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Authors: Yun-Gang Li[1], Cheng-Shu Li[2]

Affiliations: Hainan Shulin Education Group Co., Ltd.[1], Hefei University of Technology[2]

Orcid ids: 0000-0003-1382-8467[1], 0000-0002-2651-7214[2]

Contact e-mail: 576429680@qq.com

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Keywords: gravitational constant, derived constant, physical aesthetics, perihelion precession, Inverse-Square, general relativity

Study of gravitational constant and mercury's precession from perspective of physical aesthetics and ideal fluid

Yun-Gang Li^{1*} & Cheng-Shu Li²

¹Hainan Shulin Education Group Co., Ltd., Haikou 570226, China. ²Hefei University of Technology, Xuancheng 242000, China.
*e-mail:576429680@qq.com, mobile:+86 13876908506

Abstract: Newton's law of universal gravitation does not explain the abnormal precession of Mercury, and the values of gravitational constant G measured by different research teams does not coincide. This paper had study of these two problems from perspective of physical aesthetics and ideal fluid and derived a new formula for calculating the exact G value by using the speed of light in a vacuum, which including error correction formulas and verified by experimental data of other scientists. After corrected, the G values measured by some famous surveyors approximately coincides with a specific value. The formula also verified by the observation data of the abnormal precession of the perihelion of mercury, it contributes 35.94"/cy of additional observations to the abnormal precession of Mercury, which is only about 2"/cy different from the observed value of Le Verrier, this give another explanation for the abnormal precession of Mercury which is completely different from Einstein's general theory of relativity. The preliminary Conclusions is that G equals $1/(16\pi c)$. For further verify the formulas, this paper also designed an experimental plan for the space agency to disprove Einstein's GTR.

Keywords: gravitational constant, derived constant, physical aesthetics, perihelion precession, Inverse-Square, general relativity
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INTRODUCTION

The abnormal precession of Mercury's perihelion equals 43"/cy is the core proof to prove that Einstein's general relativity is right. Newton's law of universal gravitation does not explain the abnormal precession of Mercury's perihelion, and the gravitational constant G values measured by different research teams in the world do not coincide with each other within the error range for more than 200 years, for example, the difference between the results of BIPM-14 and LENS-14 collected by CODATA-2014 is as high as 544ppm¹, this may cause by undiscovered systematic errors.

In 2018, Luo Jun, an academician of the Chinese Academy of Sciences, led his team and measured the highest precise gravitational constant G in the world, including seven values by TOS method^{2,3}. We studied their experimental data and the experimental data of Cavendish in 1798⁴, Luther in 1982^{5,6}, Boys in 1895¹⁵, and many other research teams, and got a formula for calculating the exact value of the gravitational constant G using the speed of light in a vacuum, including the error correction formulas between the theoretical exact G value and the measured G value, then the measured G values approximately coincides with $1/(16\pi c)$. The correction formulas also verified by the observation data of the abnormal precession of mercury, it is another explanation for the abnormal precession of Mercury which is completely different from Einstein's general relativity.

METHOD

Physics is beautiful, it contains several aspects, such as simple, symmetry, harmonious and unity beauty, we explore Newton's law of universal gravitation and the gravitational constant G by using physical aesthetics, and treat gravitational

field as flow field of ideal fluid. Formula(1) is the mathematical expression of Newton's law of universal gravitation, and has the characteristics of physical beauty.

$$F = G \frac{Mm}{r^2} \quad (1)$$

Where G is the gravitational constant. The recommended G value (CODATA-2014) is $6.67408 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$ ¹. We found that the product of G and the speed of light in vacuum c (299792458 m/s ¹) is equal to 0.020008388, G is very close to $1/(50c)$, the difference is only 0.419 ‰.

$$F \approx \frac{1}{50c} \frac{Mm}{r^2} \quad (2)$$

The proportional factor in Eq.(2) contains an integer 50, which has simple characteristics, but lacks beauty, 50, $1/50$ and $1/(50c)$ have no special physical meaning, so $G=1/(50c)$ is, therefore, an approximation, a coincidence, but not the truth.

