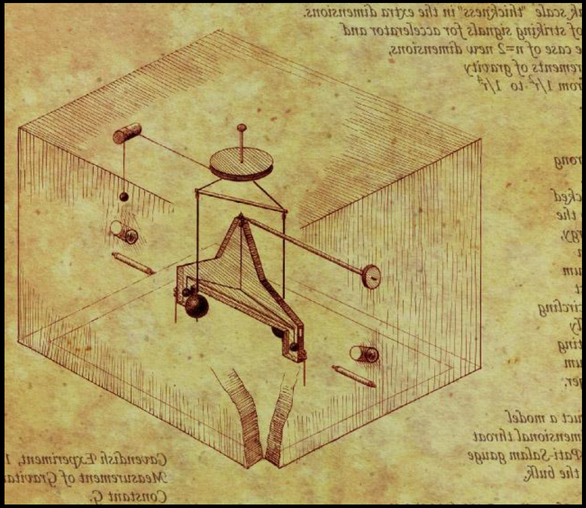
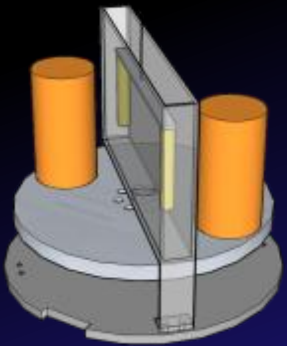
Short-Range Gravity experiment using digital image analysis

Test of Newtonian Inverse square law and weak equivalence principle

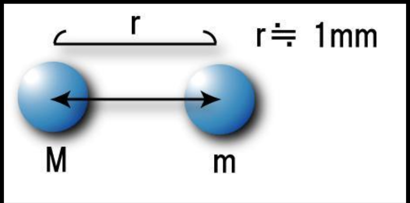




Rikkyo Univ./ RIKEN
Kazufumi Ninomiya

Rikkyo Univ. [A] RIKEN [B]
N. Ogawa [A], R. Kishi [A], A. Taketani [B], Y. Nishio [A], H. Murakami [A]
and J. Murata [A]

Motivation



Why short-range Gravity?

Hierarchy problem Gravity is extremely weak comparing to other 3 gauge interactions

→ Gravity propagates toward extra dimensions.

Large Extra Dimension model
(N. Arkani-Hamed et.. al.. PLB429(1998)263)

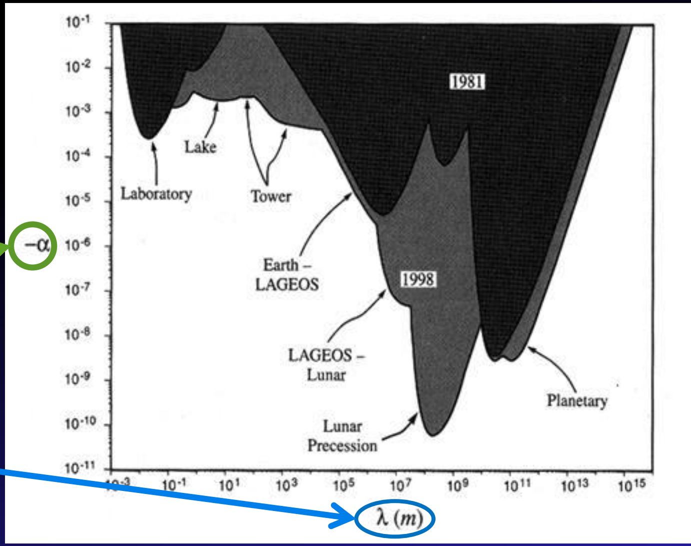
Possibility of the deviation from gravitational inverse square law below mm scale

$$V(r) = -G_N \frac{mM}{r} \qquad \lambda \leqq r$$

$$V(r) = -G_{4+n} \frac{mM}{r^{1+n}} \qquad \lambda \geqq r$$

λ：interaction length

Limit on the new Yukawa interaction

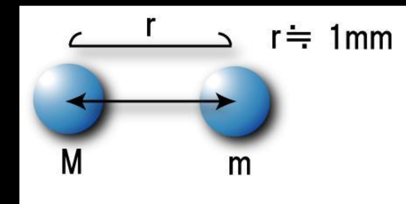


Past experiments Parameterized by Yukawa potential

$$V(r) = -G \frac{mM}{r} \left(1 + \alpha e^{-\frac{r}{\lambda}}\right)$$

λ：interaction length
α：coupling constant

Motivation



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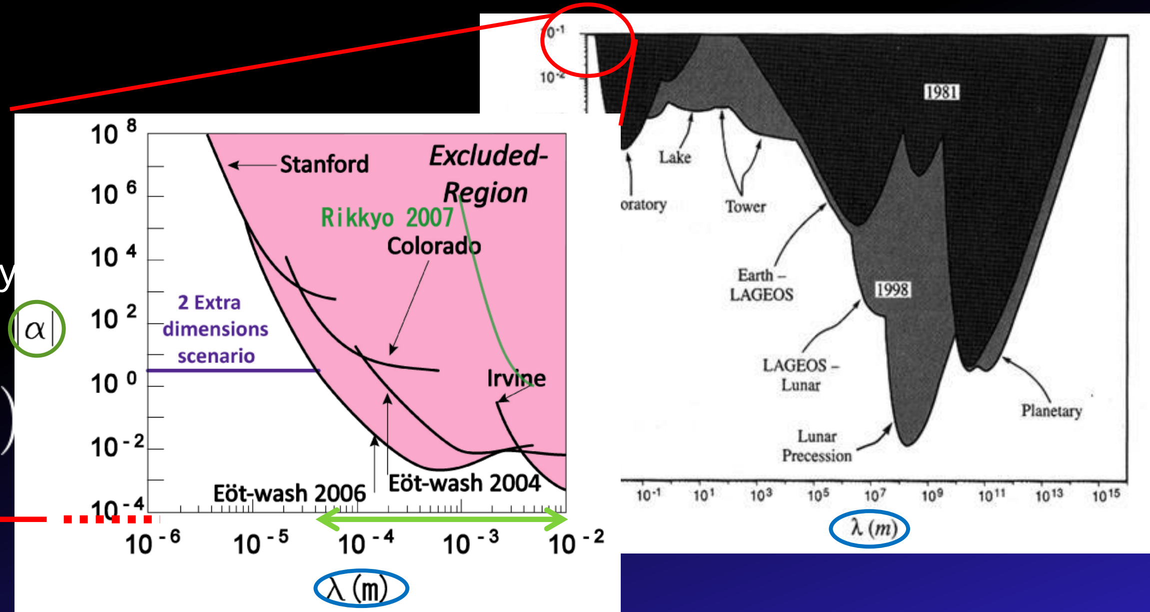


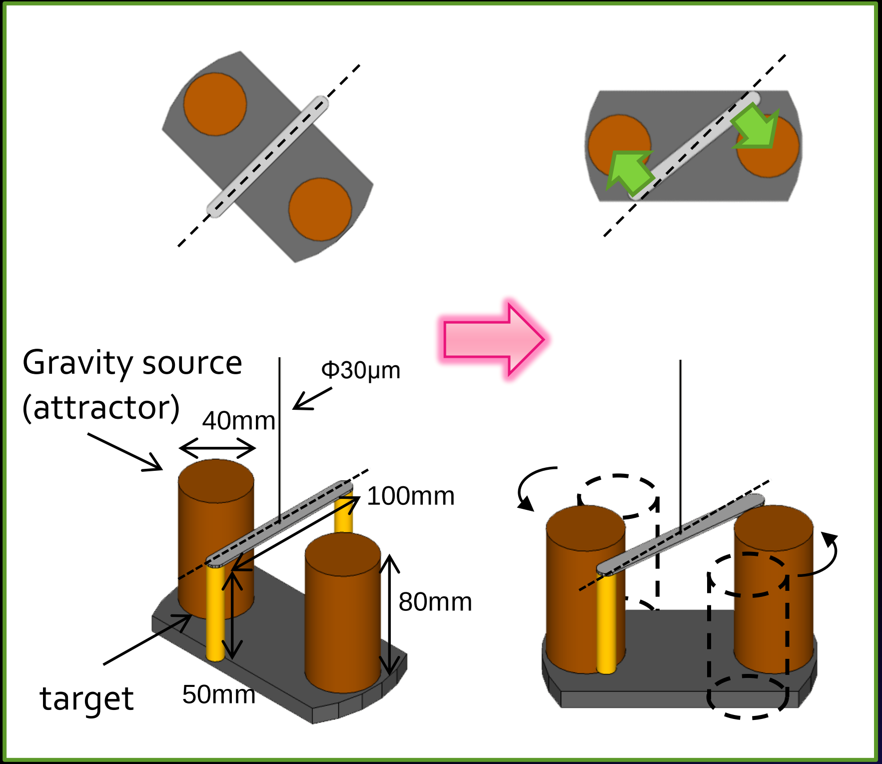
Principle

Torsion pendulum

$$\tau = -\kappa\delta\theta$$

κ : Torsional spring constant

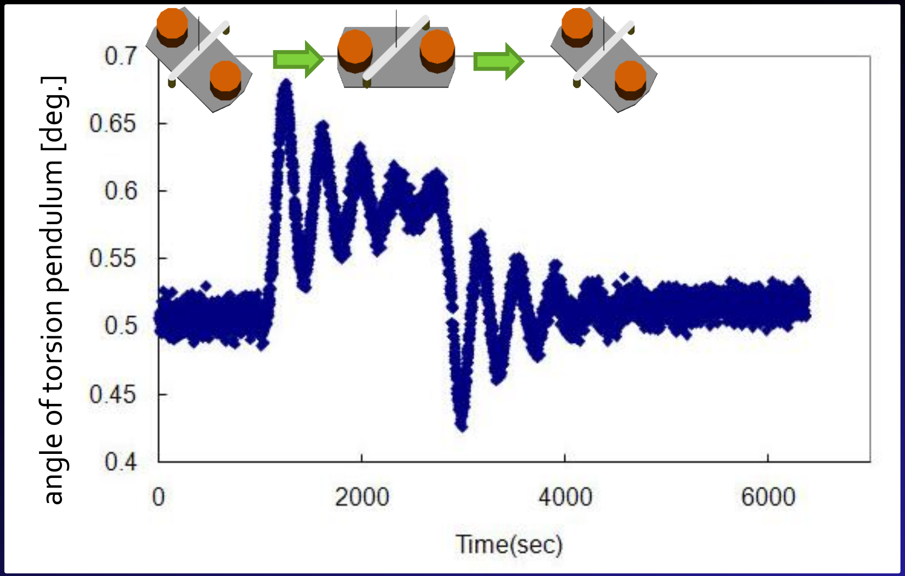
Torque ∝ Angular Displacement

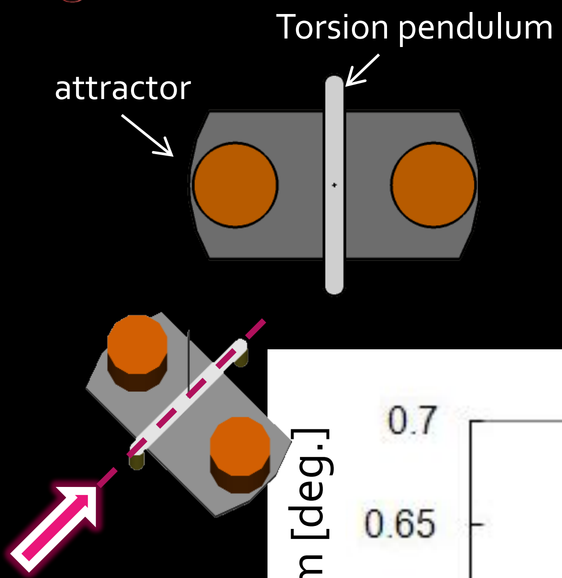


Angular displacement of torsion pendulum → **Gravitational signal from attractor source**

