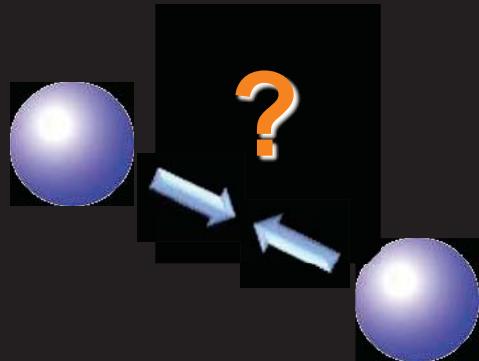


Experimental test of gravitational inverse square law at short range

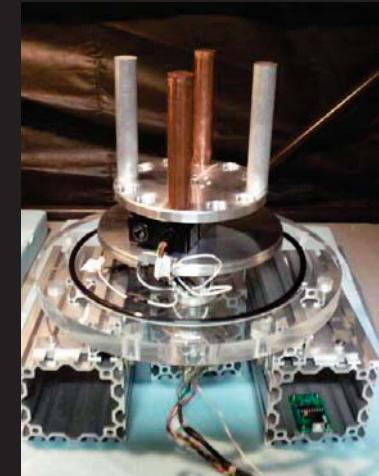


Jiro Murata (Rikkyo University)

2013/2/6
ACP Seminar, Kavli-IPMU



Research Background :

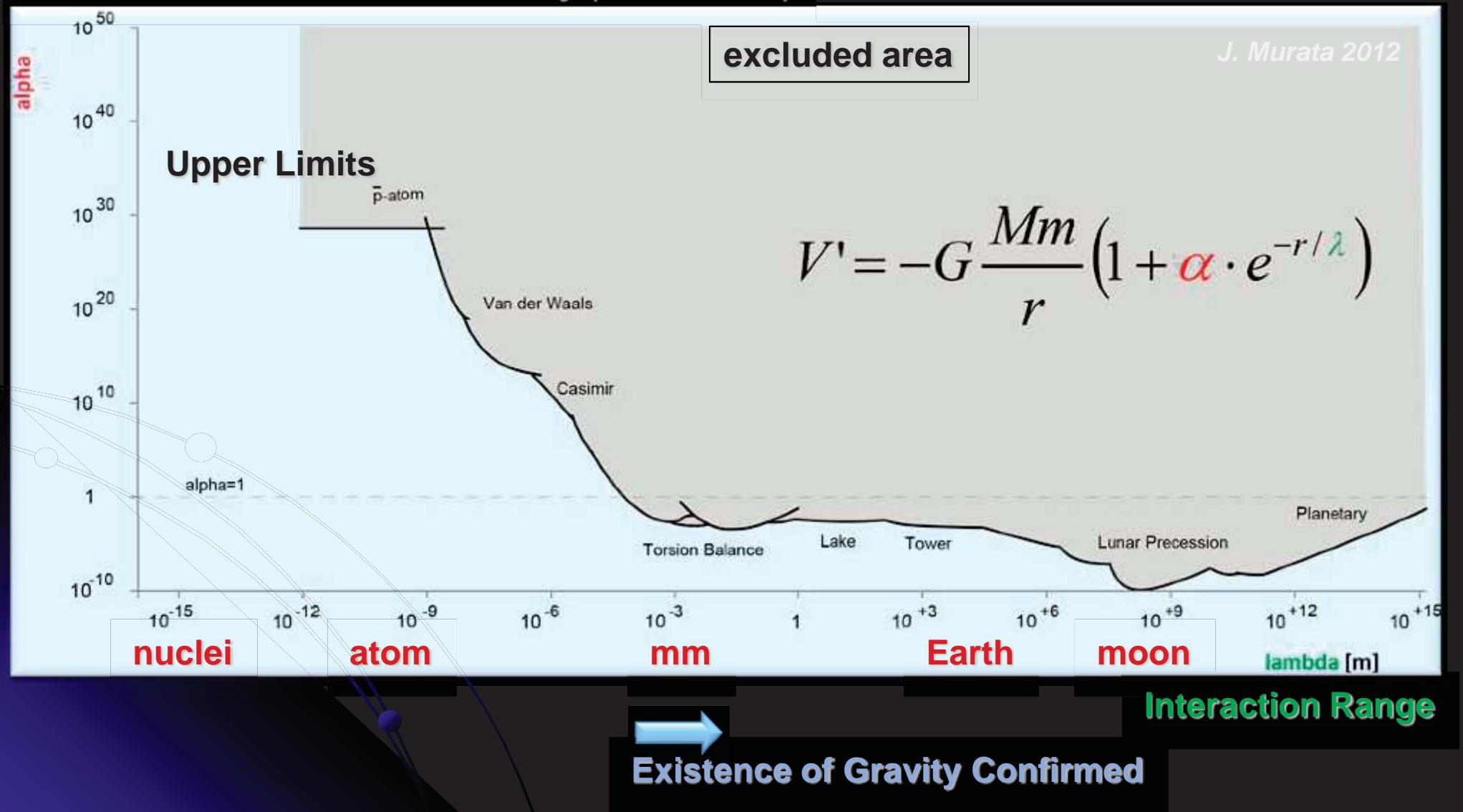


Particle and Nuclear Physics Exp.

