Astrophys Space Sci (2016) 361:388
DOI 10.1007/s10509-016-2977-8

ORIGINAL ARTICLE

A possible influence on standard model of quasars and active galactic nuclei in strong magnetic field

Qiu-He Peng[1,2] · **Jing-Jing Liu**[3] · **Chi-Kang Chou**[4]

Received: 11 October 2016 / Accepted: 11 November 2016 / Published online: 24 November 2016

Abstract Recent observational evidence indicates that the center of our Milky Way galaxy harbors a super-massive object with ultra-strong radial magnetic field (Eatough et al. in Nature 591:391, 2013). Here we demonstrate that the radiations observed in the vicinity of the Galactic Center (GC) (Falcke and Marko in arXiv:1311.1841v1, 2013) cannot be emitted by the gas of the accretion disk since the accreting plasma is prevented from approaching to the GC by the abnormally strong radial magnetic field. These fields obstruct the infalling accretion flow from the inner region of the disk and the central massive black hole in the standard model. It is expected that the observed radiations near the GC can not be generated by the central black hole. We also demonstrate that the observed ultra-strong radial magnetic field near the GC (Eatough et al. in Nature 591:391, 2013) can not be generated by the generalized α-turbulence type dynamo mechanism since preliminary qualitative estimate in terms of this mechanism gives a magnetic field strength six orders of magnitude smaller than the observed field strength at $r = 0.12$ pc. However, both these difficulties or the dilemma of the standard model can be overcome if the central black hole in the standard model is replaced by a model of a super-massive star with magnetic monopoles (SMSMM) (Peng and Chou in Astrophys. J. Lett. 551:23, 2001). Five predictions about the GC have been proposed in the SMSMM model. Especially, three of them are quantitatively consistent with the observations. They are: (1) Plenty of positrons are produced, the production rate is $6 \times 10^{42}\ e^{+}\mathrm{s}^{-1}$ or so, this prediction is confirmed by the observation (Knödlseder et al. 2003); (2) The lower limit of the observed ultra-strong radial magnetic field near the GC (Eatough et al. in Nature 591:391, 2013), is just good agreement with the predicted estimated radial magnetic field from the SMSMM model, which really is an exclusive and a key prediction; (3) The observed power peaking of the thermal radiation is essentially the same as the theoretical prediction from the SMSMM model. Furthermore, the observed ultra-strong radial magnetic field in the vicinity of the GC may be considered as the astronomical evidence for the existence of magnetic monopoles as predicted by the particle physics.

Keywords Quasars: general · Galaxies: magnetic fields · Physical date and processes: black hole physics

1 Introduction

It is now generally believed that bright quasars observed at large red-shift are supermassive and rapidly spinning black holes formed in the primordial universe. The spectacularly huge luminosity is supplied by the black hole and the surrounding accretion disk. In such models, magnetic fields play a very important role. More specifically, the magnetic coupling between the central black hole (or some supermassive stellar object) and the accretion disk enable effective transport of energy and angular momentum between them.

✉ Q.-H. Peng
qhpeng@nju.edu.cn

✉ J.-J. Liu
liujingjing68@126.com

[1] Department of Astronomy, Nanjing University, Nanjing, Jiangshu 210000, China

[2] School of Physics and Space Science, China West Normal University, Nanchong, 637009, China

[3] College of Marine Science and Technology, Hainan Tropical Ocean University, Sanya, Hainan 572022, China

[4] National Astronomical Observatory, Chinese Academy of Sciences, Beijing, 100000, China

If the black hole spins faster than the disk, energy and angular momentum can be extracted from the black hole and transferred to the disk vie the pointing flux (Blandford and Payne 1982; Blandford and Znajek 1977; Yuan and Narayan 2014). It is now well established that the transfer of energy and angular momentum in such a rotating black hole and accretion disk system with magnetic coupling can generate relativistic jet by the mechanism of Blandford and Znajek (1977) if the energy source is the spinning black hole.

The accretion model of GC is hot accretion flow. One of the most important progress in this field is the finding of strong wind from black hole hot accretion flow. For example, reformulated the adiabatic inflow and outflow solution (ADIOS) model for radiatively inefficient accretion flows, treating the inflow and outflow zones on an equal footing. Narayan et al. (2012) presented the results from two long-duration general relativistic magneto-hydrodynamic (GRMHD) simulations of advection-dominated accretion around a non-spinning black hole. However, accretion onto a super-massive black hole of a rotating inflow is a particularly difficult problem to study because of the wide range of length scales involved. By using the ZEUS code, Li et al. (2013) run hydrodynamical simulations of rotating, axisymmetric accretion flows with Bremsstrahlung cooling, considering solutions for which the centrifugal balance radius significantly exceeds the Schwarzschild radius, with and without viscous angular momentum transport.

On the other hand, Hydrodynamical (HD) and magnetohydrodynamics (MHD) numerical simulations of hot accretion flows have indicated that the inflow accretion rate decreases inward. Two models have been proposed to explain this result. In the adiabatic inflow-outflow solution (ADIOS), this is because of the loss of gas in the outflow. In the alternative convection-dominated accretion flow model, it is thought that the flow is convectively unstable and gas is locked in convective eddies. Some authors have discuss detaily these problems (e.g., Yuan et al. 2012, 2015; Bu et al. 2013). Based on the no-outflow assumption, Gu (2015) investigated steady-state, axisymmetric, optically thin accretion flows in spherical coordinates. By comparing the vertically integrated advective cooling rate with the viscous heating rate, They found that the former is generally less than 30 % of the latter, which indicates that the advective cooling itself cannot balance the viscous heating.

