Are black holes real?

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Abstract

The physical reality of the black hole, as defined in the literature, is examined by considering details of its metric field. A comparison with the gravitational field of a classical homogeneous material sphere is also taken into account.

1 Introduction

In 1916, soon after the publication of the articles on General Relativity Theory (GRT) by Albert Einstein (1879-1955), the German astronomer Karl Schwarzschild (1873-1916) solved Einstein's field equations for a very special case, at the same time simple and of great experimental and observational applicabilities. It refers to the determination of the space-time metric in the exterior of a static and spherically symmetric mass distribution M. The Schwarzschild's solution is a vacuum solution, outside the object with mass M, and valid only in this region of space-time.

The metric is very successful in its applications. It is verified in the planetary motion, in the deflection of light due to presence of a mass concentration, in the correct prediction of the advance of Mercury's perihelion — where Newtonian gravity breaks down — and in modern applications of global positioning systems.

Schwarzschild's metric has a caveat that turned out to be very fruitful in its features, namely the existence of two singularities in its mathematical expression. One of the singularities, at the so-called "Schwarzschild radius", raised theoretical discussions on a plausible inhabitant of the natural world, that is, the well-known "black hole" (BH). The existence of the black hole in the physical world is accepted by many but is questioned by others. My main goal here is to answer the question posed in the article's title. I do this both by examining details of the Schwarzschild metric and by comparing it with the gravitational field of a classical Newtonian object, that is, a homogeneous material sphere.

Schwarzschild's metric is discussed in section 2 as well as the definition of the black hole as presented by Capelo (2018). In section 3, I discuss the Newtonian equivalent to the relativistic Schwarzschild metric field, i.e., the gravitational field of a homogeneous sphere. The proposed question is answered in section 4 and additional remarks are presented in section 5.

2 Schwarzschild's metric and the definition of a black hole

The definition of the BH used in the present discussion is that by Capelo (2018). He begins with the Schwarzschild metric that is described by the expression of the space-time interval ds:

$$(ds)^2 = -(1-2GM/rc^2)(cdt)^2+\left(\frac{1}{1-2GM/rc^2}\right)(dr)^2+(rd\theta)^2+(r\sin\theta\, d\phi)^2, \tag{1}$$

where r, θ and ϕ are the usual spherical coordinates, c is the speed of light in vacuum and M is the source mass. The "Schwarzschild radius" is defined as

$$r_S = \frac{2GM}{c^2}. \tag{2}$$

This radius defines the so-called "Schwarzschild sphere". In the language of GRT the metric field is the physical equivalent to the Newtonian gravitational field (cf. Soares 2013, section 1). Its two-dimensional representation is shown in figure 1. It is worthwhile mentioning that such a representation breaks down for $r < r_S$, because in that region there is no known theoretical physical description — eq. 1 is not defined there — and hence figure 1 shows just a possible, but most certainly unphysical, extrapolation inside Schwarzschild's sphere (more on this in Soares 2017).

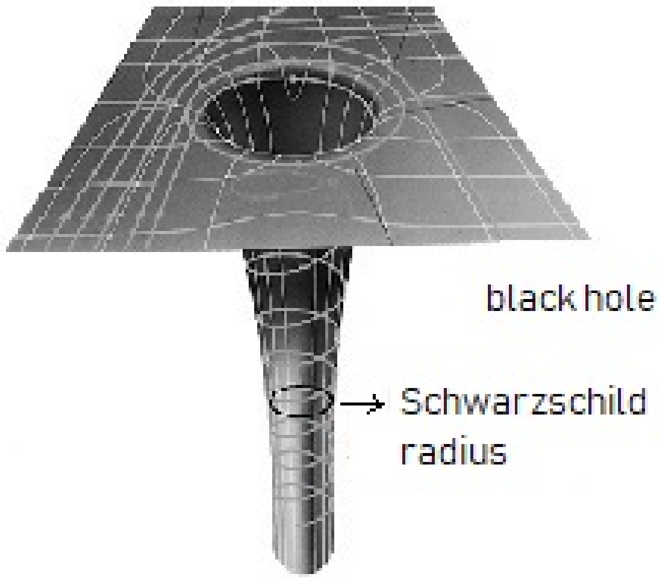

Figure 1: The metric field — i.e., the gravity — of a black hole shown as a two-dimensional warped surface. The black hole hosts a physical singularity inside the Schwarzschild sphere. The representation for $r < r_S$ is most certainly invalid because the metric is not defined there.

