Is Mass Constant in a Gravitational Field?

Zhan Likui

Chinese Academy of Science, HeFei, CHINA. zlk@iim.ac.cn

Abstract: Various gravitation theories predict that a star with a large enough mass will shrink down to a final point, a gravitational singularity. The problem of the singularity is always a difficult one. This work reviews some of the difficulties related to gravitational fields. Based on experimental analysis and theoretical verification, a hypothesis regarding mass in gravitational fields is presented. In this case, the singularity no longer appears, and the meaning of gravitation is simple to determine. And a method for verifying the hypothesis is proposed.

Keywords: Mass, Gravitational field, Energy, Covariance

1. Introduction

Of all the forces in nature, no force can prevent matter from collapsing into a point in a black hole. Scholars have long puzzled over why the singularity has zero volume and infinite density. Scientists have been trying to look for a variety of ways to uncover the secrets of black holes [1,2]. Because observation is extremely difficult, reports on black holes rely on partial information, and many black holes are considered as candidates which is treated as accurate.

Now humans have made many great achievements in the process of understanding the universe, and representative achievements in this regard in the form of various physics theories. Even so, the current theories are not sufficient to answer all the remaining questions [3,4]. For example, the reality of spacetime singularities and evidence of dark matter remain open questions [5,6]. The so-called Pioneer anomaly requires an explanation [7]. Here, we attempt to describe a way to refer to gravitation in this work. For simplicity, the nouns and terms that we use conform to the definitions of fundamental physics. The "clock" is a timepiece in the physical sense; some examples include an atomic clock, a mechanical clock, a quartz clock or another chronometric instrument, excluding a gravity pendulum, which cannot work in outer space. The “ruler” is a length-measuring tool in the physical sense; some examples include a meter stick or another instrument that measures dimensions. “Mass” is inertial mass, a measure of an object's resistance to a change in its state of motion when a force is applied.

2. Methods

2.1 Annihilation test

Experiment 1: On the ground, antimatter (mass of $0.5\ m$) and matter (mass of $0.5\ m$) could be used to annihilate one another. They could be brought into contact gradually and translated into photons. All of the photons would be collected by receiver C in outer space. Finally, a certain amount of energy, E_1, would be obtained. This scenario is labeled with an “a” in Fig. 1.

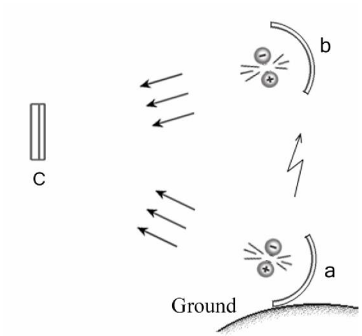

Fig. 1. Repeated annihilation would cause a gravitational field to disappear. (a): If annihilation were to occur on the ground, where would the energy that the photons lost go? (b): If annihilation were to occur in outer space, where would the energy of the external work go?

Experiment 2: Equal amounts of antimatter and matter could be weighed. They could be kept separate and lifted out of the gravitational field by an elevator. Then, the matter and antimatter could be brought together, and a given energy, E_2, would be obtained. Annihilation in outer space is labeled with a “b” in Fig. 1.

It is thought that photons would need to overcome gravity to do work when they exit the gravitational field. In other words, the photons transfer part of their energy to the gravitational field. Theoretically, experiment 1 can be repeated continuously. (This is, of course, only a thought experiment, and given antimatter and matter attracts each other [8].) Ultimately, all of the mass available on the earth would be depleted, and the gravitational field should receive a significant amount of energy. However, the gravitational field would disappear with the earth. Where would the energy go?

Experiment 2 would be also repeated indefinitely. Lifting the objects out of the gravitational field requires a third party to provide external work. Finally, all the matter and the gravitational field would disappear. Where would the energy of the external work go?

2.2 Acceleration test

Compared with a clock period in outer space, the clock period within a radius R of a gravitational field is defined by the following relation [9]:

$$T = \frac{T_0}{\sqrt{1 - 2GM/c^2 R}} \tag{2.1}$$

where T_0 is the clock period in outer space, G is the gravitational constant, c is the speed of light, and M is the mass of the body.