Some researches show that the quasi-relativistic jets and nonrelativistic wind may be produced by the joint action of Blandford and Payne (1982) and other mechanisms and the energy source in these cases is rotational energy of the accretion flow originated from the inner region of the disk (Yuan and Narayan 2014). Moreover, in magnetically arrested disk models, the accreting plasma drags in a strong poloidal magnetic field to the center such that the resulting accumulated magnetic flux disrupts the axisymmetric accretion flow at a relatively large magnetospheric radius (Narayan et al. 2003). Furthermore, magnetic flux threading the black hole, rather than black hole spin is the dominant factor in launching powerful jets and determining the radio loudness of active galactic nuclei (AGN) (Sikora and Begelman 2013). Thus, in the current models just briefly delineated above, magnetic fields always play a key role. In the absence of these fields, it is almost impossible to construct such useful, elegant and realistic models for quasars and AGN.

More latest observational evidence indicates that the center of our Milky Way harbors the closest candidate for a supermassive black hole with strong magnetic fields. Using multi-frequency measurements with several radio telescopes, Eatough et al. (2013) showed that there is a dynamically relevant magnetic field near the black hole. If this field is accreted down to the event horizon, it provides enough magnetic flux to explain the observed emission from the black hole, from radio to X-rays. In addition, Zamaninasab et al. (2014) reported that jet magnetic field and accretion disk luminosity are tightly correlated over seven orders of magnitude for a sample of 76 radio-loud active galaxies. They concluded that the jet-launching regions of these radio-loud galaxies are threaded by dynamically important magnetic fields, which will affect the disk properties. In this paper, we investigate the plausible modifications of the standard models of quasars and AGN in light of the very recent observational evidence for the important discovery of a dynamically relevant magnetic field near the GC. In particular, we focus on the possible origin of the strong magnetic field in the galactic nucleus and study some of the important effects of the ultra-strong magnetic field. The very recent astronomical observations concerning the strongly magnetized super-massive central black hole are depicted in considerable detail in Sect. 2. The key roles played by such observed ultrastrong radial magnetic fields in the standard models due to the effects of these fields are elaborated in Sect. 3. The possible origin of these strong magnetic fields near the GC will be considered in detail in Sect. 4. Our model of super-massive star with magnetic monopoles (SMSMM)is given in Sect. 5. We show explicitly there the generally accepted α-turbulence dynamo mechanism of Parker can not be used to generate the observed strong radial magnetic field by a preliminary estimate in terms of the observed W51 data. However, good agreement with observations may be achieved if the central black hole of the standard model is replaced by a supermassive stellar object containing magnetic monopoles (Peng and Chou 2001). In these model, the production of the strong radial magnetic fields can be naturally explained. We also discuss other evidences against the black hole model of quasars and AGN in Sect. 6. Finally, in Sect. 7, we briefly summarize and emphasize our results.

2 Recent astronomical observations

New progress and some discoveries of radio astronomical observations near the GC have been reported in recent years. The main performances of these are as follows:

(i) The measurement of an abnormally strong radial magnetic field near the GC has been reported by Eatough et al. (2013). The very important results are as follows, in particular, at $r = 0.12$ pc, the lower limit of the outward radial magnetic field near the GC is:

$$B \geq 8\left[\frac{RM}{66.960\ \mathrm{m}^{-2}}\right]\left[\frac{n_e}{26\ \mathrm{cm}^{-3}}\right]^{-1}\ \mathrm{mG}, \tag{1}$$

where n_e is the number density of electrons. At $r = 0.12$ pc by Chandra X-ray observation, $n_e \approx 26\ \mathrm{cm}^{-3}$ (Baganoff et al. 2003). A theoretically calculated electron density of radioactively inefficient accretion flows for the accretion disk around the GC) at is about $20 \sim 100\ \mathrm{cm}^{-3}$, near the observational value (Yuan et al. 2003).

It is well known that the interstellar magnetic field in the galaxy is usually along the galactic spiral arms, and the average strength of the magnetic field is about 1 μG. So the magnetic field shown in (1) is abnormally strong.

(ii) Some radiation have been detected in the region near the central region of the GC. We can see the review article written by Falcke and Marko (2013). First, some radiations from the radio to the sub-mm wavelength band have been detected in the region $(10\text{–}50)R_g$ around the central black hole with mass $4.3 \times 10^6\ \mathrm{M}_\odot$ for the GC. Second, Sgr A* is identified as a surprisingly weak X-ray source by Chandra and it is inferred as radiated from the region $\leq 10R_g$ due to the hour long timescale for some detected weak X-ray flare and small NIR flare. Finally, The radio flux density shows a flat-to-inverted spectrum, i.e., it rises slowly with frequency with the power peaking around 10^{12} Hz in the sub mm band.

$$L_\nu = 4\pi D^2_{\mathrm{Sgr\ A}^*} S_\nu. \tag{2}$$

At GHz frequencies, $S_\nu \propto \nu^\alpha$, $\alpha \sim 0.3 \pm 0.1$, The spectrum continues towards low frequencies (300 MHz) with no sigh of absorption. At higher frequencies the spectrum extends into Sub-mm wavelength regime, where the spectrum peaks and then suddenly cuts-off (Falcke and Marko 2013).

3 The effect of the observed strong radial magnetic field on the standard model of quasars and AGN

The most important effect of the observed ultra-strong radial magnetic field near the GC is that the assumption made in standard models of the GC is invalid. This is because in the presence of the strong radial magnetic field in the vicinity of the GC will prevent material in the accretion disk from approaching to the GC due to the magnetic freeze effect, when the kinematic energy density of the material is less than the energy density of the magnetic field, or the magnetic field is stronger than the Alphen critical value:

$$B > B_{\mathrm{Alphen}} = \left(4\pi\rho v_{\mathrm{rot}}^2\right)^{\frac{1}{2}}, \tag{3}$$

where v_{rot} is the rotation velocity of the accretion disk around the GC and ρ is the mass density. Making use of the relation $v_{\mathrm{rot}}/c = \sqrt{(R_S/r)}$, we then have

$$\begin{aligned} B_{\mathrm{Alphen}} &= \left(4\pi\rho v_{\mathrm{rot}}^2\right)^{\frac{1}{2}} = \left[\frac{4\pi nc^2}{N_A}\right]^{\frac{1}{2}}\left(\frac{R_S}{r}\right)^{\frac{1}{2}} \\ &\sim 13\left(\frac{n}{10^4\ \mathrm{cm}^{-3}}\right)^{\frac{1}{2}}\left(\frac{R_S}{r}\right)^{\frac{1}{2}}\ \mathrm{G}. \end{aligned} \tag{4}$$

