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High-energy Radiation from a Model of Quasars, AGNs, and the Galactic Center with Magnetic Monopoles

Q.-H. Peng

Department of Astronomy, Nanjing University, Nanjing, 210093, China

Abstract. The structural parameters of the supermassive object at the Galactic Center and its high-energy radiation are estimated according to observations in near-infrared radiation, under the model of a supermassive object with magnetic monopoles.

An magnetic monopole (MM) predicted by the Grand Unified Theory of particle physics may catalyze a nucleon decay (Rubakov 1983; Callan 1982; henceforth the RC effect): $pM \to Me^+\pi^0$ (85%) or $pM \to Me^+\mu^+\mu^-$ (15%). The positrons produced from the catalytic reaction and photons from decaying π^0 will undergo a cascade process and slow down within the supermassive object (SMO). The cascade multiplication number of positrons, Δ, will be more than 300, and the photon spectrum will become a continuum. In this paper, we estimate the structural parameters of the SMO at the Galactic Center (GC) and its high-energy radiation, based mainly on the near-infrared observations, under the model of the SMO with MM (Peng, Wang, & Li 1986; Peng 1989) with the RC effect´as the main energy source.

a) The mass of the SMO at GC is $\sim 2.5 \times 10^6 M_\odot$ (Eckart & Genzel 1997) and its Schwarzschild radius is $R_s \sim 7.4 \times 10^{11}$ cm. The bolometric (i.e., total thermal) luminosity L_B of the SMO is $L_B = \eta L_{tot} \sim 10^{37}\,\mathrm{ergs\,s^{-1}}$ (Gordwurm et al. 1994), where a factor (η) of the total energy produced mostly from the RC effect is transformed into thermal radiation via various physical processes. The remainder of the total luminosity is transformed into various types of nonthermal, high-energy radiation through a series of cascade processes. The factor η is estimated to be $\sim$ (0.05–0.2), according to the observation of γ-ray radiation.

b) The spectrum of Sgr A* from radio to near-infrared has been constant since the discovery of the source. The observations have been carried out from 400 MHz to $\sim 10^{14}$ Hz. According to a compilation of the radio to NIR observations, the maximum of νL_ν is at $\nu_{max} = 1.0 \times 10^{13}$ Hz (Fig. 1 of Ramesh et al. 1998). The surface temperature of the SMO is estimated in our model by the Planck blackbody radiation law, $T = h\nu_{max}/4k \sim 120.8$ K. Given both its thermal luminosity and surface temperature, the radius of the SMO is estimated to be $R \approx 8.1 \times 10^{15}$ cm or $y = R/R_s \sim 1.1 \times 10^4$, from the relation $L_B \propto R^2T^4$.

c) The positron flux emitted from the SMO may be estimated in the following way. The total energy release rate of the SMO, due to the RC effect, is $L_{tot} = 4\pi \int_0^R r_{RC} R^2 \mathrm{d}R = A_L \psi \xi m^{-1} y^{-3}$. The reaction rate of RC effect is $r_{RC} \equiv N_B N_m c\langle\sigma\beta\rangle \sim 2.07 \times 10^6 \rho^2 \xi$, where $\xi = (\zeta/\zeta_n)(\langle\sigma\beta\rangle/10^{-27}\,\mathrm{cm}^2)$ and $\zeta \equiv N_m/N_B$ is the ratio of the MM number to the baryon number of the SMO. Its Newtonian saturation value is $\zeta_n \approx 1.9 \times 10^{-25}(m_m/10^{16} m_B)$. The cross

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section of the RC reaction is σ; $c\beta$ is the average velocity of a baryon relative to the monopole; and ψ is a mass distribution parameter of the SMO, which is defined as $\psi \equiv \int v\rho^2 dV/(\langle\rho\rangle)^2$, where ρ is the mass density inside the object. We have $\psi \approx \pi/(4\varepsilon) \gg 1$ for a model with $\rho(r) \propto (r^2+\varepsilon^2)^{-1}$, $\varepsilon \ll 1$, $A_L = 4.4 \times 10^{46}\,\mathrm{ergs\,s^{-1}}$, and $m = M/(2.5\times 10^6 M_\odot.)$ The parameter ξ of the MM content inside the object may also be estimated once the bolometric luminosity L_B and the radius, R (or its dimensionless radius, y), have been estimated from observations. The result is: $\psi\eta\xi \approx 230$. The positron emission rate of the SMO due to the RC effect, and with multiplication by a cascade process, is $S_{e^+} \approx (4\pi/3)R^3 r_{RC}\Delta = A_{e^+}(\Delta/300)\psi\xi m^{-1}y^{-3} \sim 6.5\times 10^{42}(\eta/0.2)^{-1}e^+/\mathrm{sec}$, where $A_{e^+} = 7.7\times 10^{51} e^+/\mathrm{sec}$.

d) Besides the γ-rays from the positron annihilation line, radiation with energy higher than 0.5 MeV (up to 1 GeV) is also produced from the SMO, due to the RC effect and through the multiplication from the cascade process. However, the energy of the γ-ray photons decreases during the cascade. The total integrated energy of this high-energy radiation would be much greater than both the energy of positron annihilation line and the bolometric luminosity. These predictions of high-energy radiation are consistent with observations (Harris et al. 1998; Lingenfelter & Ramaty 1989; Swanenburg et al. 1981).

e) The total magnetic charge of the SMO is $Q_m = N_m q_m$, where q_m is the magnetic charge of a stable, colorless monopole; $q_m = 3hc/4\pi e = 9.88 \times 10^{-8}$ gauss. The radial magnetic field on the surface of the SMO is: $H(R) = Q_m/R^2 = (c^4 q_m \zeta_n/4Gm_B)(2.5\times 10^6 M_\odot \langle\sigma\beta\rangle/10^{-27}\,\mathrm{cm}^2)^{-1}\cdot \xi m^{-1}y^{-2} = 190(\langle\sigma\beta\rangle/10^{-27}\,\mathrm{cm}^2)^{-1}(\eta\psi)^{-1} \sim$ (20–100) gauss.

f) The SMO could be a source of cosmic rays produced by the RC effect.

g) When a couple of MM collide, more energy ($> 10^{25}$ eV) will be released. Thus, we may imagine a picture: if two such SMOs with opposite magnetic charge collide, the annihilation of these opposite MM will release an extremely huge amount of energy. For example, in the case of two active galactic nuclei, each with mass $\sim 10^8 M_\odot$ and with the Newtonian saturation of MM, but with the opposite magnetic charge, 10^{53} ergs of energy will be released when they collide. This might be an origin for one kind of gamma ray burst. It might also be a source of extremely high-energy cosmic rays with energy $> 10^{21}$ eV.

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