

Is there life inside black holes?

V I Dokuchaev

Institute for Nuclear Research of the Russian Academy of Sciences
60th October Anniversary Prospect 7a, 117312 Moscow, Russia

E-mail: dokuchaev@ms2.inr.ac.ru

Abstract. Bound inside rotating or charged black holes, there are stable periodic planetary orbits, which neither come out nor terminate at the central singularity. Stable periodic orbits inside black holes exist even for photons. These bound orbits may be defined as orbits of the third kind, following the Chandrasekhar classification of particle orbits in the black hole gravitational field. The existence domain for the third kind orbits is rather spacious, and thus there is place for life inside supermassive black holes in the galactic nuclei. Interiors of the supermassive black holes may be inhabited by advanced civilizations of the third type (according to Kardashev scale), being invisible from the outside and basking in the light of central singularity, as well as orbital photons. In principle, one can get information from the interiors of black holes by observing their white hole counterparts.

PACS numbers: 04.20.Dw, 04.70.Bw, 96.55.+z, 98.35.Jk, 98.62.Js

1. Introduction

A voyage inside the Black Hole (BH) event horizon may be not finished in the central singularity after a finite proper time of the traveler, but once again outside the event horizon. However, due to the complicated internal BH geometry [1, 2, 3, 4, 5, 6, 7], it would be an emergence in the *other* universe rather than a return to the traveler's native one. Is it possible to live long inside the BH avoiding both the downfall to the central singularity and escaping to another universe? To clarify this possibility we suppose that BH interiors are described by the Kerr-Newman metric with a maximally extended global geometry [1, 2, 3, 4, 8, 9, 10]. These BHs are named the eternal ones. The corresponding Carter-Penrose conformal diagram of the eternal black is an infinite stairway of asymptotically flat space-times, connected by the one-way Einstein-Rosen bridges. The entries and outlets of these Einstein-Rosen bridges are, respectively, the event horizons of the black and white holes. We demonstrate below that living inside the eternal BHs is possible in principle, if these BHs are rotating or charged and massive enough for weakening the tidal forces and radiation of gravitational waves to acceptable level.

After traversing the BH event horizon at radius $r = r_+$, a traveler will appear in the T -region [11], where his radial coordinate r would become a temporal one and inevitably diminishing towards the central singularity. The irresistible infall in the T -region will finish soon after traversing the inner Cauchy horizon at $r = r_- < r_+$, which is nonzero for the rotating or charged BH. The internal space-time domain $0 < r < r_-$ between the central singularity and the inner BH horizon is the R -region, where stationary observers may exist just as anywhere on the planet Earth. This internal BH domain, hidden by the two horizons from the whole external universe, is indeed a suitable place for safe inhabitation. The only thing needed is to put your vehicle or your planet to a stable periodic orbit inside BH. We discuss below some specific properties of stable periodic orbits of planets and photons inside the rotating charged BH, described by the Kerr-Newman metric.

2. Stable periodic orbits inside BH

Subramanyan Chandrasekhar [2] designated two general types of particle orbits in the BH gravitational field: orbits of the *first kind*, which are completely confined outside the BH event horizon, and orbits of the *second kind*, which penetrate inside the BH. Here we also propose to distinguish orbits of a *third kind*, which are completely bound inside the BH, not escaping outside, nor infalling into the central singularity. The bound orbits of the third kind inside the inner BH horizon were found by Jiří Bičák, Zdeněk Stuchlík and Vladimír Balek [12, 13] for charged particles around the rotating charged BHs (see also [14, 15]) and by Eva Hackmann, Claus Lämmerzahl, Valeria Kagramanova and Jutta Kunz [16] for neutral particles around rotating BHs (see also [17]). The bound orbits of the third kind are periodic and stable if gravitational and electromagnetic

radiation is neglected.

Geodesics equations for neutral test particles and photons and equations of motion for charged particles in the Kerr-Newman metric were derived by B. Carter [10]. According to these equations the motion of test particle with a mass μ and electric charge ϵ in the background gravitational field of a BH with a mass M , angular momentum $J = Ma$ and electric charge e is completely defined by three integrals of motion: the total particle energy E , the azimuthal component of the angular momentum L and the Carter constant Q , related with a total angular momentum of the particle. The Carter constant is zero, $Q = 0$, if trajectories are confined in the BH equatorial plane. In particular, the total angular momentum of the particle is $\sqrt{Q + L^2}$ in the case of nonrotating BH.

