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The Question of Singularity in Space-Time

and

the Renaissance of General Relativity

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Abstract

The Taylor-Hulse binary pulsar experiment implies a necessary modification of the Einstein equation such that the source must include the gravitational energy-stress tensor with the antigravity coupling. Thus, the gravitational energy-stress is localized as physics requires. The antigravity coupling implies that the energy conditions, which are the crucial physical assumptions of the current singularity theorems on space-time, are not valid. Concurrently, it is shown that all the arguments, which support singularity, are due to the remnant influence of Newtonian gravity. In general relativity, there is no compelling reason for a gravitational complete collapse nor the existence of a space-time singularity. Moreover, the scope of general relativity in physics should be greatly broadened.

Subject headings: black hole physics, gravitation, relativity, radiation mechanisms: nonthermal

1. Introduction.

In 1915, Albert Einstein [1] published a series of four papers in the proceedings of the Prussian Academy of Sciences which laid out the physical principles in general relativity and calculated the perihelion advance of mercury and the deflection of light. At the time of the birth of general relativity, experimental confirmation was believed to be almost a side issue [2]. Einstein's confidence was supported by subsequent experimental confirmations of the calculations based on his theory [3]. Unfortunately, this also helped a groundless belief [4] among some theorists that experimental inputs can lead to only confirmation or disapproval of general relativity, but not its modifications.

In spite of these experimental successes, unexpectedly the later theoretical development leads to the supposedly inevitable break down of general relativity. Initially, the notion of implosion for a very massive star was derived by Oppenheimer and Serber [5] with a simplified model of energy-stress tensor. Later, in spite of the then prevailing skepticism of many physicists, the theorems of Hawking and Penrose [6] seem to confirm the inevitable existence of spacetime singularities. Since at that time the inadequacy due to model dependence of these theorems (see §3) has not been recognized, it was incorrectly considered that this existence of singularities is an unavoidable consequence of general relativity [7,8]. To reconcile the unphysical singularities with physical reality, this difficulty was attributed to the limitation of classical theories. To understand this strange dissonance between experimental success and theoretical failure, one must analyze the theoretical framework of general relativity and identify the unverified implicit assumptions which are responsible for the unphysical conclusions.

In general relativity, due to the equivalence principle, the equation of motion for a neutral particle is a geodesic equation. However, Einstein's field equation, which is actually based on the correspondence principle and the principle of covariance, may be only approximately valid. As pointed out by O. Klein [9], there is no proof for the rigorous validity of Einstein's equation. Moreover, as Pauli [3] pointed out, "The general theory of relativity does not provide a physical interpretation of the sign and numerical value of the gravitational constant, but takes these data from experiment." Einstein, in his later years, also recognized this incompleteness of his field equation. He remarked [10,11] that the left-hand side of his equation is granite, but the right-hand side (the source) is sand.

Moreover, Einstein realized, as shown in his 1936 letter to Max Born [12], that his equation is incompatible with the linearized field equation. Whereas the linearized equation produces gravitational waves; his equation does not. Nevertheless, experimental evidences at that time favored the non-linear equation since the perihelion requires the second order terms [8,13]. In particular, although gravitational waves must exist from general physical considerations [14], there was no evidence for gravitational radiation. This needed experimental evidence is first provided in 1974 by the Taylor-Hulser [15] experiment on the binary pulsar PSR 1913+16. However, due to long standing theoretical errors [16,17], the full implications of this experiment was not recognized until 1992 [18,19].

The Taylor-Hulse experiment not only confirms gravitational radiation, but also provides the needed evidence for improvements on Einstein's equation. It has been shown [20] that, in addition to gravitational radiation, the binary pular experiments [15,21,22] provide the evidence for the necessary localization of the gravitational energy-stress and the existence of the antigravity coupling [3,10].

