LETTERS TO PROGRESS IN PHYSICS

On the Current Situation Concerning the Black Hole Problem

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This paper reviews a new solution which concerns the black hole problem. The new solution, by S. J. Crothers, doesn't eliminate the line-element of the classical "black hole solution" produced by the founders of the problem, but represents the gravitational collapse condition in terms of physical observable quantities accessible to a real observer whose location is in the real Schwazschild space itself, not with the quantities in an abstract flat space tangential to it at the point of observation (as it was in the classical solution). Besides, Schwarzschild space is only a very particular case of Einstein spaces of type I. There are minor studies on the physical conditions of gravitational collapse in other spaces of type I, and nothing on Einstein spaces of type II and type III (of which there are hundreds). Einstein spaces (empty spaces, without distributed matter, wherein Ricci's tensor is proportional to the fundamental metric tensor), are spaces filled by an electromagnetic field, dust, or other substances, of which there are many. As a result, studies on the physical conditions of gravitational collapse are only in their infancy.

In a series of pioneering papers, starting in 1979, Leonard S. Abrams (1924–2001) discussed [1] the physical sense of the black hole solution. Abrams claimed that the correct solution for the gravitational field in a Schwarzschild space (an empty space filled by a spherically symmetric gravitational field produced by a spherical source mass) shouldn't lead to a black hole as a physical object. Such a statement has profound consequences for astrophysics.

It is certain that if there is a formal error in the black hole solution, committed by the founders of this theroy, in the period from 1915–1920's, a long list of research produced during the subsequent decades would be brought into question. Consequently, Abrams' conclusion has attracted the attention of many physicists. Since millions of dollars have been invested by governments and private organizations into astronomical research connected with black holes, this discussion ignited the scientific community.

Leonard S. Abrams' professional reputation is beyond doubt. As a result, it is particularly noteworthy to observe that Stephen J. Crothers [2], building upon the work of Abrams, was able to deduce solutions for the gravitational field in a Schwarzschild metric space produced in terms of a physical observable (proper) radius. Crothers' solutions fully verify the initial arguments of Abrams. Therefore, the claim that the correct solution for the gravitational field in a Schwarzschild space does not lead to a black hole as a physical object requires serious attention.

Herein, it is important to give a clarification of Crothers' solution from the viewpoint of a theoretical physicist whose professional field is the General Theory of Relativity. The historical aspect of the black hole problem will not be discussed as this has been sufficiently addressed in the scientific literature and, especially, in a historical review [3]. The technical details of Crothers' solution will also not be reanalyzed: his calculations were reviewed by many professional relativists prior to publication in *Progress in Physics*. These reviewers had a combined forty years of professional employment in this field and it is thus extremely unlikely that a formal error exists within Crothers' work. Rather, our attention will be focused only upon clarification of the new result in comparison to the classical solution in Schwarzschild space. In other words, the main objective is to answer the question: what have Abrams and Crothers achieved?

In this letter, two important items must be highlighted:

1. The new solution, by Crothers, doesn't eliminate the classical "black hole solution" (i.e. the line-element thereof) produced by the founders of the black hole problem, but represents the perspective of a real observer whose location is in the real Schwazschild space itself (inhomogeneous and curved), not by quantities in an abstract flat space tangential to it at the point of observation (as it was previously, in the classical solution). Consequently, the new solution opens a doorway to new research on the specific physical conditions accompanying gravitational collapse in Schwarzschild space. This can now be studied in a reasonable manner both through a purely theoretical approach and with the methods of numerical relativity (computers);
2. Schwarzschild space is only a very particular case related to Einstein spaces of type I. There are minor studies on the physical conditions of gravitational collapse in other spaces of type I, but nothing on it in relation to Einstein spaces of type II and type III (of which there are hundreds). Besides Einstein spaces (empty spaces, without distributed matter, wherein Ricci's tensor is proportional to the fundamental metric tensor $R_{\alpha\beta} \sim k\, g_{\alpha\beta}$), there are spaces filled by an electromagnetic field, dust, or other substances, of which there are

many. As a result, studies on the physical conditions of gravitational collapse are only in their infancy.

First, the corner-stone of Crothers' solution is that it was produced in terms of the physical observed (proper) radius which is dependent on the properties of the space itself, while the classical solution was produced in terms of the coordinate radius determined in the tangentially flat space (it can be chosen at any point of the inhomogeneous, curved space). For instance, when one makes a calculation at such a proper radius where the gravitational collapse condition $g_{00} = 0$ occurs, the calculation result manifests in what might be really measurable on the surface of collapse from the perspective of a real observer who has a real reference body which is located in this space, and is bearing not on the ideal, but on real physical standards whereto this observer compares his measurements. This is in contrast to the classic procedure of calculation oriented to the coordinate quantities measurable by an "abstract" observer who has an "ideal" reference body which, in common with its ideal physical standards, is located in the flat space tangential to the real space at the point of observation, not the real space which is inhomogeneous and curved.