An orbital trajectory of test planet is governed in the Boyer-Lindquist coordinates (t, r, θ, φ) by equations of motion [10, 18]:

$$\rho^2 \frac{dr}{d\lambda} = \pm \sqrt{V_r}, \quad (1)$$

$$\rho^2 \frac{d\theta}{d\lambda} = \pm \sqrt{V_\theta}, \quad (2)$$

$$\rho^2 \frac{d\varphi}{d\lambda} = L \sin^{-2} \theta + a(\Delta^{-1} P - E), \quad (3)$$

$$\rho^2 \frac{dt}{d\lambda} = a(L - aE \sin^2 \theta) + (r^2 + a^2) \Delta^{-1} P, \quad (4)$$

where $\lambda = \tau/\mu$, τ — is a proper time of particle and

$$V_r = P^2 - \Delta[\mu^2 r^2 + (L - aE)^2 + Q], \quad (5)$$

$$V_\theta = Q - \cos^2 \theta [a^2(\mu^2 - E^2) + L^2 \sin^{-2} \theta], \quad (6)$$

$$P = E(r^2 + a^2) + \epsilon e r - aL, \quad (7)$$

$$\rho^2 = r^2 + a^2 \cos^2 \theta, \quad (8)$$

$$\Delta = r^2 - 2r + a^2 + e^2. \quad (9)$$

We will use mainly the normalized dimensionless variables and parameters: $r \Rightarrow r/M$, $a \Rightarrow a/M$, $e \Rightarrow e/M$, $\epsilon \Rightarrow \epsilon/\mu$, $E \Rightarrow E/\mu$, $L \Rightarrow L/(M\mu)$, $Q \Rightarrow Q/(M^2\mu^2)$. The radius of BH event horizon $r = r_+$ and the radius of BH inner horizon $r = r_-$ are both the roots of equation $\Delta = 0$: $r_\pm = 1 \pm \sqrt{1 - a^2 - e^2}$.

The effective potentials V_r and V_θ in (5) and (6) define the motion of particles in r - and θ -directions [18]. In particular, for a circular orbit at some radius r , equations (5) and (6) give conditions:

$$V_r(r) = 0, \quad V'_r(r) \equiv \frac{dV_r}{dr} = 0. \quad (10)$$

The circular orbits would be stable if $V''_r < 0$, i. e. in the maximum of the effective potential. In the case of a rotating BH (with $a \neq 0$), a particle on the orbit with $r = \text{const}$ may additionally be moving in the latitudinal θ -direction. These nonequatorial orbits are called *spherical orbits* [19]. The purely circular orbits will correspond to the particular case of spherical orbits with parameter $Q = 0$, completely confined in the BH equatorial plane.