In other words, it is necessary to modify the Einstein's equation,

$$G_{ab} \equiv R_{ab} - \frac{1}{2} R g_{ab} = -K T_{ab}(m), \tag{1}$$

where G_{ab} is the Einstein tensor, K is the gravitational coupling constant, and $T_{ab}(m)$ is the energy-stress tensor of matter; and the resulting modified equation [20] is

$$R_{ab} - \frac{1}{2} R g_{ab} = - K[T_{ab}(m) - t_{ab}(g)] = - K T_{ab}, \tag{2}$$

where R_{ab} is the Ricci curvature tensor, and $t_{ab}(g)$ is the gravitational energy-stress tensor. Due to the antigravity coupling of $t_{ab}(g)$, eq. (2) implies the following conservation laws,

$$\nabla^a T_{ab}(m) = 0, \tag{3a}$$

and

$$\nabla^a t_{ab}(g) = 0. \tag{3b}$$

Thus, this modification is within the theoretical framework of general relativity.

It is interesting to note that in general relativity both gravity and antigravity couplings are necessary (see also [10]). ***Due to the Taylor-Hulse experiment, both the presence of $t_{ab}(g)$ and its antigravity coupling are necessary.*** Physically, t_{ab} must be localized because of the energy exchange between a particle and the field. In this paper, in light of the modified equation (2), we shall examine the validity of arguments, which support the existence of space-time singularities.

2. The Maxwell-Newtonian Approximateion and the Gravitational Energy-Stress Tensor.

To understand the meaning of eq. (2), it is appropriate to consider the weak gravity case first. For weak gravity, due to the Maxwell-Newtonian approximation [20,23],

$$\partial^c\partial_c\bar{\gamma}_{ab} = -2KT_{ab}(m). \tag{4}$$

where $\bar{\gamma}_{ab} \equiv \gamma_{ab} - \frac{1}{2}\eta_{ab}\gamma_{cd}\eta^{cd}$ where $\gamma_{ab} = g_{ab} - \eta_{ab}$, one has approximately

$$K\, t_{ab}(g) \simeq G_{ab}{}^{(2)} + H_{ab}{}^{(1)} = G_{ab} - \frac{1}{2}\partial^c\partial_c\bar{\gamma}_{ab}\ , \tag{5}$$

where

$$H_{ab}{}^{(1)} = -\frac{1}{2}[\partial_a L_b + \partial_b L_a] + \frac{1}{2}\eta_{ab}\partial^c L_c, \quad \text{where} \quad L_b = \partial^a\bar{\gamma}_{ab}.$$

Note that the linear eq. (4) is justified on a physical ground and is independent of eq. (1), and that $t_{ab}(g)$ is of second order of deviations. While eq. (4) is the first order approximation of eq. (2), eq. (1) is the static second order approximation of eq. (2).

Eq. (2) and eq. (4) give the following radiation formula,

$$-\frac{dE}{dt} \simeq \int t_{a0}(g)dS^a = \frac{1}{K}\int G_{a0}{}^{(2)}dS^a - \frac{1}{2K}\int(\partial_0 L_a + \partial_a L_0)dS^a, \tag{6}$$

which gives essentially the same energy loss [20] as Einstein's radiation formula for the binary star

system. The difference [24] comes from the last integral whose time average is essential zero. Thus, this modification is self-consistent, valid, and inevitable [20].

In summary, the verification of Einstein's radiation formula settles:

1) The current version of Einstein eq. (1) is only a *static* approximation for *weak* gravity, and is inadequate for strong gravity. Conclusions, based on extending eq. (1), must be reexamined.
2) The implicit assumption that the source is zero in a "vacuum", is actually invalid.
3) The gravitational energy-stress $t_{ab}(g)$ is a localized tensor. Note that, in the "vacuum", $K\, t_{ab}(g)$ is equal to the Einstein tensor, which requires second order derivatives.
4) The antigravity coupling is a necessary feature of general relativity. Although the gravity of an electromagnetic wave [10,16] necessarily implies the existence of the antigravity coupling, one could argue this result as another evidence for the breaking down of general relativity.

