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

Study of universal gravitation and Mercury precession from a physical aesthetics and ideal fluid perspective

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Abstract: Newton's law of universal gravitation does not explain the Mercury's orbit anomalous precession, and the gravitational constant G values measured by different research teams do not coincide. This paper studied the two problems from a physical aesthetics and ideal fluid perspective, and derived a new formula for calculating the exact G value by using the speed of light in vacuum, including formulas for error correction, and verified by experimental results of other scientists. After being corrected, the G values measured by some famous surveyors approximately coincide with a specific value. The formulas also verified by the precession of Mercury's orbit and contribute an additional 35.94"/cy to the theoretical calculation value, the Mercury's anomalous precession, calculated by Le Verrier, is then reduced from 38"/cy to about 2"/cy. This provides another explanation for Mercury's anomalous precession which is completely different from that of Einstein's general relativity. Conclusion is that G equals $1/(16\pi c)$ when the masses are mass points and the Mercury's orbit anomalous precession equals 43"/cy should not be the evidence for prove Einstein's general relativity is correct. Further, this paper also presented an experimental plan for the space agency to verify who is right.

Keywords: physical aesthetics, general relativity, gravitational constant, derived constant, anomalous precession, inverse square

INTRODUCTION

The Mercury's orbit anomalous precession equals 43"/cy is the core evidence for prove that Einstein's GTR is right. Newton's law of universal gravitation does not explain the Mercury's orbit anomalous precession, 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 544ppm^[1], this may cause by undiscovered systematic errors. In this paper, we try to solve these problems.

We put forward a modified theory of universal gravitation and call it half-effective-field theory, and derived a new formula for calculating the exact G value by using the speed of light in vacuum, including formulas for error correction between the measured G value and the derived G value. We verify these formulas by Jun Luo's experimental data in 2018^[2,3], Cavendish's data in 1798^[4], Luther's data in 1982^[5,6], Boys' data in 1895^[7], and Karagioz's data in 1996^[8]. After being corrected, the measured G values approximately coincide with $1/(16\pi c)$.

The formulas for error correction can be used to explain the anomalous precession of Mercury's orbit, and contribute an additional 35.94"/cy to the theoretical calculation G value, then the anomalous precession of Mercury's orbit calculated by Le Verrier is reduced from 38"/cy to 2"/cy, and the value calculated by Newcomb is reduced from 43"/cy to 7"/cy. Combined with some results of other researchers, we conclude that the anomalous precession of Mercury's orbit should not be the evidence for prove that Einstein's GTR is correct.

EXPLORE METHOD

Physics is beautiful, it contains several aspects, such as simple, symmetry, harmonious, and unity beauty. We study

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.

Equation (1) is the mathematical formula of Newton's law of universal gravitation and has physical beauty features.

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

Where G is the gravitational constant. The CODATA-2014 recommended G value 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 features, 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.

Equation (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, radius r is the distance between the point charges, and one of the point charges is the center of the virtual sphere. By analogy with Coulomb's law, spherical area $4\pi r^2$ can be added into Eq. (1), and analogy with Eq. (2), c can be added into Eq. (1), then:

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

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

The integer one, two, and four are the most common numbers with simple beauty features in many mathematical formulas or physical 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 of integer four, it can get two integer two, and then add them into Eq.(4), then:

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

From Eq. (1), (5), it can obtain that $K_2=16\pi cG=1.005731 \approx 1$. 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:

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

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:

$$Fc = P \frac{M}{2} \frac{m}{2} \quad (8)$$

When a physical equation has physical beauty features, and each variables and coefficients have a specific physical meaning, it may be 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 beauty and the simplest features, so we inferred that Eq. (6) ~ (8) is close to the truth.

When the mass M and m are mass points, Eq. (7) can be used for calculating the exact theoretical gravitational constant G . 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 $6.67408E-11 N \cdot m^2/kg^2$ [1]. 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 condition that Eq. (1) is correct is that the mass M and m must be mass points. However, it is found that uniform spherical shell or uniform sphere can be regarded as mass point by integral calculation, this is why all the research teams treat the uniform sphere as a mass point and do not correct the measured G value.

When the gravitational field is regard as an ideal fluid, the gravitational field around the mass is a point sink, and gravitation is the difference between the field "pressure" 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 the large mass M , K_m is the correction coefficient of the small mass m , S_M is a projection area when M is projected onto a virtual sphere

surface with r as a radius and the centroid of m as the projection center, S_m is a projection area when m is projected onto a virtual sphere surface with r as a radius and 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) approximates to Eq. (13), it has simple beauty features and a similar form as the formula of Newton's law of universal gravitation:

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

Furthermore, we guess that the essence of blocking is blocking mass flux, then:

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

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

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

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

Exponent a is related to the shape of the mass, when the mass is spherical, exponent $a=0.5$, for cuboid, $a=1$.

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

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

In order to explain Eq. (6), (8), we put forward a new viewpoint and call it half-effective-field theory:

In the gravitational field of two mass points M and m : for the gravitational field of mass point M , only half that on the m side is affected by mass m ; for the gravitational field of mass point m , only half that on the M side is affected by mass M .