In the years 1910–1920's people had no clear understanding of physical observable quantities in General Relativity. Later, in the years 1930–1940's, many researchers such as Einstein, Lichnerowicz, Cattaneo and others, were working on methods for determination of physical observable quantities in the inhomogeneous curved space of General Relativity. For instance, Landau and Lifshitz, in §84 of their famous book, *The Classical Theory of Fields*, first published in 1939, introduced observable time and the observable three-dimensional interval. But they all limited themselves to only a few particular cases and did not arrive at general mathematical methods to define physical observable quantities in pseudo-Riemannian spaces. The complete mathematical apparatus for calculating physical observable quantities in four-dimensional pseudo-Riemannian space, that is a strict solution to the problem of physical observable quantities in General Relativity, was only constructed in the 1940's, by Abraham Zelmanov (1913–1987), and first published in 1944 in his doctoral dissertation [4].

Therefore David Hilbert and the other founders of the black hole problem*, who did their work during the period 1916–1920's, worked in the circumstances of the gravitational collapse condition $g_{00} = 0$ in Schwarzschild space in terms of the coordinate radius (which isn't the same as the real distance in this space). As a result, they concluded that the spherical mass which produces the gravitational field in Schwarzschild space, with the increase of its density, becomes a a "self-closed" object surrounded by the gravitational collapse surface of the condition $g_{00} = 0$ so that all events can occur only inside it (this means a singular break in the surface of collapse).

By the new solution, which was obtained by Crothers in terms of the proper radius, there is no observable singular break under any physical conditions: so a real spherical body of a Schwarzschild metric cannot become a "self-closed" object observable as a "black hole" in the space.

This new solution, in common with the classical solution, means that we have two actual pictures of gravitational collapse, drawn by two observers who are respectively located in different spaces: (1) a real observer located in the same Schwarzschild space where the gravitational collapse occurs; (2) an "abstract" observer whose location is in the flat space tangential to the Schwarzschild space at the point of observation.

So, the new solution doesn't eliminate the classical "black hole solution" (i.e. the line-element thereof), but represents the same phenomenon of gravitational collapse in a Schwarzschild space from another perspective, related to real observation and experiment.

Second, Schwarzschild space is only a very particular case of Einstein spaces of Type I. Einstein spaces [5] are empty spaces without distributed matter, wherein Ricci's tensor is proportional to the fundamental metric tensor ($R_{\alpha\beta} \sim k\, g_{\alpha\beta}$). There are three known kinds of Einstein spaces, and there are many spaces related to each kind (hundreds, as expected, and nobody knows exactly how many). There are almost no studies of the gravitational collapse condition $g_{00} = 0$ in most other Einstein spaces of Type I. There are no studies at all of the collapse condition in Einstein spaces of Type II and Type III. Besides that, General Relativity has many spaces beyond Einstein spaces: spaces filled by distributed matter such as an electromagnetic field, dust, or other substances, of which there are many. Such spaces are closer to real observation and experiment than Schwarzschild space, so it would be very interesting to study the collapse condition in spaces beyond Einstein spaces.

This is why Schwarzschild (empty) space is good for basic considerations, where there are no sharp boundaries for the physical conditions therein. However, such a space becomes unusable under some ultimate physical conditions, which are smooth in the real Universe due to the influences of many other space bodies and fields. Gravitational collapse as the ultimate condition in Scwarzschild space leads to black holes outside a real physical space, with the consequence that the black hole solution in Schwarzschild space has no real meaning (despite the fact that it can be formally obtained). Mathematical curiosities are always interesting, but if these things have no real meaning, then one must make it clear in the end. Consequently, the current mathematical treatment of black holes in Schwarzschild space does not have physical validity in nature, as Crothers explains.

These results are not amazing: many solutions to Ein-

*Karl Schwarzschild died in 1916, and had no relation to the black hole solution. He only deduced the metric of a space filled by the spherically symmetric gravitational field produced by a spherical mass therein (such a space is known as a space with a Schwarzschild metric or, alternatively, a Schwarzschild space).

stein's equation have no validity in the physical world. Therefore the collapse condition in a real case, which could be met in the real Universe filled by fields and substance, should be a subject of numerical relativity which produces approximate solutions to Einstein's equations with the use of computers, not an exact theory of the phenomenon.

As a result we see that studies on the physical conditions of gravitational collapse are only beginning. New solutions, given in terms of physical observable quantities, do not close the gravitational collapse problem, but open new horizons for studies by both exact theory and numerical methods of General Relativity.

Submitted on November 06, 2007
Accepted on December 18, 2007

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