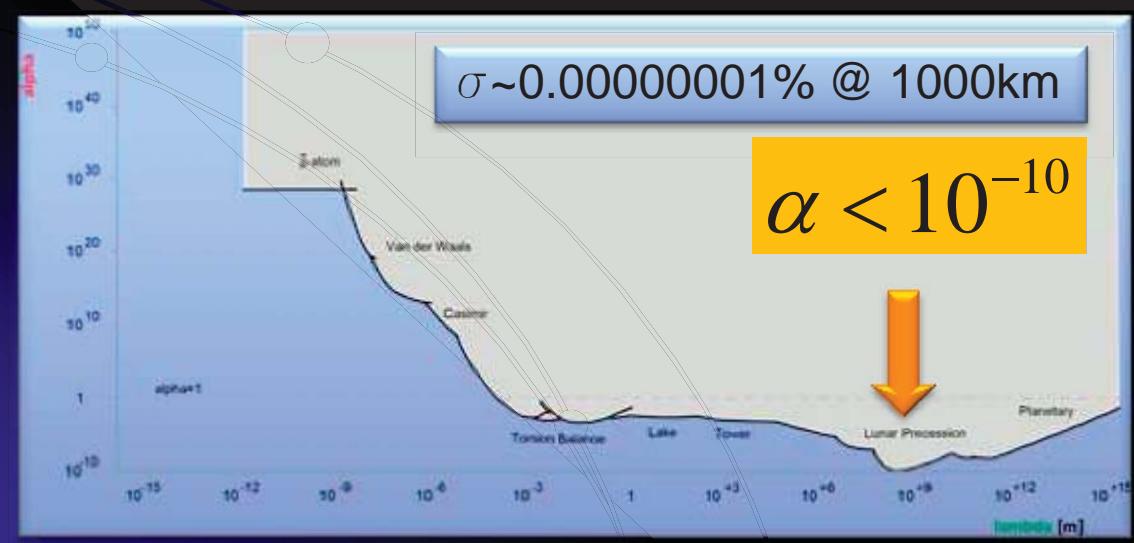
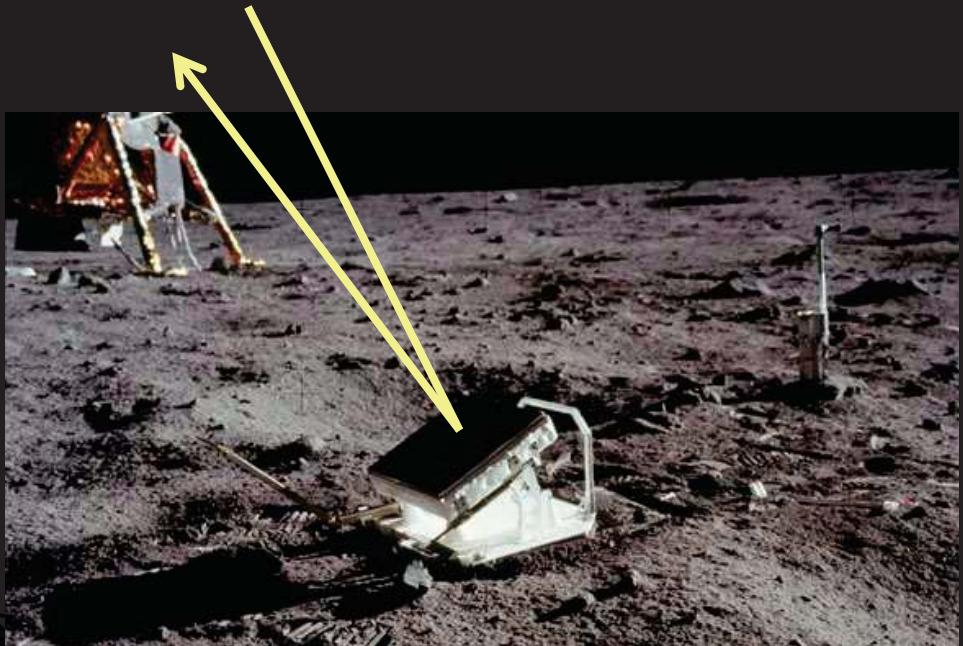
Table-top Gravity Exp.

Experimental Constraints

Deviation from Newtonian Gravity (Newton = 1)