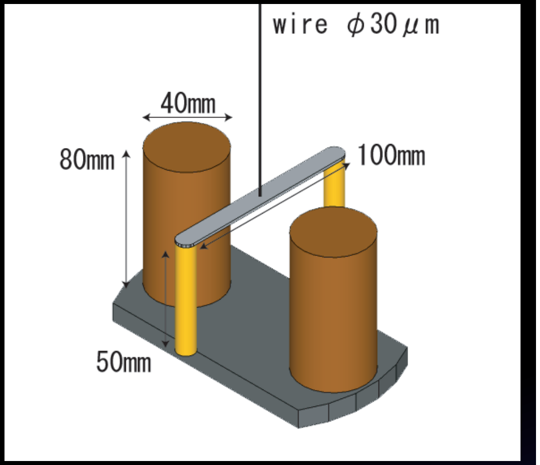
Measurement of the angular displacement

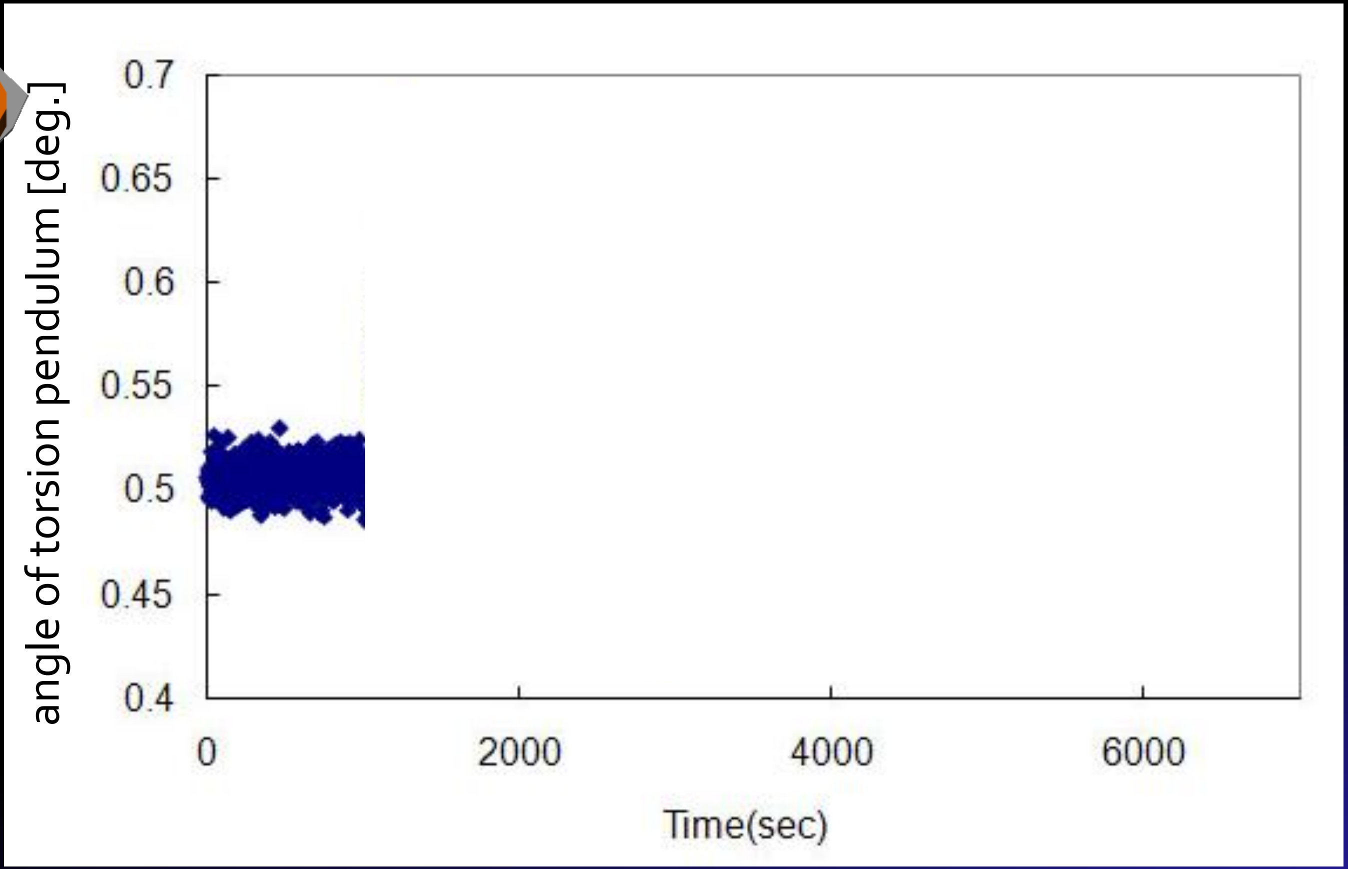
Our typical experimental data

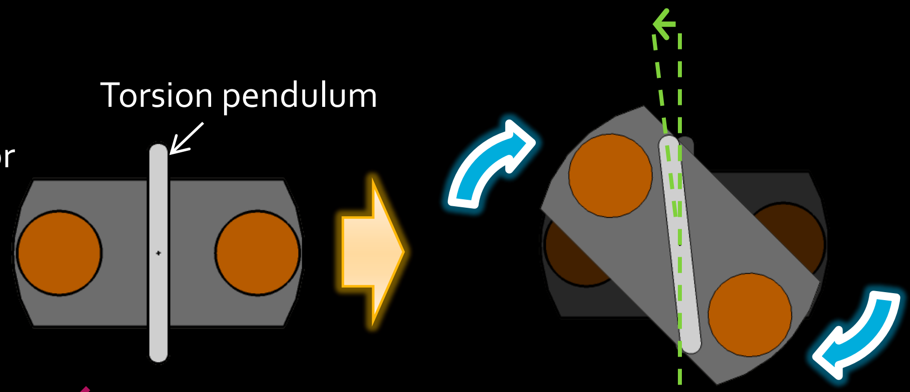


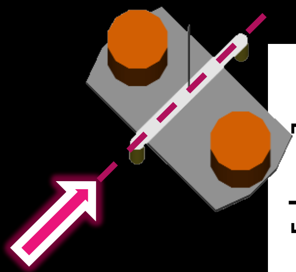


Torque
∝ Angular Displacement









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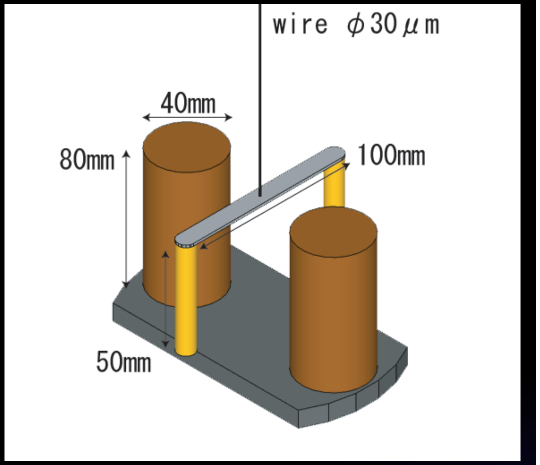