Formula (3) is the expression of Coulomb's law:

$$F = k \frac{q_1 q_2}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} = \frac{1}{\epsilon_0} \frac{q_1 q_2}{4\pi r^2} \quad (3)$$

Where $4\pi r^2$ is the spherical area of a virtual sphere which radius is equal the distance of the two point charges and one of the point charges is the sphere center. By analogy with Coulomb's law, we add spherical area $4\pi r^2$ into Newton's gravitational formula, and reserved c (The speed of light in vacuum, which was added in Eq.(2)), the gravitational formula becomes:

$$F = G \frac{Mm}{r^2} = \frac{1}{K_1 c} \frac{Mm}{4\pi r^2} \quad (4)$$

$$\text{Where } K_1 = \frac{1}{4\pi c G} \approx 3.9772 \approx 4$$

The integer one, two and four are the most common numbers with simple beauty in many physical and mathematical formulas, so it can be inferred that K_1 is equal to integer four, but the denominator of Eq.(4) already contains $4\pi r^2$, if the

denominator contains another integer four, it obviously does not have physical meaning, therefore, calculate the square root for integer four and get two integer two, and add to Eq.(4), then:

$$F = \frac{K_2 \frac{M}{2} \frac{m}{2}}{c \ 4\pi r^2} \quad (5)$$

We can obtain $K_2=16\pi cG=1.005731\approx 1$ from Eq.(1),(5). If K_2 equal to integer one, the proportional coefficient is only related to the speed of light in vacuum, and becomes extremely simple and has special physical significance, then Eq.(5) becomes another equation with simple beauty:

$$F = \frac{1}{c} \frac{M}{2} \frac{m}{2} \frac{1}{4\pi r^2} \quad (6)$$

From Eq.(1),(6):

$$G = \frac{1}{16\pi c} \quad (7)$$

The constant one in Eq.(6),(7) is containing units Wm^2/kg^2 . We use P to represent this constant and move c to the left, then:

$$Fc = P \frac{M}{2} \frac{m}{2} \frac{1}{4\pi r^2} \quad (8)$$

When a physical equation has the characteristics of physical beauty, and each variables and coefficients had a specific physical meaning, it may close to the truth. For Eq.(8), the left side Fc is the expression of power, and the right side, $P=1 \ W \cdot m^2/kg^2$, it has the most simple beauty, so we inferred that Eq.(6) ~ (8) is close to the truth.

In order to explain this, we put forward a new theory called half-effective-field theory: In the gravitational field of two particles of M and m , only the half gravitational field that near the m side of the particle M has an influence on the particle m , and for the particle m , only the half gravitational field that near the M side of the particle m has an influence on the particle M .

Eq.(7) can be used for calculating the theoretical gravitational constant G when the mass M and m are particles, but we obtain that $G=6.6360468E-11 \ N \cdot m^2/kg^2$, there is still a large deviation from the CODATA-2014 recommended value $6.67408E-11 \ N \cdot m^2/kg^2$, there may be some system errors not considered in the measurement of G value, so the measured G value needs to be corrected.

In general, the correct condition of formula (1) is that the mass M and m must be particles. However, it is found that the mass of uniform spherical shell or uniform sphere can be regarded as particle by integral calculation, this is why all the research teams treat the uniform sphere as a particle and do not correct the measured value of G .

If the gravitational field is regard as an ideal fluid, and the gravitational field around the mass is regard as a point sink, gravitation is the difference between the forces on both sides of the mass, one tangible sphere is bound to block part of the flow field (gravitational field) of another mass, and resulting increase the gravitation. The gravitational correction coefficient is proportional to the geometric average value of blocking area of the two mass and inversely proportional to the surface area S_r of the virtual sphere, where $S_r=4\pi r^2$, r is the centroids distance of the two masses.

$$F = (1 + K)G \frac{Mm}{r^2} \quad (9)$$

$$K = \frac{\sqrt{S_M S_m}}{S_r} = \sqrt{\frac{S_M}{S_r}} \sqrt{\frac{S_m}{S_r}} = K_M K_m \quad (10)$$

Where K_M is the correction coefficient of attractive mass M , K_m is the correction coefficient for measuring mass m , S_M is the projection area when M is projected to a virtual sphere with r as the radius, taking the centroid of m as the projection center, S_m is the projection area when m is projected to a virtual sphere with r as the radius, taking the centroid of M as the projection center.