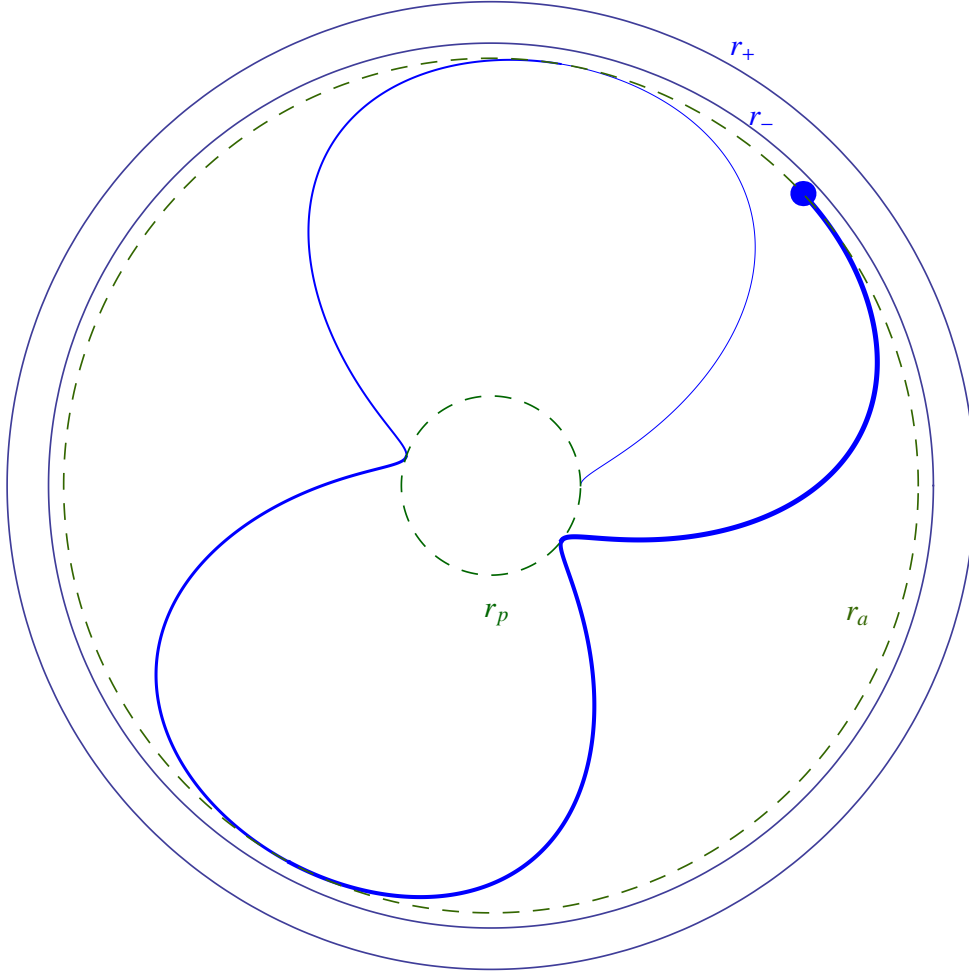


Figure 1. The stable periodic orbit of planet with a mass μ and charge $\epsilon = -1.45\mu$ entirely inside the BH with a mass M and charge $e = 0.999M$. Orbit parameters: $E = 1.5\mu$, $L = 0.2M\mu$, azimuthal and radial periods $(T_\varphi, T_r) = (14.9M, 7.17M)$, the perigee and apogee radii $(r_p, r_a) = (0.19M, 0.92M)$.

2.1. Circular orbits inside nonrotating charged BH

We first consider the Reissner-Nordström case of nonrotating charged BH. From the joint resolution of equations (10) we find two pairs of solutions, respectively, for the energy E and angular momentum L of massive particle with charge ϵ on the circular orbit with radius r :

$$E_{1,2} = \frac{\pm \Delta D_1 - e\epsilon(r^2 - 4r + 3e^2)}{2r(r^2 - 3r + 2e^2)}, \quad (11)$$

$$L_{1,2}^2 = \frac{r^2}{r^2 - 3r + 2e^2} \left[r - e^2 + \frac{e\epsilon\Delta(e\epsilon \pm D_1)}{2(r^2 - 3r + 2e^2)} \right]. \quad (12)$$

where

$$D_1^2 = e^2(\epsilon^2 + 8) + 4r(r - 3). \quad (13)$$

The stability condition $V_r''(r, E, L) < 0$ for circular orbits inside the inner horizon, $0 < r < r_-$, is satisfied for the first pair of solution $(E_1, L_1,)$ in equations (11) and (12), if $\epsilon > \mu$, and for the second pair $(E_2, L_2,)$, if $\epsilon < -\mu$. Figure 1 is an example of a stable periodic orbit of a charged particle inside a nonrotating BH, calculated from equations (1) and (3), using a general formalism for motion in the central field [20].

2.2. Spherical orbits of neutral particles inside BH

In the Kerr-Newman case the stable circular orbits (and also the stable spherical ones) exist inside the inner horizon not only for charged particles, but also for neutral ones ($\epsilon = 0$) and photons ($\mu = 0$). From equations (10) we find two pairs of solutions for energy E and azimuthal impact parameter $b = L/E$ of neutral massive particle on the spherical orbit:

$$E_{1,2}^2 = \frac{\mp 2D_2 + \beta_1 r^2 + a^2[2(r - e^2)\Delta - r^2(r - 1)^2]Q}{r^4[(r^2 - 3r + 2e^2)^2 - 4a^2(r - e^2)]}, \quad (14)$$

$$b_{1,2} = \frac{\pm D_2 r - a^2(r - e^2)\{\beta_2 r + [a^2 - r(r - e^2)]Q\}}{a(r - e^2)\{r[(\Delta - a^2)^2 - a^2(r - e^2)] + a^2(1 - r)Q\}},$$

where

$$\beta_1 = (r^2 - 3r + 2e^2)(r^2 - 2r + e^2)^2 - a^2(r - e^2)[r(3r - 5) + 2e^2], \quad (15)$$

$$\beta_2 = e^4 - a^2(r - e^2) + 2e^2 r(r - 2) - r^2(3r - 4), \quad (16)$$

$$D_2^2 = [a(r - e^2)\Delta]^2[(r - e^2)r^4 - r^2(r^2 - 3r + 2e^2)Q + a^2Q^2]. \quad (17)$$