Here we note that magnetic field lines may be brought by a intense turbulent plasma fluid. Turbulent Richardson advection brings field lines implosively together from distances far apart to separations of the order of gyro radii (Eyink et al. 2013). This effect of advection in rough velocity fields, which appear non-differentiable in space, leads to line motions that are completely indeterministic or 'spontaneously stochastic'. The turbulent breakdown of standard flux freezing at scales greater than the ion gyro radius can explain fast reconnection of very large-scale flux structures, both observed (solar flares and coronal mass ejections) and predicted (the inner heliosheath, accretion disks, γ-ray bursts and so on). For laminar plasma flows with smooth velocity fields or for low turbulence intensity, stochastic flux freezing reduces to the usual frozen-in condition (Eyink et al. 2013).

No violent active phenomena such as explosion or mass ejection has been detected in the region near $r \approx 0.12$ pc, so the foregoing usual frozen-in condition is valid. However, the lower limit of the outward radial magnetic field at $r = 0.12$ pc, from the GC is $B \geq 8\ [RM/(66.960\ \mathrm{m}^{-2})] \times [n_e/26\ \mathrm{cm}^{-3}]^{-1}$ mG.

As is well known in the popular black hole model of the GC, the radiation from the vicinity of the black hole originates from the inflowing material of the accretion disk (Yuan and Narayan 2014). However, the accretion plasma is clearly prevented from approaching to the GC by the radial magnetic field in the region near $r \sim 0.12$ pc around the GC at least as explicitly demonstrated above. Thus, the accretion material can't reach the region near the central black hole. Consequently, the radiations observed near the GC cannot be emitted by the gas of the accretion disk. This is a dilemma of the standard accretion disk model of black hole at the GC.

4 The origin of the radial magnetic field and the α-turbulence dynamo mechanism

Now another important question is how to generate the strong magnetic field near the GC by use of the known common conventional physics.

A rotating magnetic instabilities (RMI) is proposed as a angular momentum transfer mechanism in an ionized plasma stream for producing a thin hot coronal plasma jet in the polar region out of the accretion disk (Balbus and Hawley 1991, 1998). The magnetic field will be enhanced due to increases of RMI. Under normal circumstances, the magnetic field may be enhanced to that the magnetic pressure reaches at about $1/10$ of the hot gas pressure in general. But in a special case, the magnetic pressure may reach at near the hot gas pressure.

The distribution of the enhanced magnetic field in the region $100R_g$ ($R_g = R_S/2$) around the central black hole at the GC has been shown in the Fig. 4 of a review paper written by Yuan and Narayan (2014). You may see that the enhance of the magnetic field is in the polar thin hot coronal plasma region perpendicular to the main accretion disk. However, it is impossible to produce the observed strong radial magnetic field ($\geq$ 8 mG) at a distance $r = 0.12$ pc from the GC by RMI mechanism. The reasons are given as follows: (1) The plasma with electron density, $n_e \approx 26\ \mathrm{cm}^{-3}$, is one on the main accretion disk rather than one of the polar thin hot coronal plasma outside the main disk. RMI mechanism is negligible for this region; (2) The enhanced magnetic field is less than 1 μG, even though RMI is taken into account.

The most famous dynamo known up to now is a type of α-turbulence dynamo mechanism firstly proposed by Parker in 1953 (Mestel 1999; Chatteriee et al. 2011) in the solar convection zone. The key idea of the α-turbulence dynamo mechanism is that the induced electro-dynamic potential of turbulence is parallel to the magnetic field (Mestel 1999)

$$\vec{\varepsilon} = \alpha \vec{B}, \tag{5}$$

$$\alpha \equiv \alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}}) = -\frac{\sigma t_c}{3c} \overline{\vec{v} \cdot \nabla \times \vec{v}} = -\frac{\sigma t_c}{3c} \overline{\vec{v} \cdot \vec{w}}, \tag{6}$$

where $\vec{\omega} = \nabla \times \vec{v}$ is the curl of the turbulent velocity of the fluid, and it is approximately equivalent to the large-scale vortex rotational angular velocity. σ is the electrical conductivity of the fluid and t_c is the typical timescale of the turbulence. Equation (5) shows that the electro-dynamic potential of turbulence is proportional to the scalar product of the turbulent velocity with vorticity.

In order to appreciate the important physical significance of the α-turbulence dynamo mechanism, it is appropriate at this point to elaborate more clearly about the novel idea of the mechanism. It is easy to visualize the production of the toroidal magnetic field by the stretching poloidal field lines due to differential rotation, if an astronomical body has some internal differential rotation and a poloidal field that can be stretched. However, if the poloidal field cannot be sustained, it will eventually decay and the production of the toroidal field will also stop. In a famous paper, Parker argued that in a rotating stellar object, turbulent convective motions would be able to complete the cycle by generating a poloidal field from a toroidal field. If the convection takes place in a rotating stellar object, as a rising blob of plasma expands it feels a Coriolis force so that the fluid motion become helical in nature. The nearly frozen-in toroidal field is thus twisted so as to yield poloidal field. The small scale poloidal loops so formed are coalesced through reconnection to yield a large-scale poloidal magnetic field because turbulent diffusion in partially ionized plasma can smoothen out the magnetic fields of the loops. The poloidal and toroidal field can sustain each other through a cyclic feedback process. Thus, briefly, the poloidal field can be stretched by the differential rotation to generate the toroidal field whereas the helical turbulence associated with convection in a rotating frame to give back a field in the poloidal plane.

