X-Ray Flares from Sagittarius A* and Black Hole Universe

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Sagittarius (Sgr) A* is a massive black hole at the Milky Way center with mass of about 4.5 million solar masses. It is usually quite faint, emiting steadily at all wavelengths including X-rays. Since the beginning of this century, rapid and intensive X-ray flares are regularly detected from Sgr A* at a rate of about once a day. Conventionally, these mysterious events daily occurred at the Milky Way center are believed to be caused by the falling of objects such as asteroids, comets, and planets onto the massive black hole. However, the physical process of how the falling objects to produce the observed X-ray flares is still poorly understood. It is unclear why the gases, formed by tearing the falling objects apart, can be heated up to 100 million degrees Celsius so suddenly on a regular basis. This study develops a new alternative mechanism and provides a possible explanation for the observations of X-ray flares from Sgr A*, in accordance with the black hole universe model that was recently proposed by Zhang. The results obtained from this study indicate that X-ray flares from the Milky Way center can be understood as emissions of the dynamic massive black hole (i.e. Sgr A*). A massive or supermassive black hole, when accreting matter or objects from the outside, becomes dynamic and breaks its event horizon, which leads to the inside hot (or high-frequency) blackbody radiation leaking and produces X-ray flares or bursts. The energies and spectra of X-ray flares that Sgr A* can produce when it accretes objects with various sizes including asteroids, comets, planets, and stars are theoretically analyzed and numerically calculated. In terms of results obtained from these analyses and calculations, we explain the current measurements of X-ray flares from Sgr A*, predict events that will possibly occur at our galactic center in future, and compare the extremely intensive events predicted with the strong X-ray flares measured from other normal and active galactic centers. This study develops a new physical mechanism for the origin of X-ray flares from galactic centers and deepens our understanding to the black hole dynamics, galactic activities, and cosmological evolutions.

1 Introduction

Sagittarius (Sgr) A* is a compact astronomical radio source that was first discovered by [1] at the center of the Milky Way, near the border of the constellations, Sagittarius and Scorpius. The orbital motions of stars around the Milky Way center indicate the presence of a massive black hole with about 4.5 million solar masses, which is spatially coincident with Sgr A* [2–3].

In general, Sgr A* is very faint and emits steadily at all wavelengths, especially in the range of soft X-rays (2-10 keV) with luminosity about 2×10^{33} erg/s [4]. Recently, NASA Chandra X-ray Observatory and other missions such as Swift, NuStar, XMM-Newton, and Roast have discovered intensive and rapid X-ray flares at a rate of about once a day from Sgr A*, with luminosity at the peak up to a few times 10^{35} erg/s [5–7]. The brightest X-ray flare ever observed so far emits in total $\sim 10^{39} - 10^{40}$ ergs of X-rays (2-10 keV) and last a few thousand seconds or hours [8–9]. The X-ray echoes recently discovered reveal that Sgr A* would have been a very violent past with luminosity of $\sim 10^{39}$ erg/s (i.e., a million times brighter than its present normal emission) during the X-ray outbursts of the past few hundred years [10]. X-ray outbursts from some other inactive galaxies can be even much more intensive with luminosity $\sim 10^{44}$ erg/s [11–12]. Luminosities of an active galactic nuclei or a quasar can be extremely high up to 10^{46} erg/s [13–15].

To explain the mysterious X-ray flares, astronomers have suggested that there exists a gas cloud around Sgr A* containing hundred-trillions of asteroids, comets, and planets that are stripped from their parent stars by the tidal forces of the massive black hole. When these objects rain down or are accreted onto the massive black hole, X-ray flares take place via physical processes such as the non-thermal synchrotron emission [16], the inverse-Compton scattering [17], and stochastic electron acceleration [18]. To emit the high-energy X-rays detected, an object that was striped from its parent star had to be torn apart into gases during its falling and the gases when arriving nearly at the massive black hole had to spike to hundreds of million degrees Celsius, which is ten or more times hotter than the center of the Sun. However, why the gases heats up so suddenly and efficiently on a regular basis is still poorly understood. One possible heating scenario recently guessed is based on the physics of solar flares by considering that the lines of magnetic energy contained in the gas flowing into Sgr A* got tangled and the reconnection of magnetic lines leads [19-20], but there still lacks of a quantitative study on this magnetic mechanism. Especially, Sgr A* may not be able to gravitationally tear an asteroid into parts as small as a human body, because the gravitational field difference between the head and feet of a 2-meter height person, who stands on Sgr A* surface is only 10^{-3} m/s^2. Up to the date, astronomical communities are still out on what really caused these giant X-ray flares from Sgr A*. The mechanism for the origin of X-ray flares from the galactic center is still a mystery and in pending for a physical explanation.