When the mass M and m are spheres:

$$S_M = 2\pi r^2 \left(1 - \sqrt{1 - \frac{R_M^2}{r^2}}\right) \quad (11)$$

$$S_m = 2\pi r^2 \left(1 - \sqrt{1 - \frac{R_m^2}{r^2}}\right) \quad (12)$$

When $r \gg R_m$ and $r \gg R_M$, Eq.(10) can approximately become Eq.(13) and has simple beauty with the same form as formula(1):

$$K = \frac{\sqrt{S_M S_m}}{S_r} \approx \frac{R_M R_m}{4r^2} \quad (13)$$

Furthermore, we think that the essence of blocking is blocking mass flux, so:

$$K_m = \sqrt{\frac{M_b}{M}} \quad (14)$$

Where $M_b=MS_m/S_r$ and the maximum M_b should not exceed $m/2$, and then we obtain more inclusive equations:

$$K_M = \left(\frac{S_M}{S_r}\right)^a \quad (15)$$

$$K_m = \begin{cases} \left(\frac{S_m}{S_r}\right)^a, & \frac{m}{2} > \frac{S_m}{S_r} M \\ \left(\frac{m}{2M}\right)^a, & \frac{m}{2} \leq \frac{S_m}{S_r} M \end{cases} \quad (16)$$

The $m/2$ in Eq.(16) shows that the half-effective-field theory is self-consistency. Exponent a is related to the shape of the mass, when the mass is spherical, the exponent $a=0.5$, for cuboid, $a=1$.

Finally, the G value can be calculate from the measured value G_{measured} by Eq.(17):

$$G = \frac{G_{\text{measured}}}{(1+K)} \quad (17)$$

EXPERIMENTAL RESULT

We verified our theory by the measured data of other scientists in two aspects, the measurement of G and the abnormal precession of Mercury.

1. GRAVITATIONAL CONSTANT G

At present, it is recognized that the G value measured by Cavendish is $6.754E-11 \ N \cdot m^2/kg^2$, this G value can be calculate from the density of the earth he measured, the dimensions selected in the experiment with torsion balance of Cavendish are as follows: Large mass(ball) M is 12 inches in diameter, small mass(ball) m is 2 inches in diameter, the centroid distance of the large ball and the small ball is 8.85 inches⁴, the selected dimensions meets the condition $m/2 < MS_m/S_r$, and the second term of Eq.(16) should be selected for calculating K , then $K=0.017504$, the measured G value is corrected to $6.6378E-11 \ N \cdot m^2/kg^2$, the error between $6.6378E-11$ and $1/(16\pi c)$ is 264

ppm, and it's unbelievably precise in 1798.

In 1982, Luther's experiment, the measured G value is $6.6726E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$, the large mass M are two spheres with an average diameter of 101.6509 mm, the centroid distance between the large mass is 140.59454mm, the two small mass m are disks with diameter of 7.166 mm, and mounted on a hollow tube, rod 28.5472mm long, the mass of the two disks is $5g$ ⁵. Although the small mass is different from the sphere, but because the disks very thin and has little influence in other direction, we choose 0.5 for exponent a just like spheres. The centroid distance between M and m is 59.60667mm, and the correction coefficient $K=0.005334$, the corrected G value is $6.6372E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$, the error between $6.6372E-11$ and $1/(16\pi c)$ is 173 ppm.

In 2018, Luo Jun, an academician of the Chinese Academy of Sciences, measured the highest precision gravitational constant in the world at present, include seven values by TOS method. Because Luo Jun's team adopted the periodic method, the pendulum is a cuboid about 90mm long^{2,3}, so the pendulum need to be treated as two connected small mass m. And because the part of gravitation that needs to be corrected is proportional to the reciprocal of the quartic power of r, therefore, the short-range configuration only needs to consider the gravitational correction between the small mass m and the large mass M, the influence of another large mass M can be ignored. For remote configuration, at the equilibrium position, the gravitation between the two small masses m and each large mass M is almost the same, so for remote configurations, the effect of placing the two large balls M is almost same as not placing the two large balls, when the torsional angle of the cuboid pendulum is very small, therefore, the correction of gravitation can be ignored. And because the pendulum is a cuboid, so exponent $a=1$. We try to calculate the correction coefficient K_m :

$$K_m = \frac{S_m}{S_r} = \frac{1}{\pi} \times \arctan\left(\frac{W}{2r-L}\right) \times \arctan\left(\frac{H}{2r-L}\right) \quad (18)$$