Historically, the original treatment of Parker was very much based on intuitive arguments. A formal and systematic approach was developed later by Steenbeck, Krause and Rädler, known as mean field magneto-hydrodynamics. The most important physical quantity in this mathematical theory is the mean e.m.f. (or electrical potential) $\vec{\varepsilon}$ induced by the fluctuating flow $\vec{v}$ and magnetic fields $\vec{B}$, namely, $\vec{\varepsilon} = \overline{\vec{v} \times \vec{B}}$, where the overline denotes the ensemble average. For a homogeneous, weakly anisotropic turbulence, the mean electromotive force in the α-turbulence dynamo mechanism is given by (5) and (6). In particular, we note that the helical turbulent motions can twist the toroidal field lines to produce the poloidal field as mentioned before. It is the α-coefficient which encapsulates this effect of helical motions in the mathematical theory.

Therefore, the principle of the α-turbulent dynamo may be briefly sketched as follows: A toroidal magnetic field $\Longrightarrow$ A toroidal electro-dynamic potential$\Longrightarrow$ A toroidal current $\Longrightarrow$ A poloidal magnetic field $\Longrightarrow$ A poloidal electro dynamic potential $\Longrightarrow$ A poloidal current $\Longrightarrow$ A toroidal magnetic field (Priest 1984).

In 1980s, the simulation showed that the intensity of the magnetic flux tube on the surface of the sun is about 10^5 G. Such a strong magnetic tube should be formed at the bottom of the troposphere rather than in the troposphere. The traditional α-turbulence generator cannot operate in such an intense circular magnetic field. To give a more convincible explanation for the periodicity of the sunspot, lots of similar α effect dynamo theories are developed (Charbonneau 2010; Dikpati and Gilman 2001; Ferriz-Mas et al. 1994). For example, the instability of rotational magnetic field may magnify the magnetic field'. That means the toroidal magnetic field is transformed to the poloidal field due to the magnetofluid instability that results from the interaction of the Coriolis force and the differential rotation (in different latitude) in the sun. Generally speaking, the magnification of the magnetic field is driven by the differential rotation that interacts with the Coriolis force.

In fact, the Babcock–Leighton mechanism that is developed at the same time as the turbulent dynamo is recently regarded as the most prospective explanation for the periodicity of the magnetic field activity in the sun (Cameron and Schassler 2015). In accordance with the turbulent dynamo, the poloidal magnetic field is also generated by the Coriolis force. But the Babcock–Leighton mechanism is the Coriolis force acting on the magnetic flux tube in a large scale, leading to the tilt angle that is observed on the surface of the sun in the activation region. So the toroidal magnetic flux tube has a certain poloidal component when it emerges on the surface of the sun. The poloidal component is the result of the attenuation of the active region. The authors in the paper (Ferriz-Mas et al. 1994) indicated that the nonaxisymmetric instability of the toroidal magnetic flux tube in a rotating star can provide a dynamo effect. This instability occurs in the form of spiral waves. The increase in their amplitude causes a phase shift between the disturbed magnetic field and the disturbed flow field, which leads to the generation of an electric field in a direction parallel to the undisturbed field. Coupled with the differential rotation, this effect will produce a type of dynamo. The difference between the traditional turbulence dynamo and it is the traditional turbulence dynamo cannot be applied to the magnetic field that is quite strong while this new type of dynamo qualifies in this case.

Dikpati and Gilman (2001) propose an $\alpha\Omega$ flux-transport dynamo for the Sun that is driven by a tachocline effect. This α-effect comes from the global hydrodynamic instability of latitudinal differential rotation in the tachocline, as calculated using a shallow-water model. Growing, unstable shallow-water modes propagating longitudinally in the tachocline create vortices that correlate with radial motion in the layer to produce a longitude-averaged net kinetic helicity and, hence, an α-effect. It is shown that such a dynamo is equally successful as a Babcock–Leighton-type flux-transport dynamo in reproducing many large-scale solar cycle features (Dikpati and Gilman 2001). The success of both dynamo types depends on the inclusion of meridional circulation of a sign and magnitude similar to that seen on the Sun. Both α-effects (the Babcock–Leighton-type and tachocline α-effect) are likely to exist in the Sun, but it is hard to estimate their relative magnitudes. By extending the simulation to a full spherical shell, it is shown that the flux-transport dynamo driven by the tachocline α-effect selects a toroidal field that is antisymmetric about the equator, while the Babcock–Leighton flux-transport dynamo selects a symmetric toroidal field (Dikpati and Gilman 2001). Since our present Sun selects antisymmetric fields, the tachocline α-effect must be more important than the Babcock–Leighton α-effect.

These theories are still under further research and discussion. The average electric potential generated by them (e.g., see the discussions by Ferriz-Mas et al. (1994)) is just proportional to the magnetic field strength, and its direction is parallel to the magnetic field direction. However, the proportional coefficient α in (5) differs a lot in different theories (Charbonneau 2010). We start the discussion from (5). They are called by a joint name α-turbulent dynamo' while the proportional coefficient α may have an uncertainty in 1–2 orders of magnitude. In the theory of α-turbulent dynamo, the energy of magnetic field per unit volume is equal to the energy of induced electric current per unit volume, thus,

$$\frac{B^2}{4\pi} = ne\varepsilon = ynea(\sigma t_c, \overline{\vec{v}\cdot\vec{\omega}})B \tag{7}$$

so we have

$$B = 8\pi eyn\alpha(\sigma t_c, \overline{\vec{v}\cdot\vec{\omega}}), \tag{8}$$

where n is the number density of the plasma particles, y is the degree of ionization.

Some relevant data in the Sun are given as follows. The mass density in the solar convection zone where dynamo mechanism is valid, is $\rho \approx 8\ \mathrm{g\,cm^{-3}}$, or the number density of particles $n = 5 \times 10^{24}\ \mathrm{cm}^3$; the maximum magnetic field in the solar convection zone is $B_{\max} \sim 10^5$ G. (The details of the differential rotation in solar interior can be found from the following webpage of http://www.aip.de/en/press/images/.)