Recently, postulating the equivalence between a spactime and a black hole, Zhang [21–22] developed a new cosmological model called black hole universe, which is consistent with Mach's principle, governed by Einstein's general relativity with the cosmological principle of spactime isotropy and homogeneity, and able to explain the existing observations of the universe without encountering difficulties such as the flatness, horizon, inflation, dark matter, and dark energy problems. The studies that have been conducted so far have explained the origin, structure, evolution, expansion, cosmic microwave background radiation, quasar formation and emission, gamma ray bursts (GRBs), and acceleration of black hole universe [15, 22–27]. According to this new cosmological model, the universe originated from a star-like black hole with several solar masses, grew up through a supermassive black hole with billions of solar masses to the present state with hundred sextillions of solar masses by accreting ambient matter and merging with other black holes. More aspects about the black hole universe model have been presented in a sequence of American Astronomical Society (AAS) meetings [28–37]. The black hole universe model establishes a complete new understanding to the dynamics of black holes, so that offers a unique explanation to the observations of various events that relate to the activities of black holes such as quasars [15], gamma ray bursts [25], and X-ray flares from galactic centers (this paper).

This study will focus our investigations on the physical mechanism of X-ray flares from Sgr A*, a massive black hole at the Milky Way center, and provides an alternative explanation for the energy and spectrum measurements of X-ray flares according to the black hole universe model. The results indicate that X-ray flares from the galactic center can be understood as emissions of the dynamic massive black hole. As pointed out in Zhang's early studies, a black hole, when it accretes its ambient matter or objects, becomes dynamic. A dynamic black hole has a broken event horizon and thus cannot hold the inside hot (or high-frequency) blackbody radiation, which leaks out and produces a gamma ray burst if it is a star-like black hole or an X-ray flare if it is a massive or supermassive black hole. The energies and spectra of X-rays obtained by this study for the X-ray emissions from Sgr A* when it accretes appropriate size objects such as asteroids, comets, and planets can be consistent with the measurements.

2 X-ray emissions of dynamic massive black holes

In accordance with the black hole model of the universe developed recently by [21–22], a black hole constructs an individual spacetime (spatially singular and temporally noncausal to the outside) and a spacetime encloses a black hole. Black hole and spactime are equivalent. According to this equivalence, our four-dimensional (4D) spacetime universe is a fully grown extremely supermassive black hole. The observed star-like, massive, and supermassive black holes are subspacetimes of our black hole universe. Upon the view from the outside, a star-like or supermassive black hole is a singular sphere, from which no matter and radiation can escape. In general, a star-like (or larger) black hole can be considered as an ideal blackbody, with the following Mach-Schwarzschild mass-radius (M-R) relation

$$\frac{2GM}{c^2R} = 1, \tag{1}$$

where c is the light speed in the free space and G is the gravitational constant.

The temperature inside a star-like black hole, though it cannot be measured from outside, should be as high as that of a neutron star because both types of objects are comparably compact. At the moment of its birth via a supernova explosion, a neutron star can reach 10^{12} K and then quickly cools down to about 10^8 K because of its strong radiation and neutrino emission [38]. A black hole can hold the high temperature reached at the moment of its birth because it does not radiate significantly. When a star-like black hole accretes matter and radiation from outside, it expands and cools down. As a star-like black hole grows up as big as the present universe, the inside temperature decreases from 10^{12} K to about 3 K. In the black hole universe model, the observed 3 K cosmic microwave background radiation is the internal blackbody radiation of the black hole universe, an ideal blackbody [23, 29].