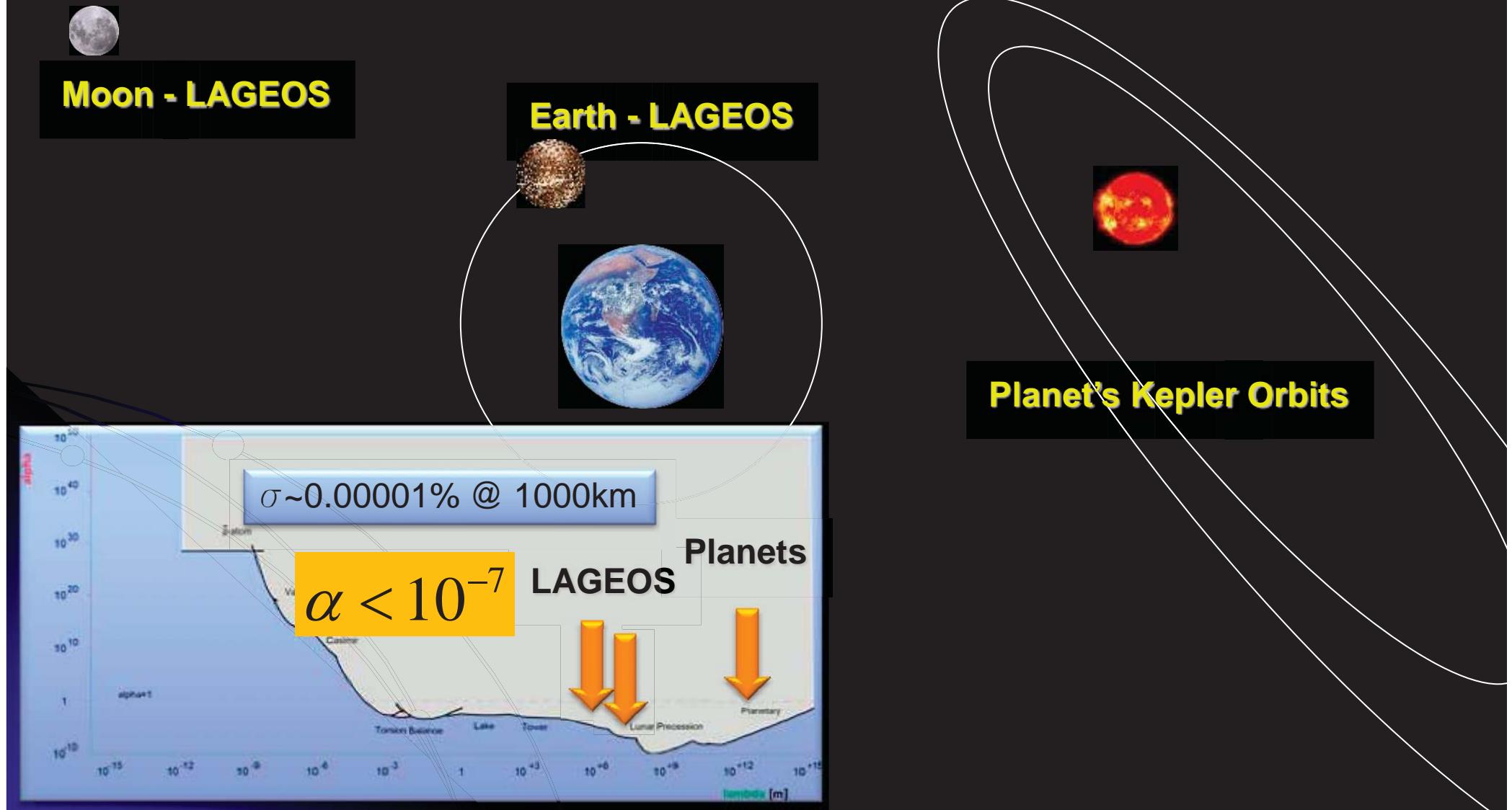
Lunar Laser Ranging (LLR) Measurement : Apollo-11, 1969



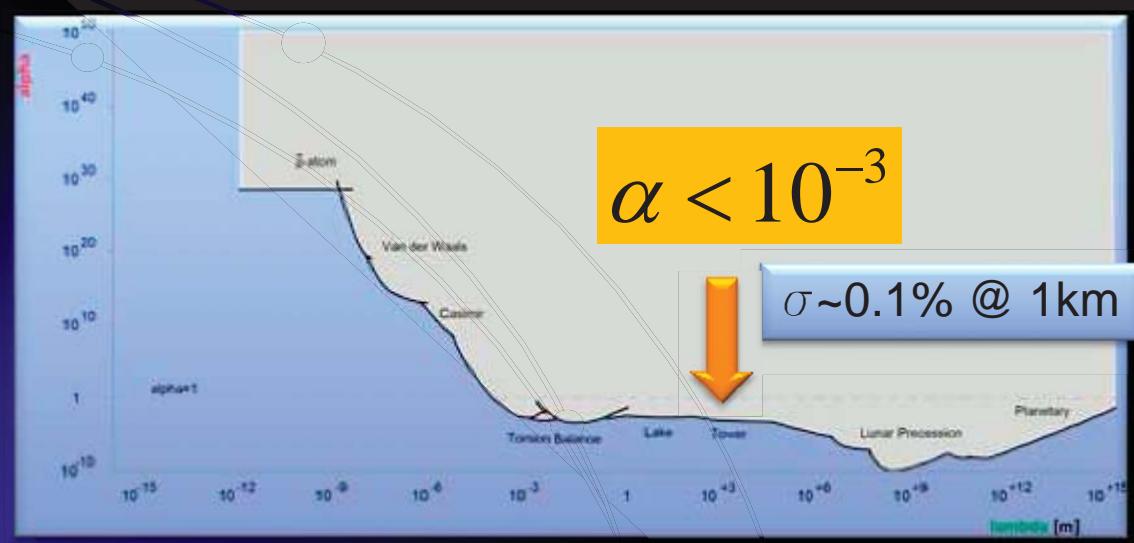
Dickey, Science 265 (1994) 482

Satellite / Planets Kepler Orbit : LAGEOS-NASA (1985)