Where m is a half of the cuboid pendulum, and the center of mass m is located at 1/4 length of the pendulum. S_m is the projection area when the near half pendulum (m) is projected to the virtual sphere with r as the radius with the center of mass of M as the projection center. W is the width of the pendulum, H is the height of the pendulum, L is half the length of the pendulum(That is, the length of m). But it also meets the condition $m/2 < MS_m/S_r$, so, the second term of Eq.(16) should be selected, then we obtain the corrected G values and the errors between the theoretical value $6.6360468 \text{ E-11 N}\cdot\text{m}^2/\text{kg}^2$.

Table1 Corrected G value of Luo Jun and errors (2018)

Experiment	Measured ^[2,3] $10^{-11} \text{ Nm}^2/\text{kg}^2$	Corrected $10^{-11} \text{ Nm}^2/\text{kg}^2$	error ppm	weighted mean values $10^{-11} \text{ Nm}^2/\text{kg}^2$	
G1	6.674154	6.635627	-63	6.635661	6.635704 TOS-I
G2	6.674222	6.635695	-53	Fibre1	
G3	6.674237	6.635710	-51	6.635710 Fibre2	
G4	6.674274	6.635747	-45	6.635743 Fibre3	
G5	6.674266	6.635739	-46		
G6	6.674017	6.636464	63	6.636508	6.636508 TOS-II
G7	6.674105	6.636552	76	Fibre4	
Average	6.674182	6.635933	-17		6.636106

Table1 shows the simple average of the corrected G values

is 6.635933 with error -17ppm, and the weighted mean value is 6.636106 with error 9ppm.

2. ABNORMAL PRECESSION OF THE PLANETS

Eq.(19) is the differential equation of motion of the planets, where $u=1/r$, GM is the heliocentric gravitational constant, M is the mass of the Sun, $J = r^2\dot{\theta} = rv = v/u$.

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{J^2} = \frac{F}{mu^2J^2} \quad (19)$$

We get the necessary data from the NASA official website and display it in Table2 and Table3.

Table2 parameters of Planets⁷

parameters	Mercury	Venus	Earth	Mars
Mass (10^{24} kg)	0.33011	4.8675	5.9723	0.64171
Radius R_m (10^6 m)	2.4397	6.0518	6.371	3.3895
perihelion r_{min} (10^9 m)	46.00	107.48	147.09	206.62
aphelion r_{max} (10^9 m)	69.82	108.94	152.10	249.23
Period (day)	87.969	224.701	365.256	686.980
velocity $\bar{v}$ (m/s)	47360	35020	29780	24070
J ($10^{15} \text{ m}^2/\text{s}$)	2.712981	3.789459	4.455097	5.475773

Table3 parameters of Sun⁸

parameters	values
Mass (10^{30} kg)	1.9885
GM ($10^{20} \text{ m}^3/\text{s}^2$)	1.32712
Radius R_M (10^8 m)	6.957

All planets in the solar system meet the condition $m/2 > MS_m/S$, the correction coefficient K of gravitation can be calculate using the Eq.(10) (11) (12), and because $r \gg R_m$ and $r \gg R_M$ it can be simplified to the form of Eq.(20) by using curve fitting, the fitting results are shown in Table4.

$$K = \frac{\sqrt{S_M S_m}}{S_r} \approx Au^2 \quad (20)$$

Table4 results of curve fitting of Eq.(20)

Planets	the value of A	Absolute error of K
Mercury	4.243335E14	$\pm 1.6E-12$
Venus	1.05256477E15	$\pm 7.1E-15$
Earth	1.10807918E15	$\pm 5.6E-15$
Mars	5.8951947E14	$\pm 6.3E-15$