It is known that the standard ruler is defined by the speed of light. We use L_0 to express its length in outer space and L to express its length at the radius R of the gravitational field. Because the speed of light is a constant anywhere:

$$\frac{L_0}{T_0} = \frac{L}{T}$$

$$L = \frac{L_0}{\sqrt{1 - 2GM/c^2 R}} \tag{2.2}$$

Experiment 3: In outer space, a force F could be exerted on a mass m for a duration T_0 (labeled with a “b” in Fig. 2). The displacement is represented by

$$L_0 = \frac{1}{2} \cdot \frac{F}{m} \cdot T_0^2 \tag{2.3}$$

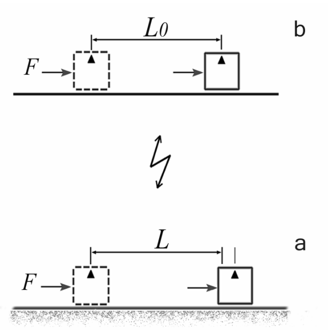

Fig. 2. An acceleration test could be staged on the ground (a) and in outer space (b). In both places, the clock and the ruler would be change and the mass would be constant. Are the results same?

Experiment 4: On the ground, the object is accelerated in a smooth horizontal plane (no resistance), labeled “a” in Fig. 2. The displacement would be given by

$$\frac{1}{2}\cdot\frac{F}{m}T^2=\frac{F}{2m}\left(\frac{T_0}{\sqrt{1\text{-}2GM/c^2R}}\right)^2 \tag{2.4}$$

Given the above two equations:

$$=\frac{L_0}{(\sqrt{1\text{-}2GM/c^2R})^2}=\frac{L}{\sqrt{1\text{-}2GM/c^2R}}>L \tag{2.5}$$

Different results would be observed in the experiments. However, there is no evidence to indicate that Newton's second law takes a different form at different altitudes.

2.3 Energy in a gravitational field

In order to solve the antinomies in Fig .1, the following hypotheses have to be made:

ⅰ). Energy cannot be transferred between a photon and a gravitational field.

ⅱ). Mass is variable in a gravitational field.

We use m_0 to express the mass in outer space and W express the external work, thus:

$$E_1=mc^2 \tag{3.1}$$

$$E_2=mc^2+W=m_0c^2 \tag{3.2}$$

$$E_2 - E_1 = W \tag{3.3}$$

In the case of the reverse process, a meteoroid is captured by the gravitational field, it accelerates toward the ground, and finally, the meteoroid gains a great amount of kinetic energy, hits the ground, and gives off light and heat. By this time, the intensity of the gravitational field has increased, and the gravitational potential energy of all matter in the gravitational field has been increased by the addition of the meteoroid. No object has lost energy. However, considering the increased energy, light and heat, when a star collapses and becomes a black hole (a naked singularity with zero radius), its mass should increase infinitely, which would be disastrous.

From the perspective of photon potential energy,

$$E_1 = mc^2 - W \tag{3.4}$$

$$E_2 = mc^2 \tag{3.5}$$

$$E_2 - E_1 = W \tag{3.6}$$

This perspective requires the photon to have gravitational mass. Anything with gravitational mass must have inertial mass according to the equivalence principle [11]. It is not allowed that anything with mass moves at the speed of light in special relativity; the zero rest mass of a photon is a prerequisite in electromagnetic theory [10]; On the other hand, a gravitational field receives energy from photons, the trace and form of the energy cannot be explained reasonably, as was the case for the Sun for quite a long time. The photon potential energy theory cannot actually illustrate the energy relationships in Fig. 1, because both E_1 and E_2 have lost energy W.

In experimental measurements of the gravitational red shift using the Mossbauer Effect [12], the radiation source is placed at the top of a tower, and the absorber is placed on the ground. Photons can thus be absorbed. Now, an operator takes the absorber and ascends to the top of the tower. Photons cannot be absorbed. What happened? We have thought, if photons accelerate in the process of free fall, the speed of light cannot be constant, which is not allowed. On the other hand, in a black hole, if the energy of the removed photons decreases to zero, the reverse process must be allowed. In other words, a zero-energy photon can increase in energy. Quantum field theory states that photons and particles exist in a vacuum and can be excited to production in a strong field [13]. Furthermore, cosmic microwave background radiation (2.7 K) fills the cosmic space. In such an event, the black hole continuously grows stronger without any matter. Thus, we can only believe that the change results from the absorber, and its atomic energy level has increased.

