A Hypothesis that the Non-gravitational Anomalous Acceleration of 1I/2017 U1 'Oumuamua and Lunar Orbital Expansion May Cause by One Same Reason

Author
Dongcheng Zhao (Caihui Zhao) The Orphan school of Jilin, China

Orcid:0000-0001-6141-757x

Abstract
The Newtonian gravity considers gravity is a force that action at a distance, however, if gravity is quantized, then it should not be an instantaneous force, but propagates toward a direction at the speed of light by gravitational quanta. The quantum kinematic gravitational effect may be able to adapt the Newton's gravitational equation to quantum gravity theory, and may improve its accuracy in some dynamic scenes. Here is a possible method of using quantum kinematic gravitational effect to describe the anomalous acceleration of 1I/2017 U1'Oumuamua, the margin of error between the calculated result and the astronomical observations during Oct 19, 2017 - May 3, 2018 is less than 20%. The accumulation of extra velocity caused by quantum kinematic gravitational effect may provide extra kinetic energy, and this may be one of the reasons which caused Lunar orbital expansion.

Key words
Quantum kinematic gravitational effect, quantum kinematic gravitational equation, the anomalous acceleration of Oumuamua, $\alpha$ angle, Lunar orbital expansion

Main
Through precise scientific measurements, scientists have discovered that there is an expansion in the Lunar orbit, the moon is moving away the earth at a rate of 3.8 cm per year,$^{1,2,3}$ the current dominant explanation for this phenomenon is the theory of
conservation of angular momentum in the Earth-Moon system.\textsuperscript{4,5,6,7} The momentum of the Earth's rotation converted by tidal action into the momentum of the expansion of Lunar orbit, so the expansion of Lunar orbit and the slowdown of the Earth's rotation should occur simultaneously, and this is consistent with previous observations. Although this explanation is controversial, it has impossible to prove it or disprove it, and fortunately the time for verification has now come. Recently, scientists have observed that the Earth's rotation speed is accelerating,\textsuperscript{8,9,10} now the explanation can be verified with precise observations of Lunar orbit, according to the theory above, Lunar orbit should stop expanding even shrink while the Earth’s rotation is accelerating, if the observations are consistent with this, it can prove that the theory is correct. In case Lunar orbit continues to expand as usual, then what gives it sustained momentum should be other reason. A new theory based on quantum gravity is discussed here to explain the problem of power sources of the Lunar orbit expansion, it considers that the driving force of Lunar orbit expansion comes from quantum kinematic gravitational effect which should be independent of the rotation of the Earth. The theory suggests that objects moving in a gravitational field are affected by quantum kinematic gravitational effect, the strength of which is related to its velocity and $\alpha$ angle (included angle between object moving direction and direction of gravitational line emission, see \textit{figure 1}), the effect is minimum in case $\alpha$ angle is 90$^\circ$. Lunar gains tiny momentum under the continuous influence of the quantum kinematic gravitational effect come from the Earth and the Sun while it moving in their gravitational field. Since the orbital velocity of the Earth and Lunar is much lower than the speed of light, and their orbital eccentricities are only 0.0167 and 0.0549 respectively, this means the $\alpha$ angles are close to 90$^\circ$, so when Lunar orbits around the Earth and the Sun, the extra acceleration caused by the quantum kinematic gravitational effect is minimal. However, the acceleration caused by quantum kinematic gravitational effect should be large enough to be observed easily, when celestial body's velocity and eccentricity are large enough.