This modification is not exactly complete since $t_{ab}(g)$ can only be approximated through eq. (4). Nevertheless, point 1) implies that all the calculations based on eq. (1) may not be valid for strong gravity. The necessary existence of the antigravity coupling manifests the scope of general relativity should be much larger than that currently envisioned, and testifies the intrinsic differences from Newtonian gravity. Moreover, owing to the ***antigravity coupling*** is verified, this enables one to show that, based on general relativity, there is no valid argument to support the existence of singularities.

3. Physical Invalidity of Singularity Theorems on Space-Time.

In physics, a singularity (or infinite) is usually either a convenient idealization such as the δ-function or an indication of imperfectness of the theory such as an renormalizable infinite in quantum electrodynamics. However, in current cosmology, a mathematical existence of singularities in space-time is considered as the evidence for the "inevitable" collapse to a black hole or its reverse, the big bang beginning of the universe. It will be shown that such theoreticalsingularities are actually due to inadequate modeling. Now, let us examine these singularity theorems. They are [24]:

<u>Theorem 1.</u> Let $(M, g_{\mu\nu})$ be a globally hyperbolic space-time with $R_{\mu\nu}\xi^{\mu}\xi^{\nu} \leq 0$ for all timelike ξ^{μ}, which will be the case if Einstein's equation is satisfied with the strong energy condition holding

for matter. Suppose there exists a smooth (or at least C^2) spacelike Cauchy surface Σ for which the trace of the extrinsic curvature (for the past directed normal geodesic congruence) satisfies $K \leq C < 0$ everywhere, where C is a constant. Then no past directed timelike curve from Σ can gave length greater than $3/|C|$. In particular, all past directed timelike geodesics are incomplete.

Theorem 2. Let $(M, g_{\mu\nu})$ be a strongly causal spacetime with $R_{\mu\nu}\xi^\mu\xi^\nu \leq 0$ for all timelike ξ^μ as will be the case if Einstein's equation is satisfied with the strong energy condition holding for matter. Suppose there exists a compact, edgeless, achronal, smooth spacelike hypersurface S such that for the past directed normal geodesic congruence from S we have $K < 0$ every on S. Let C denote the maximum value of K, so $K \leq C < 0$ everywhere on S. Then at least one inextendible past directed timelike geodesic from S has length no greater than $3/|C|$.

Theorem 3. Let $(M, g_{\mu\nu})$ be a connected, globally hyperbolic spacetime with a noncompact Cauchy surface Σ. Suppose $R_{\mu\nu}k^\mu k^\nu \leq 0$ for all null k^μ, as will be the case if $(M, g_{\mu\nu})$ is a solution of Einstein's equation with matter satisfying the weak or strong energy condition. Suppose, further, that M contains a trapped surface T. Let $\theta_0 < 0$ denote the maximum value of θ for both sets of orthogonal geodesics on T. Then at least one inextendible future directed orthogonal null geodesic from T has affine length no greater than $2/|\theta_0|$.

Theorem 4. Suppose a spacetime $(M, g_{\mu\nu})$ satisfies the following four conditions. (1) $R_{\mu\nu}\zeta^\mu\zeta^\nu \leq 0$ for all timelike and null ζ^μ as will be the case if Einstein's equation is satisfied with the strong energy condition holding for matter. (2) The timelike and null generic conditions are satisfied. (3) No closed timelike curve exists. (4) At least one of the following three properties holds: (a) $(M, g_{\mu\nu})$ possesses a compact achronal set without edge [i.e. $(M, g_{\mu\nu})$ is a closed universe], (b) $(M, g_{\mu\nu})$ possesses a trapped surface, or (c) there exists a point $p \in M$ such that the expansion of the future (or past) directed null geodesics emanating from p becomes negative along each geodesic in this congruence. Then $(M, g_{\mu\nu})$ must contain at least one incomplete timelike or null geodesic.