Smith J. Geophys. Res. 90 (1985) 9221

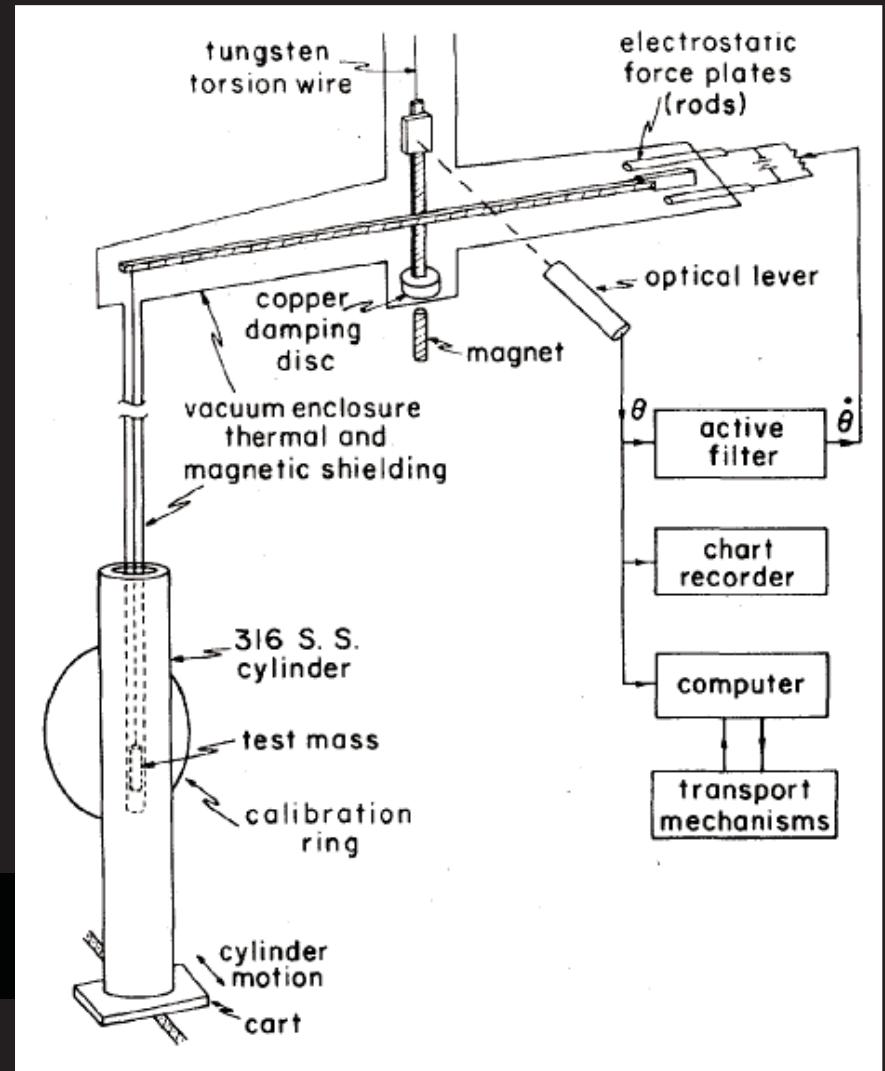
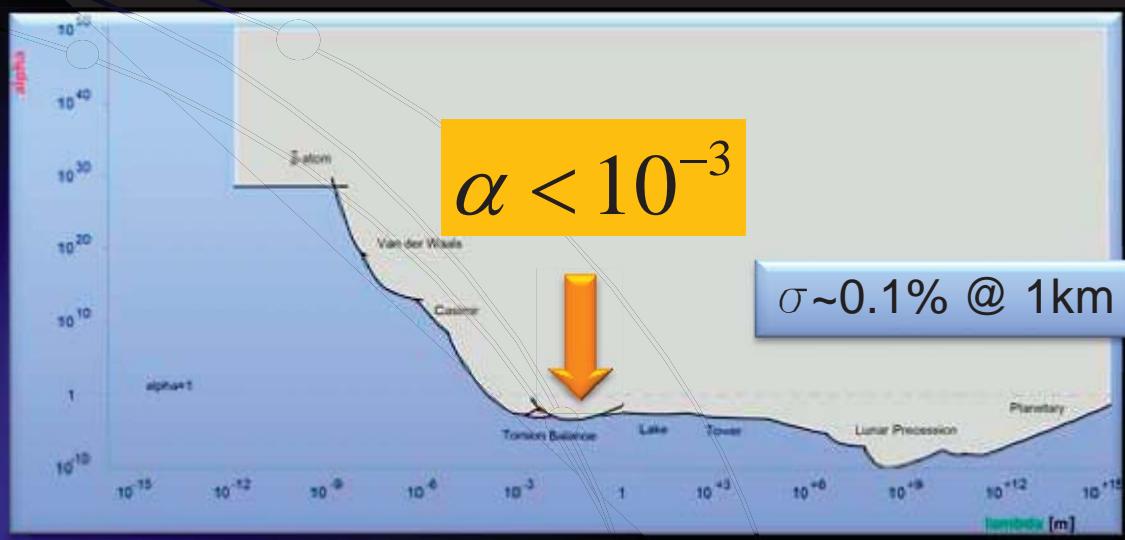
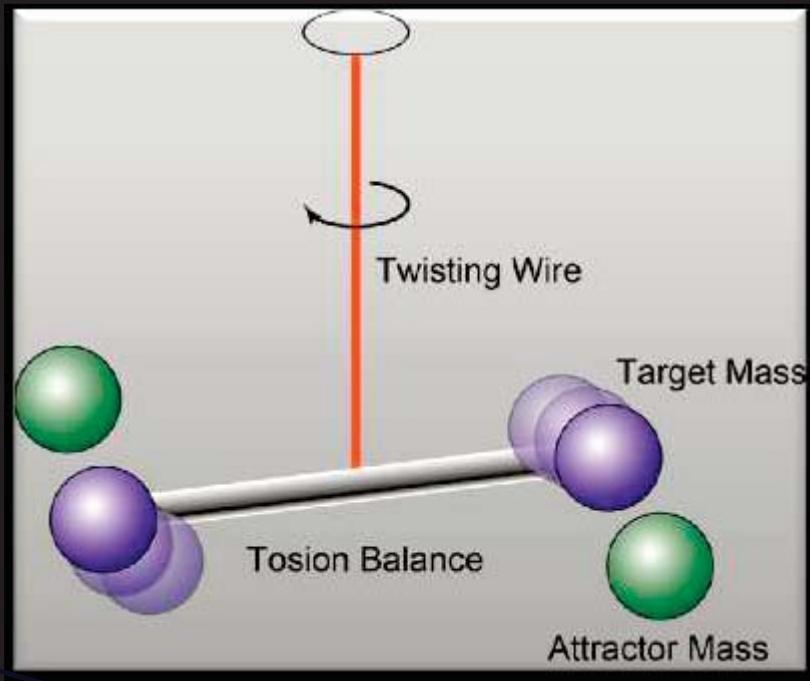