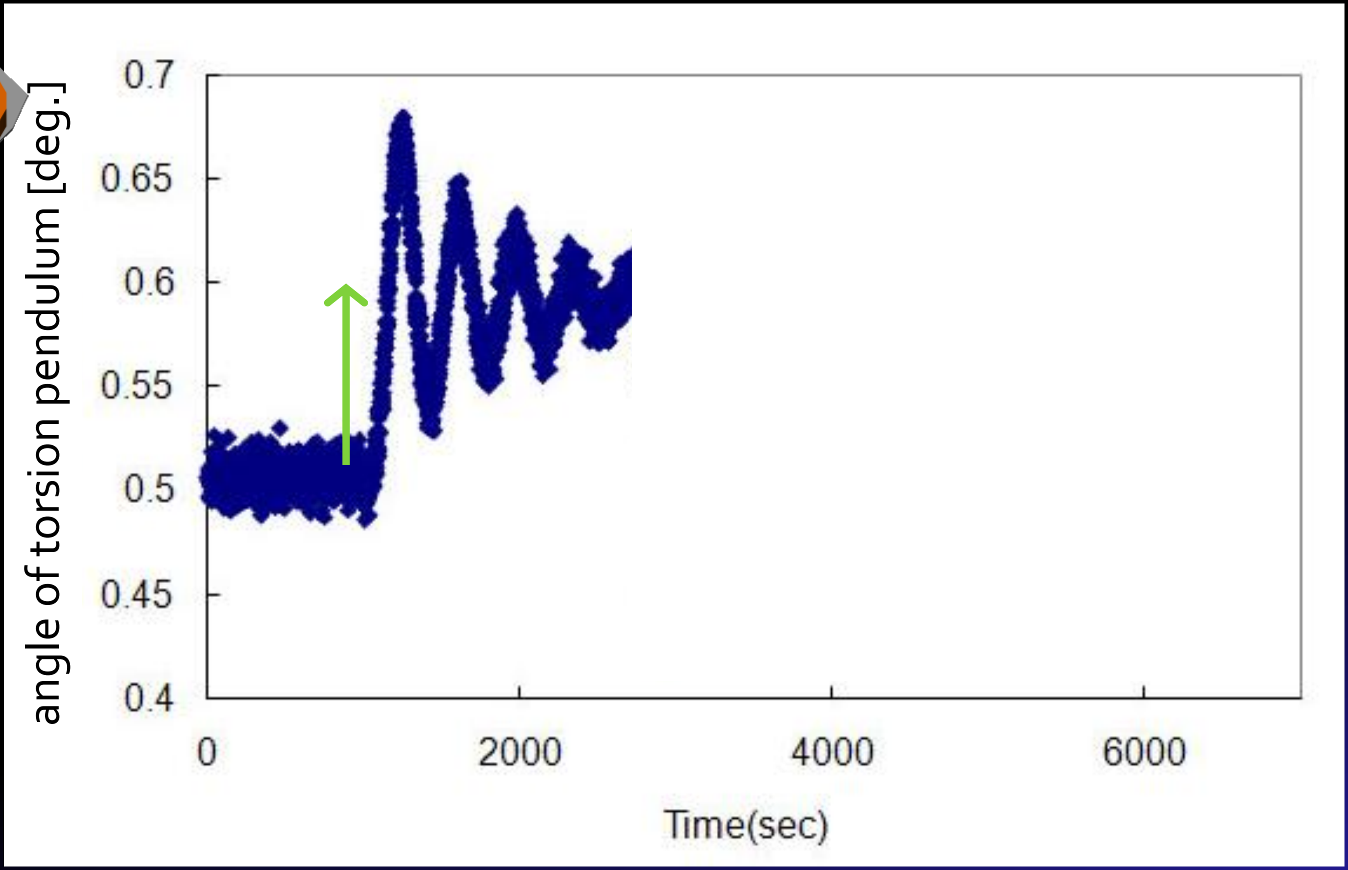

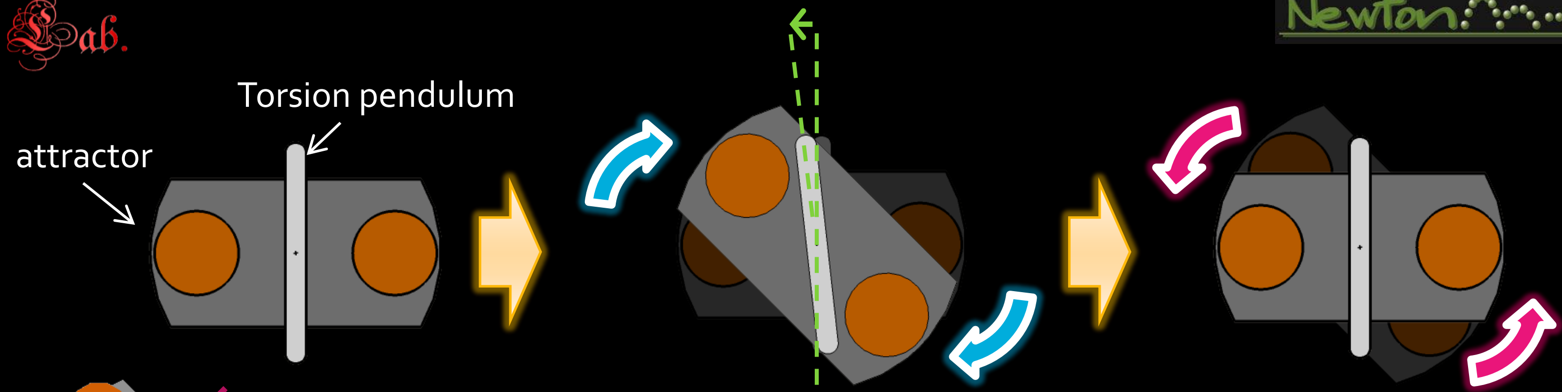

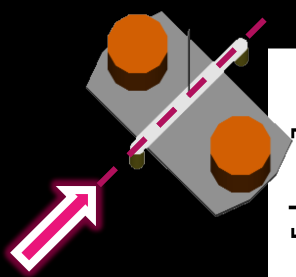

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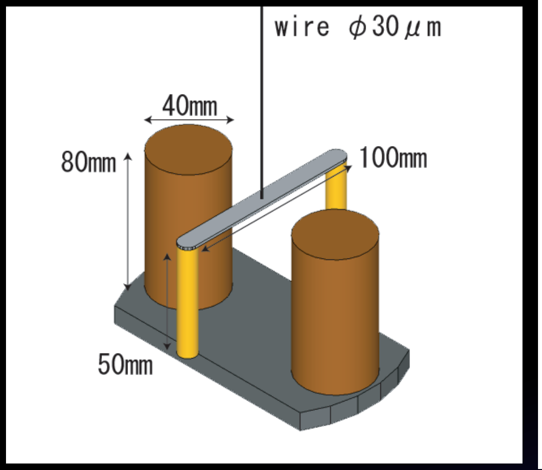
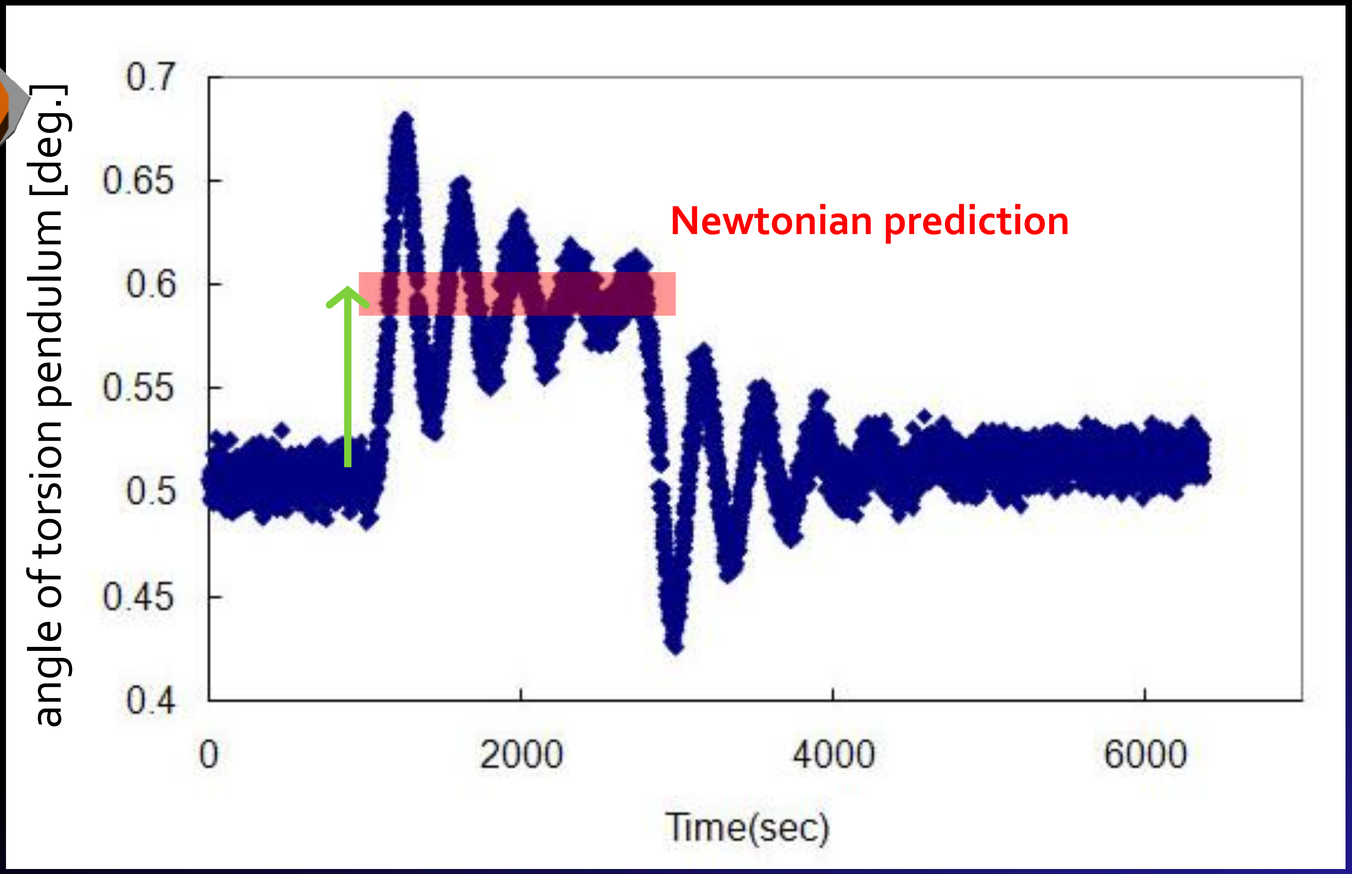
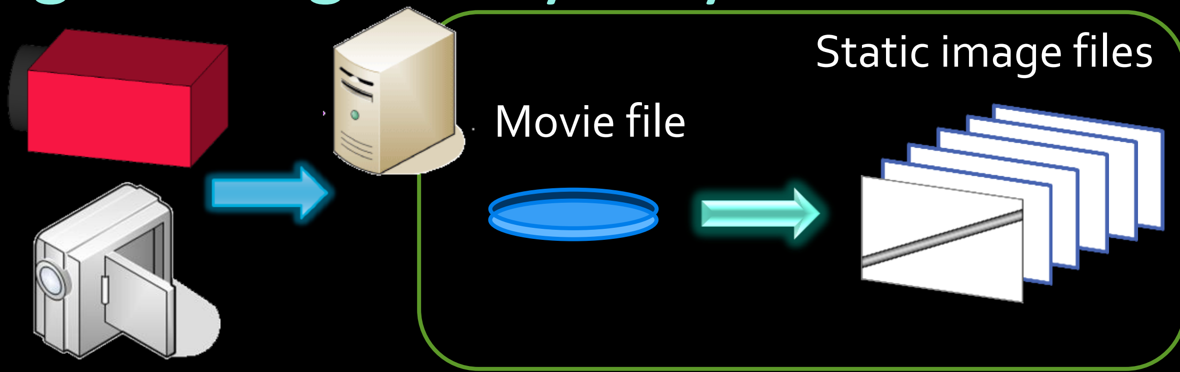
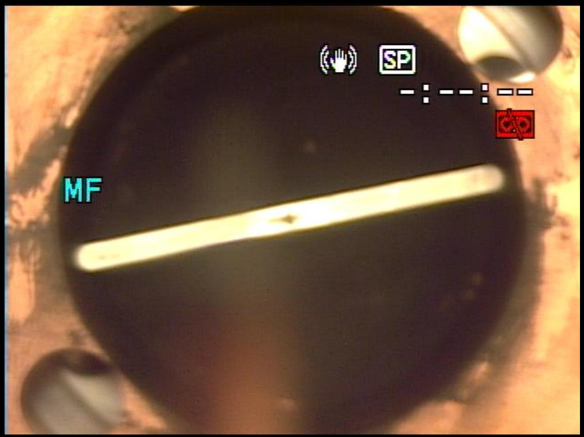