The spectral energy density of blackbody radiation within a black hole including the black hole universe can be determined according to Planck's law as

$$u(\nu, T) = \frac{8\pi h\nu^3}{c^3} \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}, \tag{2}$$

where ν is the radiation frequency, T is the temperature, h is the Planck constant, and k is the Boltzmann constant. In the SI unit system, the unit of $u(\nu, T)$ is J/m^3/Hz, which is equivalent to 2.41×10^{17} J/m^3/keV. Figure 1 plots the spectral energy density as a function of photon energy $\epsilon = h\nu$ at temperature equal to 10^6, 10^7, 10^8, and 10^9 K, respectively. It is seen that the spectral energy density significantly varies with the temperature and photon energy. Inside a black hole

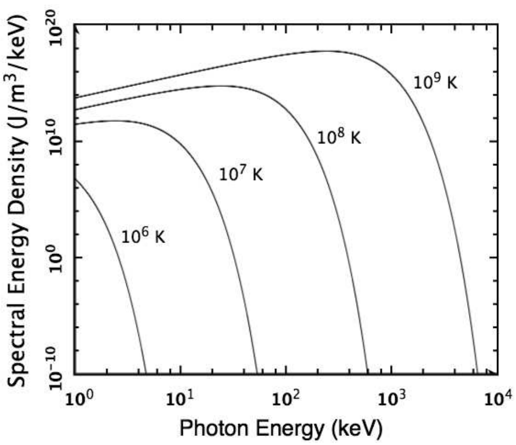

Fig. 1: The spectral energy density of blackbody radiation as a function of radiation energy at temperature equal to 10^6, 10^7, 10^8 K and 10^9 K, respectively.

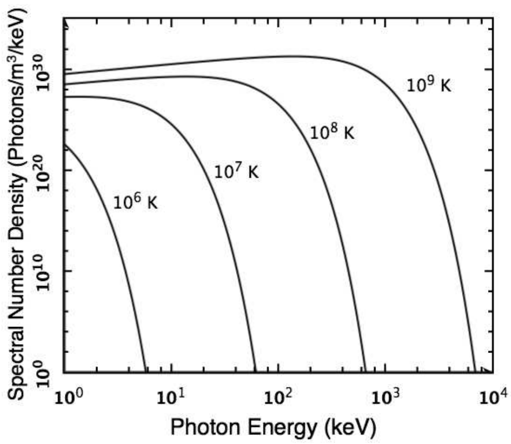

Fig. 2: The spectral number density of blackbody radiation as a function of radiation energy at temperature equal to 10^6, 10^7, 10^9 K and 10^{12} K, respectively.

with temperature of $10^7 - 10^8$ K (e.g. a massive black hole with millions of solar masses), the blackbody radiation dominates at the frequency of X-rays with photon energy in the range of $1 - 200$ keV. The spectral photon number density $f(\nu, T) \equiv u(\nu, T)/\epsilon$ is plotted in Figure 2

Integrating the spectral energy density (Eq. 2) with respect to the frequency of radiation in the entire range, we have the energy density of the blackbody radiation inside a black hole including the black hole universe,

$$\rho_\gamma \equiv \int_0^\infty u(\nu, T) d\nu = \beta T^4, \tag{3}$$

where the constant β is given by $\beta \equiv 8\pi^5 k^4/(15h^3c^3) \simeq 7.54 \times 10^{-16}$ J/m^3/K^4. Inside a black hole with temperature $\sim 10^7 - 10^8$ K, the energy densities of radiation are $\sim 10^{13} - 10^{17}$ J/m^3.

As a black hole including the black hole universe accretes its outside matter and radiation, it expands and cools down. Considering that the increase of the Planck radiation energy within the black hole equals to the radiation energy inhaled from the outside space, we have [23]

$$\frac{dT}{dR} = -\frac{3T}{4R}\left[1 - \left(\frac{T_p}{T}\right)^4\right]. \tag{4}$$

where T is the temperature inside the black hole and T_p is the temperature outside the black hole. This equation determines the temperature inside a black hole in accordance with its size. The solution of Eq. (4) for the dependence of T on R depends on T_p or on the relation between T and T_p. In the early studies [23, 29], Eq. (4) was solved for the present black hole universe that grew up from a hot star-like black hole through a supermassive black hole.