On October 19, 2017, Pan-STARRS1 astronomical telescope discovered a celestial body with relatively high velocity and orbital eccentricity of 1.92, named 1I/2017 U1
'Oumuamua, which has significant anomalous acceleration.\textsuperscript{11,12} Normally, this kind of anomalous acceleration is belongs to non-gravitational acceleration which caused by cometary outgassing.\textsuperscript{13,14,15,16} However, based on the observations of Spitzer Space Telescope, since no obvious evidence of outgassing has been observed,\textsuperscript{17,18,19,20} it has been classified as an asteroid, so its anomalous acceleration is difficult to be explained by cometary outgassing theories. As a result, scientists have tried in recent years to come up with some new ways to solve this dilemma.\textsuperscript{21,22,23,24,25} However, these interpretations are still disputed. Here is a new way to explain the anomalous acceleration of Oumuamua with gravitational method. Under the premise of gravity is quantized,\textsuperscript{26,27,28} with the help of quantum kinematic gravitational effect, the Newton's gravitational equation should be able to describe the anomalous acceleration of Oumuamua.

Quantum kinematic gravitational effect is a kinematic effect based on quantum theory of gravity; it describes that the gravitational force act on an object is related to its state of motion in the gravitational field, the intensity of gravitational force changes with the changing of object's moving state. If gravity has quantum kinematic properties, then gravitational quanta should emanate from objects and propagate far away at the speed of light, in this case the gravitational effect on an object that remains relatively static should be different with the gravitational effect on fast moving objects. First, it is assumed that gravity is quantized, countless gravitons are emitted from objects and move away at the speed of light, forming a gravitational field. The gravitational effect on an object that remains relatively static in this gravitational field is $F$.

\begin{equation}
F = G \frac{Mm}{r^2}
\end{equation}

Therefore, based on the theory of quantum kinematic gravitational effect, the quantum kinematic gravitational force between them not only depends the product of their masses and the square of the distance between them, but also depends the object moving velocity in gravitational field and the $\alpha$ angle. The relationship between quantum kinematic gravitational force and static gravitational force can be described by using
Figure 1

$x$ represents the object moving direction A to B, with the velocity of $v$.

$y$ represents the gravity quanta propagate direction A to C, with the velocity of $c$.

$\alpha =$ the included angle between $x$ and $y$.

$F$ is the Newton’s gravitational force on static object, its strength can be represented by the length of $y$.

$F_k$ is the quantum kinematic gravitational force on moving object, its strength can be represented by the length of $z$. Because $z$ does not have a velocity component, so when the value of $z$ is greater than $y$, it does not mean its relative velocity is greater than the speed of light, it just means the object is under greater gravitational force than when it is at static.

In figure 1, $x$, $y$ and $z$ formed a triangle $\Delta ABC$, then the relationship between them can be solved with the Cosine theorem, so the relationship between $F_k$ and $F$ can be described by the following equation:

$$F_k = \frac{\sqrt{v^2 + c^2 - 2vc \cos \alpha}}{c} F$$

(2)

Thus, the form of the Newton’s gravitational equation while incorporating the
quantum kinematic gravitational effect, can be expressed as:

\[ F_k = G \frac{\sqrt{v^2 + c^2} - 2vc \cos \alpha \cdot Mm}{cr^2} \]  

(3)

When an object remains static, its velocity \( v=0 \), then \( F_k = F \), then the Newton’s gravitational equation remains unchanged, when \( v>0 \), then \( F_k - F \) is the value of quantum kinematic effect. This is no velocity parameters in the Newton’s gravitational equation, so its calculation results will not change as the velocity of celestial bodies change; when consider the quantum kinematic gravitational effect, the calculation result of Newton’s gravitational equation will slightly change as the velocity of celestial bodies changes.

The quantum kinematic gravitational effect will also be affected by the \( \alpha \) angle, when the celestial orbital eccentricity is close to 0, the corresponding \( \alpha \) angle is close to 90°, then the effect is weakest, thus the influence of this effect on the celestial orbit is difficult to be directly observed in case the celestial body's velocity is far less the speed of light. For an example, the magnifications of gravitational force of a celestial body with the velocity of 30 km/s (the Earth’s revolution speed) in difference \( \alpha \) angle are shown in Table 1:
The eccentricity of the Earth's orbit is 0.0167086, for most of the year, its α angle near 90°, so relative to the result calculated by pure Newtonian gravitational equation, the instant difference caused by quantum kinematic gravitational effect may less than one millionth, which is hardly to observe directly. However, as the increase of the celestial bodies' moving speed and the increase of their orbital eccentricity, the difference between the calculated results of equation (1) and equation (3) will also increase, and making it easier to observe.