In his article, Capelo defines the BH and review the main features of various types of BHs. An excerpt of the abstract of Capelo's article reads:

> *"...we introduce the concept of a black hole (BH) and recount the initial theoretical predictions. We then review the possible types of BHs in nature, from primordial, to stellar-mass, to supermassive BHs."*

I treat here only of the definition of a BH; the reader is referred to Capelo's article for the other considerations.

There are two singularities in eq. 1. The equation diverges at both $r = 0$ and $r = r_S$. From Capelo's words, *only the former is a true physical singularity (i.e. the Riemann curvature tensor is infinite only at $r = 0$), with the space-time being nonsingular at the so-called Schwarzschild radius.* This fact can be easily seen, according to Capelo, by transforming the system of coordinates in which eq. 1 is presented (e.g., Kruskal 1960).

However, the vicinity of Schwarzschild's radius is a quite peculiar region, because the future of a particle traveling towards the centre is inevitable, that is, when it crosses $r = r_S$ *the only possible future of that particle is the singularity.* The BH is then *unstable* at its conception or, more precisely, it sets off instabilities wherever it is formed (see also Kruskal 1960, figure 2).

The external surface of Schwarzschild's sphere is called "event horizon" of the BH. Capelo then describes a very drastic property of the BH with respect to a particle moving near the boundary represented by the event horizon, namely that *a static observer at infinity will never observe such a boundary (or event horizon) crossing, as the observed time will reach infinity (even though the proper time of the particle is finite) and any radiation sent from the particle and reaching the observer will be infinitely redshifted. In other words, a photon sent from* r_S *would need infinite energy to reach the observer, effectively making the space-time region within the event horizon causally disconnected from the rest of the Universe.* This is the rigorous technical reason for why a mass M confined to r_S is called a "black hole" and represents, therefore, its definition.

Since the mass is confined to the Schwarzschild sphere, it prompts for a parallel with a mass M confined to a given radius R, i.e., a classical Newtonian homogeneous sphere. The great difference between the two is that the gravitational field of the homogeneous sphere is well defined inside the confinement radius ($r < R$) and the great similarity is, obviously, that in both the total mass sits inside a sphere of known radius.

3 Gravity of a homogeneous sphere

I consider now a Newtonian classical object, that is, the above-mentioned homogeneous sphere (HS) of mass M and radius R. (Notice that the black hole is, strictly speaking, a classical object as well, since it does not require any quantum mechanical fundamentals in its prescription.) The gravitational field of the sphere is described by:

$$\vec{g}(r) = -\mathrm{Gm(r)}\frac{\vec{r}}{\mathrm{r}^3} \tag{3}$$

with

$$m(r) = \frac{M}{R^3} r^3 \qquad\qquad (0 \leq r < R),$$
$$m(r) = M \qquad\qquad\qquad (r \geq R).$$

The magnitude of $\overrightarrow{g}$(r) is plotted in figure 2.

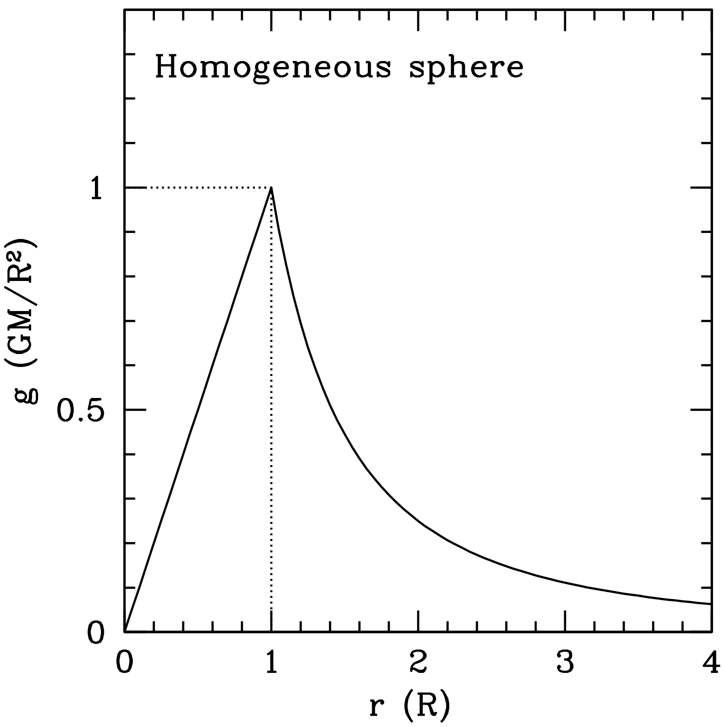

Figure 2: The magnitude of the gravitational field inside (r < R) and outside (r ≥ R) a homogeneous sphere of mass M and radius R (eq. 3). Notice the absence of singularities.