Digital Image analysis system

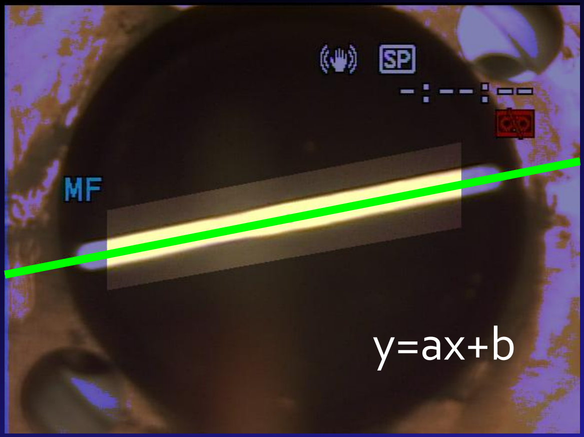




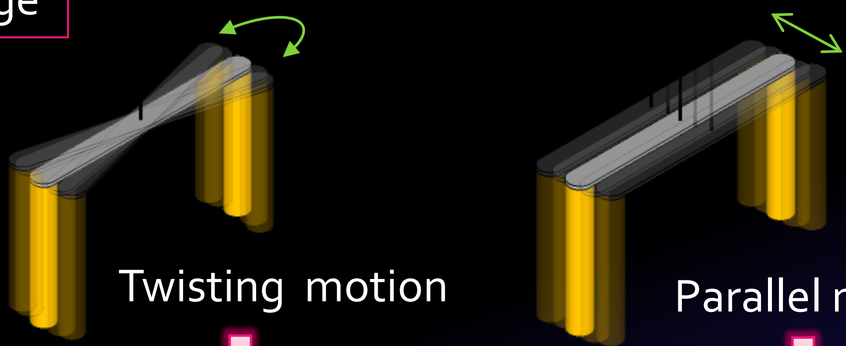
Determining of the angle of the torsion balance bar using pixel intensity

angular resolution : 1μ degree

Offline analysis



Advantage



Twisting motion

Signal

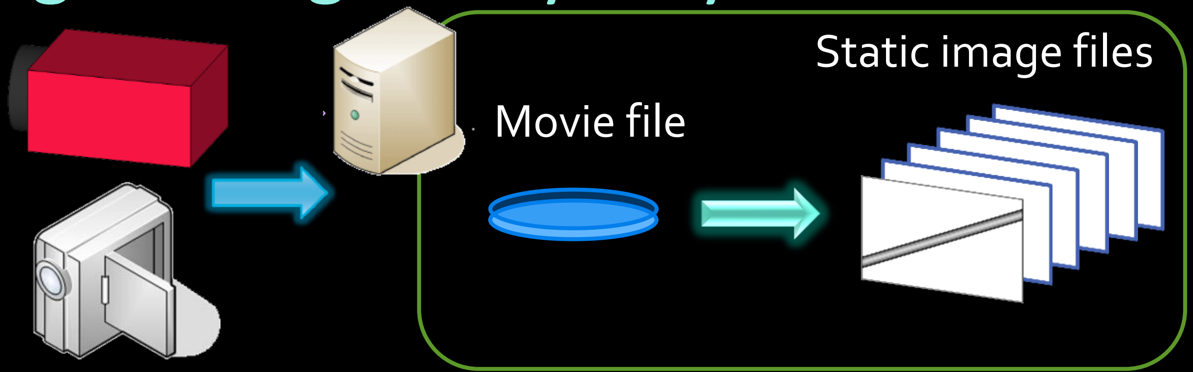
Parallel motion

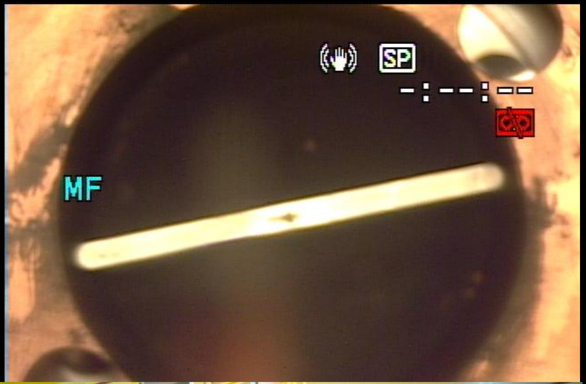
Fake signal

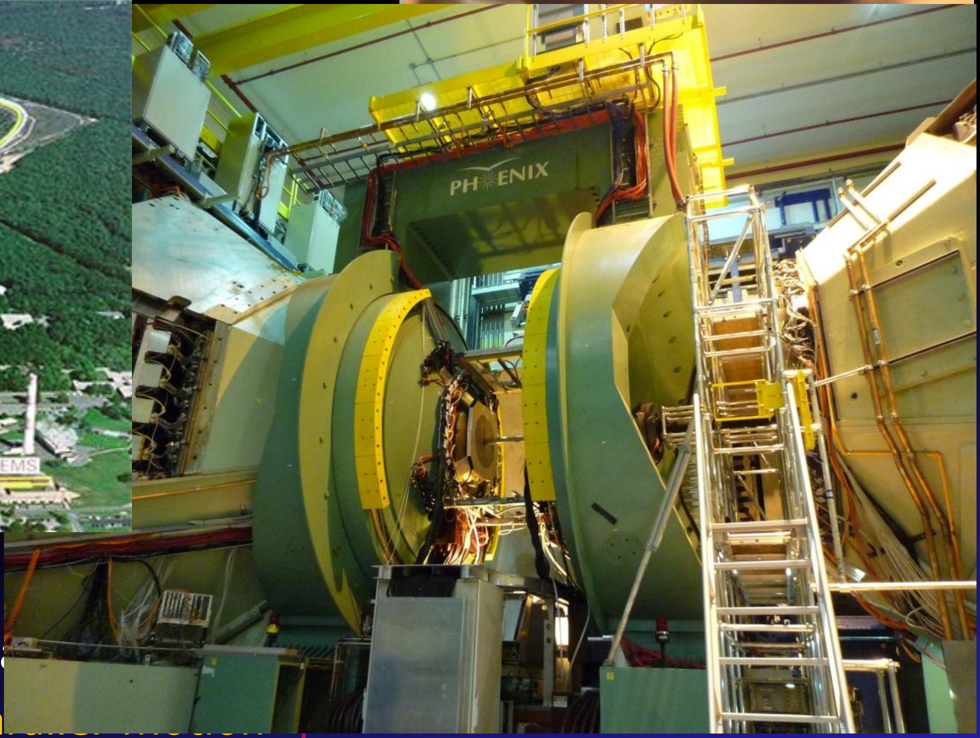
Suppression of the parallel motion

Murata Lab.

Digital Image analysis system





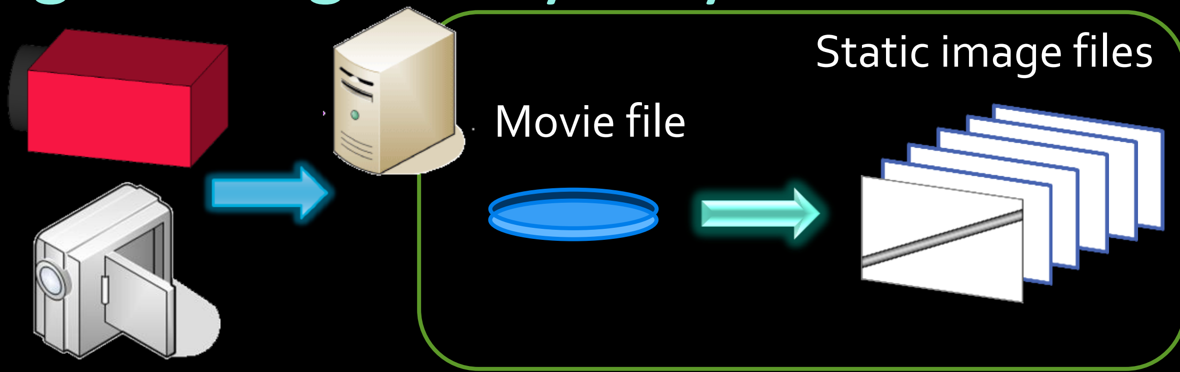


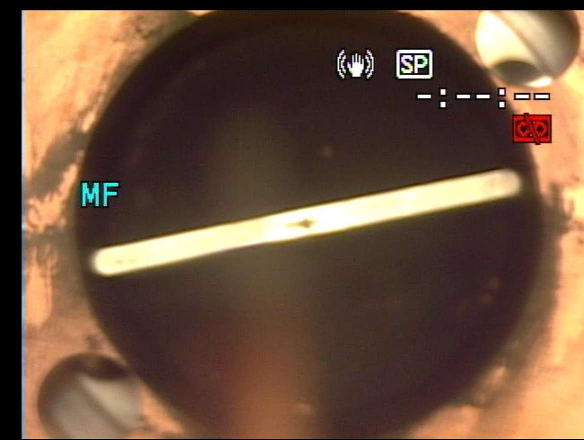
Signal

F

Suppression of the pa

Digital Image analysis system





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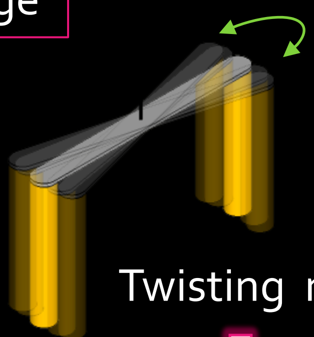

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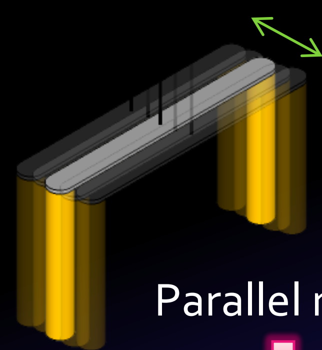