In Fig. 1, the external work belongs to the lifted object. In reference to special relativity, after external work *W* is done to an object of mass *m*, the final mass:

$$m_0 = \frac{m}{\sqrt{1 - 2W/mc^2}}$$

$$W = \frac{GMm}{R}$$

$$m = m_0\sqrt{1 - 2GM/c^2R} \qquad (3.7)$$

This relationship describes the difference in the mass of an object when in a gravitational field versus in outer space.

By the same reasoning, a ruler on the ground with length *L* and mass *m* lifted to outer space require external work *W*, the final length:

$$L_0 = L\sqrt{1 - 2W/mc^2}$$

So, the relationship of length is

$$L = \frac{L_0}{\sqrt{1 - 2GM/c^2R}} \qquad (3.8)$$

Similarly, the relationship of time can be solved in the same way.

2.4 Covariance in a gravitational field

Lorentz covariance is a key property of space-time that follows from the special theory of relativity; the covariance requirement states that physical laws take the same form in any inertial coordinate system. For example, an experiment of acceleration can be demonstrated in a high-speed spacecraft. Although the track becomes shorter and the clock ticks more slowly, the object increases in mass. All the coordinated changes lead to the same experimental result as that in a motionless spacecraft. If the mass were to remain constant, the acceleration of an object would be easier in the high-speed spacecraft. Therefore, we can determine the absolute velocity of an inertial coordinate system by measuring the acceleration in different directions. However, no an attempt to explore absolute movement has succeeded.

From a certain perspective, mass refers to the rest mass, and everything else is kinetic energy. We know that the kinetic energy represents the relationships between two systems of relative motion, and a single system do not involve kinetic energy. For example, a person on the ground cannot tell how much kinetic energy his or her body has, because he or she cannot identify the speed of the earth in the universe. The relativity principle is reliable. However, time slows down 100 times on a high-speed muon [14].

Einstein theorized that physical laws have the same form in all reference frames and that they have the same covariance in any coordinate transformation [15]. Today, many laser interferometers are located around the world for detecting gravitational waves day and night [16]. Some of them have been in operation for several years. They have improved the precision of the Michelson-Morley experiments to an unprecedented degree. However, no report has stated that the absolute movement of the earth has been detected. The fundamental principle of the unchanging speed of light is irrefutable. There is no evidence that different forms of a physical law are needed between outer space and a gravitational field [17].

Consider the centripetal force of a circular motion in outer space:

$$F_0 = \frac{4p^2 m_0 r_0}{T_0^2} \tag{4.1}$$

where r_0 is the radius of the circular motion in outer space, T_0 is the period, and m_0 is the mass of the particle.

In a horizontal plane in a gravitational field,

$$F = \frac{4p^2 mr}{T^2} \tag{4.2}$$

Given the relationship of mass, length and time given above

$$F = F_0(\sqrt{1-2GM/c^2R})^2 \tag{4.3}$$

Based on the above discussion, it can be proved in the gravitational field,

$$\frac{1}{2}\cdot\frac{F}{m}T^2 = \frac{L_0}{\sqrt{1\text{-}2GM/c^2R}} = L \tag{4.4}$$

Thus, Newton's second law takes the same form.

As Albert Einstein suggested, experiments that are conducted in a free-falling elevator or in outer space are indistinguishable. Nevertheless, people have found that a clock slows down in a gravitational field. Why? The reason is that two identical clocks are used, and they are placed in the spaces to accomplish this. To be more precise, physical parameters from two different spaces are compared in this research method. Two flat coordinate systems are combined by external work, and the concept of space warp is much simpler. If an equation is established in a single coordinate system on a large scale, given a local test get the same result regardless of any location, and standard rulers and standard clocks are different at different radius, it will inevitably result in that the reality is a little more complicated.