It is expected that the α-turbulent dynamo model originally developed by Parker valid in the solar convection region can be applied also in accretion disks surrounding massive black holes. The origin of the magnetic fields in the inner region of the accretion disks may be explained in terms of the α-turbulent dynamo model. To estimate the value of α in the inner regions near the GC we may compare the value of relevant parameters involved in the solar convection zone with those in the star forming region in the interstellar clouds. Using this method, it is plausible to believe that the uncertainties of the turbulent velocity $\vec{v}$, he electrical conductivity σ, the time scale for turbulence t_c, and the vorticity $\vec{\omega}$ of the fluid in the solar convection region (see Charbonneau 2010) would not seriously affect the accuracy of our estimation for the magnetic field strength in the inner region of accretion disk near the GC.

Assuming the validity of the α-turbulence dynamo mechanism similar to that in the solar convection zone, and comparing the interstellar magnetic field strength with that of the sunspot, we may estimate the uncertainty of the value of α in terms of the recent observation for the collapsing core W51e2 of the star forming region (Koch et al. 2012).

We deduce from (8)

$$B = B_{\odot\max} \frac{n}{n_\odot} \frac{y}{y_\odot} \frac{\alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}})}{\alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}})_\odot}, \tag{9}$$

$$B \sim 10^{-19} \frac{n}{5\ \mathrm{cm}^{-3}} r(\vec{v}_{\mathrm{turb}}, \sigma t_c)\ \mathrm{G}, \tag{10}$$

where $r(\vec{v}_{\mathrm{turb}}, \sigma t_c) = \frac{n}{n_\odot} \frac{y}{y_\odot} \frac{\alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}})}{\alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}})_\odot}$.

Though the turbulent velocity in an interstellar cloud nay reach $\vec{v}_{\mathrm{turb}} \sim 10\ \mathrm{km\,s^{-1}}$, the curl of the turbulence velocity in the interstellar cloud is far smaller than that in the Sun, but both the typical timescale of turbulence, t_c and the electric conductivity (σ) may be much larger than those of the sun. Thus, the value of the factor $\alpha(\sigma t_c, \overline{\vec{v} \cdot \vec{\omega}})$ is rather uncertain.

However, we may estimate it as follows. In some interstellar cloud, the strongest magnetic field may reach 20 mG and the number density is $n = 2.7 \times 10^7\ \mathrm{cm}^{-3}$ near the collapsing core W51e2. Using (10), the uncertain factor, $r(\vec{v}_{\mathrm{turb}}, \sigma t_c)$, may be determined in terms of the observed data for W51e2 just delineated, thus

$$r(\vec{v}_{\mathrm{turb}}, \sigma t_c) \sim 3.7 \times 10^{10}. \tag{11}$$

In recent work by Qiu et al. (2014), Submillimeter Array Observations of magnetic fields in a H_2 molecular cloud has been made. the magnetic field is estimated about 1 mG, and the corresponding number density is about $2.7 \times 10^5\ \mathrm{cm}^{-3}$. Thus

$$r(\vec{v}_{\mathrm{turb}}, \sigma t_c) \sim 1.85 \times 10^{11}. \tag{12}$$

We can find that the difference of (11) with (12) is a factor of 5 and it is in the uncertainty region of the α-coefficient (it is may be to reach to (1–2) orders of magnitude, see the discussions from Chatteriee et al. (2011)).

Using (9) in (11), with the observed electron number density $n \sim 26\ \mathrm{cm}^{-3}$ at the distance of 0.12 pc from GC (Eatough et al. 2013), the resulting magnetic field is given by $B \le 0.1\ \mu\mathrm{G}$ which is five order of magnitude smaller than the observed lower limit for the field strength, 8 mG (Eatough et al. 2013). At this point, we would like to mention that such strong magnetic field at the distance of 0.12 pc from GC can not be generated by the recent Magnetically arrested accretion disk model (Yuan and Narayan 2014), although a strong vertical bipolar magnetic field is pushed into the central black hole by the thermal and ram pressure of the accreting gas and the maximum magnetic field strength at the horizon ($R_S \approx 10^{12}$ cm) is roughly 10^3 G.

A broad class of astronomical accretion disks is shown to be dynamically unstable to axisymmetric disturbances in the presence of a weak magnetic field by Balbus and Hawley (1991, 1998), an insight with consequently broad applicability to gaseous, differentially-rotating systems. However, we have shown that the RMI (Balbus and Hawley 1991) can not generate the observed strong magnetic field. Also, the magnetic field is not generated by α-dynamo. In addition to the two mechanisms of magnetic field amplification, Cao (2011) proposed that the radial inward advection can also generate strong magnetic field. Cao (2011) calculate the advection/diffusion of the large-scale magnetic field threading an advection-dominated accretion flow (ADAF) and find that the magnetic field can be dragged inward by the accretion flow. The measurement of an abnormally strong radial magnetic field near the GC has been reported in 2013 by Eatough et al. (2013). The lower limit of the outward radial magnetic field near the GC is: $B \ge 8$ mG (at $r = 0.12$ pc). In our paper, we have discussed and demonstrated that the kinematic energy density of the material is less than the energy density of the magnetic field at $r = 0.12$ pc.

On the other hand, the problems discussed and the results obtained by Cao (2011) shall not apply to the content of our paper discussed according to the astronomical observation. We know that for magnetic field, the magnetic flux is conserved. For the radial magnetic field, if the field is adverted inward by gas, Strength of B is proportional to reciprocal of radius square. Therefore, the magnetic field can be easily amplified by inward motion of gas. At this point, we would like to mention that such strong magnetic field at the distance of 0.12 pc from the GC cannot be generated by the recent Magnetically arrested accretion disk model (Yuan and Narayan 2014) due to the strength of B is proportional to reciprocal of radius square, although a strong vertical bipolar magnetic field is pushed into the central black hole by the thermal and ram pressure of the accreting gas and the maximum magnetic field strength at the horizon ($R_S \approx 10^{12}$ cm) is roughly 10^3 Gauss. Thus the inward advection of magnetic field by gas from larger radii (0.12 pc) can produce magnetic field about 0.1 μG much less than observed $B \ge 8$ mG.