It can be shown that stable spherical orbits are realized for the first pair of solution (E_1, b_1) with $0 < Q < Q_{\max}$, where Q_{\max} is a root of the marginal stability equation $V_r'' = 0$. All spherical orbits with $Q < 0$ are unstable (see also [19]). The analogous formulae for spherical orbits of charged particles in the Kerr-Newman case are very cumbersome, and we are not reproducing them here.

2.3. Spherical orbits of photons inside BH

The spherical photon orbit corresponds to the ultrarelativistic limit for massive particle energy on the spherical orbit, $E \rightarrow \infty$. This limit is equivalent to the case $\mu = 0$. Photon orbit depends on two parameters, the azimuthal impact parameter $b = L/E$ and the latitudinal (tangential) impact parameter $q = Q/E^2$. Equations (14) in the ultrarelativistic limit are very simplified:

$$b_1 = \frac{a^2(1 + r) + r(r^2 - 3r + 2e^2)]}{a(1 - r)}, \quad b_2 = \frac{a^2 + r^2}{a}, \quad (18)$$

$$q_1 = \frac{r^2[4a^2(r - e^2) - (r^2 - 3r + 2e^2)^2]}{a^2(1 - r)^2}, \quad q_2 = -\frac{r^4}{a^2}. \quad (19)$$

Here the first pair of impact parameters, (b_1, q_1) , corresponds to stable spherical photon orbits, while the second pair, (b_2, q_2) , to unstable ones. The stability condition $V_r'' \leq 0$