When consider the quantum kinematic gravitational effect, comets traveling along a high eccentricity orbit will show a weaker extra acceleration that does not exactly match the calculation of pure Newton's gravitational equation. Oumuamua moving at a relative high velocity in the solar system, and its orbital eccentricity of is 1.92, so it should be significant influenced by quantum kinematic gravitational effect. In case the anomalous acceleration of Oumuamua is generated by quantum kinematic gravitational effect, then it should able to be described by equation (2) or equation (3). By bring the orbital parameters of Oumuamua in to the equations, then it is able to know whether the calculated results agree with the astronomical observed results.
Methods

The instantaneous acceleration calculated by Newton's gravitational equation which extended by quantum kinematic gravitational effect without considering the cumulative effect

Equation 2 and 3 describe the instantaneous value of the quantum kinematic gravitational effect, however, this effect will continue acting on the celestial bodies, so its influence on the movement of celestial bodies will continue to accumulate over time, the longer the action time, the greater the impact. If the cumulative effect is not taken into account in the celestial orbit calculations, then the calculation will be smaller than they really are. From the orbital fits (Micheli et al) know that the non-gravitational acceleration on 'Oumuamua on October 25 at r = 1.4 au was $A_1 r^{-2} = 2.7 \times 10^{-6} \text{ms}^{-2}$.

Under the case without considering the accumulated velocity of Oumuamua during the whole journey, based on the trajectory data of Oumuamua, the instantaneous acceleration at 1.4au calculated by quantum kinematic gravitational equation is $4.2 \times 10^{-7} \text{ms}^{-2}$, which is much smaller than that given by Micheli et al.

The accumulated extra average velocity of Oumuamua calculated by Newton's gravitational equation which extended by quantum kinematic gravitational effect

Based on the astronomical observation and Newton's gravitational equation, scientists have calculated the trajectory of Oumuamua in the Solar system, which entered the solar system with an initial speed of about 26km/s, then gradually accelerated to a maximum speed of 87km/s at the perihelion, and after then gradually decelerated to 32km/s at May,3, 2018. Spacein3D, using the NASA JPL HORIZONS database and the International Astronomical Union's Minor Planet Center's data, made a simulation of Oumuamua's orbit in the solar system, and Oumuamua's orbit information can be seen in this simulation, such as velocity and $\alpha$ angle at each moment. Bringing these data in to equation 2, 3, it is possible to calculate the instantaneous value of quantum kinematic gravitational effect on Oumuamua, then with the help of its velocity change, it is able to calculate the cumulative influence of quantum kinematic gravitational effect
Based on the theory of the quantum kinematic gravitational effect, Oumuamua will get extra accelerations during all the time Oumuamua moving inbound and outbound the solar system, due to it had already past the perihelion before it was discovered, so there is no way to confirm whether the anomalous acceleration was existed before the date it has been discovered by directly astronomical observe. However, the extra acceleration would be accumulated into the extra increase of its velocity over time, and it would not disappear without interference of external forces, after pass through perihelion, it would decelerate at the same proportion with the main velocity due to the decelerating effect of sun’s gravity. The extra velocity would lead to an extra distance traveled, and this can be observed after a sufficiently long period of time. According to the observational data, by compare the observed trajectory with the trajectory calculated by Newtonian gravitational equation, (since Oct 19, 2017) location of Oumuamua had been boosted by about $40000 \text{ km}$ until Jan 2, 2018, and $100000 \text{ km}$ until May 3, 2018. The additional average velocity during this period can be obtained by dividing the extra distance by the time spent. By using the average velocity equation:

$$V_a = \frac{s}{t}$$

the observed additional average velocity during Oct 19, 2017 – May 3, 2018 is:

$$V_a = \frac{100000000}{196 \times 24 \times 3600} = 5.9 \text{ m/s}$$

the observed additional average velocity during Oct 19, 2017 – Jan 2, 2018 is:

$$V_a = \frac{40000000}{75 \times 24 \times 3600} = 6.17 \text{ m/s}$$

the observed additional average velocity during Jan 2, 2018– May 3, 2018 is:

$$V_a = \frac{60000000}{121 \times 24 \times 3600} = 5.74 \text{ m/s}$$

Now calculate the additional average velocity by the Newton's gravitational equation which extended by quantum kinematic gravitational effect, and then compare it with the observed results to verify whether it is matches the observations.