FIG. 1. sketch of gravitational field of half-effective-field theory, case of the first term of Eq. (16): the red gravitational lines of the two spheres never cross, the blue line does not cross through another sphere.

EXPERIMENTAL RESULT

The formulas obtained above constitute a modified model of Newton's law of universal gravitation. We try to verify this model by the experimental result of other scientists in two aspects: measurements of G and observations of the Mercury's orbit precession.

1. EXPERIMENTAL RESULT OF G MEASUREMENTS

At present, it is recognized that the G value measured by Cavendish is $6.754E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$, 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 inches^[4], 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 $6.6378E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$, the error between $6.6378E-11$ and $6.6360468E-11$ 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 101.6509mm, 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^[5,6]. Although the small mass is different from the sphere, but because the disk is very thin and has little influence in other direction, it can choose 0.5 for exponent a, just like spheres. The centroid distance between M and m is 59.60667mm, and then the correction coefficient $K = 0.005334$, the corrected G value is corrected to $6.6372E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$, the error between $6.6372E-11$ and $6.6360468E-11$ is 173 ppm.

In 2018, Jun Luo, 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 Jun Luo's team adopted the periodic method, the pendulum is a cuboid about 90mm long^[2,3], so the pendulum needs 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 near position of the two configurations only needs to consider the correction between the small mass m and the near large mass M, the influence of another large mass M can be ignored. For the far position, the gravitation between the two small masses m and each large mass M is almost the same, when the torsional angle of the cuboid pendulum is very small, the influence can be ignored and do not need correction. 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 a projection area when m (the near half pendulum) is projected onto a virtual sphere surface with r as a radius and the centroid of large mass M as the projection center. W is the pendulum width, H is the pendulum height, L is a half of the pendulum length

(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, see table1.

Table1 G values measured by Jun Luo in 2018, with their corrected G values, and errors between corrected G values and $6.6360468E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$.

Exp.	Measured ^[2,3] $10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$	Corrected $10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$	error ppm	weighted mean values $10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$	
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	
G5	6.674266	6.635739	-46	Fibre3	6.636508 TOS-II
G6	6.674017	6.636464	63	6.636508	
G7	6.674105	6.636552	76	Fibre4	
Average	6.674182	6.635933	-17		6.636106

Simple average value is $6.635933E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$ with error -17ppm, and weighted mean value is $6.636106E-11 \text{ N}\cdot\text{m}^2/\text{kg}^2$ with error -9ppm.

2. ANOMALOUS PRECESSION OF MERCURY

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

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

The relevant data can be got from the NASA official website, see table2 and table3.

Table2 parameters of Planets^[9]

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 Sun^[10]

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 calculated by Eq. (10) (11) (12), and because $r \gg R_m$ and $r \gg R_M$, it can be simplified to 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) can be approximately changed into:

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

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

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

And then:

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

The second part in the parentheses of Eq. (23) is a very small value, the variable u can be regarded as a tiny disturbance, and all contents in the parentheses can be approximately regarded as a constant when integrating. Then Eq. (23) can be approximately regarded as a differential equation of simple harmonic motion, the contents in the parentheses is the square of the planets' orbital angular frequency, then:

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

The angular frequency ω of the orbit in Eq.(24) is a variable that depends on u, so it 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 additional precession value in one orbit period is:

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

Table5 additional theoretical calculation value of the precession of planets in a century

Planets	observed ^[11]	GTR ^[11]	$\Delta\theta_{1cy}$
Mercury	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

Einstein's GTR predicted that light could deflect in the gravitational field, and predicted black holes, gravitational waves, gravitational redshift, etc. Our new model is not in conflict with these, on the contrary, the deflection of light in the gravitational field, gravitational redshift, gravitational waves prove that the gravitational field can be regarded as flow field of ideal fluid and the gravitational field around the mass can be regarded as a point sink, which is the basis of our model.

The core evidence of Einstein GTR is that the anomalous precession of Mercury's orbit is equal to about 43"/cy, Einstein use Eq. (27) to calculate the Mercury's anomalous precession [12,13,14].

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

According to Einstein GTR, the Mercury's anomalous precession should be a fix value, either the observed value or the theoretical calculation value has errors, the anomalous precession value will be changed, and then this core evidence will not hold water.

The mass ring model is use for calculating the perturbation

of the planets to Mercury, Newcomb and Le Verrier had made some approximation this model. Michael P. Price's paper and Kin-Ho Lo's paper also show the calculating process of the mass ring model [15,16]. This model only considers the influence of radial direction and does not consider other directions. And, in fact, all planets revolve around the centroid 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 do not think the theoretical calculation value of the Mercury's anomalous precession is a fixed value, it changes over time, Rydin also shows a similar viewpoint in 2011 [17].