Tower Measurement : BREN tower 465m, Nevada, 1989



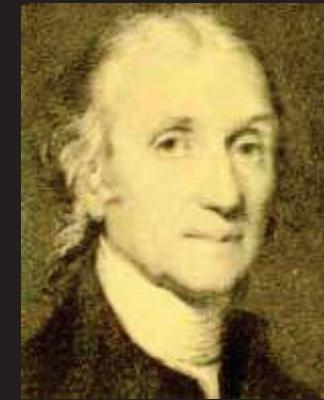
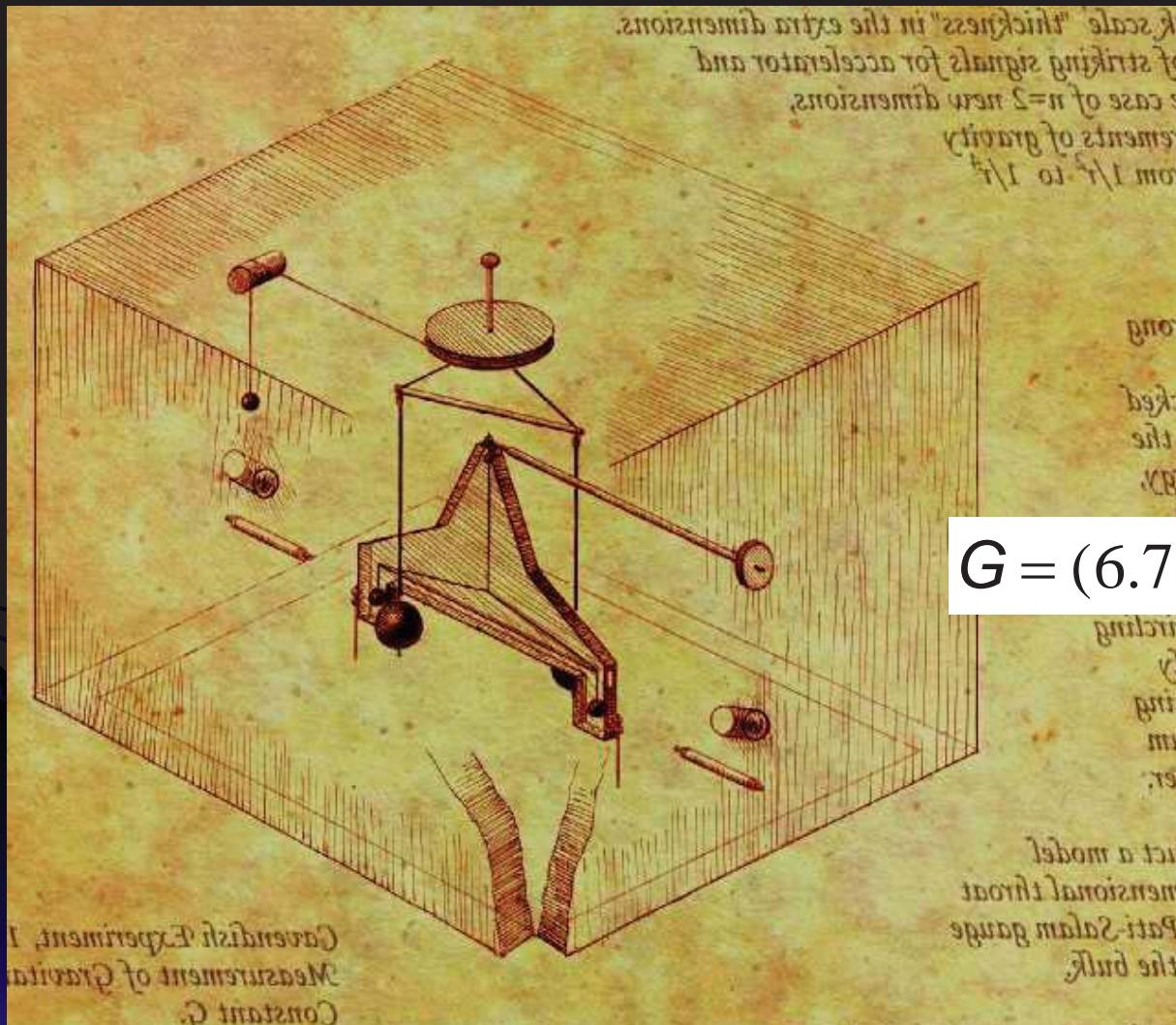
Thomas PRL 63 (1989) 1902

Torsion Balance Measurement : UC – Irvine 1985



Hoskins PRD 32 (1985) 3085

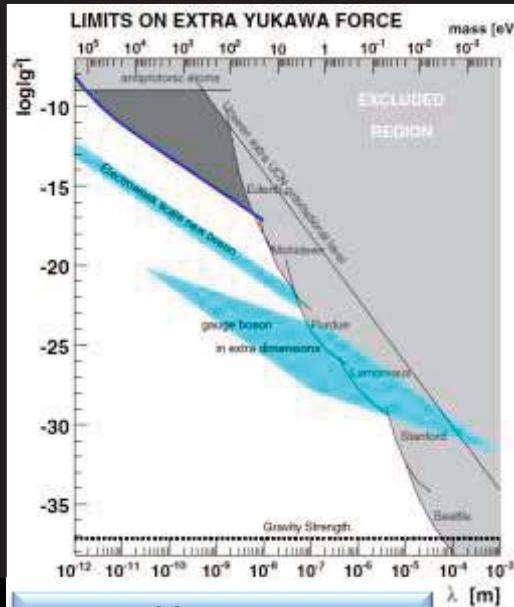
Torsion Balance Measurement : Cavendish 1797 ...