The average velocity can be calculated by the follow equation:

$$V_a = \frac{(v_0 + vt)}{2}$$
Due to $F$ and $F_k$ are the reason the $v$ and $v_k$ (velocity of Oumuamua) increase or decrease, then:

$$\frac{F_k - F}{F} = \frac{v_k - v}{v} \quad \text{(6)}$$

then

$$v_k - v = \frac{F_k - F}{F} v \quad \text{(7)}$$

The calculated extra average velocity of Oumuamua accumulated during inbound the solar system

The real-time simulation trajectory data of Oumuamua during Oct 19, 2017 – May 3, 2018 is cited from Space in 3D orbit simulator website,

Oumuamua to display its real-time trajectory data, it is able to fix its display panel and adjust simulate rate) their simulation was built on data provided by NASA JPL HORIZONS database for solar system objects and International Astronomical Union’s Minor Planet Center. The trajectory data used in the following calculations are estimated values, which may be subject to some error, based on these data the calculations of equation (2) show that:

*When $v=26000\text{m/s}$, $a=178^\circ$ then $F_k=(1+8.6\times10^{-5})F$*

*When $v=40000\text{m/s}$, $a=160^\circ$ then $F_k=(1+1.25\times10^{-4})F$*

Bring these values in to equation (5) and equation (7), the calculation shows that:

$$(v_k - v) = \frac{(8.6\times10^{-5}+1.25\times10^{-4})}{2\times(40000-26000)} =1.48\text{m/s}$$

This calculation means that Oumuamua will get an extra velocity of $1.48\text{m/s}$ caused by quantum kinematic gravitational effect, during its velocity increase to $40000\text{m/s}$ from $26000\text{m/s}$. Similarly, it can be inferred that:

*When $v=50000\text{m/s}$, $a=150^\circ$ then $F_k=(1+1.44\times10^{-4})F$*

$$(v_k - v) = \frac{(1.25\times10^{-4}+1.44\times10^{-4})}{2\times(50000-40000)} =1.35\text{m/s}$$

*When $v=60000\text{m/s}$, $a=135^\circ$ then $F_k=(1+1.4\times10^{-4})F$*

$$(v_k - v) = \frac{(1.4\times10^{-4}+1.4\times10^{-4})}{2\times(60000-50000)} =1.42\text{m/s}$$

*When $v=70000\text{m/s}$, $a=125^\circ$ then $F_k=(1+1.34\times10^{-4})F$*

$$(v_k - v) = \frac{(1.4\times10^{-4}+1.34\times10^{-4})}{2\times(70000-60000)} =1.37\text{m/s}$$

*When $v=87000\text{m/s}$, $a=90^\circ$ then $F_k=(1+4.3\times10^{-8})F$*

$$(v_k - v) = \frac{(1.34\times10^{-4}+4.3\times10^{-8})}{2\times(87000-70000)} =1.14\text{m/s}$$
When Oumuamua arrived at the perihelion, the difference of its inbound velocity between respectively calculated by equation (2) and equation (1) will accumulate to be:

\[1.48 + 1.35 + 1.42 + 1.37 + 1.14 = 6.76 \text{m/s}\]

After perihelion, due to the deceleration of the Sun's gravity, the extra velocity will decrease at the same rate with the main velocity of Oumuamua, during Jan 2, 2018 - May 3, 2018, the main velocity of Oumuamua decreased to be between 36km-32km from 87km, so the average extra velocity accumulated during inbound decreased to be:

\[v_{FK} - v_F = 6.76 \times (36/87 + 32/87) / 2 = 2.64 \text{m/s}\]