When an electron enters a gravitational field, its mass decreases, the charge-mass ratio remains unchanged according to general covariance. Thus, the quantity of the electric charge decreases. This situation is also adapt to a proton. In other words, the bonding forces in atoms are weakened. (Protons and electrons have weaker electric field strengths, which can explain the origin of the gravitational red shift very well, and the size of an object increases in a gravitational field. Put another way, a spring has a smaller force in a gravitational field). A light source has wavelengths with unlimited length in the Schwarzschild radius. Why is this significant?

2.5 Mercury's perihelion advance

Of all the planets in the solar system, Mercury is the closest to the sun, and changes of physical parameters cannot be ignored. Namely, the weaker the gravitational field, the more precise Newton's theory will be. Let

$$x = \frac{R_0}{R} \tag{5.1}$$

where R is the true orbit radius of a particle and R_0 is the expectation.Then,

$$R = \int_0^{Rs} \frac{dr}{\sqrt{1 - 2GM/c^2Rs - GMr^2/c^2Rs^3}} + \int_{Rs}^{R} \frac{dr}{\sqrt{1 - 2GM/c^2r}} \tag{5.2}$$

where R_s is the radius of the body of the gravitational field.

This equation can be solved numerically with a computer. We will give the approximate solution here. The length of a ruler in the gravitational field is shown in Fig. 3.

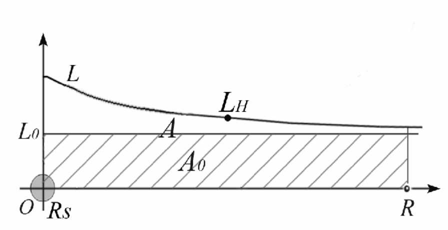

Fig. 3. L – the actual length curve of a ruler in a gravitational field.

Integration of L can provide the real orbit radius of a particle, namely, (A); and (A_0) is the expected value.

It can be proven according to Gauss's theorem that

$$x = \frac{A_0}{A} = \frac{L_0}{L_H} \tag{5.3}$$

where L_H is the length of the ruler at one-half of the orbit radius. So,

$$x = \frac{1}{\sqrt{1 - 2GM/c^2(R/2)}} = \frac{1}{\sqrt{1 - 4GM/c^2R}} \tag{5.4}$$

The description of mass that m in a gravitational field versus m_0 in out space can also be deduced by the same method. So,

$$R_0 = R \cdot x, \quad m_0 = m/x \tag{5.5}$$

The modified parameters can applied to the equation of complete square:

$$F_G = \frac{GM(m/x)}{(R \cdot x)^2} \tag{5.6}$$

The equation can be expanded, and negligibly small terms are ignored:

$$F_G = \frac{GMm}{R^2} + \frac{6G^2M^2m}{c^2R^3} \tag{5.7}$$

The parameter F_G is substituted into the Binet equation:

$$\frac{d^2u}{dq^2}+u=\frac{GM}{h^2}+\frac{6G^2M^2}{h^2c^2}u \tag{5.8}$$

where u=1/R and h are the moment of momentum of unit mass.

The differential equations is easy to solve, and the precession of the perihelion after one revolution is given by

$$\Delta q=\frac{6pGM}{a(1-e^2)c^2} \tag{5.9}$$

$$\Delta q=5.022\times10^{-7}rad$$

In a century, Mercury revolves around the sun 4.1521 times. Thus, the additional advance value is

$$\Delta q_C=43.001''$$

2.6 Delay of radar waves

In 1964, Shapiro, an American scholar, made radar waves pass the edge of the Sun. They reached Venus on the other side of the Sun and were reflected back to Earth. The actual time of travel was more than 200 microseconds longer than expected.

In reality, an observer outside the gravitational field uses his or her own clock and ruler to measure the speed of light at a radius R of the gravitational field. In view of the difference of the clocks and rulers, the result is

$$c_R=c(1-2GM/rc^2) \tag{6.1}$$

However, at the radius R, the measured speed of light remains "c" [8]. We divided the course of the radar waves into two parts. The actual time is

$$T_A=\int_{R_E}^{R_\Theta}\frac{dr}{c(1-2GM_\Theta/rc^2)}+\int_{R_D}^{R_\Theta}\frac{dr}{c(1-2GM_\Theta/rc^2)} \tag{6.2}$$

where R_E is the radius of Earth's orbit and R_D is the radius of Venus's orbit.