An arcsec is about $7.716E-07$ of one circumference, so the absolute error of K in Table4 is small enough, and then the Eq.(9) approximate becomes:

$$F = (1 + Au^2)GMmu^2 \quad (21)$$

From Eq. (19) and Eq.(21) we obtain:

$$\frac{d^2u}{d\theta^2} + u = \frac{GM}{J^2} (1 + Au^2) \quad (22)$$

And then:

$$\frac{d^2u}{d\theta^2} + u(1 - \frac{GMAu}{J^2}) = \frac{GM}{J^2} \quad (23)$$

Eq.(23) can be approximately regarded as a differential equation of simple harmonic motion, the contents in parentheses of Eq.(23) is the square of the orbital angular frequency of the planet, then:

$$\omega = \sqrt{1 - \frac{GMAu}{J^2}} \quad (24)$$

The orbit angular frequency ω in Eq.(24) is a variable that depends on u , so the ω needs to be averaged, and it is more reasonable to use orbital average velocity $\bar{v}$ instead of $\bar{u}$ to find $\bar{\omega}$ (the average value of ω), and because $u=v/J$, then:

$$\bar{\omega} = \sqrt{1 - \frac{GMA\bar{v}}{J^3}} \quad (25)$$

The precession value in one orbit period is:

$$\Delta\phi = 360 \times 3600 \times \left(\frac{1}{\bar{\omega}} - 1\right) \quad (26)$$

Table5 the precession of perihelion of planets in a century

Planets	observed ⁹ "/cy	GTR ⁹ "/cy	$\Delta\phi_{1cy}$ "/cy
Mercury	Le Verrier: 38 Newcomb:43.11±0.45	43.5	35.94
Venus	8.4±4.8	8.62	9.47
Earth	5.0±1.2	3.87	3.21
Mars	1.3624±0.0005	1.36	0.395

ANALYSIS AND DISCUSSION

Our error correction formulas significantly reduced the abnormal precession of Mercury: The total observed precession of Mercury is 5600"/cy¹¹, the abnormal precession calculated by Newcomb is about 43"/cy⁹, and the error =43/5600=7.68%, the abnormal precession calculated by Le Verrier is 38"/cy⁹, the error is 6.79%, our new theory contributes 35.94"/cy, compared with Newcomb's data, the abnormal precession reduce to about 7"/cy with an error 1.25%, compared with the data of Le Verrier, the abnormal precession reduce to about 2"/cy with error 0.357%.

Many papers question that the abnormal precession of mercury perihelion equals 43"/cy. Einstein use formula (27) for calculating the abnormal precession of Mercury, in fact, Einstein had made several approximate treatments when he got formula (27)^{12,13,14}.

$$\varepsilon = \frac{24\pi^3 a^2}{(1-e^2)c^2 T^2} \quad (27)$$

Hua Di's paper shows that Einstein was wrong in integral calculation, the abnormal precession of Mercury calculate by Einstein's GTR should be 71.5"/cy¹², and Kupryaev agrees with Hua Di's viewpoint, his paper shows a result 71.63"/cy¹³. However, the maximum absolute error of K caused by the approximate treatment of Eq. (20) in this paper is only about 1.6e-12 (equivalent to 0.00086"/cy).

The mass ring model used by Newcomb and Le Verrier in the calculation of the perturbation of the planets to Mercury had made approximate treatment too. Price and Rush shows the calculating process by the mass ring model in their paper in 1979.¹⁰ This model only considers the influence of radial direction and does not consider other directions, and all planets actually revolve around the center of mass of the solar system, not around the sun, for example, the common center of mass of Jupiter and the sun is located at about 1.07 times of the radius of the sun, that is to say, outside the surface of the sun. So, we don't think the observed value of the precession of Mercury is a fixed value, it changes over time, Rydin also shows a similar viewpoint in 2011¹¹.

So, 43"/cy should not be the evidence for prove that Einstein's GTR is correct. The 35.94"/cy is not the exact abnormal precession value too, our formulas just only

contributes about 36"/cy to theoretical calculation value of mercury precession. Obviously, measurement errors always exist, no one can eliminate it completely. If convert the remaining abnormal precession 2"/cy to the measurement error of Mercury's parameters, it will be incredibly accurate. So, Eq. (16) in this paper is reliable.

And it is not a coincidence that some of the measured G values by some famous surveyors using different devices at different positions coincide with $1/(16\pi c)$.