Even in strongly magnetized magnetically arrested disk (MAD) state, the black hole can accrete gas through non-axisymmetric spiral streams. Therefore, there should be radiation from the black hole hot accretion flow. Igumenshchev (2008) investigated the dynamics and structure of accretion disks, which accumulate a vertical magnetic field in their centers by using two- and three-dimensional MHD simulations. The central field can be built up to the equipartition level, where it disrupts a nearly axisymmetric outer accretion disk inside a magnetospheric radius, forming a magnetically arrested disk (MAD). On the other hand, the black hole (BH) accretion flows and jets are qualitatively affected by the presence of ordered magnetic fields. McKinney et al. (2012) discuss fully 3D global general relativistic MHD simulations of radially extended and thick (height H-to-cylindrical radius R ratio of $|H/R| \sim 0.2$–1) accretion flows around BHs with various dimensionless spins (a/M, with BH mass M) and with initially toroidally dominated (φ-directed) and poloidally dominated (R–z directed) magnetic fields. However, the above opinions expressed have nothing to do with the problem of radial magnetic field (i.e., $B \geq 8$ mG) at the distance of 0.12 pc from the GC in our paper.

In addition, someone once put forward whether the plasma or gas of accretion disks can flow into a black hole along the radial magnetic field at the center of the Milky Way galaxy. It is simple answer that if there are the material flow along the radial magnetic field to the center of the galaxy, the speed of the radial free fall material will be close to the speed of light. Therefore, the strong powerful radiation will be produced. But this kind of abnormal quite powerful radiation has always been not observed. So this kind of circumstance should be ruled out.

5 Our model of super-massive star with magnetic monopoles (SMSMM)

We note that the important discovery of very strong radial magnetic field in the Vicinity of the GC is consistent with the prediction from our model of SMSMM (Peng 2002). Thus, it is plausible to believe that this is just the astronomical evidence needed for the existence of magnetic monopoles as predicted by the grand unified theory of particle physics. In addition, the observed radiation from radio to sub-mm wavelength band with power peaking around 10^{12} Hz in the sub mm band and the x-ray radiation near the GC are also essentially in agreement with the prediction of our paper (Peng and Chou 2001). In other words, the dilemma of the standard accretion disk model with supermassive black holes at the GC would disappear.

We have investigated the model of SMSMM in a series of papers since 1985 (Peng 1989, 2002; Peng and Chou 1998, 2001; Peng and Wang 1985; Peng et al. 1985a,b; Wang and Peng 1986), and the main ideas of our model are as follows:

(1) The fact that magnetic monopoles (M) may catalyze nucleons to decay (the Rubakov–Callan (RC) effect, $pM \to e^+\pi^0 M$ (85 %) or $pM \to e^+\mu^+\mu^- M$ (15 %), with the number of baryons being non-conserved) as predicted by the grand unified theory of particle physics is invoked as the main energy source of quasars and AGN. The supermassive central black hole in the standard model is replaced by a supermassive object containing magnetic monopoles. And the accretion disk acts only as a minor energy supply.

(2) The gravitational effect around the SMSMM in the galactic center is similar to that around a massive black hole. However, the supermassive object containing sufficient magnetic monopoles has neither the horizon nor the central singularity. This is because the reaction rate of the nucleon decay catalyzed by magnetic monopoles is proportional to the square of mass density. Both the leptons and photons from the decay are emitted outward, and the central density cannot approach infinity. Combined with the RC effect from particle physics, our model can avoid the central singularity problem in the standard model of black hole theory.

On the other hand, some predictions about the GC in our model are as follows (Peng and Chou 2001):

(1) Plenty of positrons are generated and are emitted from the GC. The producing rate is about $6.0 \times 10^{42}\ e^+\mathrm{s}^{-1}$. This prediction is quantitatively confirmed by observation of high energy astrophysics quantitatively (3.4–$6.30 \times 10^{42}\ e^+\mathrm{s}^{-1}$).

(2) Some higher energy radiation above 0.5 MeV may be emitted. The integral energy of the high energy radiation is much higher than both the total energy of the spectra of electron and positron annihilation, and the total thermal luminosity of the central object. This prediction is also consistent with observations.

(3) The magnetic monopole condensed in the core region of the supermassive object can generate radial magnetic field. The magnetic field strength at the surface of the object is about 20–100 Gauss (the radius of the object is about 8.1×10^{15} cm or $1.1 \times 10^4 R_S$ (R_S is the Schwarzschild radius). We declared previously in our article that this prediction is the most crucial one, which can be testified by future radio observations (Peng and Chou 2001). Because the decrease of the magnetic field strength is proportional to the inverse square of the distance from the source, so we have $B \approx (10$–$50)$ mG at $r = 0.12$ pc. This prediction is in agreement with the lower limit of the observed magnetic field (the detailed discussions can be found from the article of Eatough et al. 2013).

(4) The super-massive objects containing saturated magnetic monopoles in the centers of all the AGN in the region $D \leq 50$ Mpc from the earth may be the sources of observed ultra-high energy cosmic rays ($E_\gamma \sim (10^{18}$–$10^{21})$ eV), which can not be explained up to date except our model (Peng and Chou 2001).

(5) The surface temperature of the super-massive object in the galactic center is about 120 K and the corresponding spectrum peak of the thermal radiation is at 10^{12} Hz in the sub-mm wavelength regime. This prediction is basically consistent with the recent observation (Falcke and Marko 2013).

The non-thermal radiation such as synchrotron radiation, may be emitted due to the motion of the relativistic electrons in the magnetic field. However, quantitative comparison of observations with theory is rather difficult now, because the power indexes of both the thermal radiation and the non-thermal radiation for the radio wavelength band have not been well determined yet up to now. The predictions (1), (3), (5) have been confirmed by the astronomical or by the astrophysical observations in quantitative. Especially, the third one is an exclusive prediction. It is hardly a coincidence.

6 Other evidences against the black hole model of quasars and AGN

We now briefly mention some other relevant evidences against the black hole model of quasars and active galactic nuclei (AGN).

