has a spatial dependent feature. Finally, it is interesting to ask "What are the origins of these high energy photons?" and "Are they correlated to each other?"

The spatial distribution of these three energy bands are as follows: the 511 keV annihilation lines are emitted from a non-spherical symmetric extended region with about 6–8° FWHM centered at the GC. The emission appears to be diffused and does not show any clear point source in the emission region. The GeV photons detected by EGRET is known as 3EG J1746-2851, which has an emission region

* Corresponding author.
E-mail address: hrspksc@hkucc.hku.hk (K.S. Cheng).

0273-1177/$34.00 © 2007 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2007.04.103

around 0.5° in radius, and the GC is at the rim of its emission region. The emission position of TeV photons can be determined to less than 10 pc and its center is almost overlapped with the Galactic black hole. Although the emission regions of GeV and TeV photons have some overlapped, it is unclear if they are related. In general, 511 keV photons are not considered to be related to both GeV and TeV photons. Furthermore, the annihilation line are considered to be the most difficult problem to be explained. (Unless the sources of positrons are more or less uniformly distributed in the bulge there is no such problem of propagation (e.g., Wang et al., 2006).) The main reason is that it takes at least 10 million years for positrons to diffuse to a 6–8° region if positrons are ejected from a central region of the Galactic center with a size much smaller than 6–8°, which implies the energy content necessary to create the observed annihilation flux is $\sim 3\times10^{54}$ erg if positrons result from proton–proton collisions. This amount of energy is very difficult to be provided by any known except γ-ray bursts occurred at the cosmological distance. Parizot et al. (2005) argued that indeed the observed positrons result from the hypernova explosion, which is the progenitor of the γ-ray bursts. However, the energy claim of γ-ray bursts can reach 3×10^{54} erg is assumed isotropic emission. It is generally accepted that the emission of γ-ray bursts is beaming and hence the energy emitted is actually two to three order of magnitudes lower than the isotropic case. Prantzos (2006) suggests that most positrons are produced in the disk but they are transported to the bulge by the regular magnetic field. If this is true, then similar propagation should be assumed for relativistic protons and electrons which propagate also by diffusion along magnetic field line. Their propagation in perpendicular direction is due to random fluctuations (spaghetti-like structure). If Prontzos's model is correct we would observe extremely high fluxes of radio and γ-ray emission from the Galactic center. In fact the actual galactic magnetic field is quite complicated (Han et al., 2006), it is not clear if such transport process is efficient. Mastichiadis and Ozernoy (1994) argued that the γ-rays originated from the Galactic black hole may possibly produce from relativistic particles accelerated by a shock in the accreting plasma. In the same time, the γ-rays could also come from some extended features like radio arcs, where relativistic particles are present (Pohl, 1997). Markoff et al. (1997) discussed in detail the γ-ray spectrum of GC produced by synchrotron, inverse Compton scattering, and mesonic decay resulting from the interaction of relativistic protons with hydrogen accreting onto a point-like sources (e.g., the massive black hole). However, the above models cannot produce the hard γ-ray spectrum with a sharp turnover at a few GeV, which is observed for the GC source. Recently, Oka and Manmoto (2003) have suggested that the γ-rays produced in the inner portion of ADAF through the decay of neutral pions created by p–p collisions may contribute to the γ-rays observed by EGRET. However, their model predicted γ-ray intensity is at least two order of magnitude lower than the observed intensity.

We will organize the paper as follows. In §2, we summarize the model proposed by Cheng et al. (2006), in which they assume that relativistic protons will be ejected by the Galactic black hole when a star is captured and positrons are produced via p–p collisions. In §3, we apply the model to explain the observed high energy radiation data from GC. In §4, we present a brief discussion.

2. Model

We first estimate how much energy could be released from the Galactic black hole, which is activated by capturing a star.

2.1. Energy release supplied by a black hole

It has been suggested that the capture and tidal disruption of stars by a massive black hole can result in flare-like activities in the central regions of AGNs, and even in normal galaxies and globular clusters. According to the theoretical predictions (e.g., Rees, 1988; Phinney, 1989), the flare results from the rapid release of gravitational energy as the matter from the disrupted star plummets toward the black hole. For $t > t_{\rm peak}$, the accretion rate evolves as (Rees, 1988; Phinney, 1989),

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

where $t_{\rm peak} \sim 1.59 t_{\rm min}$, $t_{\rm min} \approx 0.2(\frac{M_\odot}{M_*})(\frac{R_*}{R_\odot})^{3/2}(\frac{M_{\rm bh}}{10^6 M_\odot})^{1/2}$ yr is the characteristic time for the debris to return to the pericenter (Lu et al., 2006) and M_* and R_* are the mass and the radius of the captured star, respectively. Cheng et al. (2006) have estimated that the maximum accretion energy carried away by relativistic protons is given by

$$\Delta E_{\rm p} \sim 6\times10^{52}(\eta_{\rm p}/10^{-1})(M_*/M_\odot)\ {\rm erg}, \quad (2)$$

where $\eta_{\rm p}$ is the conversion efficiency from accretion power ($\dot{M}c^2$) into the the energy of jet motion.

2.2. Proton spectrum

Since most accretion energy will be released in a time scale of $t_{\rm min} \sim$ yr, We take the source function of protons as

$$Q(r, E_{\rm p}, t) = A(E_{\rm p})\delta(\mathbf{r})\delta(t), \quad (3)$$

where $A(E_{\rm p}) \propto E_{\rm p}^{-\gamma_0}$ and the spectral index γ_0 is taken to be between 2 and 3 (cf. Berezinskii et al., 1990). The spatial distribution of the protons can easily be derived from the well-known equation of cosmic ray propagation (see Berezinskii et al., 1990),

$$\frac{\partial n_{\rm p}}{\partial t} - \nabla(D\nabla n_{\rm p}) + \frac{\partial}{\partial t}\left(\frac{{\rm d}E}{{\rm d}t}n_{\rm p}\right) + \frac{n_{\rm p}}{\tau_{\rm p}} = Q(\mathbf{r}, E_{\rm p}, t). \quad (4)$$