A Supermassive Black Hole or a Compact Object Without Events Horizon?

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Abstract

Previously it was shown that gravitation theory allows the existence of supermassive stable compact configurations of the degenerated electronic gas (L.V.Verozub, Astr. Nacr. 317 (1996) 107) without events horizon. In the present paper the simplest model of such kind of objects in gas environment has been considered. It is shown that at the spherically symmetric accretion onto the object the luminosity is about $10^{37}$ erg/s for the mass accretion rate of the order of $M \approx 10^{-6} M_\odot / \text{year}$. The wavelength of the radiation maximum is about $400 \div 500$ Å. There is an ionization zone around the central objects with the radius about $10^{-3}$ pc.

1 Introduction

The analysis of the observation data gives evidence for the existence of a massive (about $2.5 \cdot 10^6 M_\odot$) compact object in the Galactic Center [1]. The observation data do not allow to make a definite conclusion about the nature of the object. For this reason it is identified, as a rule, with a supermassive black hole. Another possibility is considered in the present paper.

The gravitation equations whose spherically symmetric solution have no and physical singularity in flat space-time from the viewpoint of a remote observer where proposed in the paper [2]. According to the equations the
events horizon is absent in the spherically symmetric solution. The radial component of the gravity force $F$ affecting a test particle with mass $m$ in the spherical coordinate system in flat space-time is given by

$$F = -m \left[ c^2 B_{00}^1 + (2B_{01}^0 - B_{11}^1) v^2 \right]. \tag{1}$$

Here $B_{00}^1$, $B_{01}^0$ and $B_{11}^1$ are the nonzero components of the strength tensor $B_{\alpha\beta}^\gamma$ of gravity field in flat space-time:

$$B_{00}^1 = \frac{1}{2} \frac{\alpha f' f^4 (1 - \alpha/f)}{f^2 r^4}, \tag{2}$$

$$B_{01}^0 = \frac{2}{r}, \tag{3}$$

$$B_{11}^1 = \frac{1}{2} \frac{\alpha f'}{f^2 (1 - \alpha/f)}. \tag{4}$$

$$f = (\alpha^3 + r^3), \tag{5}$$

$\alpha = 2GM/c^2$ is the Schwarzshild radius and $v$ is the radial component of the particle velocity.

Fig 1 shows the value of $|F|$ for the particle at rest as a function of $\tau = r/\alpha$.

It is shown in the paper [3] that in the above theory there can exist equilibrium stable configurations of the degenerated electronic gas with masses up to $10^9 M_\odot$ or more than that. This kind of objects there can exist in the Galactic Center.

Fortunately, there are some consequences available for observations which can help us to identify the objects with one of the proposed hypotheses.

2 Peculiarity of Accretion Onto the Massive Objects Without Events Horizon

Consider the object without the events horizon with the mass $2.5 \cdot M_\odot$ in the center of a spherical symmetric gas medium. Let us assume that the gas density is sufficient to describe the gas motion by using the hydrodynamics equations and the state equation is $P = K \rho^\gamma$ where $P$ is the gas pressure, $\rho$ is the density, $K$ and $\gamma$ are the constants. (For numerical estimates we assume in this paper that $\gamma = 4/3$).
The following equations are used here for describing the system [4].

1. The integral of the continuity equation

\[ 4\pi r^2 v \rho = \dot{M} \]  

where \( v \) is the radial gas velocity at the distance \( r \) from the center, \( \dot{M} \) is the mass rate of accretion.

2. The adiabatic relationship between the sound velocity \( a \) and the density \( \rho \)

\[ \rho = \text{Const} \ a^{2/(\gamma-1)} \]  

3. The Euler equation

\[ uu' + a^2 \rho' + F/m = 0 \]  

where \( F \) is given by eq. (1)

The velocity of the gas falling from infinity to the center reaches the sound velocity \( a \) at the distance \( r_s \) which is defined by the equations

\[ 2a_s^2 = F(r_s, a_s) \]  

\[ r_s^2 a_s^{\gamma+1} = \frac{\dot{M}}{4\pi Q} \]

where \( a_s \) is the value of \( a \) at \( r = r_s \),

\[ Q = \frac{\rho_{\infty}}{a_{\infty}^{2/(\gamma-1)}} \],

\( v_{\infty} \) and \( \rho_{\infty} \) are the velocity and density at infinity. In contrast to the Newtonian gravity law equations [10] have two solutions. At \( v_{\infty} = 10^7 \text{cm/s} \), at the density of the particles number \( n = 10^2 \text{cm}^{-3} \) and at \( \dot{M} = 10^{-6} M_\odot/\text{year} \), the numerical solution of eqs. [10] yields

\[ r_{1s} = 0.83 \cdot 10^{18} \text{cm} \quad r_{2s} = 1.4 \cdot 10^{11} \text{cm} \]

\[ a_{1s} = 1.40 \cdot 10^7 \text{cm} \quad a_{2s} = 1.1 \cdot 10^9 \text{cm} \]

The reason of the second solution is that the gas velocity of a particle falling from infinity increases up to the distances of the order of the
Schwarzschild radius and after that decreases according to the peculiarity of the gravity force.