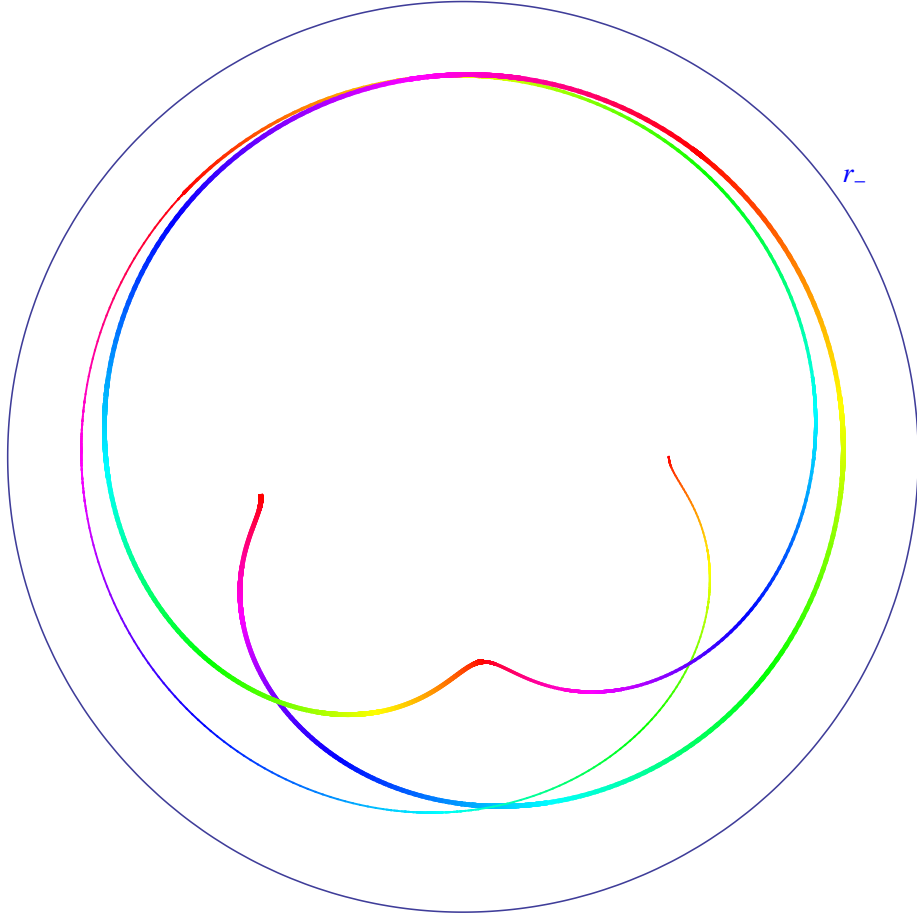


Figure 2. The stable periodic equatorial photon orbit with the impact parameter $b = 1.53$ inside the BH with $a = 0.75$ and $e = 0.6$. Orbit parameters: $(T_r, T_\varphi) = (2.7, 2.1)$, $(r_p, r_a) = (0.33, 0.61)$. The external circle is the inner horizon with $r = r_-$. Note that the equatorial photon, starting at azimuth angle $\varphi = 0$, is orbiting in opposite direction with respect to BH rotation.

for spherical photons with the first pair of impact parameters (b_1, q_1) is written in the form

$$a^2 + e^2 - r(r^2 - 3r + 3) \leq 0. \quad (20)$$

From this inequality we find the upper limit of impact parameter $q_1 > 0$ for stable spherical photons:

$$q_1 \leq \left(\frac{1 - \delta^{1/3}}{a} \right)^2 [3 - 4e^2 - 2(3 - 2e^2)\delta^{1/3} + 3\delta^{2/3}], \quad (21)$$

where $\delta = 1 - a^2 - e^2$. The maximal allowable value for q_1 is reached for the extreme BH with $a = \sqrt{1 - e^2} \leq 1/2$, $e \leq \sqrt{3}/2$:

$$q_{1,max} = 4 - a^{-2} \leq 3. \quad (22)$$

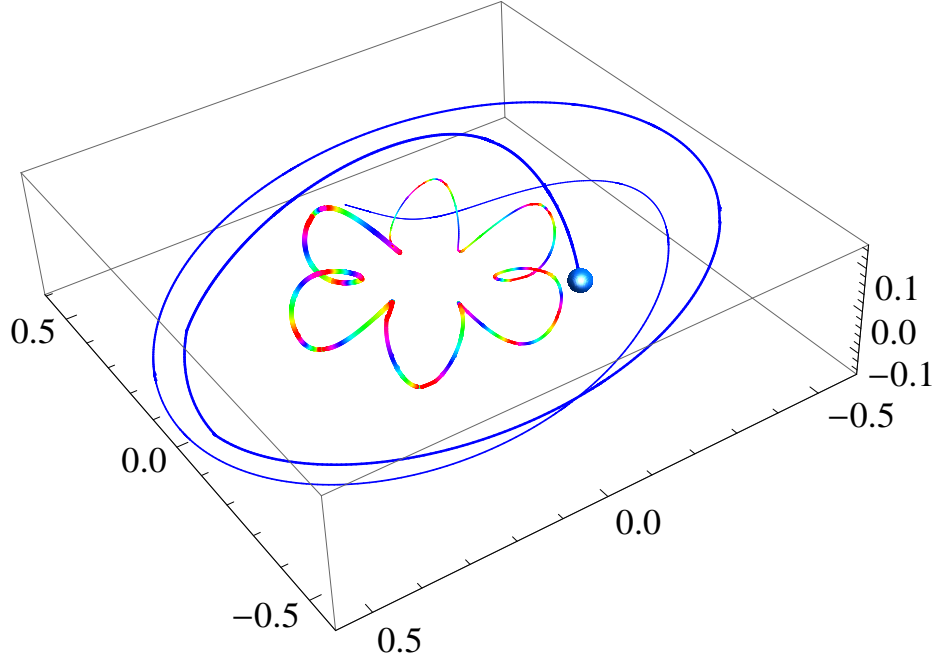


Figure 3. *Outer curve:* the stable periodic orbit of planet with orbital parameters $(E, L, Q) = (0.568, 1.13, 0.13)$, periods $(T_\varphi, T_r, T_\theta) = (1.63, 3.70, 1.17)$, apogee and perigee radii $(r_p, r_a) = (0.32, 0.59)$ and the maximum angle of latitude elevation relative to the equatorial plane $\theta_{\max} = 14.6^\circ$ inside the BH with $a = 0.9982$ and $e = 0.05$. *Inner curve:* the stable periodic nonequatorial photon orbit with orbit parameters: $(b, q) = (1.38, 0.03)$, $(T_\varphi, T_r, T_\theta) = (2.95, 0.49, 0.33)$, $(r_p, r_a) = (0.14, 0.29)$ and $\theta_{\max} = 10.1^\circ$ inside the same BH. The starting parts of orbits are thin, while the ending parts are thick