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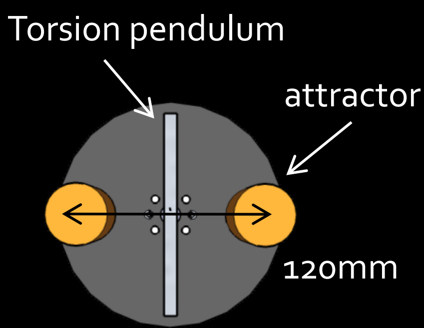
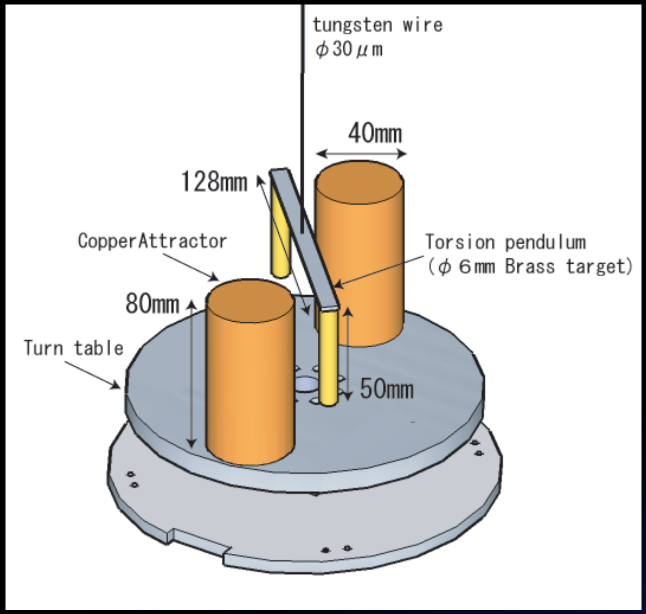
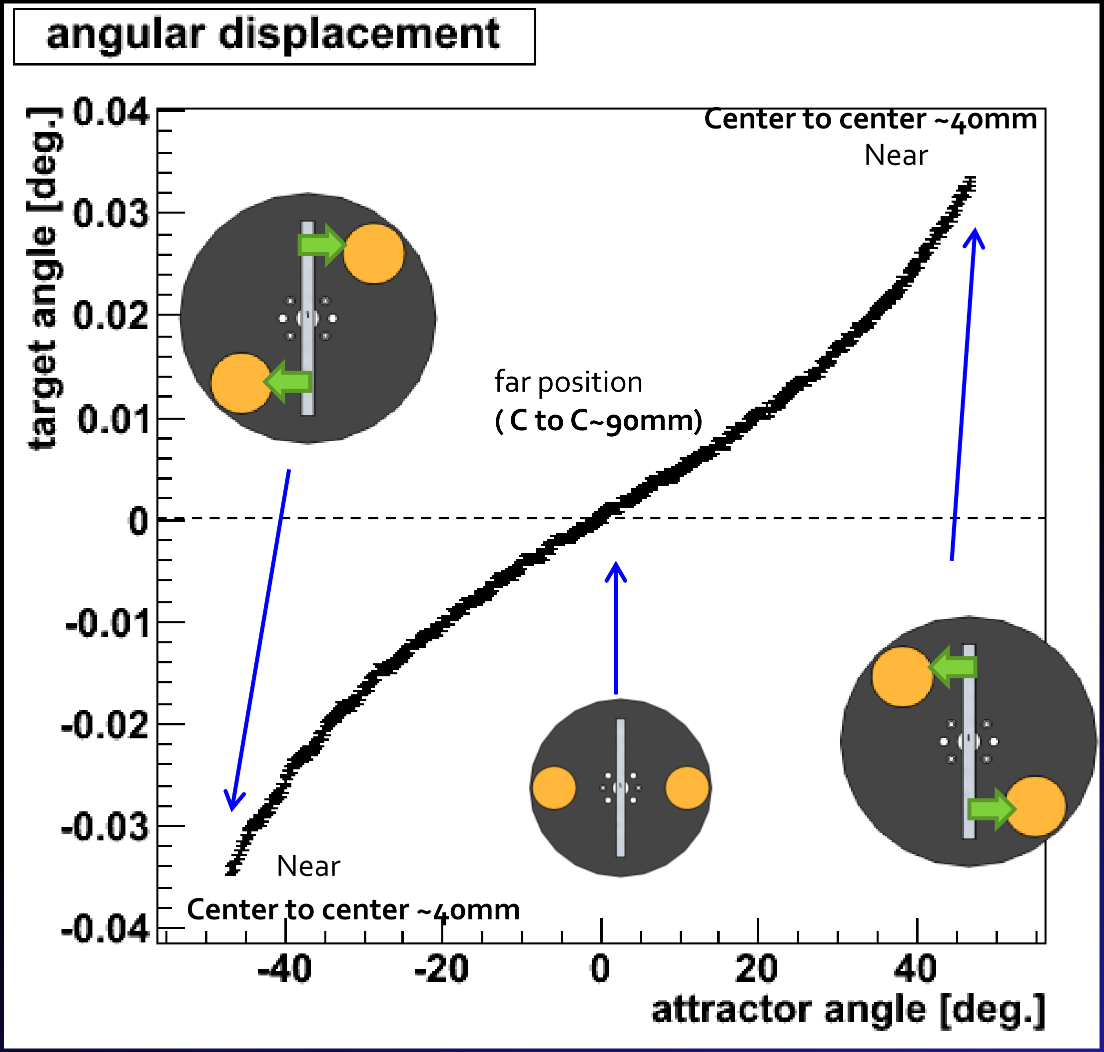
Gravitational Inverse Square Law

Experiment







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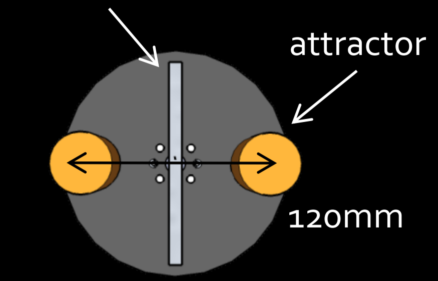