Note that the code for a singularity is an incomplete or inextendible geodesic. In Theorem 3, which is due to Penrose and Hawking [6], the assumption of globally hyperbolic is entirely eliminated, and thus would have much wider applications.

It is crucial to note that a common physical assumption in all these theorems is that the Einstein's equation satisfies either the weak and/or the strong energy condition. ***However, the validity of these energy conditions are actually due to inadequate modeling in the current theory. They are not valid for general relativity because of radiation.*** Now, let us rewrite Einstein's equation (2) as $R_{\mu\nu} = -K\,[T_{\mu\nu} - g_{\mu\nu}T/2]$. For any timelike ξ^μ, one has

$$R_{\mu\nu}\xi^\mu\xi^\nu = -K[T_{\mu\nu}\xi^\mu\xi^\nu - \xi^2T/2], \quad \text{and} \quad R_{\mu\nu}k^\mu k^\nu = -K[T_{\mu\nu}k^\mu k^\nu] \tag{7}$$

for any null vector k^μ. A necessary condition for either expressions in (7) to be non-positive is that the time-time component, $T_{tt} \geq 0$. But, this is posssible only if there is no antigravity coupling. (It seems, for a similar reason, Hawking does not agree with the suggestion of exotic matter [25] whose negative energy is needed to keep a "worm hole" open.)

Thus, according to eq. (2), these theorems can be interpreted as stating that, under some general assumptions on the universe, the existence of singularities is inevitable if there is no radiation. Also, if one does not believe in sigularity, ***the singularity theorems of Hawking and Penrose can be interpreted as necessitating the existence of the antigravity coupling.***

Now, the supposedly strongest argument for black holes is, in fact, invalid. Consequently, the assertion that general relativity must break down due to the existence of spacetime singularities is simply groundless. Moreover, if gravity, as suggested by Hawking [26], produces his radiation and causes his explosion, there is little reason to believe that these would not happen before a star reached a black hole state. If they do happen, why such a star must form a black hole first? Thus, one should ask "are there enough justifications to consider black holes as a possibility in reality?"

4. Black Hole and Newtonian Gravity.

The idea of a black hole is actually originated from Newtonian theory, which defines gravity as an attractive force. In 1783 the British natural philosopher John Michel [25] and in 1796, the French scientist Pierre Simon Laplace theorized that there could be a strong enough gravitational attraction to

recapture all the star's radiation, including light [27].

If gravity is only an attractive force as manifested in Newtonian gravity, gravitational collapse is inevitable when there is insufficient energy of other forms to counter gravity. Physically, such a collapse should not depend on the geometry of a star [28]. Then, the life of a star would be described as essentially a tug-of-war between gravity and the outward-directed force of its heat and radiation which is maintained by energy supplied by other interactions taking place within the star. When all forms of energy supplies are exhausted, a star would be mainly supported by "cold matter" pressure [24]. If the mass of the star is sufficiently small, the star simply cools down and remains in equilibrium. However, if the mass of the star were greater than the cold matter upper limit, the star would have to undergo a gravitational collapse [29]. Once gravitational collapse started, what prevents it from continuing forever, and the star crushing itself down to an infinitesimal speck containing all its matter, a single point of infinite density? When the star collapsed to a single point, the gravity became infinitely strong in the neighborhood and naturally nothing can escape would be the conclusion.

This scenario includes two implicit assumptions: 1) Interactions are triggered by gravity only indirectly; 2) Strong gravity would not generate resistence in the collapsing process. These two assumptions are explicitly included in Newtonian gravity, but not in general relativity.