Gravitational fields of the BH and the HS have different descriptions, but it can be shown that in the limit of weak field, i.e., for $r \gg r_S$, the metric field given by eq. 1 reduces to Newton's gravitational law (e.g., Soares 2015). Gravity fields of the BH and of the HS show a perfect symmetry for large r. That is not the case for small r, $r < r_S$ (BH) and $r < R$ (HS). The gravitational field is perfectly well defined for the former and diverges for the latter, that is, they show here a perfect asymmetry.

The gravitational field inside the HS is well defined including at $r = 0$. In contrast, the BH has a physical singularity at the very center of the Schwarzschild sphere. Such an asymmetry is striking and indicates that something very crucial is missing in the theoretical description of the Schwarzschild metric, which is, of course, a quantum gravity theory.

4 The answer

A tentative answer to the question posed in the title might be framed within three remarkable features of the BH presented in sections 2 and 3. They are:

1. The BH sets off instabilities wherever it is formed (section 2).

2. The space-time region within r_S (the radius of the event horizon) is causally disconnected from the rest of the Universe (section 2).

3. Gravity fields of the BH and of the HS show a perfect symmetry for large r, but a perfect asymmetry for small r (section 3).

Although points 1 and 2 above are by themselves sufficient to a "no" answer, the most remarkable argument for the answer resides in item 3. The asymmetry observed at small r in the description of these two classical objects is fundamentally an asymmetry between physical and unphysical realms. That is to say, it is not necessarily required that the gravitational fields be the same at small radii as they are for large ones. The crucial requirement is that both fields be physical. Since they are not, the only possible answer is "no".

A well-defined and physical object is suggested in Soares (2018) as an alternative to the BH.

5 Additional remarks

Although a change of coordinates is able to transform the character of a singularity from physical to non physical (section 2), the singularities at $r = 0$ and $r = r_S$ are still uncomfortably concrete in the coordinates of eq. 1. Furthermore, it is conceivable that there might exist a system of coordinates in which the singularity at $r = 0$ is removed whilst the singularity at $r = r_S$ is kept and, if that is realized, one would be led to the conclusion that changing coordinates are mere mathematical artifacts that in the end are not really able to remove non physical descriptions.

Assuming that indeed the singularity at the Schwarzschild radius is not physical, it did not exclude the fact that the Schwarzschild sphere harbors a very real physical singularity. Would not that suffice to declare a BH as a non physical object and inexistent in nature? Is not the so-called “Object of Gravitational Extreme” (OGE), put forward by Soares (2018), a much more palatable concept than the BH? The OGE has all the physical features of a BH except the singularities at $r = 0$ and at $r = r_S$.

Mathematical maneuvers, such as changing coordinate systems, are incapable of removing non physical characteristics of a BH, because the main issue in all of this is that GRT is an incomplete gravity theory, i.e., still there does not exist a quantum gravity theory that certainly would remove in a natural way both singularities present in the Schwarzschild metric.

The brilliant and clear exposition by Capelo (2018) is very useful for those interested in the wonders of the intriguing concept of a black hole. The article almost shook my conviction that BHs are the most subtle expression of a very refined “scientific digression” (cf. Soares 2017).

Additionally, one might want to read the article written by Bernstein (1996), which presents a very interesting historical perspective on black holes, featuring the first scientific proposition of the black-hole concept by J.R. Oppenheimer (1904-1967) and H.S. Snyder (1913-1962) in 1939 and Einstein’s denial of its existence in that same year. The article has much information, without a single equation, but the title **“The Reluctant Father of Black Holes”** sounded intriguing to me. Initially it seemed, obviously, refers to Einstein and that might be the author intention. Two points, however, contradict such an interpretation: Einstein **was not** the father of black holes and, consequently, **cannot** have been reluctant. The title, on the other hand, fits like a glove in Oppenheimer. Besides Bernstein’s statements, one has also the testimony of the Anglo-American physicist Freeman Dyson about the total lack of interest of Oppenheimer on the subject when, in the decade of 1950, Dyson worked at Princeton’s Institute for Advanced Study under his direction. The testimony presented in Dyson (2016) makes this very clear.

Acknowledgment – Figure 2 was made in one of the computers of the Kapteyn Astronomical Institute, Groningen, The Netherlands, under the

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