For star-like or supermassive black holes, the temperatures inside should be much greater than the temperatures outside, i.e., $T \gg T_p$. In this case, Eq. (4) can be simply solved as

$$R^3T^4 = C, \tag{5}$$

where C is a constant. Zhang [26] has assumed this constant to be the same for all size star-like or supermassive black holes and quantitatively explained the measurements of GRBs as emissions of dynamic star-like black holes. The value of the constant was determined according to the radius R_s and temperature T_s of a particular (or reference) black hole as $C = R_s^3 T_s^4$. For a three-solar-mass black hole ($M_s = 3M_{\rm Sun}$) to be the reference black hole, its radius is about $R_s = 2GM_s/c^2 \sim 8.89$ km. Choosing its temperature to be $T_s = 10^{12}$ K, we have $C \sim 7 \times 10^{59}$ m^3 K^4. The temperature of a star-like or supermassive black hole decreases as it expands in size according to $T \propto R^{-3/4}$.

Figure 3 plots the temperature of a black hole as a function of the radius or mass of the black hole. The the temperature of a three-solar mass black hole is chosen to be $T_s = 5 \times 10^{11}$ K and 10^{12} K. For Sgr A* with mass of 4.5 million solar masses or radius of 1.33×10^{10} m, the temperature is $\sim 10^7 - 10^8$ K. The frequency of blackbody radiation at the peak to this temperature range is $\sim 10^{18} - 10^{19}$ Hz (or the energy of X-rays at the peak is $\sim 4 - 40$ keV).

From Eqs. (3) and (5), we obtain the total radiation energy U inside a black hole with volume V or radius R to be a constant and independent of its size or mass,

$$U \equiv \rho_\gamma V = \frac{4}{3}\pi\beta R^3 T^4 = \text{Constant}. \tag{6}$$

It is seen that the total radiation energy inside a black hole (either a star-like or supermassive black hole) remains the same or is conserved. A black hole can grow its size by accreting mater from the outside space or merging with other black holes, but cannot increase its total radiation energy.

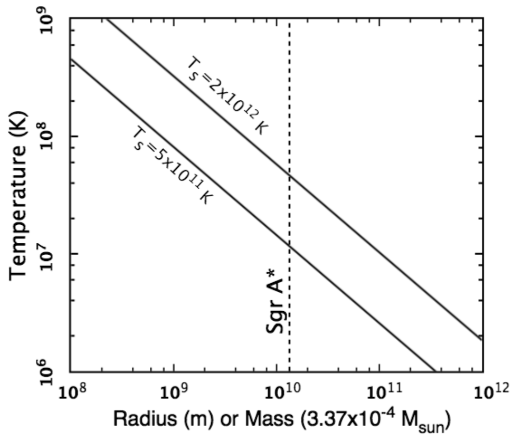

Fig. 3: The temperature of a massive black hole as a function of the radius or mass of the black hole with $T_s = 10^{12}$ K or 5×10^{11}. The vertical dashed line represents the radius, mass, and range of temperature.

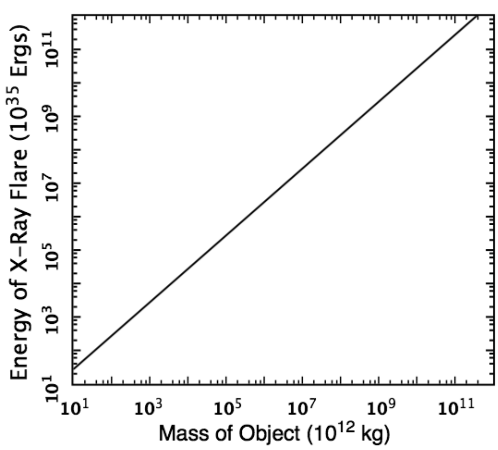

Fig. 4: The energy of X-ray flares from Sgr A* versus the mass of the object accreted.

A star-like black hole with several solar masses holds the same amount of radiation energy as a supermassive black hole with billions of solar masses does. The difference is only the temperature or frequency of the radiation. Dynamic star-like black holes with thousand billions of Kelvins radiate gamma rays [26], while dynamic massive or supermassive black holes with millions to billions of Kelvins radiate X-rays such as X-ray emissions from quasars [15] and X-ray flares from Sgr A*, a massive black hole at the Milky Way center as shown in this study.

3 Energy and energy spectrum of X-ray flares from Sgr A*

According to the black hole universe model, X-ray flares from the Milky Way center are the emissions of the dynamic massive black hole, Sgr A*, which is accreting objects that fail to orbit around Sgr A*.

