Short Range Gravity Experiment in NEWTON experiment

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Abstract

According to the ADD model [1], deviation from Newtonfs inverse square law is expected at below sub-millimeter scale. We have developed an experimental setup using torsion balance pendulum, aiming to test the Newtonfs inverse square law at below millimeter scale. Current status and preliminary results will be presented.

1 Physics motivation

1.1 Test of Inverse Square Law

Weakness of gravitational force comparing to other three interactions is considered as one of the most severe problem in the theoretical physics. It is necessary to resolve this problem, in order to unify the three gauge interaction and gravitational force. According to a recent unified theory (super string theory, M-theory, ADD model and etc.), gravitational field may spread toward extra dimensions. In the ADD model [1], extra dimensions are predicted to exist at below mm scale. Then, an observation of a deviation from Newton's inverse square law is expected at below mm scale. If extra dimensions exist, gravitational potential should be modified. Modified gravitational potential is historically expressed using Yukawa interaction form.

$$V(r) \quad = \quad G\frac{Mm}{r}(1+\alpha e^{-r/\lambda}) \tag{1}$$

Here, α is coupling constant and λ is the range of the new interaction. To search for the new Yukawa term, Newton's inverse square law has been experimentally tested. However, high precision test of the inverse square law is performed at only astronomical scales [2]. Therefore, it is necessary to test the gravitational force at below mm scale.

1.2 Test of Weak Equivalence Principle

The weak equivalence principle is expressed as that, ratio between gravitational mass and inertia mass is independent of its composition. If the ratio between gravitational mass and inertia mass is constant for every material, universality of free fall must be kept. Therefore, test of the universality of free fall can be used as a test of the weak equivalence principle. Number of experimental tests confirmed that ratio between inertial mass for different compositions is same for the ratio between gravitational mass, using gravity from the earth and the sun. On the other hand, there are no experimental tests at short range below cm scale. There is also a theoretical model which predicts a violation of weak equivalence principle. Baryon number coupling force is one of such models [3]. If a new interaction which couples to baryon number, the weak equivalence principle seems to be violated. We can test the weak equivalence principle measuring the composition dependant of the gravitational constant G.

2 Experimental technique

2.1 Torsion Pendulum

In Our experiment, gravitational force is measured using torsion pendulum and online image analyzing system [7]. Principle of the measurement is shown in fig. 1.

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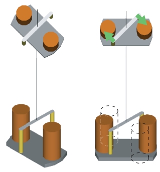

Figure 1: Torsion balance pendulum.

Angular displacement between before and after attractor position is measured as gravitational signal. It is because torsion pendulum is twisted toward balanced position where restoring force equals to the gravitational force. The torque of the torsion pendulum can be expressed using angular displacement $\Delta\theta$.

$$N = \kappa \cdot \Delta\theta \tag{2}$$

Here, N is the torque, κ is the torsional spring constant. The torsional spring constant κ is calculated using inertia moment and the periodic oscillation of the torsion pendulum.

2.2 Digital image analysis

The data taking system is originally developed for PHENIX experiment at RHIC (Relativistic Heavy Ion Collider) at Brook Heaven National laboratory, as an optical alignment system (OASys) [4]. Position resolution of 10 nanometer is achieved using the OASys. Applying this system, we developed digital image analyzing system using digital video camera for short range gravity experiment [5]. In this system, the angular displacement of the torsion pendulum can be obtained from intensity of digital images. Typical angular resolution of 1.2×10^{-6} degrees is achieved using our digital image analyzing system.

3 Experiment

3.1 Newton I experiment

In prototype experiment named Newton I, we succeeded to test the Newton's inverse square law at cm scale. To suppress the electromagnetic force, all the components used in the device are electrically connected and used non-magnetic metals (aluminum, copper, lead, brass and etc.).

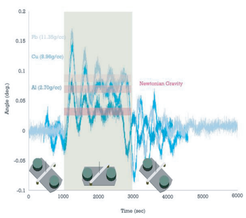

Figure 2: Time evolution of torsion pendulum.

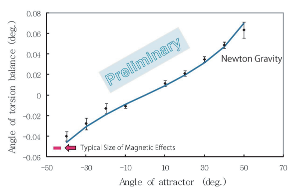

Figure 3: Inverse square law.