The expected time is thus

$$T_E=\frac{R_E-R_\Theta}{c}+\frac{R_D-R_\Theta}{c} \tag{6.3}$$

$$\Delta T=T_A-T_E=\frac{2GM_\Theta}{c^3}(\ln R_E+\ln R_D-2\ln R_\Theta) \tag{6.4}$$

$2\Delta T = 205.11ms$

3. Conclusions

Based on the above study, when equal amounts of matter and antimatter experience complete annihilation, energy of the photons missing cannot be found. A black hole grows stronger indefinitely without any matter is illogical. A photon is accelerated or decelerated by a gravitation field breaks the principle of the constant speed of light. A photon has gravitational mass contradicts the equivalence principle and electromagnetic theory. Thus, hypothesis (i) that energy cannot be transferred between a photon and a gravitational field is tenable. On the other hand, an object that is taken away from a gravitational field requires a third party to provide energy. Time and length are variable, and the physical laws have the same form in a gravitational field and in outer space. A gravitational singularity does not have infinite mass. Therefore, hypothesis (ii) that mass is variable in a gravitational field is tenable. Above two hypotheses are connected, can mutually confirm each other and can resolve issues regarding a gravitational field satisfactorily and consistent with the fundamental principle of general relativity.

4. Discussion

Reviewing some basic facts is suggestive. The uncertainty principle has been proclaimed that a particle with greater mass occupy smaller space, as the basic law in the microscopic world which is the theoretical basis of electron microscopes. De Broglie successfully extended the wave-particle duality of photons to the microcosmic field, and a particle with greater energy has a shorter wavelength. A high-energy photon has a shorter wavelength. Particle physicists usually use use mass to extrapolate the size of particles [18]. Today, it has become common knowledge that a heavier particle must have a smaller size in the microscopic world.

String theory uses a vibrated string to represent a particle, instead of a point, and succeeds in working out the problem of the divergence of the point model [19]. Planck length is recognized as the basic length in nature. In theory, the space size of a string should be restricted by the basic length. Usually, a larger stone is heavier, but in the microscopic world, the opposite is true. However, there is also evidence of the same phenomenon in the macroscopic world, for example, when an object is moving at a high speed, its size decreases, and its mass increases; when an object enters a gravitational field, its size increases, and its mass decreases, this change is a reflection of the microcosmic scale. In this sense, mass should be variable in a gravitational field.

It is not difficult to understand gravitation, given that an object entering a gravitational field can release energy. The space in a gravitational field has a lower energy state, and any particle will always jump toward the lower energy state and release energy, that is, gravitation.

We use the U to represent the gravitational potential energy, and the mass-field relationship can be expressed as that

$$\Delta U = \Delta mc^2$$

The typical proof of the mass-field relationship is the gravitational red shift. An experiment to test the theory shows as Fig. 4. Two copper balls are fixed on both sides of an axis. The structure of device labeled “a” rotates in the horizontal plane; another labeled “b” rotates in the vertical plane. They are driven and receive the same initial velocity. S is a double-decked superconducting magnetic bearing used to monitor the energy loss. The axis of device b should be perpendicular to the earth's axis (east-west direction) such that the directions of the axes have the same change in a day.

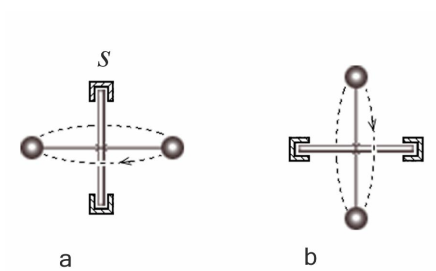

Fig. 4. Balls rotate around an axis in the horizontal plane (a) and in the vertical plane (b). The height of the balls in device b changes continuously, which causes transformations between mass and gravitational potential energy.

Based on this fact, any transformation of different forms of energy must take time, which is the theoretical basis of the clocks. From the standpoint of the mass-field relationship, the height of the balls in device b changes continuously, which causes transformations between the mass and the gravitational potential energy. A delayed change of mass is equivalent to attaching a resistance to device b. Lastly, the rotation of device b would lag behind that of device a.