The energy emitted by Sgr A* with mass M and radius R, after it has accreted an object with mass m and radius r, can be determined by the difference of gravitational potential energies subtracting all other losses or dissipations during the falling of the object towards Sgr A*

$$E = U_{\rm M} + U_{\rm m} + U_{\rm Mm} - U_{\rm M+m} - E_{\rm loss}\,, \tag{7}$$

where $U_{\rm M}$ is the gravitational potential energy of Sgr A* before the object is accreted,

$$U_{\rm M} = -\frac{3GM^2}{5R} = -\frac{3}{10}\,Mc^2; \tag{8}$$

$U_{\rm m}$ is the gravitational potential energy of the object (e.g. an asteroid),

$$U_{\rm m} = -\frac{3Gm^2}{5r} = -\frac{3}{10}\frac{r_g}{r}\,mc^2, \tag{9}$$

with $r_g = 2Gm/c^2$ is the Schwarzschild radius of an object with mass m; $U_{\rm M+m}$ is the gravitational potential energy of Sgr A* after the object is accreted,

$$U_{\rm M+m} = -\frac{3G(M+m)^2}{5(R+\delta R)} = -\frac{3}{10}\,(M+m)\,c^2; \tag{10}$$

and $U_{\rm Mm}$ is the gravitational potential energy between Sgr A* and the object when the object is initially on the orbit,

$$U_{\rm Mm} = -\frac{GMm}{R_{\rm orbit}} = -\frac{1}{2}\frac{R}{R_{\rm orbit}}\,mc^2, \tag{11}$$

with $R_{\rm orbit}$ is the radius of asteroid's initial orbit around Sgr A*; and $E_{\rm loss}$ is the energy lost or dissipated during the object is falling into Sgr A*. Substituting Eq. (8) through Eq. (11) into Eq. (7), we have

$$E = \frac{3}{10}\left(1 - \frac{r_g}{r} - \frac{5R}{3R_{\rm orbit}}\right)mc^2 - E_{\rm loss}. \tag{12}$$

Since $r_g \ll r$ and $R \ll R_{\rm orbit}$, Eq. (12) simply reduces to

$$E \sim \frac{3}{10}\,mc^2, \tag{13}$$

if the loss or dissipation is negligible in comparison with the rest energy of the object. Therefore, the energy of X-ray flares from Sgr A* approximately depends on the mass of the object that Sgr A* has accreted from outside. Figure 4 plots the energy of X-rays emitted by the massive black hole Sgr A* when it accretes an object as a function of the object mass. It is seen that Sgr A* emit more X-rays if it accretes more massive object. For instance, Sgr A* can emit up to 10^{39} ergs of X-rays if it accretes an asteroid with mass of 10^{17} kg.

Table 1 lists the energies of X-ray flares from Sgr A* by accreting some particular objects. Hourly accreting some small-sized asteroids can explain the faint and steady emissions of Sgr A* ($\sim 10^{33}$ ergs/s). Daily accreting one medium-sized asteroid can explain the present observations of X-ray

Type of Object	Mass (kg)	Energy (erg)
Asteroid (small size)	10^{13}	3×10^{36}
Asteroid (medium size)	10^{16}	3×10^{39}
Asteroid (large size)	10^{20}	3×10^{43}
Planet (Pluto size)	1.3×10^{22}	4×10^{45}
Planet (Earth size)	6×10^{24}	2×10^{48}
Planet (Jupiter size)	2×10^{27}	6×10^{50}
Star (1 solar mass)	2×10^{30}	6×10^{53}
Star (100 solar mass)	2×10^{32}	6×10^{55}

Table 1: Mass of various objects and energy of X-ray flares from Sgr A* when it accretes these objects.

flares (about hundred times more luminous than the steady emission) from Sgr A* at a rate of once a day. Occasionally accreting of large-sized asteroids or pluto-sized planets can explain the X-rays outbursts of a million times brighter than the normal emission of Sgr A*, which occurred during the past few hundred years. For big size planets, this may also explain the X-ray outbursts from some other inactive galactic centers. In future, when Sgr A* accretes a star including neutron star daily (or yearly for a large star), an active galactic nucleus (AGN) or quasar will form or is born in our galaxy. It should be noted that the G2 cloud with 3 Earth masses, if it is accreted by Sgr A*, will produce a super X-ray flare, billions times brighter than the normal emissions.