5. Gravitational "Complete" Collapse and General Relativity.

In "current" theory of general relativity, the influence of Newtonian theory lingers. Although the cause of gravity is extended to all energy forms, it was incorrectly believed [25] that all energy has a mass equivalence in gravity although a traceless energy-stress tensor clearly cannot have a massive equivalence as manifested by the Reissner-Nordstrom metric [8,24]. Since the Schwarzschild solution, which is a result of inadequate modeling which ignore effects due to other interactions, seems consistent with this physical picture, diverse gravitational effects due to different energy forms were inadequately investigated. Weisskopf [30] commented that "The existence of black holes follows from an extrapolation of Einstein's theory of gravity by many orders of magnitude beyond the range for which its validity has not yet been established beyond doubt".

The above two implicit assumptions could be valid if gravitational energy were not localized. However, as shown in eq. (2), gravitational energy-stress is localized and has an antigravity coupling. A localized gravitational energy would also trigger interactions directly. (It is difficult to imagine that matter cannot be transformed under intensive gravity especially if one believes in the possibility of a gravitational complete collapse.) The antigravity coupling is also a mechanism which reduces and suppresses gravitational intensity. Note that the gravitational energy-stress tensor also increases as the gravitational intensity increases and therefore this antigravity mechanism resists a gravitational complete collapse. Another observable effect of this mechanism would be that for agglomerations of gas and dust to shine as stars, the minimum mass would be considerably larger than that (which is about 8% of the sun mass) required by the current theory.

In conclusion, there is no compelling reason which leads to black holes; and eq. (2) implies that the rejection [25] by Eddington and Einstein would be correct. The law of Nature that Edington, the leading authority on the structure of stars, looked for to counter gravitational collapse, seems just general relativity. Note that observation suggests that a super star would have a death as a supernova.

6. On Expansion of the Universe.

In 1922, a Russian mathematician, Alexander Friedman, solved Einstein's equation and came up with an expanding universe model. His basic assumption is that the universe is isotropic and homogeneous. Friedman's model gained creditability because Hubble's observations can be interpreted as supporting an expanding universe [24]. Also, its extrapolation would mean that there was a singular epoch in the past in which all the matter of the universe was concentrated into a single point. This creation of the universe was not taken seriously because the real universe contains irregularities which might grow large and cause the individual particles converging to miss each other. But, the theorems of Hawking and Penrose made the Big Bang not just plausible but even necessary.

Currently, it seems, the only direct evidence to support global expansion of the universe is the Hubble's law (an interpretation rejected by Hubble himself [31]). However, one may not be sure that these red shifts of lights are due to speeds of the sources unless one can verify these velocities inde-

pendently. For instance, one might also attribute the red shifts as due to energy losses in the long travelling. In other words, the red shifts could be due to combined effects. Given the over all complexity, the extreme conditions, and the vast scale of the universe, it is difficult to assure that the laws of physics, which are discovered on earth, would cover all large scale problems in the universe.

Nevertheless, all theories of the cosmos must be somewhat hypothetical because it is very hard to make empirical observations regarding the totality of the universe and therefore one does not know whether the real facts have been caught [29]. Moreover, if scientists have to be right all the time, there would not be science. What required for a scientist is to be sufficiently objective.

In short, while an expandinding universe is a viable assumption, the supporting evidences are not yet conclusive.

7. Conclusions and Discussions.

General relativity is accepted because all its predictions, which are different from naive visualization, are verified. However, these great successes also lead to over confidence. The self-consistency of the theory has not been thoroughly examined, and this opens the door for incorrect theoretical developments [16]. To begin with, the equivalence principle as a requirement for physical coordinates, is overlooked. This makes it possible to "establish" that any mathematical coordinate system was valid in physics [17,24]. Also, in the name of abandoning naive visualization, physical principles (such as causality) are often ignored. Consequently, general relativity was effectively reduced to a branch of mathematics which is often unrelated to reality.