(1) On strong radial magnetic fields in the galactic center for 76 radio-loud active galaxies

Zamaninasab et al. (2014) did a statistical analysis on 76 radio-loud active galaxies and concluded that there are very strong radial magnetic fields in the galactic center preventing material in the accretion disk from falling in, i.e. the accretion disk is not near the central black holes in AGN. This could invalidate the standard accretion disk model of black holes in AGN.

(2) On two hot dust-free quasars

Using the Spitzer Space Telescope, Jiang et al. (2006, 2010) discovered two quasars without hot-dust emission in a sample of 21 ($z \approx 6$) quasars by deep infrared photometry.

It is generally believed that quasars are powered by mass accretion onto the central black holes and hot dust is directly heated by quasar activity. So the discovery of the two hot-dust-free quasars becomes a puzzle. The puzzle may be explained in terms of the standard model for quasars with central black holes as follows.

We note that the two hot dust-free quasars with the lowest hot-dust abundances have the smallest black hole masses ($(2\text{–}3) \times 10^8\ \mathrm{M}_\odot$) and highest Eddington luminosity ratios (~ 2) in the $z \approx 6$ sample, thus they are in an early stage of quasar evolution with rapid mass accretion, but are too young to have formed a detectable amount of hot dust around them.

Since the accretion disk is not near the central black holes in the quasars and AGN due to the presence of the observed strong radial magnetic field near the GC, no material can reach the central region of the quasars and AGN and the ultra -luminous radiation cannot be emitted by the accretion disk model of black holes. The observations of the two hot dust-free quasars may be considered as the important evidence that the ultra-luminous radiation of the very young quasars in the early stage of the universe cannot be emitted by the accretion material flow from the accretion disk around, but it may be produced by the RC effect in our AGN model containing magnetic monopoles.

(3) On the mass of the quasars

It is now generally believed by most astronomers that bright quasars observed at large redshift (for example, $z > 1$ or even $z > 5$) are supermassive black holes ($m > 10^{10}\ \mathrm{M}_\odot$) formed in the primordial universe. The spectacularly huge luminosity is supplied by the accretion of matter outside these black holes. As a result, the mass of nearby galactic nuclei and quasars must be greater than that of the remote quasars with larger redshift. This is because the mass of the black holes must continuously increase due to accretion. But the deduction is just contrary to the observation that no supermassive black hole with mass $m > 10^9\ \mathrm{M}_\odot$. Indeed, this is the dilemma of the black hole model of quasars and active galactic nuclei (AGN), although some proposals had been suggested such as: (i) the merger of two galactic nuclei may also form a larger quasar or an AGN; (ii) the mass of the supermassive black holes at the center of AGN (and quasars) in the high red shift region are much larger than those in the low red shift region is only a select effect in observation because the supermassive quasars are easy to observe due to their huge luminosities. But, these proposals cannot explain the fact that why no supermassive black holes ($m > 10^9\ \mathrm{M}_\odot$) have been found near the Milky Way galaxy ($D < 1$ Gpc).

However, it is naturally explained by our AGN model containing magnetic monopoles. The mass of the supermassive object must decrease gradually due to the baryons decay catalyzed by the magnetic monopoles and the decaying products (including pions, muons, positrons and the radiation) are lost from the central massive stellar object continuously. So the conclusion from our AGN model containing magnetic monopoles is that the mass of the quasars and AGN would decrease with the redshift (z). This is consistent with observations.

(4) On Jets of AGNs

Sell et al. (2014) investigated the process of rapid star formation quenching in a sample of 12 massive galaxies at intermediate redshift ($z \sim 0.6$) that host high-velocity ionized gas outflows ($v > 1000\ \mathrm{km\,s^{-1}}$).They conclude that these fast outflows are most likely driven by feedback from star formation rather than active galactic nuclei (AGN). They use multiwavelength survey and targeted observations of the galaxies to assess their star formation, AGN activity, and morphology. Common attributes include diffuse tidal features indicative of recent mergers accompanied by bright, unresolved cores with effective radii less than a few hundred parsecs. The galaxies are extraordinarily compact for their stellar mass, even when compared with galaxies at $z \sim 2\text{–}3$. For 9/12 galaxies, we rule out an AGN contribution to the nuclear light and hypothesize that the unresolved core comes from a compact central starburst triggered by the dissipative collapse of very gas-rich progenitor merging disks. They find evidence of AGN activity in half the sample but we argue that it accounts for only a small fraction ($\sim 10\ \%$) of the total bolometric luminosity. They find no correlation between AGN activity and outflow velocity and they conclude that the fast outflows in our galaxies are not powered by ongoing AGN activity, but rather by recent, extremely compact star-bursts.

Numerical simulations of hot accretion flows around black holes have shown the existence of strong wind Bu et al. (2016a,b). They performed hydrodynamic (HD) simulations and the MHD simulations by taking into account the gravitational potential of both the black hole and the nuclear star cluster. they found that, just as for the accretion flow at small radii, the mass inflow rate decreases inward, and the flow is convectively unstable. However, a trajectory analysis shows that there is very little wind launched from the flow. They concluded the result that wind cannot be produced in the region $R > R_A$ (here R_A is similar to the Bondi radius). The winds are mainly determined by the galactic nuclei clusters of gravitational potential. Near the event horizon surface accretion flow is determined by the black hole's gravitational potential. Their results shown that Jets of active galactic nuclei (i.e., Jet, stellar winds) is actually dominated by the gravitational potential of the galactic nuclei clusters, and has nothing to do with the central black hole. This is very obvious that they do not support the popular view, which the active galactic nuclei jets are strong evidence of black holes model.