The spectral energy flux $S(\nu, T)$ of the blackbody radiation from a dynamic black hole can be determined by,

$$S(\nu, T) = cu(\nu, T). \tag{14}$$

Dividing the spectral energy flux $S(\nu, T)$ by the energy of photon, we have the spectral photon flux as,

$$J(\nu, T) \equiv \frac{S(\nu, T)}{h\nu} = cf(\nu, T). \tag{15}$$

For the radiation observed at the Earth, the spectral flux of an X-ray flare produced by the dynamic massive black hole Sgr A*, when it accretes an object, is given by,

$$J(\nu, T) = cf(\nu, T)\left(\frac{r_0}{d_L}\right)^2, \tag{16}$$

where d_L is the luminosity distance and r_0 is the radius of radiation area, which is the area of the horizon broken. The temperature T of Sgr A* can be estimated, according to Eq. (5), by

$$T = T_s\left(\frac{R_s}{R}\right)^{3/4} = T_s\left(\frac{c^2 R_s}{2GM}\right)^{3/4}, \tag{17}$$

where M is the mass of Sgr A* and equals to about 4.5 million solar masses. As mentioned above or in [25–26], R_s is the radius of the three-solar-mass black hole and is equal to ~ 8.89 km; T_s is the temperature of the three-solar-mass black hole and is usually chosen to be around one trillion Kelvins, i.e. $T_s \sim 10^{12}$ K. Then we have the temperature of inside Sgr A* is $T \sim 2.3 \times 10^7$ K.

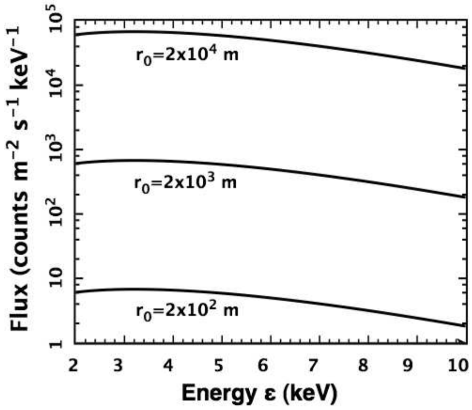

Fig. 5: The spectral flux of dynamic massive black hole Sgr A* as a function of radiation photon energy.

For the massive black hole Sgr A*, $d_L \sim 2.46 \times 10^{20}$ m or 26,000 light-years. The radius of radiation area r_0 can be considered to be about the radius of the object accreted by Sgr A* times a factor, $r_0 = br$. The factor b is equal to the unity if the full area of radiation faces towards to the observer or the Earth. Otherwise, we have $b < 1$ or $r_0 < r$. In addition, since the object is usually broken by the tidal force during the falling, the factor b should be smaller. An X-ray flare occurred at the opposite side of Sgr A* cannot be directly observed by an observer on the Earth. In this case, the factor b is zero. The 400 brighter than normal emission X-ray flare caught by Chandra on September 14, 2013 flares its X-rays in the upright direction according to the image [9,19]. Considering that an asteroid, whose density is usually given by about 2000 kg/m^3, has mass of 10^{17} kg, we can find its radius $r \sim 23$ km and choose r_0 equal or less than 23 km. Figure 5 plots the average spectral flux of an X-ray flare from Sgr A* as a function of the X-ray photon energy. In this plot, we have chosen $r_0 = 200, 2000, 20000$ m, respectively, and $T_s = 10^{12}$ K. It is seen that the spectral flux of X-ray flares from Sgr A*, according to this new mechanism, increases with r_0. Increasing T_s also increases the spectral flux especially in high energy end. Quantitatively, the spectral flux of X-ray flares from Sgr A* obtained from this study as emissions of dynamic massive black hole can be consistent with the measurements [39].

4 Discussion and conclusion

According to this new mechanism, the duration or time scale of an X-ray flare is the time needed for the broken horizon to be recovered. It depends on the size of the object accreted and also the rate or speed of matter diffusion. In general, the bigger the events are, the longer the flares can last, which agrees with the measurements. The rate of matter diffusion depends on the state of matter. The rate of diffusion is faster if the matter is hotter and/or less dense. The falling of the object is usually dissipated due to radiation of lower frequencies such as near infrared as measured usually prior to the X-ray flares. In addition, the observed spectral flux of X-ray flares from Sgr A* may be significantly affected by the gravitational redshift. In future, we will address these issues in more details.