The calculated extra average velocity of Oumuamua accumulated during outbound the solar system

When Oumuamua moving outbound in the hyperbolic trajectory, the effect of the sun's gravity on its velocity is dominated by deceleration, and the gravitational force on it calculated by equation (2) is a bit weaker than the calculation of Newton’s equation, thus this will also lead to an extra acceleration. In the period of Jan 2, 2018 – May 3, 2018, the calculation of equation (2) shows that:

- When \(v=87000\text{m/s}, a = 90^\circ\) then \(F_k = (1+4.3 \times 10^{-8})F\)
- When \(v=70000\text{m/s}, a = 55^\circ\) then \(F_k = (1-1.34 \times 10^{-4})F\)

The average extra velocity accumulated in the period is:

\[(v_k - v) = (4.3 \times 10^{-8} - 1.34 \times 10^{-4}) / 2 \times (70000-87000) = 1.14 \text{m/s}\]

This calculation means that Oumuamua will get an extra velocity of 1.14m/s caused by quantum kinematic gravitational effect, during its velocity decrease to 70000m/s from 87000m/s.

The average main velocity of Oumuamua between 87km to 70km is:

\[(87 + 70) / 2 = 78.5 \text{km}\]

During Jan 2, 2018 – May 3, 2018, the main velocity of Oumuamua decelerate to be between 36km-32km, with the same reduction ratio of the Oumuamua's main velocity the extra velocity will approximately accelerate to be:

\[1.14 \times (36/78.5 + 32/78.5) / 2 = 0.49 \text{m/s}\]
Similarly, it can be inferred that:

When $v=60000m/s$, $a=45^\circ$ then $F_k=(1-1.41\times10^{-4})F_k(v_k-v) = 1.38 m/s$

$1.38 \times (36/65 + 32/65)/2 = 0.72 m/s$

When $v=50000m/s$, $a=30^\circ$ then $F_k=(1-1.44\times10^{-4})F_k(v_k-v) = 1.42 m/s$

$1.42 \times (36/55 + 32/55)/2 = 0.88 m/s$

When $v=36000m/s$, $a=15^\circ$ then $F_k=(1-1.16\times10^{-4})F_k(v_k-v) = 1.82 m/s$

$1.82 \times (36/43 + 32/43)/2 = 1.44 m/s$

When $v=32000m/s$, $a=10^\circ$ then $F_k=(1-1.0\times10^{-4})F_k(v_k-v) = 0.43 m/s$

The accumulation of solar gravitational acceleration during this stage of journey is

should be calculated independently, with an extra velocity of $0$ at the beginning and $-0.43 m/s$ at the end. So, the average extra velocity accumulation during this journey is

half about $0.43 m/s$.

$0.43/2 = 0.215 m/s$

After perihelion, the extra velocity of Oumuamua during outbound is accumulated to be:

$0.49 + 0.72 + 0.88 + 1.44 + 0.215 = 3.75 m/s$

During the period of Jan 2, 2018 – May 3, 2018, the acceleration of Oumuamua of the whole journey will accumulate to be an extra average velocity:

$2.64 + 3.75 = 6.39 m/s$

Due to the Earth is mainly at the same side with the sun when Oumuamua get close to it at the distance less than 0.2 $au$, so the earth's gravitational force may approximately slow down the velocity of Oumuamua close to $0.2 m/s$. The influence has been considered in trajectory established by Newtonian gravitational equation, so here must consider the influence of the gravity of the earth too, then the extra average velocity should be:
During the period of Jan 2, 2018 – May 3, 2018, the margin of error between the result calculated by the Newton's gravitational equation extended by quantum gravitational effect and the observed result is about 8%. Based on the same method and trajectory data of Oumuamua, the extra average velocity during Oct 19, 2017 – Jan 2, 2018 is about 6.65m/s, which with the margin of error about 8% to the observed result; and the extra average velocity during Oct 19, 2017 – May 3, 2018 is about 6.51m/s, which with the margin of error about 10% to the observed result.