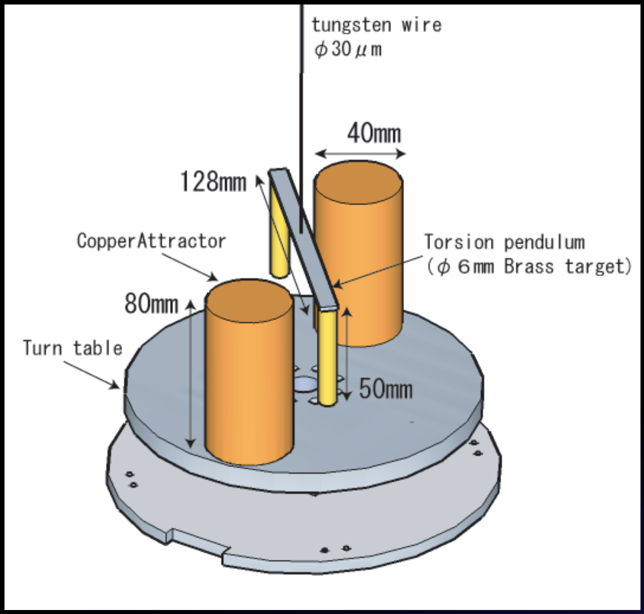

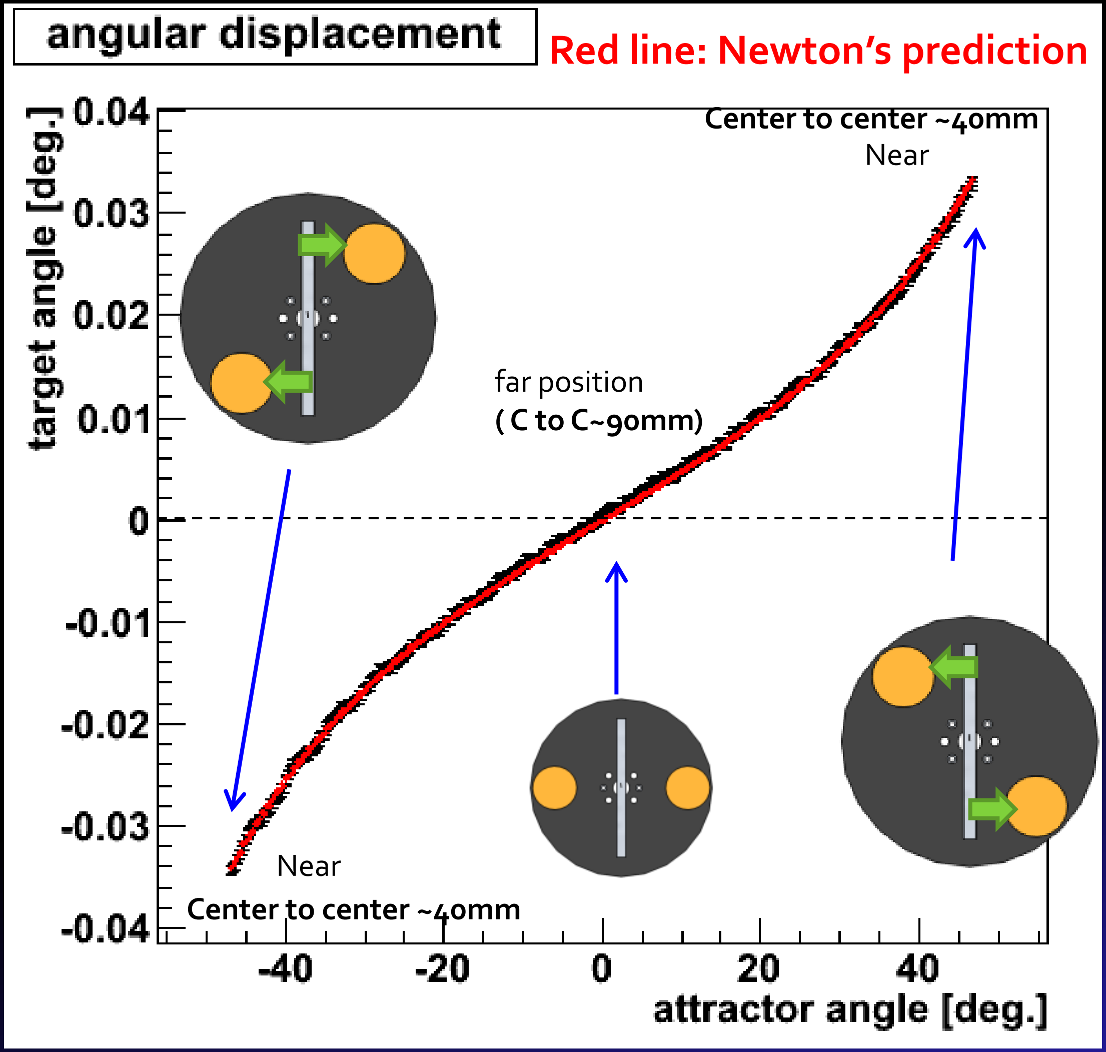

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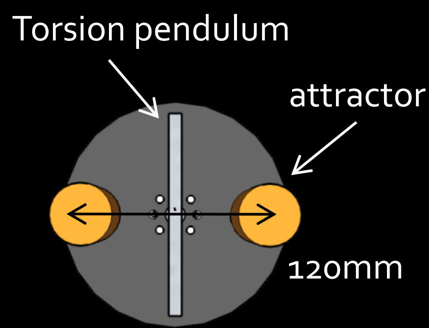
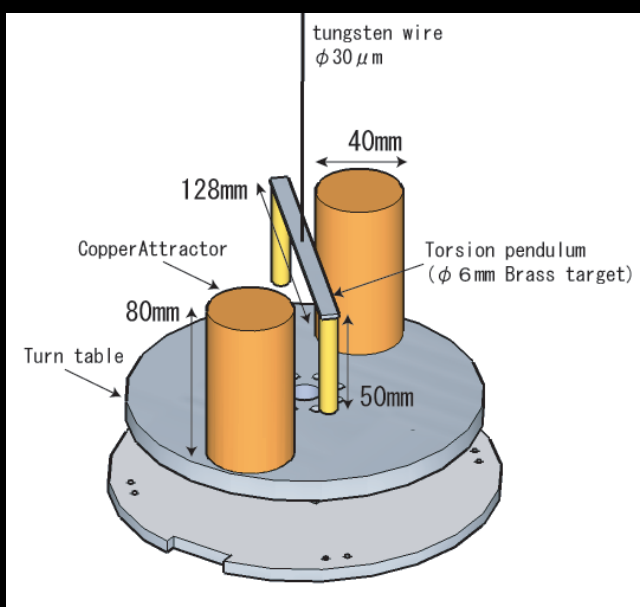
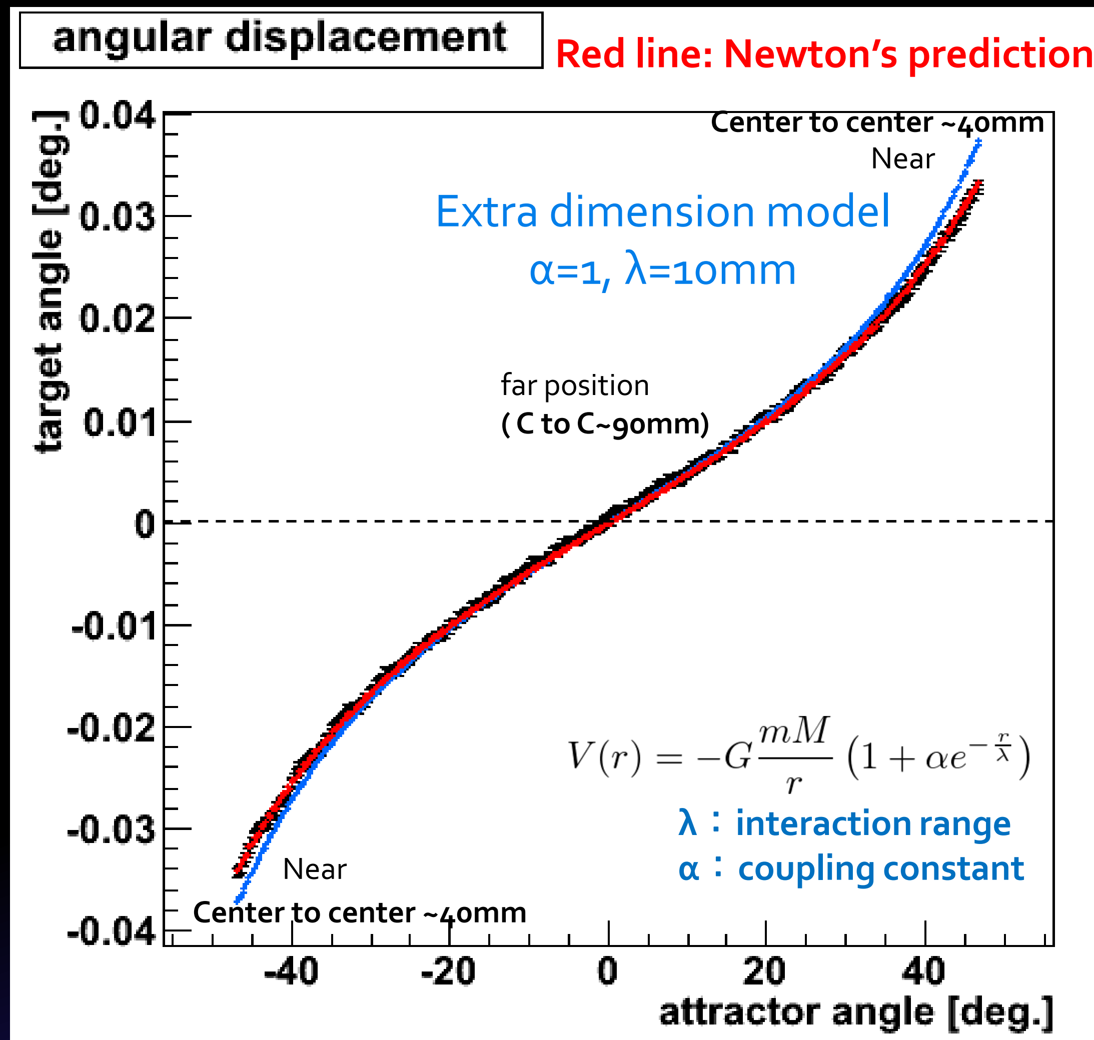
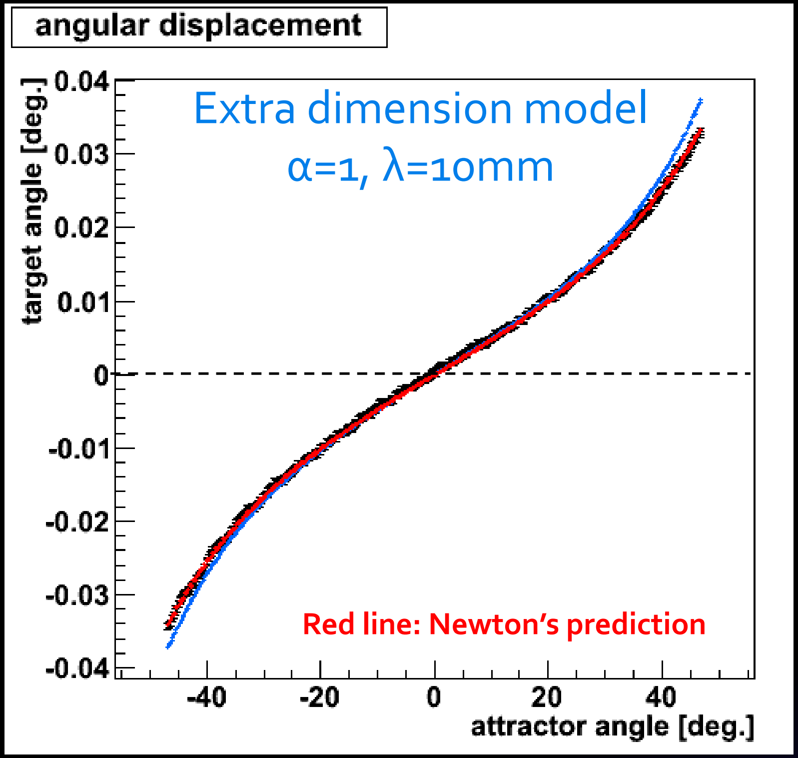