7 Conclusions

In conclusion, we have demonstrated that the radiations observed in the contiguous region of the central black hole cannot be emitted by the gas of the disk since the accreting plasma is prevented from approaching to the GC by the ultrastrong magnetic fields. In addition, we have also shown that the observed strong radial magnetic fields near the GC by Eatough et al. (2013), cannot be generated by the α-turbulence dynamo mechanism of Parker because qualitative estimate gives a magnetic field strength six orders of magnitude smaller than the observed field strength at $r = 0.12$ pc. The dilemma of the standard model for quasars and AGN can be avoided if the central black hole in the standard model is replaced by a supermassive stellar object containing magnetic monopoles. The radiations emitted from the inner region of the galactic nucleus and the discovery of the strong radial magnetic field near the GC can all be naturally explained by our model (Peng and Chou 2001). Moreover, the observed ultra-strong radial magnetic field in the vicinity of the GC may be considered as important astronomical evidence for the existence of magnetic monopoles as predicted by the Grand Unified Theory of particle physics.

Acknowledgements We would like to thank Prof. Daniel Wang, Prof. Y.F. Huang, Prof. P.F. Chen and Prof. J.L. Han for their help to inform us some new information of observations. This work was supported in part by the National Natural Science Foundation of China under grants 10773005, 11273020, 11565020, and the Counterpart Foundation of Sanya under grant 2016PT43, the Special Foundation of Science and Technology Cooperation for Advanced Academy and Regional of Sanya under grant 2016YD28, and the Natural Science Foundation of Hainan province under grant 114012.

References

Baganoff, F.K., et al.: Astrophys. J. **591**, 891 (2003)
Balbus, S.A., Hawley, J.F.: Astrophys. J. **376**, 214 (1991)
Balbus, S.A., Hawley, J.F.: Rev. Mod. Phys. **70**, 1 (1998)
Begelman, M.C.: Mon. Not. R. Astron. Soc. **420**, 2912 (2012)
Blandford, R.D., Payne, D.G.: Mon. Not. R. Astron. Soc. **199**, 883 (1982)
Blandford, R.D., Znajek, R.L.: Mon. Not. R. Astron. Soc. **179**, 433 (1977)
Bu, D.F., Yuan, F., Wu, M., Cuadra, J.: Mon. Not. R. Astron. Soc. **434**, 1692 (2013)
Bu, D.F., Yuan, F., Gan, Z.M., Yang, X.H.: Astrophys. J. **823**, 90 (2016a)
Bu, D.F., Yuan, F., Gan, Z.M., Yang, X.H.: Astrophys. J. **818**, 83 (2016b)
Cameron, R., Schassler, M.: Science **347**, 1333 (2015)
Cao, X.W.: Nature **737**, 94 (2011)
Charbonneau, P.: Living Rev. Sol. Phys. **7**, 3 (2010)
Chatteriee, P., et al.: Astron. Astrophys. **534**, 15 (2011)
Dikpati, M., Gilman, P.A.: Astrophys. J. **559**, 428 (2001)
Eatough, R.P., et al.: Nature **591**, 391 (2013)
Eyink, G., et al.: Nature **497**, 4668 (2013)
Falcke, H., Marko, S.B.: (2013). arXiv:1311.1841v1
Ferriz-Mas, A., et al.: Astron. Astrophys. **289**, 949 (1994)
Gu, W.M.: Astrophys. J. **799**, 71 (2015)
Igumenshchev, I.V.: Astrophys. J. **677**, 317 (2008)
Jiang, L., et al.: Astron. J. **132**, 2127 (2006)
Jiang, L., et al.: Nature **464**, 380 (2010)
Knödlseder, J., et al.: Astron. Astrophys. **411**, 457 (2003)
Koch, P.M., Tang, Y.W., Ho, P.T.P.: Astrophys. J. **747**, 79 (2012)
Li, J., Ostriker, J., Sunyaev, R.: Astrophys. J. **767**, 105 (2013)
McKinney, J.C., Tchekhovskoy, A., Blandford, R.D.: Mon. Not. R. Astron. Soc. **423**, 3083 (2012)
Mestel, L.: Stellar Magnetism. International Series of Monographs on Physics, vol. 99. Clarendon, Oxford (1999)
Narayan, R., Igumenshchev, I.V., Abramowicz, M.A.: Publ. Astron. Soc. Jpn. **55**, 69 (2003)
Narayan, R., Sadowski, A., Penna, R.F., Kulkarni, A.K.: Mon. Not. R. Astron. Soc. **426**, 3241 (2012)
Peng, Q.H.: Astrophys. Space Sci. **154**, 271 (1989)
Peng, Q.H.: High Energy Phys. Nucl. Phys. **26**, 104 (2002) (in Chinese)
Peng, Q.H., Chou, C.K.: Astrophys. Space Sci. **257**, 149 (1998)
Peng, Q.H., Chou, C.K.: Astrophys. J. Lett. **551**, 23 (2001)
Peng, Q.H., Wang, Y.: KexT **30**, 1586 (1985)
Peng, Q.H., Li, Z., Wang, D.: SSSMP **28**, 970 (1985a)
Peng, Q.H., Wang, D., Li, Z.: KexT **30**, 1056 (1985b)
Priest, E.R.: Solar Magnetohydrodynamics. Geophysics and Astrophysics Monographs. Reidel, Dordrecht (1984)
Qiu, K., et al.: Astrophys. J. Lett. **794**, 18 (2014)
Sell, P.H., Tremonti, C.A., Hickox, R.C., et al.: Mon. Not. R. Astron. Soc. **441**, 3417 (2014)
Sikora, M., Begelman, M.C.: Astrophys. J. Lett. **764**, 24 (2013)
Wang, D., Peng, Q.: Adv. Space Res. **6**, 177 (1986)

Yuan, F., Narayan, R.: Annu. Rev. Astron. Astrophys. **52**, 529 (2014)
Yuan, F., et al.: Astrophys. J. **598**, 301 (2003)
Yuan, F., Bu, D.F., Wu, M.: Astrophys. J. **761**, 130 (2012)
Yuan, F., Gan, Z.M., Narayan, R., et al.: Astrophys. J. **804**, 101 (2015)
Zamaninasab, M., Clausen-Brown, E., Savolainen, T., Tchekhovskoy, A.: Nature **510**, 126 (2014)