**Discussions**

Due to astronomical observations of Oumuamua are unrepeatable, so the quantum kinematic gravitational effect requires more validation, and Lunar is exactly the best object that can be observed repeatedly with high precision over a long period of time. The Moon's orbital eccentricity is about 0.0549, based on its orbital parameters, when at difference positions in its orbit, it will under the influence of weak extra kinematic gravitational effect, that about between $-6 \times 10^{-8}$ and $6 \times 10^{-8}$ times the Newton's gravity from the Earth (corresponding estimate $\alpha$ angle about $89^{\circ}-90^{\circ}-91^{\circ}$), this may lead to instantaneous accelerations and accumulated velocity in Lunar orbit. The influence of quantum kinematic gravitational effect from the Sun will further increase the extra acceleration of the Moon. The Moon's kinetic energy increasing as the extra velocity accumulating, this will lead a weak continuous expansion in its orbit, the Lunar Laser Ranging Experiment shown that the Earth and Moon are slowly drifting apart at the rate of 1.5 inches (3.8 centimeters) per year, this is consistent with the predictions of the quantum kinematic gravitational effect on the overall trend. For the conservation of angular momentum explanation, the momentum of Lunar orbital expansion comes from the portion of momentum lost by the deceleration of the Earth's rotation. Lunar orbit should stop expanding even shrink if the Earth's rotation is accelerating, since in that
case Lunar cannot earn angular momentum from the earth’s rotation through tidal action. Based on the recently study that Earth’s rotation appears to be speeding up, it is able to know Lunar orbit is expanding or contracting now through Laser Beam Reflect Experiment, and whether angular momentum conservation is the main reason of Lunar orbital expansion can be determined then. According to the quantum kinematic gravitational effect theory, this effect will not only expand Lunar orbit but also expand all eligible celestial body's orbit or trajectory, such as asteroids, comets, planets, stars in galaxies, even galaxies themselves, starting from the galactic level, it seems to exhibit some weaker characteristics similar to dark energy. In solar system, Mercury which has the highest velocity and orbital eccentricity should has the largest orbital expansion. NASA MESSENGER mission has preliminarily proofed there is the most significant expansion of Mercury's orbit.\(^{35}\) However, Lunar still is the best observe object when the rotation of the earth is accelerating, and Lunar is easier to observe precisely.

**Conclusion**

The calculated result of the anomalous acceleration of Oumuamua with the Newtonian gravitational equation extended by quantum kinematic gravitational effect consistent with the astronomical observations with a margin of error about 10\%, taking into account the deviations caused by the accuracy of $\alpha$ angle used in the calculations and some other mistakes, the margin of error may be less than 20\%. This may mean that the quantum kinematic gravitational effect is the main reason which lead to the anomalous acceleration of Oumuamua. In case Lunar orbital still expanding while the earth's rotation accelerating, if it is able to prove the extra acceleration of Lunar caused by quantum kinematic gravitational effect and the acceleration leads to its orbital expansion are basically equal to each other, then the hypothesis will be true. The acceleration caused by quantum kinematic gravitational effect can be obtained by the method that used in calculating the anomalous acceleration of Oumuamua; the acceleration caused the Lunar orbital expansion can be obtained by the method that used in calculating satellites orbital transfer.
Since the quantum kinematic gravitational effect on Lunar from the Earth and the Sun is different at different orbital positions, so Lunar orbit should be divided into multiple small segments, after calculation and accumulation based on Lunar segmented velocity, the acceleration caused by this effect on the moon can be obtained. This requires knowing the precise velocity and \( \alpha \) angle of Lunar on each segment of its orbit, these data can only be obtained by precise astronomical observations. Due to the lack of these important data and some other reasons, the calculation cannot be completed at present, the final proof of this hypothesis requires participation and efforts of more people.

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