Cavendish

$$G = (6.75 \pm 0.05) \times 10^{-11} \text{ m}^3 / \text{kg} / \text{s}^2$$

Determination of the Earth's mass -> constant G

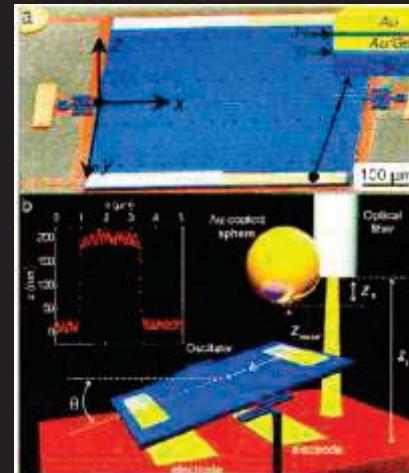


$\sigma \sim 10^{28} @ 100\text{pm}$

Nesvizhevsky PRD 77 (2008) 034010

anti-protonic atom

Nano-tech Measurements



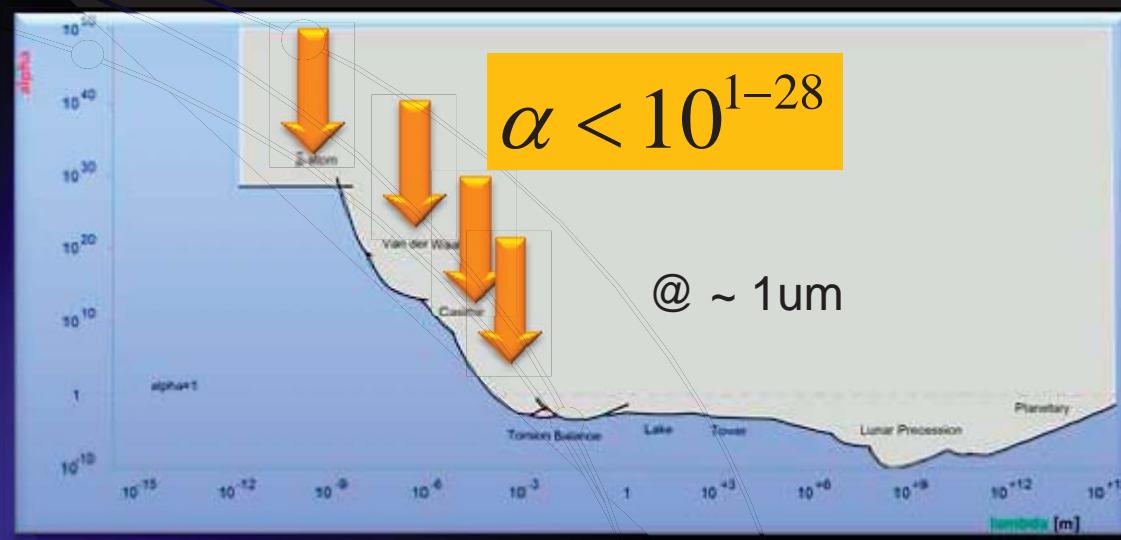
Casimir Force

$\sigma \sim 10^{11} @ 100\text{nm}$

Decca PRL 94 (2005) 240401 Lamoreaux PRL 78 (1997) 5

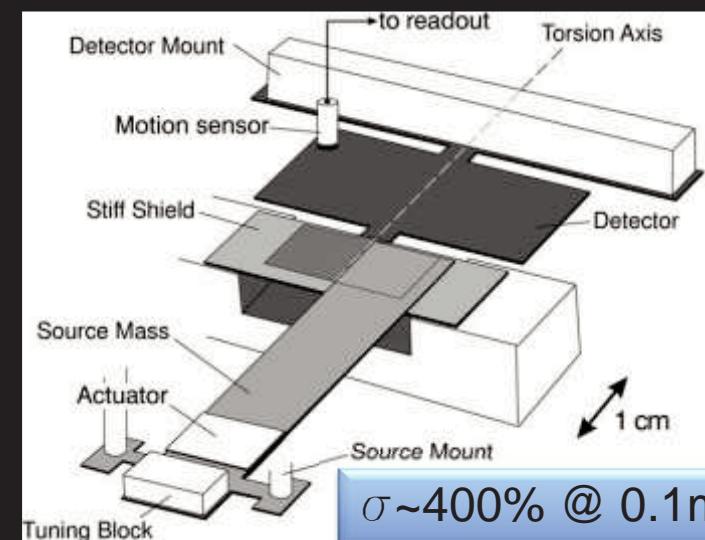
$\sigma \sim 10^8 @ 1\text{micron}$

FIG. 2. Details of the pendulum. The body has total mass 397 g. The ends of the W fiber were plated with a Cu cyanide solution; the fiber ends were bent into hairpins of 1 cm length and then soldered into a 0.5 mm diam, 7 mm deep holes in the body. The pendulum is suspended by two hairpins from the plating bath support.