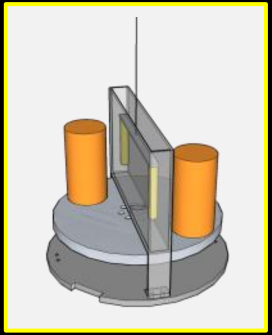


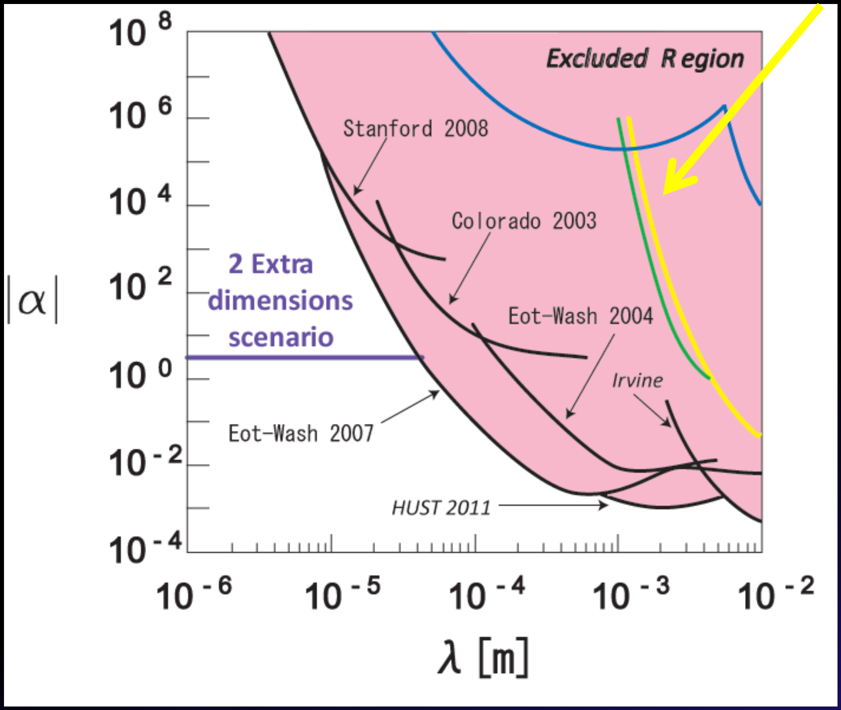
Gravitational Inverse Square Law

Our experimental result



Upper limit of the new Yukawa interaction



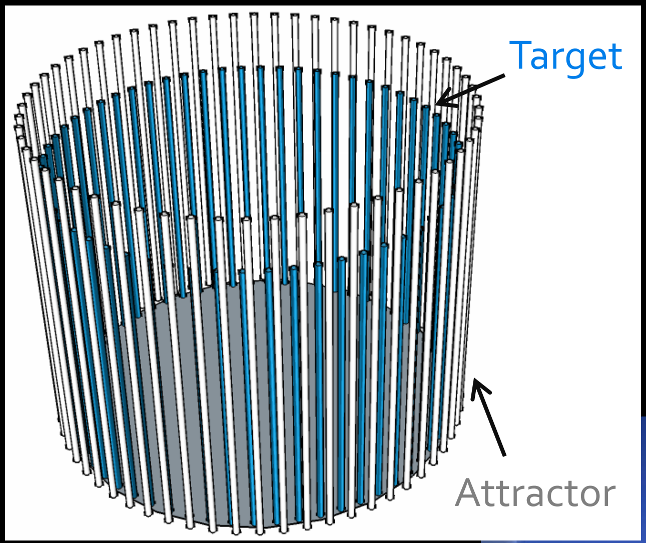


$$V(r) = -G\frac{mM}{r}\left(1 + \alpha e^{-\frac{r}{\lambda}}\right)$$

λ : interaction range

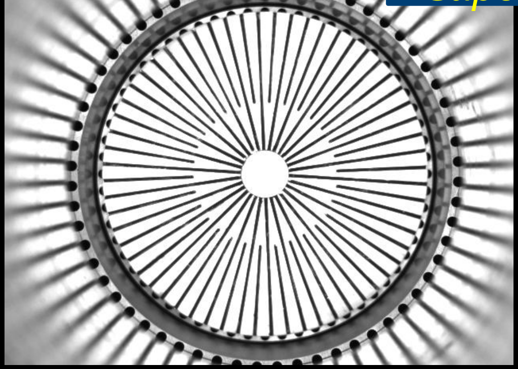
α : coupling constant

Next generation device

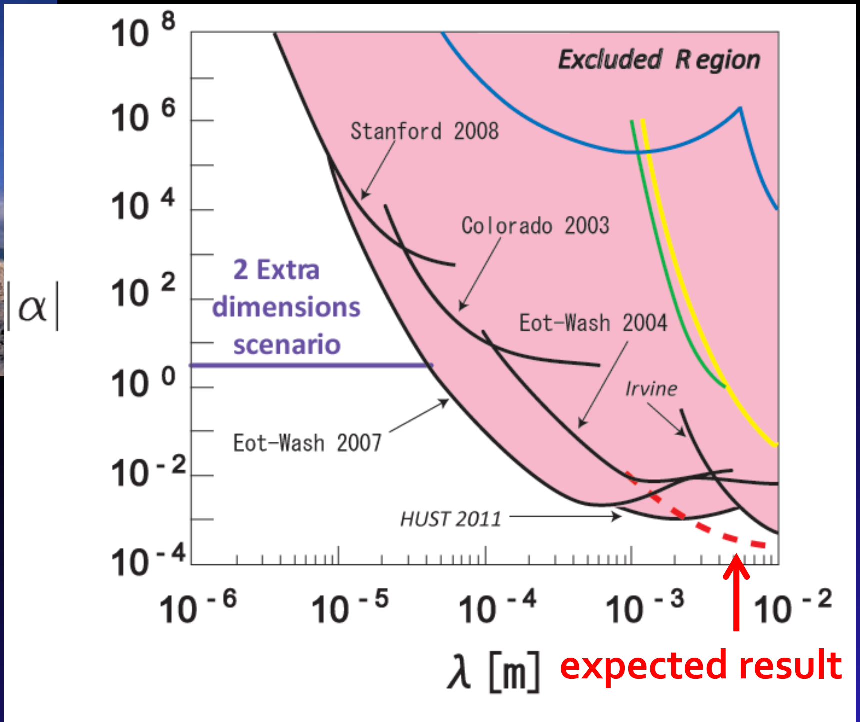


Center to center of 1.9 mm

Capture Image



- NULL type experiment
- Suppression the systematic error



Composition dependence of gravitational constant G

Weak Equivalence Principle (WEP)

$$\frac{m_g}{m_I} = 1 + \kappa \ (\kappa = const.)$$

gravitational mass m_g
inertia mass m_I

Universality of the Free Fall → Test of WEP

Composition dependence of the gravitational constant

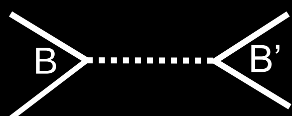
if WEP is violated…

$$\kappa_{ij} - \kappa_{ik} \neq 0$$

→ Gravitational acceleration would have material dependence

Model of WEPV

For example…



Baryon number coupling force (BNC)
(Lee and Yang Phys. Rev.98(1955))

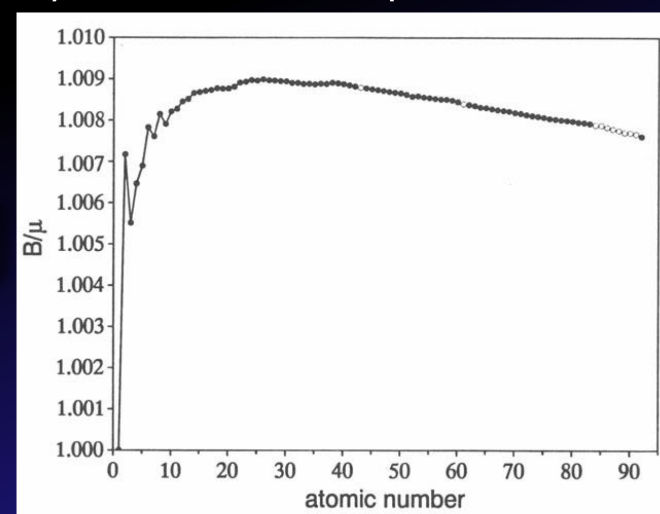
Conservation of baryon number → Possibility of new interaction coupled baryon number

nuclear mass ∼ nucleon mass × nucleon number

Distinguishable BNC and Gravity, compering with different ratios between baryon number and gravitational mass

→ atomic number dependence

Baryon number is dependence of Z



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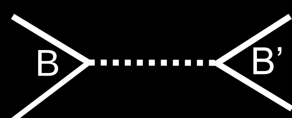

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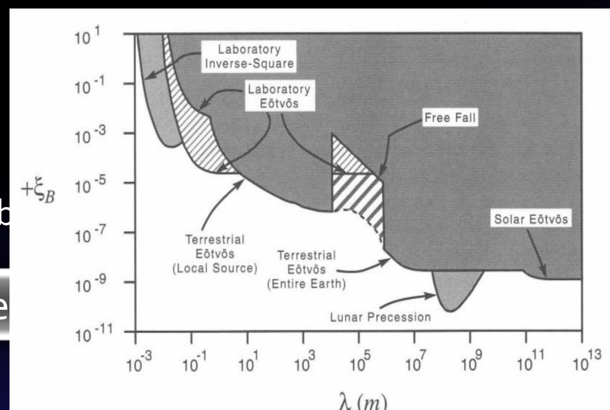
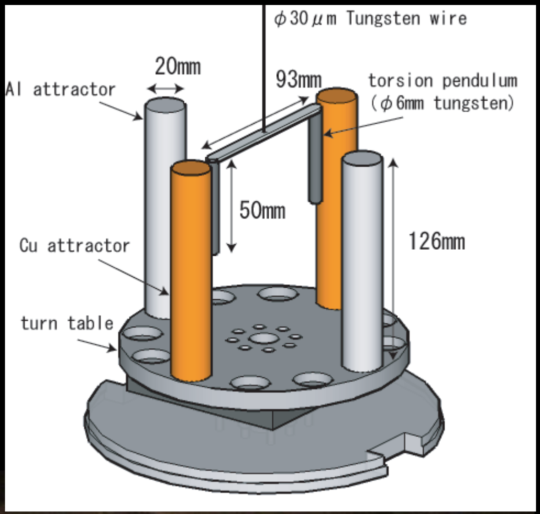
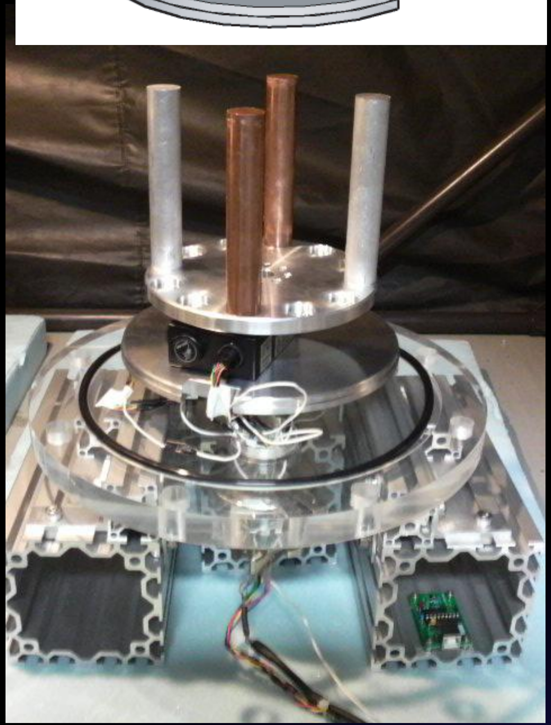