Typical results in Newton I are shown in fig. 2. Time evolution of torsion pendulum is plotted for lead, copper and aluminum attractors. From this result, composition dependence is confirmed. Position dependence of the torsion pendulum is shown in fig. 3, which is measured by changing the attractor angle. Solid line is Newtonian gravitational prediction. From this result, we can confirm Newton's inverse square law at cm scale.

3.2 Newton II experiment

In Newton I experiment, we have confirmed the inverse square law at cm scale. However, the largest systematic error of Newton I is caused from attractor replacement. In order to suppress this systematic effect, Newton II is developed [7]. The results of Newton II experiment is shown fig. 4 and fig. 5.

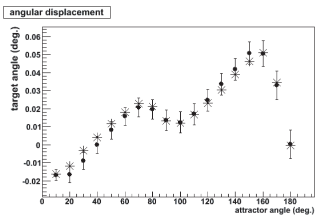

Figure 4: Gravity signal. * shows simulation data from Newtonian gravitational prediction.

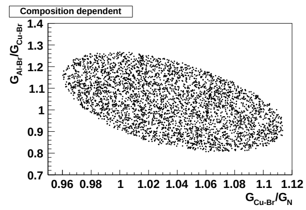

Figure 5: Composition dependence of gravitational constant G. This result is obtained at the 95% confidences level.

In Newton II, we used two materials (Cu and Al) as attractor. The gravity signal from the two materials is shown in fig.5. Using this data, Composition dependence of gravitational constant is obtained. Ratio between G_{Br-Al}/G_{Br-Cu} and G_{Br-Cu}/G_{Newton} is shown in fig.6. We have obtained the ratios, as $G_{Br-Al}/G_{Br-Cu} = 1.03 \pm 0.23$ and $G_{Br-Cu}/G_{Newton} = 1.04 \pm 0.08$. From the results, there is no composition dependence of gravitational constant G between G_{Br-Al} and G_{Br-Cu}. A new interaction coupling to the baryon number which violates the weak equivalence principle at only short range, can be parameterized as a new Yukawa term [2].

$$V(r) = G\frac{Mm}{r}(1+\xi\frac{B_i}{\mu_i}\frac{B_j}{\mu_j}e^{-r/\lambda}) \tag{3}$$

Here, B_A is baryon number for material A, and μ_A is gravitational mass in hydrogen mass unit. Using these results, we can extract the upper limit on ξ. The results are shown in fig. 6.

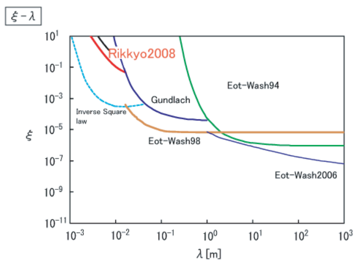

Figure 6: $\xi - \lambda$ plot. Red line is our result. This result is obtained at the 95% confidences level.

3.3 Newton SC experiment

In Newton SC experiment, new measuring method is tested, aiming high precision measurement. If moving speed of the attractor is very slow comparing to the oscillation period of the torsion pendulum, balanced position of torsion pendulum is moving with the attractor motion (forced oscillation). We have succeeded to test the inverse square law in this method. Angular displacement of the torsion pendulum is obtained for all the attractor angles from -50^o to 50^o at single measurement. Therefore, obtained data is directly used as a test of the inverse square law. Typical result from Newton SC is shown in fig. 7.

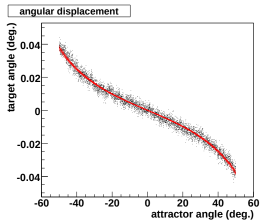

Figure 7: Time evolution of the gravity signal. Red line is Newton's gravitational prediction.

4 Summary

In Newton I experiment, we succeeded to demonstrate its ability to test the Newton's inverse square law at centimeter scale. We succeeded to confirm weak equivalence principle at mm scale in Newton II experiment. Now, we are starting new experiment named Newton III. In this experiment, we will also be able to test the inverse square law at below sum-millimeter scale.

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