In fact, Einstein had also made several approximations when he got Eq. (27) [12,13,14]. And many researchers question Eq. (27) [13,14]. Hua Di's paper shows that Einstein was wrong in his integral calculation, the Mercury's anomalous precession calculated by Einstein's GTR should be 71.5"/cy [13], and Kupryaev agrees with Hua Di's viewpoint, his paper shows a result 71.63"/cy [14]. However, the maximum absolute error of K caused by the approximation of Eq. (20) in this paper is only about 1.6e-12 (equivalent to 0.00086"/cy), and that our model observably reduces the Mercury's anomalous precession: the total Mercury's precession is 5599.7"/cy [17,18], the anomalous precession of Mercury calculated by Newcomb is about 43"/cy [11,17,18,19], and the error = 43/5599.7 = 7.68‰, the value calculated by Le Verrier is about 38"/cy [17,18,19,20] with an error 6.79‰, our new model contributes 35.94"/cy, compared with Newcomb's data, the anomalous precession is reduced to about 7"/cy with error 1.25‰, and compared with the data of Le Verrier, the anomalous precession is reduced to about 2"/cy with error 0.357‰. Obviously, measurement errors always exist, no one can eliminate it completely. If the remaining anomalous precession 2"/cy is converted to the measurement error of Mercury's parameters, this would be incredibly accurate in that era. So, Eq. (16) in this paper is reliable.

And then analyze the other side, when the gravitational field is regard 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, the following principles should be considered when choosing the experimental data of G measurement to verify the new model: the torsion balance experiment adopts direct tilt method or periodic method, the large mass must be sphere, and no more than two large masses per measurement, and the surveyors provides all need dimensions in their papers, including diameter of the large mass and the small mass, and the distance between the centers of the large masse and the small mass. Therefore, there are some unsatisfactory respects for the correction by using the G measurements data:

Many surveyors did not use uniform spheres for both large mass and small mass in their experimenters, which makes the gravitational field too complex to be corrected by Eq. (16).

Boys only provided the centroid distance between the large ball and the small ball of the Exp8 in his paper in 1895 [7]. It can only assume the dimension of p or b (in Fig. E) [7] 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. So, Boys' data in 1895 should be give up.

Luther used the same large mass M in 1997 as the experiments in 1982^[6], the diameter of the large mass M is about 101.65mm^[5], 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.#2^[6], less than 101.65mm, this is impossible, and the determination employing low-Q torsion pendulums have an upward bias^[6], so the experimental data of Luther in 1997 may had problems and should be give up.

When the gravitational field is 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 of large mass M is much greater than the influence of the small mass on the gravitational field of large mass M . Thus, there may be an illusion, the accuracy of the measured G value is very high for one team. But the measured G values do not coincide with other teams as the equipment used is not the same.

CONCLUSIONS

Although more evidence is needed, it is not a coincidence that the corrected G values measured by some famous surveyors using different devices at different positions coincide with $1/(16\pi c)$. And the $m/2$ in Eq. (16) shows that the half-effective-field theory is self-consistency. Compare with Einstein's GTR, our model only uses elementary mathematics, each variable and coefficient in the equations has a specific physical meaning, and has simple beauty features, and can be applied in a wider range, while Einstein's GTR can not explain why the G values measured by different teams do not coincide. So, preliminary conclusions can be drawn:

1. The exact value of gravitational constant can be derived from the speed of light in vacuum, $G=1/(16\pi c)$.

2. In the gravitational field of two mass points M and m : for the gravitational field of mass point M , only half that on the m side is affected by mass m ; for the gravitational field of mass point m , only half that on the M side is affected by mass M .

3. In the gravitational field of two tangible masses, the gravitation and centroid distance is not strictly inverse square relation, it needs to be corrected according to the geometric dimension.

Combine with some other researchers' doubts about Einstein's GTR^[13,14], another conclusion can be drawn:

4. The Mercury's anomalous precession equals 43"/cy should not be the evidence for prove that Einstein's GTR is correct.

For the explanation of Mercury's anomalous precession, only one is right, our model or Einstein's GTR. We presented an experiment for the space agency to 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. Consider Kepler's law, Eq. (27) becomes:

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

Where e is the eccentricity of the orbit, R_p is the distance of the orbit's perihelion. Eq. (28) is use for qualitative analysis, not for accurate calculation, it can be approximated that M is the mass of the Sun.

According to Eq. (28), if the R_p is kept constant, the spacecraft's anomalous precession ε will only change with the eccentricity e of the orbit. And because the spacecraft is very small, according to Eq. (16), K_m is very small too, and then, the calculated spacecraft's anomalous precession by Eq. (26) should be close to zero. So, it can verify which is right by measuring the spacecraft's precession. If the measured spacecraft's precession is close to that of Mercury, Einstein is right, and if the measured spacecraft's precession is less than that of Mercury (about 36"/cy), our model is right. Then change the orbit and let the eccentricity e to be a large value, and the R_p kept constant, according to Eq. (28), the spacecraft's anomalous precession should change a lot, according to our model, the spacecraft's anomalous precession should change too, but the change value is very close to zero. So, if the measured spacecraft's precession is still about 36"/cy less than that of Mercury, our model is right.

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DATA AVAILABILITY

All data of this paper openly available in public repository that issues datasets with DOIs or URLs.

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