Figure 2 is an example of stable periodic equatorial photon orbit inside the slightly charged but near extremely rotating BH. Figures 3 and 4 are, respectively, the examples of stable periodic planet and photon orbits inside a slightly charged but near extremely rotating BH with the canonical specific angular momentum $a_{\text{lim}} = 0.09982$ due to untwisting by a thin accretion disk [21].

2.4. Circular orbits of photons inside BH

The spherical orbits become circular ones in the particular case of $Q = 0$. A corresponding relation for circular photon orbits follows in the relativistic limit from equation (14) or from (18) and (19):

$$4a^2(r - e^2) = (r^2 - 3r + 2e^2)^2. \quad (23)$$

with two possible solutions for impact parameter

$$b_{1,2} = \frac{a\beta_2 \pm r^2 \sqrt{(r - e^2)\Delta^2}}{(r^2 - 2r + e^2)^2 - a^2(r - e^2)}, \quad (24)$$

where Δ and β_2 are, respectively, from (9) and (16). In (24) the first solution q_1 (with a plus sign) corresponds to the stable orbit, whereas q_2 corresponds to the unstable one.

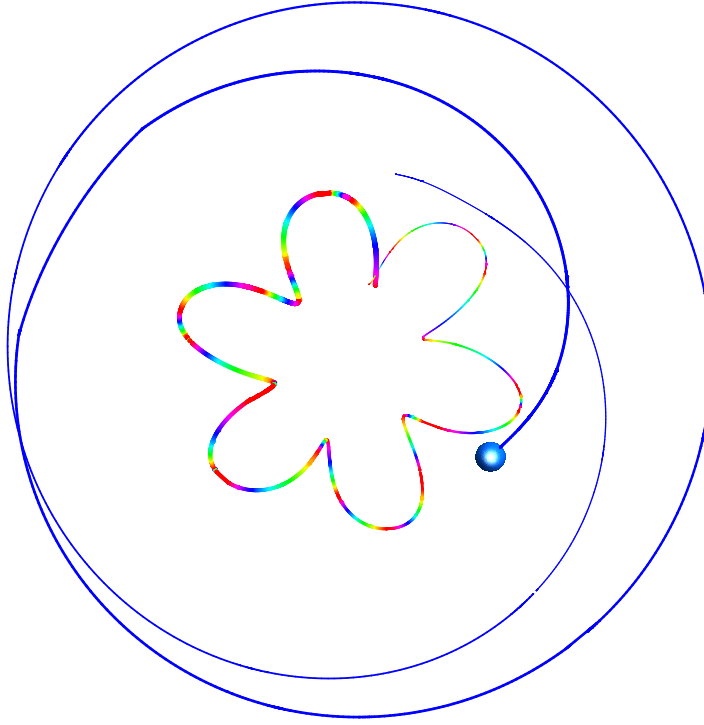


Figure 4. The stable periodic orbits of photon and planet (shown in figure 3) viewed from the coordinate frame north pole. The naked central singularity is glowing in the center. The starting parts of orbits are thin and the finishing parts are thick.

See in figure 5 the $3D$ domain of existence for the stable circular photons inside BH. These orbits exist at $e^2 \leq r \leq (4/3)e^2$, $a \neq 0$, $0 < e \leq \sqrt{3}/2$ and $0 < b < 5/2$. Note, that equatorial stable orbits for planets and photons inside the Kerr BH ($e = 0$) are absent at all. They are only nonequatorial ones.