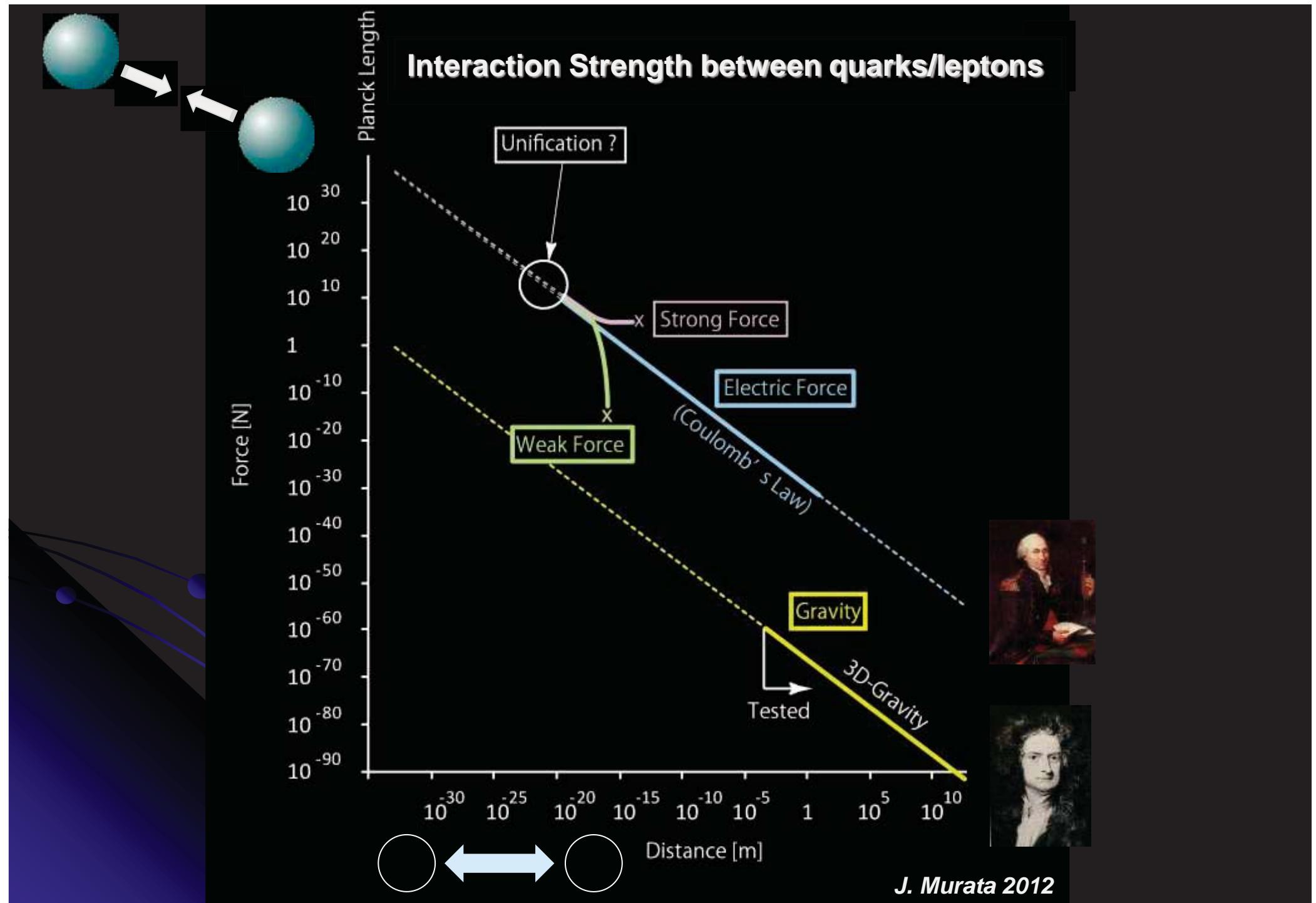
$$\alpha < 10^{1-28}$$

@ $\sim 1\mu\text{m}$

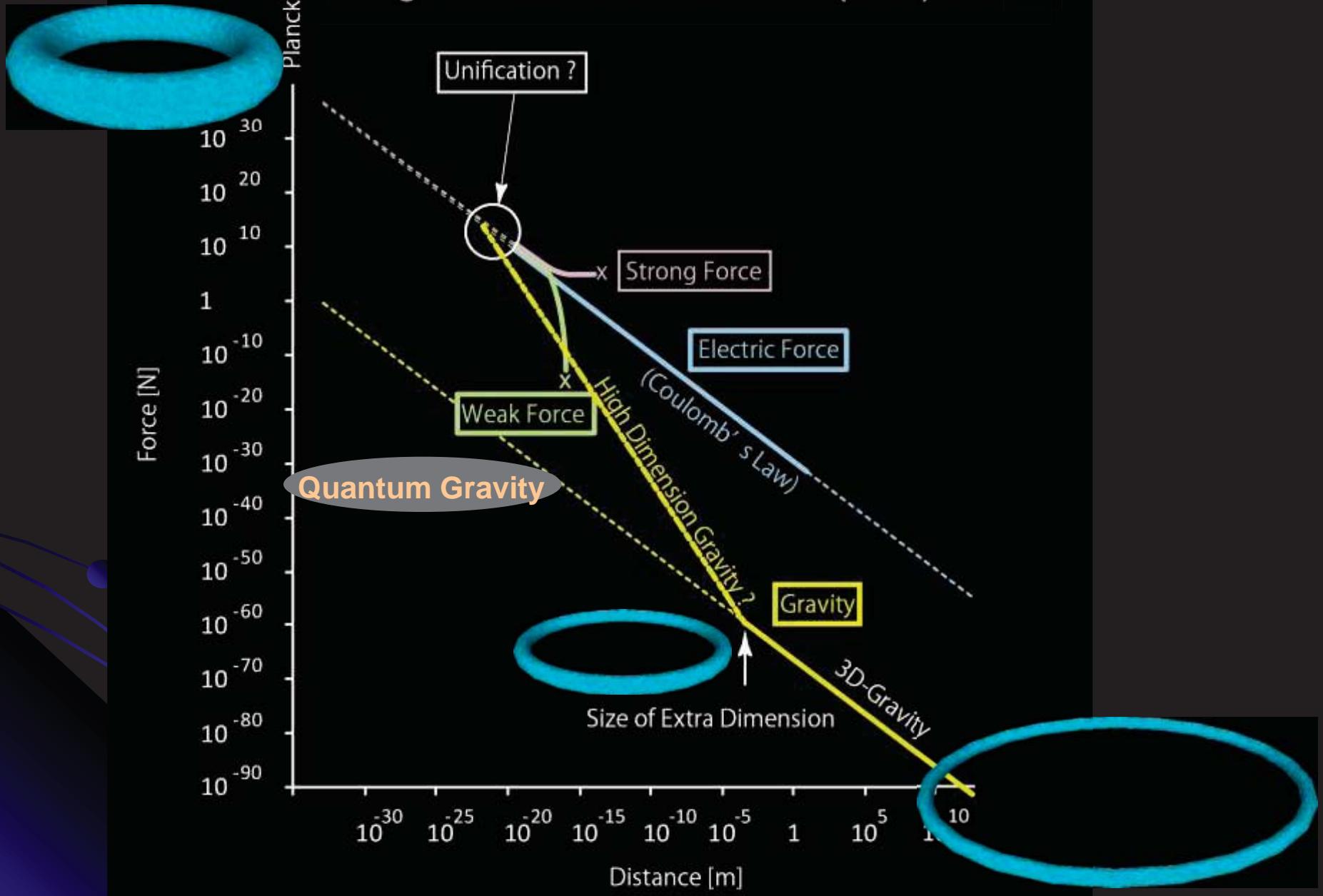


$\sigma \sim 400\% @ 0.1\text{mm}$