We often think whether the mass-field relationship is a universal relationship. An observer outside the gravitational field obtains a slower speed of light which in the gravitational field. This kind of phenomenon can be seen often. For Example, when a ray of light enters a piece of glass, it is slowed down. That is because that the evaluated clock and ruler in a vacuum instead of in the glass (atomic electric field). If the mass-field relationship can apply to the electromagnetic force, the weak force and the nuclear force, it might explain the origin of the mass defect and even provide a way to construct a universal theory. For example, the receptor of a Mossbauer spectroscope could be put into a strong electric field or magnetic field to study the change of the atomic energy level. Confirming the mass-field relationship might generate additional ideas about the current difficulties in the field [20-23].

References

[1] S. W. Hawking: *Particle Creation by Black Holes*, Commun. Math. Phys. **43** [3] (1975) 199.

[2] M. K. Parikh and F. Wilczek: *Hawking radiation as tunnelling,* Phys. Rev. Lett., **85** [24] (2000) 5042.

[3] J. Maddox: *What Remains To Be Discovered* (Macmillan, 1998) p. 25-124

[4] R.Penrose: *The Road to Reality* (Jonathan Cape 2004) p. 655-868.

[5] Wald Robert M: *General Relativity* (University of Chicago Press, 1984)

[6] P. D. Mannheim: *Alternatives to Dark Matter and Dark Energy,* Prog. Part. Nucl. Phys. **56** [2] (2006) 340.

[7] Nieto, Michael Martin: *The quest to understand the Pioneer anomaly,* Europhysics News **37** [6] (2006) 30.

[8] S. Pakvasa, W. A. Simmons, and T. J. Weiler: *Test of equivalence principle for neutrinos and antineutrinos,* Phys. Rev. D **39** [6] (1989) 1761.

[9] Z. Qingzhang, C. Shizi: *Relativity and space-time* (Shanxi Science and Technology Press 1999) [In Chinese].

[10] Tu L C, Luo J, Gillies G T: *The mass of the photon,* Rep. Prog. Phys. **68** [1] (2005) 77.

[11] S Schlamminger, K..-Y. Choi, T. A. Wagner, J. H. Gundlach, and E. G. Adelberger: *Test of the Equivalence Principle Using a Rotating Torsion Balance,* Phys. Rev. Lett. **100** [4] (2008) 041101.

[12] T. E. Cranshaw and J. P. Schiffer: *Measurement of the gravitational red shift with the Mossbauer effect*, Proc. Phys. Soc., **84** [2] (1964) 245.

[13] P. A. M. Dirac: *Principles of Quantum Mechanics* (Oxford university press, 1958).

[14] D. H. Frisch and J .B. Smith: *Measurement of the Relativistic Time Dilation Using Muons,* Am. J. Phys. **31** [5] (1963) 342.

[15] S. Weinberg: *Gravitation and Cosmology* (John Wiley, New York, 1972) p. 91-93

[16] http://www.johnstonsarchive.net/relativity/gwdtable.html

[17] W. Renchuan: *Introduction to General Relativity* (University of Science and Technology of China Press 1996) pp. 131-132 [In Chinese].

[18] R. Eisberg and R. Resnick: *Quantum Physics of Atoms, Molecules, Solids, Nuclei and Particles* (John Wiley and Sons, 1985) 2nd ed., p. 96.

[19] G. Veneziano: *Elementary particles,* Physics Today **22**[9] (1969) 31.

[20] G. Vedrenne, Jean-Luc Atteia: *The brightest explosions in the Universe* (Springer Berlin Heidelberg New York 2009).

[21] P. Laurent, J. Rodriguez, J. Wilms, M. Cadolle Bel, K. Pottschmidt, and V. Grinberg: *Polarized Gamma-Ray Emission from the Galactic Black Hole Cygnus X-1,* Science. **332** [6028] p. 438 (2011).

[22) B. W. Ritchie, J.S. Clark, I. Negueruela, and N. Langer: *A VLT/FLAMES survey for massive binaries in Westerlund 1,* A&A. **520** [A48] (2010).

[23] D. J. Mortlock, et al: *A luminous quasar at a redshift of z = 7.085,* Nature **474** (2011) p. 616