3. Conclusions

Inside the inner Cauchy horizon of the Kerr-Newman BH there are stable periodic orbits of particles (planets) and photons (orbits of the third kind). In the case of a nonrotating charged BH ($a = 0$) the stable periodic orbits exist only for particles with a large enough charge. All the stable periodic planet and photon orbits inside the rotating and noncharged BH ($e = 0$) are nonequatorial. We hypothesize that the advanced civilizations may live safely inside the supermassive BHs in the galactic nuclei being invisible from the outside. The naked central singularity illuminates the orbiting internal planets and provides the energy supply for life supporting. Some additional highlighting during the night time comes from eternally circulating photons. Yet, some difficulties (or advantages?) of a life inside BH are worth mentioning, such as a possible causality violation [10, 8, 9] and the growing energy density in the close vicinity of the Cauchy horizon [22, 23, 24, 25, 26]. The existence of third kind orbits inside the event horizon may be falsified in principle by observations of white holes.

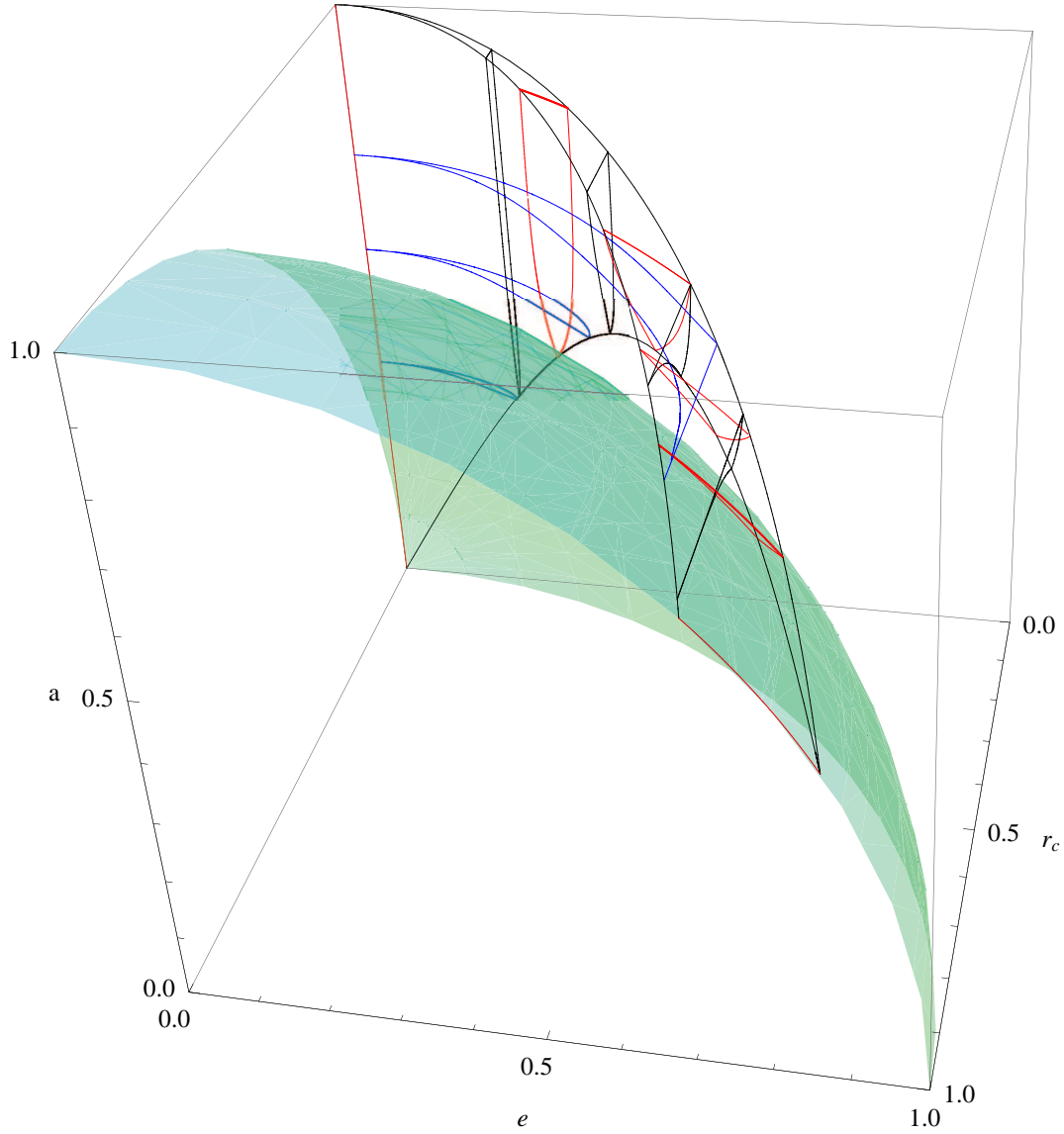


Figure 5. 3D domain of existence (marked by the level curves $r = \text{const}$, $a = \text{const}$, $e = \text{const}$) for the stable circular (equatorial) orbits of neutral particles inside the inner BH horizon (a filled part of sphere). The rear filled surface corresponds to the ultrarelativistic limit or circular photon orbits. The stable spherical (nonequatorial) orbits for massive particle exist at radii, limited by the rear surface of circular photons and the inner horizon.

Acknowledgments

Author acknowledges E. O. Babichev, V. A. Berezin, Yu. N. Eroshenko and I. D. Novikov for fruitful discussions. This work was supported in part by the Russian Foundation for Basic Research grant 10-02-00635.

References

- [1] Mizner C W, Thorne K S and Wheeler J A 1973 *Gravitation* (W. H. Freeman and Company, San Francisco) Chapter 34
- [2] Chandrasekhar S 1983 *The mathematical theory of black holes* (Oxford University Press, Oxford) Chapters 5 and 7
- [3] Wald R M 1984 *General Relativity* (The University of Chicago Press, Chicago 60673)