We regard the gravitational field as flow field of ideal fluid, the gravitation between tangible masses is not a strict inverse square relation when the distance is very close, which needs to be corrected. For tangible mass, the simplest case is that both masses are uniform spheres, just like Cavendish's experiment. So, we consider the following principles when we choose the experimental data of G measurement to verify Eq. (7) (15) (16): the large mass must be sphere, and only two large masses per measurement, and the surveyors provides all dimensions of the large and the small masses and the distance between the centers of the large masse and the small masse. In fact, most of the surveyors did not use uniform spheres for the large mass and the small mass at the same time in their experimenters, this will cause the gravitational field to become complex.

If the gravitational field can be regard as flow field of ideal fluid, in addition to the correction method we mentioned, there are other factors may affect the measurement accuracy of G values. For example, modern equipment for measuring G value is very compact, the distance between the supporting parts of the torsion balance and the large ball and the small ball is very small, it may interfere with the gravitational field. And the test mass is too small, for example, the two small masses used by Luther is only 5 grams^{5,6}, the influence of the supporting parts of the torsion balance on the gravitational field is much greater than the influence of the small mass. Thus, there may be an illusion, the accuracy of the measured G value is very high for one team. But the measured G value do not coincide with other teams as the equipment used is not the same.

We gave up some experimental data, here are some examples:

Boys only provided the centroid distance between the large ball and the small ball of the Exp8 in his paper in 1895¹⁵. We can only assume the dimension of p or b (in Fig. E)¹⁵ invariant to correct the measured G value of other experiments, and the relative errors between the results of boys are very large, three of which are more than 2000ppm.

Luther used the same large mass M in 1997 as the experiments in 1982⁶, the diameter of the large mass M is about 101.65mm⁵, but his paper in 1997 shows that the separation of the centers of the tungsten spheres (large mass) is 71.9092mm for Expt.#1 and 69.8567mm for Expt.#2⁶, less than 101.65mm, this is impossible, and the determination employing low-Q torsion pendulums have an upward bias, so we think the experimental data of Luther in 1997 may had problems and did not use his data in paper 1997.

Our theory given a completely different explanation from Einstein's GTR for the abnormal precession of Mercury, and only one of the explanations is right. We designed an experiment for the space agency to further verify which is right:

Launch a spacecraft that rotates around the sun which orbit

parameters is close to the Mercury's orbit, is about 180 degrees of phase difference. It can verify whether Einstein's GTR is correct or our theory is correct by measuring the orbit precession of the spacecraft. Consider Kepler's law, we can obtain Eq. (28) from formula (27):

$$\varepsilon = \frac{3GM}{c^2 R_p} \cdot \frac{2-e}{(1-e^2)} = \frac{3GM}{c^2 R_p} \cdot f(e) \quad (28)$$

We using Eq.(28) for qualitative analysis, not for accurate calculation, it can be approximately considered that M is the mass of the sun, R_p is the distance between the sun and the perihelion, and e is the eccentricity of the orbit. According to Eq. (28), if the perihelion of the spacecraft is kept constant, the orbit precession of the spacecraft will only change with the eccentricity of the orbit. And because the spacecraft is very small, according to Eq. (16), K_m is very small too, and then the calculated orbit precession value of the spacecraft is close to zero. So, if the measured orbit precession value of the spacecraft is close to that of Mercury, Einstein is right, if the measured orbit precession value of the spacecraft is close to zero (no precession), our theory is right. Change the orbit and let the eccentricity e to be a large value, and the perihelion kept constant, according to Eq.(28), the orbit precession value should change a lot, according to our theory, the orbit precession value of the spacecraft change too, but still very close to zero.

Compared with Einstein's theory of relativity, our theory only uses elementary mathematics, each variable and coefficient in the equations has a specific physical meaning, and has the characteristics of simple beauty, and the correction method can be applied in a wider range, while Einstein's GTR does not explain why the G value measured by different teams do not coincide.

CONCLUSIONS

- 1.The exact value of gravitational constant can be derived from the speed of light in vacuum, $G=1/(16\pi c)$.
- 2.If two masses are tangible and very close, the gravitation and centroid distance is not strictly inverse square relation.
- 3.The gravitation in the measurement of G value by torsion balance needs to be corrected.
- 4.The abnormal precession of Mercury equals 43"/cy should not be the evidence for prove that Einstein's GTR is correct.

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