We have developed a new mechanism for X-ray flares from Sgr A*, in accordance with the black hole model of the universe that Zhang [21–22] recently proposed. According to this new mechanism, we can understand X-ray flares from Sgr A* as emissions of dynamic massive black hole at the Milky Ways center. A black hole (from star-like with several solar masses through supermasive with billions of solar masses), when accreting matter, becomes dynamic and breaks its event horizon, which leads to the inside hot (or high-frequency) blackbody radiation leaking out of it and produces an X-ray flare or burst. We calculate the energies and spectra of X-rays emitted by the galactic center massive black hole when various sized objects from asteroids through comets and planets to stars fall into Sgr A*. Then, through these calculations, we explain the current measurements of X-ray flares from Sgr A* including its steady emissions, predict big events that possibly occurred in the past or will possibly occur in future at our galactic center, and compare the predicted intensive events with the measurements of strong X-ray flares from other normal and active galactic centers. This study develops a possible mechanism for the origin of the X-ray flares from galactic centers and deepens our understanding to the black hole dynamics, galactic activities, and cosmological evolutions.

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References

1. Balick B., Brown R.L. Intense sub-arcsecond structure in the galactic center. *Astrophysics and Space Science*, 1974, v. 194, 265–270.
2. Schödel R. et al. A star in a 15.2-year orbit around the supermassive black hole at the centre of the Milky Way. *Nature*, 2002, v. 419, 694–696.
3. Gillessen S., Eisenhauer F., Trippe S., Alexander T., Genzel R., Martins F., Ott T. Monitoring stellar orbits around the massive black hole in the galactic center. *Astrophysical Journal*, 2009, v. 692, 1075–1109.
4. Degenaar N, Miller J.M., Kennea J., Gehrels N., Reynoids M.T., Wijnands R. The X-ray flaring properties of Sgr A* during six years of monitoring with Swift. *Astrophysical Journal*, 2013, v. 769, article id. 155, 7 pages.
5. Baganoff F.K. et al. Rapid X-ray flaring from the direction of the supermassive black hole at the Galactic Centre. *Nature*, 2001, v. 413, 45–48.
6. Porquet D. et al. XMM-Newton observation of the brightest X-ray flare detected so far from Sgr A*. *Astronomy and Astrophysics*, 2003, v. 407, L17–L20.
7. Neilsen J. et al. A Chandra/HETGS census of X-ray variability from Sgr A* during 2012. *Astrophysics Journal*, 2013, v. 774, article id. 42.
8. Nowak M.A. et al. Chandra/HETGS observations of the brightest flare seen from Sgr A*. *Astrophysical Journal*, 2012, v. 759, article id. 95.
9. Haggard D. et al. An update on Chandra/VLA galactic center campaigns targeting Sgr A* and G2. *American Astronomical Society 225th Meeting*, 2015, Abstract #102.09.
10. Clavel M. et al. The reflection of two past outbursts of Sagittarius A* observed by Chandra during the last decade. *Proceedings of the International Astronomical Union*, 2014, v. 303, 344–348.
11. Komossa S., Greiner J. Discovery of a giant and luminous X-ray outburst from the optically inactive galaxy pair RX J1242.6-1119. *Astronomy and Astrophysics*, 1999, v. 349, L45–L48.
12. Saxton R.D. et al. An X-ray and UV flare from the galaxy XMMSL1 J061927.1-655311. *Astronomy and Astrophysics*, 2014, v. 572, article id. A1, 9 pages.
13. Bahcall J.N., Kirhakos S., Saxe D.H., Schneider D.P. Hubble space telescope images of a sample of 20 nearby luminous quasars. *Astrophysical Journal*, 1997, v. 479, 642–658.
14. Begelman M.C., King A. R., Pringle J. E. The nature of SS433 and the ultraluminous X-ray sources. *Monthly Notices of the Royal Astronomical Society*, 2006, v. 370, 399–404.
15. Zhang T.X. Quasar formation and energy emission in black hole universe. *Progress in Physics*, 2012, v. 8, issue 3, 48–53.
16. Kusunose M., Takahara F. Synchrotron blob model of infrared and X-ray flares from Sagittarius A*. *Astrophysical Journal*, 2011, v. 726, article id. 54, 6 pages.
17. Yusef-Zadeh F. et al. An Inverse compton scattering origin of X-ray flares from Sgr A*. *Astronomical Journal*, 2012, v. 144, article id. #1, 10 pages.
18. Liu S.M., Fulvio M., and Yahe F. Stochastic electron acceleration during the near-infrared and X-ray flares in Sagittarius A*. *Astrophysical Journal*, 2006, v. 636, 798–803
19. Sagittarius A*: NASA Chandra Detects Record-Breaking Outburst from Milky Way's Black Hole (2015). Accessed from: http://chandra.harvard.edu/photo/2015/sgra
20. Li Y.P. et al. Statistics of X-Ray Flares of Sagittarius A*: Evidence for Solar-like Self-organized Criticality Phenomena. *Astrophysical Journal*, 2015, v. 810, article id. 19, 8 pages.
21. Zhang T.X. A new cosmological model: Black hole universe. *American Astronomical Society 211st Meeting*, 2007, Abstract #152.04.
22. Zhang T.X. A new cosmological model: Black hole universe. *Progress in Physics*, 2009a, v. 2, 3-11.
23. Zhang T.X. Cosmic microwave background radiation of black hole universe. *Astrophysics and Space Science*, 2010a, v. 330, 157-165
24. Zhang T.X. Key to the mystery of dark energy: Corrected relationship between luminosity distance and redshift. *Progress in Physics*, 2013, v. 5, issue 3, 1–6.
25. Zhang T.X. A new mechanism for gamma ray bursts: Emissions of dynamic black holes. *Proceeding of Gamma Ray Burst 2013 Symposium*, 2013b, SNSN-323-63.
26. Zhang T.X. Gamma ray bursts of black hole universe. *Astrophysics and Space Science*, 2015, v. 358, article id. #14, 8 pages.
27. Zhang T.X., Frederick C. Acceleration of black hole universe. *Astrophysics and Space Science*, 2014, v. 349, 567–573.
28. Zhang T.X. Anisotropic expansion of the black hole universe. *American Astronomical Society 213rd Meeting*, 2009b, Abstract #357.03.
29. Zhang T.X. Cosmic microwave background radiation of black hole universe. *American Astronomical Society 214th Meeting*, 2009c, Abstract #303.01.