- [4] Frolov V P and Novikov I D 1998 *Black hole physics: basic concepts and new developments* (Dordrecht: Kluwer Academic) Chapters 6 and 14
- [5] Frolov V P, Markov M A and Mukhanov V F 1989 *Phys. Lett. B* **216** 272
- [6] Frolov V P, Markov M A and Mukhanov V F 1990 *Phys. Rev. D* **41** 383
- [7] Barrabes C and Frolov V P 1996 *Phys. Rev. D* **53** 3215
- [8] Carter B 1966 *Phys. Rev.* **141** 1242
- [9] Carter B 1966 *Phys. Lett.* **21** 423
- [10] Carter B 1968 *Phys. Rev.* **174** 1550
- [11] Zeldovich Ya B and Novikov I D 1971 *Relativistic astrophysics* Vol 1: *Stars and relativity* (Chicago: University of Chicago Press) Chapter 3
- [12] Bičák J, Stuchlík Z and Balek V 1989 *Bull. Astron. Inst. Czechosl.* **40** 65
- [13] Balek V, Bičák J and Stuchlík Z 1989 *Bull. Astron. Inst. Czechosl.* **40** 133
- [14] Grunau S and Kagramanova V 2011 Geodesics of electrically and magnetically charged test particles in the Reissner-Nordström space-time: analytical solutions *Preprint* arXiv:1011.5399 [gr-qc]
- [15] Olivares M, Saavedra J, Leiva C and Villanueva J R 2011 Motion of charged particles on the Reissner-Nordström (Anti)-de Sitter black holes *Preprint* arXiv:1101.0748 [gr-qc]
- [16] Hackmann E, Kagramanova V, Kunz J and Lañmerzahl C 2010 *Phys. Rev. D* **81** 044020
- [17] Pugliese D, Quevedo H and Ruffini R 2010 Circular motion of neutral test particles in Reissner-Nordström spacetime *Preprint* arXiv:1012.5411 [astro-ph.HE]
- [18] Bardeen J M, Press W H and Teukolsky S A 1972 *Astrophys. J* **178** 347
- [19] Wilkins D C 1972 *Phys. Rev. D* **5** 814
- [20] Landau L D and Lifshitz E M 1969 *Mechanics, Course of theoretical physics* (Oxford: Pergamon Press, 2nd ed.) Chapter III
- [21] Thorne K S 1974 *Astrophys. J.* **191** 507
- [22] Simpson M and Penrose R 1973 *Intern. J. Theor. Phys.* **7** 183
- [23] Gursel Y, Sandberg V D, Novikov I D and Starobinsky A A 1979 *Phys. Rev. D* **19** 413
- [24] Gursel Y, Sandberg V D, Novikov I D and Starobinsky A A 1979 *Phys. Rev. D* **20** 1260
- [25] Novikov I D and Starobinsky A A 1980 *Sov. Phys. – JETP* **51** 1
- [26] Chandrasekhar S and Hartle J B 1982 *Proc. Roy. Soc. Ser. A* **384** 301