We find the function $v(r)$ as the result of the numerical solution of the following equation resulting from eqs. (6), (7) and (8)

$$v' - \frac{2K}{D} r^{1-2\gamma} v^{1-\gamma} + \frac{F}{D} = 0 \quad (10)$$

where

$$D = v - Kr^{-2(\gamma-1)} v^{-\gamma},$$

$$K = a^2_\infty (A/\rho_\infty)^{\gamma-1}$$

and

$$A = \dot{M}/4\pi$$

Fig. 2 shows $v$ as the function of $r$ from $r = r_{2s}$ to the surface of the central object. It is the result of the numerical solution of eq. (8) with the help (6) and (7). The radius $R$ of the central object has been found by the numerical solution of the equation of the hydrodynamical equilibrium and is equal to $0.04 \alpha$, or $10^{11} cm$.

### 3 Luminosity

The Eddington’s limit of the luminosity near the surface of the central object is given by

$$L = \frac{4\pi c GM}{\sigma} \left[ 1 - \frac{\alpha}{(\alpha^3 + R^3)^{1/3}} \right], \quad (11)$$

where the eq. (11) for the force at $v = 0$ has been used.

For the used mass of the central object we obtain $L = 6.7 \cdot 10^{39} erg/s$.

The realy luminosity of the central object in the absence of magnetic fields is of the order of

$$L = v^2(r) \dot{M}, \quad (12)$$

where $v(R)$ is defined by eq. (11). For the object under consideration $v(R) = 2.3 \cdot 10^8 cm/s$ and at $\dot{M} = 10^{-6} M_\odot/year$ we obtain $L = 0.3 \cdot 10^{37} erg/s$. Thus, in spite of a sufficiently large the accretion rate the object has a low luminosity.
4 Ionization Radius

There must be an ionization zone around the central object with events horizon which depends on the temperature of the central object and the physical conditions in the gas environment.

An effective temperature of the object is given by

$$ T_* = \left( \frac{L}{4\pi\sigma R^2} \right)^{1/4} $$

(13)

where $L$ is the luminosity of the object and $\sigma$ is the Stephan-Boltzman constant.

At $L = 10^{37}$ erg/s the temperature $T_* = 4.8 \cdot 10^4 K$. The maximum of the radiation corresponds to the wavelength about $\lambda = 500 \text{ Å}$.

Let number of neutral atoms, ions and electrons per unit volume be $n_1$, $n_+$ and $n_e$, respectively. We shall assume that $n_e = n_+$. At these conditions $n_1 = (1 - X)n$, where

$$ n = n_1 + n_+ $$

is the total number density and

$$ X = n_+/(n_1 + n_+) $$

is degree of ionization at the distance $r$ from the center.

Then at the distance $r$ from the center the Saha formula yields:

$$ n \frac{X^2}{X-1} = B \ W \ \exp(-\tau), $$

(14)

where

$$ B = \frac{g_+ R^2}{4g_1} \left( \frac{T_e}{T_*} \right)^{1/2} \frac{(2\pi mkT_*)^{3/2}}{h^3} \ln \left( 1 - \exp\left(\frac{-h\nu_1}{kT_*}\right) \right)^{-1}, $$

(15)

$T_*$ is the electronic temperature, $g_+$ and $g_1$ are the statistical weights of the ions and the ground state of the atoms, respectively, $\nu_1$ is the ionization frequency,

$$ W = \frac{1}{2} \left[ 1 - \sqrt{1 - \left( \frac{R}{r} \right)^2} \right] $$

(16)
is the dilution factor, $\tau$ is the optical thickness that we define as

$$\tau = [1 - X(r)] k_\nu \int_R^r n(r') dr',$$  \hspace{1cm} (17)

where function $X(r)$ is the solution of eqs. (15) and (17). The constant $k_\nu$ is the averaged absorption coefficient.

The function $n(r)$ can be found as

$$n(r) = \frac{\dot{M}}{4\pi r^2 m_p v}$$  \hspace{1cm} (18)

and $v(r)$ is the solution of eq.(10).

For numerical estimates we assume that $T_e$ as the function of the distance $r$ is given by

$$T_e = T_{e\infty} (\rho/\rho_{\infty})^{\gamma-1}$$  \hspace{1cm} (19)

Setting, for example, $T_e = 6 \cdot 10^4 K$ (which corresponds to $L = 10^{37} \text{ erg/s}$) and $T_e = 220 K$ (which corresponds to $v_{\infty} = 10^7 \text{ cm/s}$) we obtain by a numerical solution of eq. (17) the function $X$ of $r$. The function $Z(r)$ decreases from 1 to 0.1 when $r$ increases from $R$ to $10^{14} \text{ cm}$. Fig. 3 shows the function of the ionization degree $X$ from the $z = \log_{10}(r)$ at the interval from $R$ to $1 \cdot 10^{14} \text{ cm}$.

5 Conclusion

We have considered the simplest model of the compact object without events horizon in gas medium with properties of the Galactic center. It leads to some available for observations consequences. The observation data speak in favour these consequences rather than against them. Consequently, we have an alternative to the supermassive Black Hole hypothesis. We hope that later a more detail consideration of the problem and an analysis of observations will lead to more definite conclusions.

References

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Gravitational force vs. Distance from center