30. Zhang T.X. Observation evidences of black hole universe. *American Astronomical Society 215th Meeting*, 2010b, Abstract #313.06.
31. Zhang T.X. Black hole universe model and dark energy. *American Astronomical Society 217th Meeting*, 2011, Abstract #404.05.
32. Zhang T.X. Mechanism for gamma-ray bursts and black hole universe. *American Astronomical Society 219th Meeting*, 2012b, Abstract #310.02.
33. Zhang T.X. Acceleration of black hole universe. *American Astronomical Society 220th Meeting*, 2012c, Abstract #321.07.
34. Zhang T.X. Key to the mystery of dark energy: Corrected relationship between luminosity distance and redshift. *American Astronomical Society 221st Meeting*, 2013c, Abstract #323.06.
35. Zhang T. X. Evidences for supporting the black hole universe model. *American Astronomical Society 222nd Meeting*, 2013d, Abstract #103.02.
36. Zhang T.X. Black hole universe model for explaining GRBs, X-ray flares, and quasars as emissions of dynamic star-like, massive, and supermassive black holes. *American Astronomical Society 223rd Meeting*, 2014a, Abstract #427.05.
37. Zhang T.X. The black hole universe model. *American Astronomical Society 224th Meeting*, 2014b, Abstract #304.03.
38. Yakovlev D.G., Gnedin O.Y., Kaminker A.D., Levenfish K.P., Potekhin A.Y. Neutron star cooling: Theoretical aspects and observational constraints. *Advances in Space Research*, 2004, v. 33, 523–530.
39. Barriére N.M. et al. NuSTAR detection of high-energy X-ray emission and rapid variability from Sagittarius A* flares. *Astrophysical Journal*, 2014, v. 786, article id. 46, 10 pages.