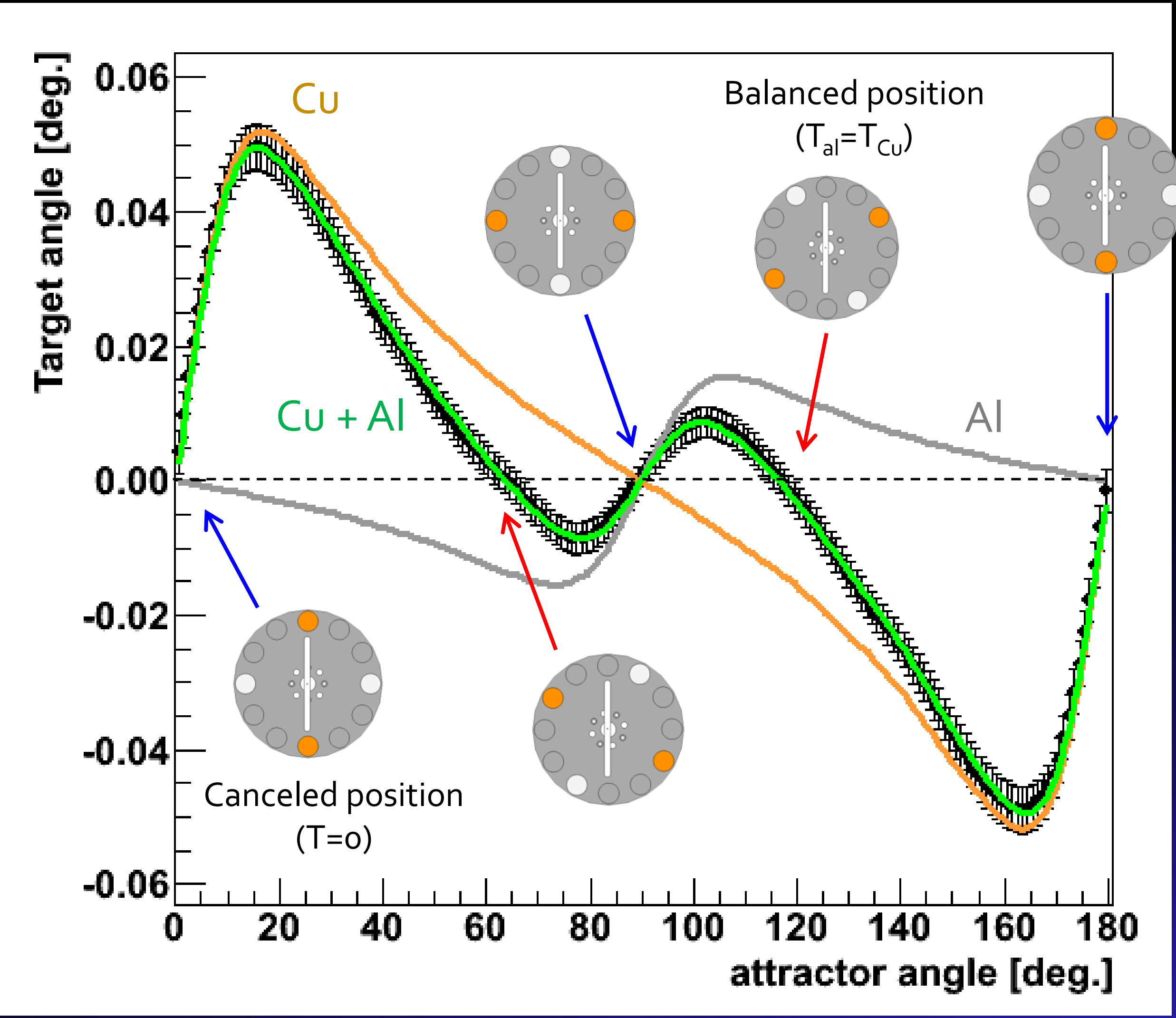
No direct experimental test at cm

Result



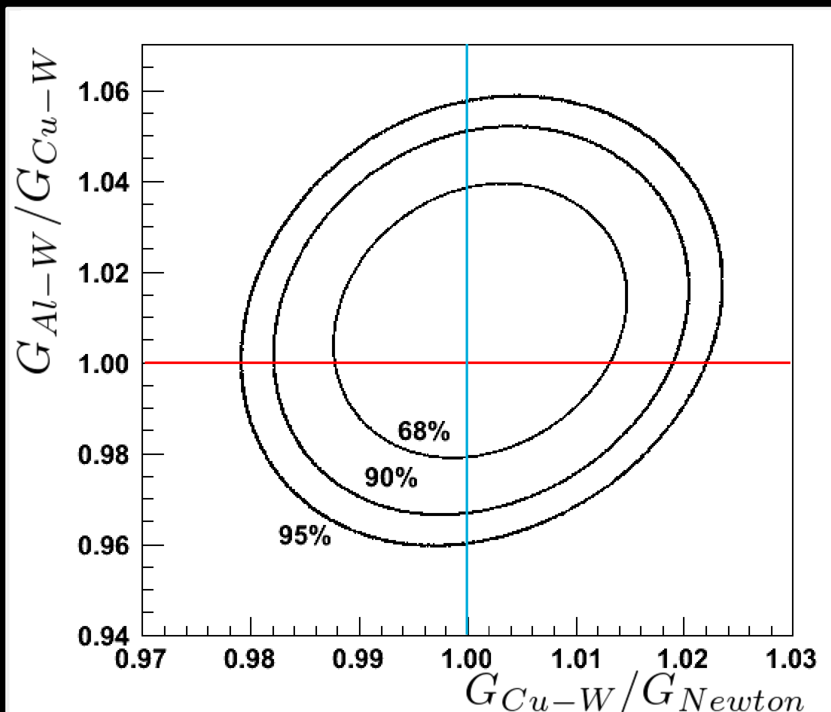


Torque ∝ angular displacement



Result

Composition dependence of the gravitational constant

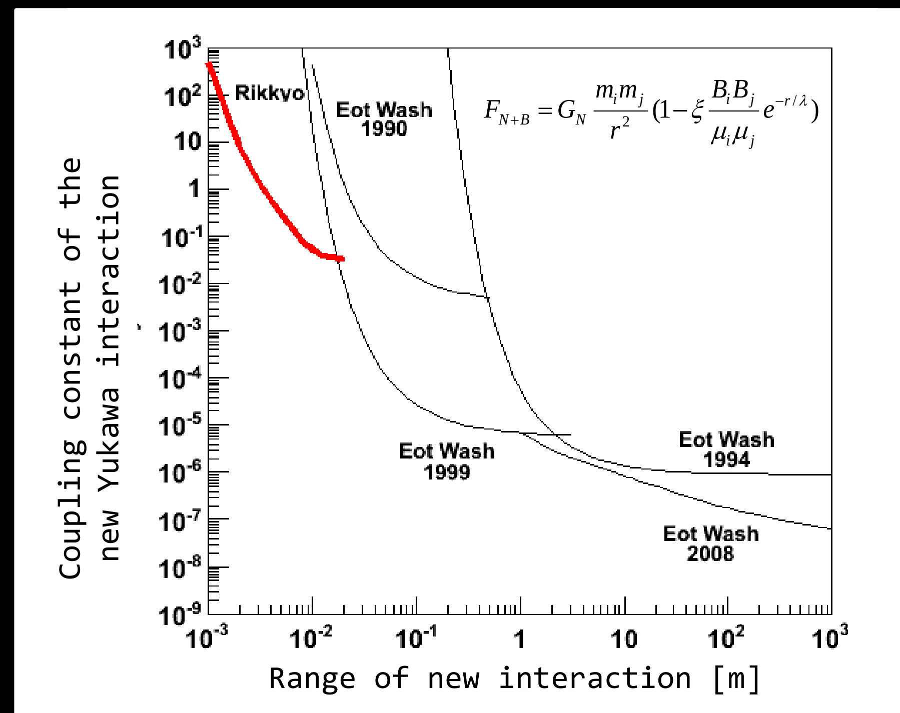


G_{Newton} : PDG value

$$\frac{G_{Al-W}}{G_{Cu-W}} = 1.009 \pm 0.010_{\mathrm{stat}} \pm 0.048_{\mathrm{syst}}$$

$$\frac{G_{Cu-W}}{G_{Newton}} = 1.001 \pm 0.007_{\mathrm{stat}} \pm 0.021_{\mathrm{syst}}$$

Upper limit of the baryon number coupling force

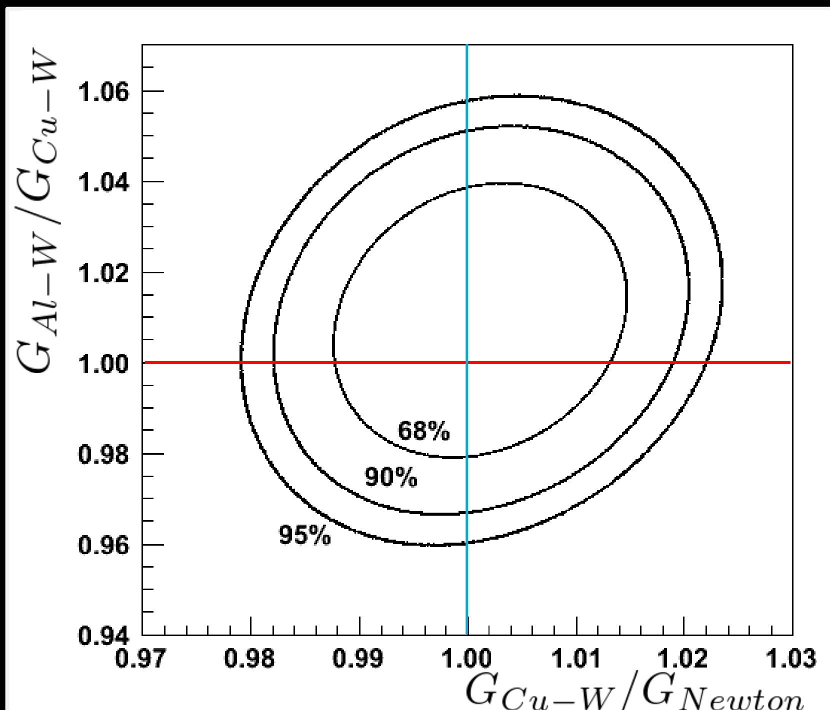


First direct test below cm

Center to center of 1.7 cm between attractor and target

Result

Composition dependence of the gravitational constant



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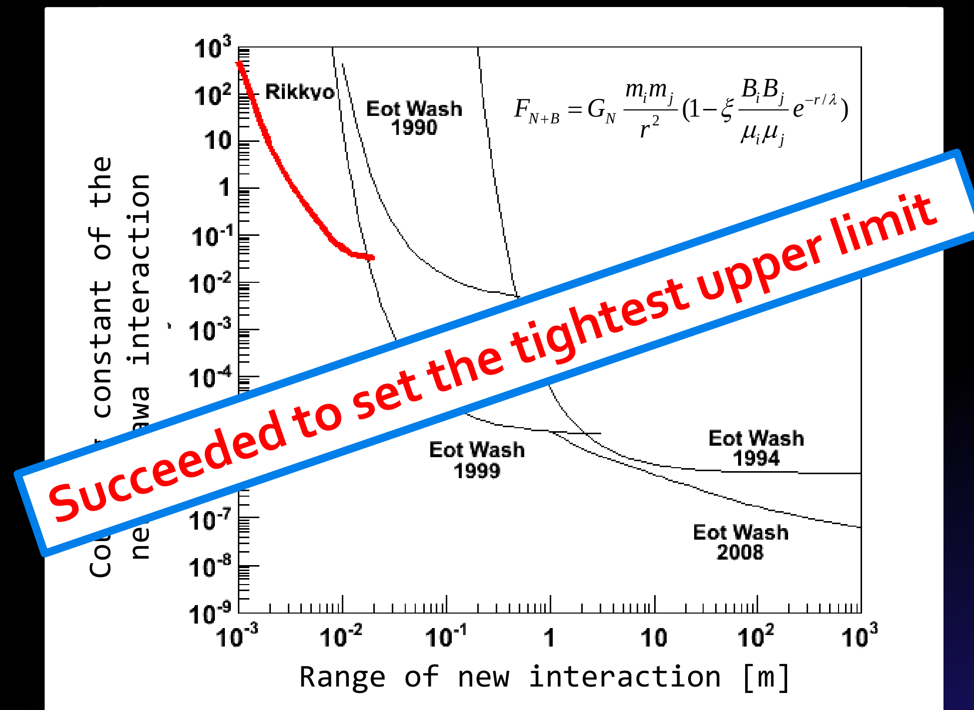


First direct test below cm

Center to center of 1.7 cm between attractor and target

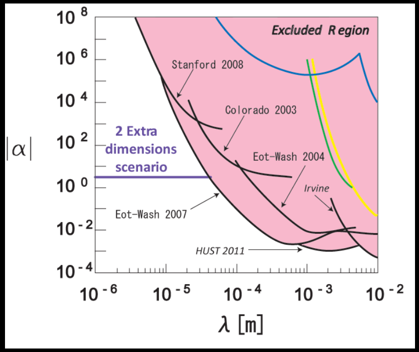
Murata Lab.

Newton

Conclusion

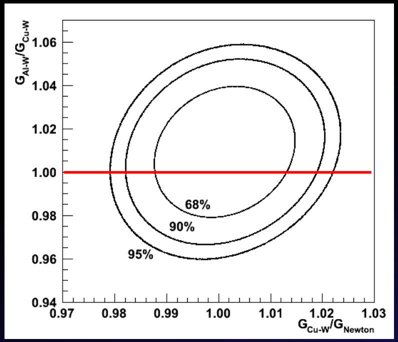
Test of the inverse square law

・Not contradicted with Newtonian inverse square law within our experimental precision at cm scale.



Test of the equivalence principle

・Confirmed the composition independence of the gravitational constant G at mm scale, for the first time.
・Succeeded to set the tightest upper limit of the baryon number coupling force below cm scale



The next Generation experiment

・Most precise test of Newtonian inverse square law below mm scale