This surrealistic theoretical development is culminated in the singularity theorems [5,6,32] which in turn serve as a foundation for the collapse of a star to a single point and etc.. Ironically, this also proclaims the inevitable break down of general relativity. However, it should be noted that logically the very existence of spacetime singularities depends on the validity of equation (1). Thus, the singularities may not be just a question of the domain of validity. Moreover, although quantum theory concerns the behavior of microscopic particles, the space-time involved can be macroscopically considerable. Thus, it may not be valid to attribute the singularity problem as due to the limitation of classical theory.

Now, it has been proven that these singularity theorems are irrelevant in physics because, among others, the energy assumptions in these theorems are not valid due to the existence of antigravity coupling, which was first suggested by Pauli [3]. This conclusion is achieved by first, based on the principle of causality, the necessity of the antigravity coupling is theoretically established in studying the gravity of electromagnetic waves [10]. Finally, based on the equivalence principle and the observed radiation loss of the binary pulsar PSR 1913+16, the antigravity coupling is experimentally verified.

Theoretically, the antigravity coupling testifies not only that general relativity is more accurate but that it is intrinsically different from Newtonian gravity. Moreover, the antigravity coupling manifests that the scope of general relativity, as envisioned by Einstein, is far broader than the current theory.

Upon examining the arguments for the supposed inevitable gravitational complete collapse, the improved understanding makes clearer that such a concept is actually due to the remnant influence of Newtonian gravity. But, outstanding scientists such as Einstein and Eddington, who can see beyond existing equations (Black holes just didn't smell right!), found immediately such a collapse unacceptable [25]. Also, on Oppenheimer's star imploding to a black hole, Wheeler had commented, his idealizations prevented it from doing any thing else [25]! Apparently, Wheeler was on the right line of reasoning. However, unlike Eddington, Einstein and Weisskopf [29], Wheeler did not recognized the possible inadequacy of the current theory when matter is extremely dense.

In this paper, it has been shown that, due to the antigravity coupling, there is no compelling reason for a gravitational complete collapse, and a super star would likely end up as a supernova.

Einstein [33] believes "The phenomenological representation of the matter is, in fact, only a crude substitute for a representation which would do justice to all known properties of matter." Recent theoretical developments confirm his foresight, and general relativity does not break down. Moreover, the principle of causality leads to the discovery that not only is the particle-wave duality compatible with [8] but is also necessary for general relativity [10,16]. Thus, the scope of general relativity should be much broadened; and Einstein's belief [12] that "physics of the future" would be based on general relativity, is supported. Therefore, the claim that there is nothing in general relativity to take into account the quantum behavior of subatomic particle, is groundless although such a claim could be a

self-fulfilled prophecy if nobody works on that direction.

In 1950, Einstein [34] wrote, "I do not see any reason to assume that the heuristic significance of the principle of general relativity is restricted to gravitation and that the rest of physics can be dealt with separately on the basis of special relativity, with the hope that later on the whole may be fitted consistently into a general relativistic scheme," and "The comparative smallness of what we know today as gravitational effects is not a conclusive reason for ignoring the principle of general relativity in theoretical investigations of a fundamental character." Unfortunately, it is precisely due to such implicit assumptions, which separate gravity from the rest of the physics, that the gravitational complete collapse became "inevitable".

In 1956, Pauli [3] pointed out that the most important aspect of Einstein's theory is his critical attitude, which abandoned naive visualizations in favour of a conceptual analysis of the correspondence between observational data and the mathematical quantities in a theoretical formalism. But, some theorists believe that mathematical consistency has been one of the most reliable guides to physicists in the last century. The development of general relativity shows that such a belief can be misleading. Einstein [35] pointed out "The propositions of mathematics referred to objects of our imagination, and not to reality." The subtlety of nature is often revealed in experiment and observation. The developments in relativity and quantum theory support this view. Thus, although mathematics is an indispensable tool, the guidiance for physics must come from experiments.

In closing, let us quote a remark by Pauli [3] that the theory of relativity is "an example showing how a fundamental scientific discovery, sometimes even against the resistence of its creator, gives birth to further fruitful developments, following its own autonomous course."

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