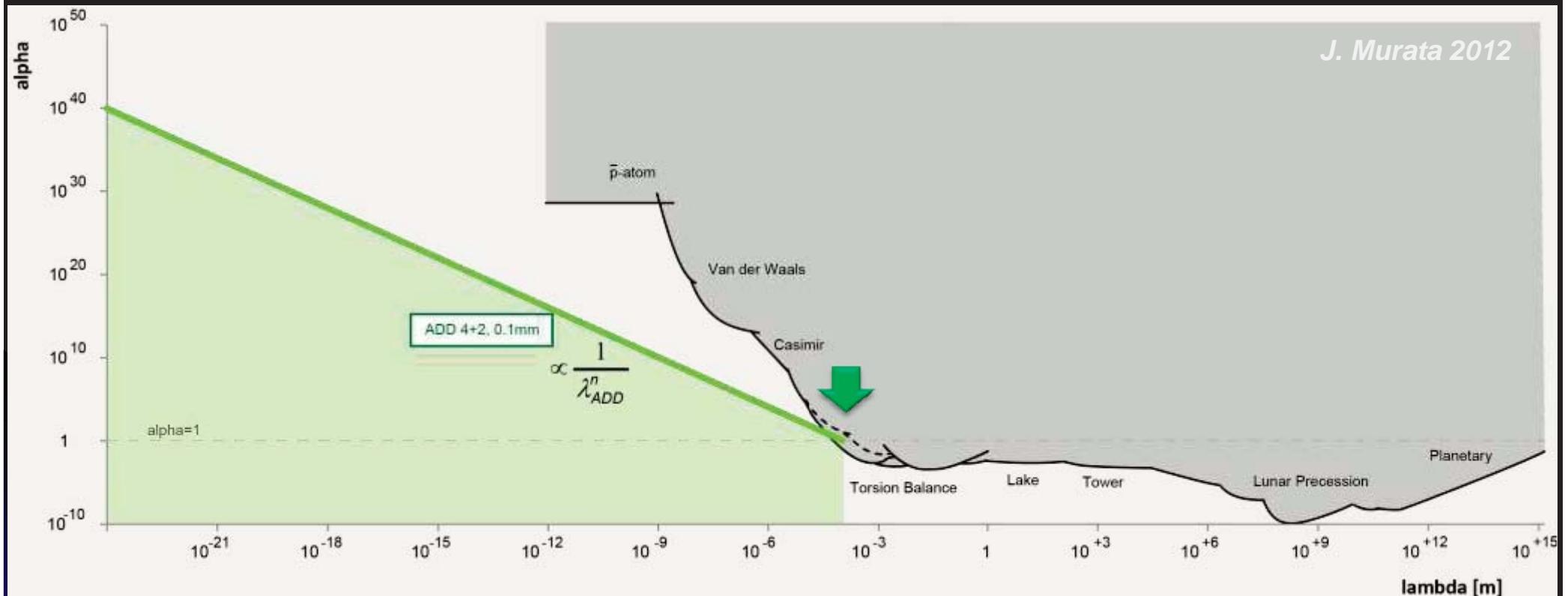
Long Nature 421 (2003) 922



Large Extra Dimension Model (ADD) 1998



Possible Searching Window of the ADD gravity



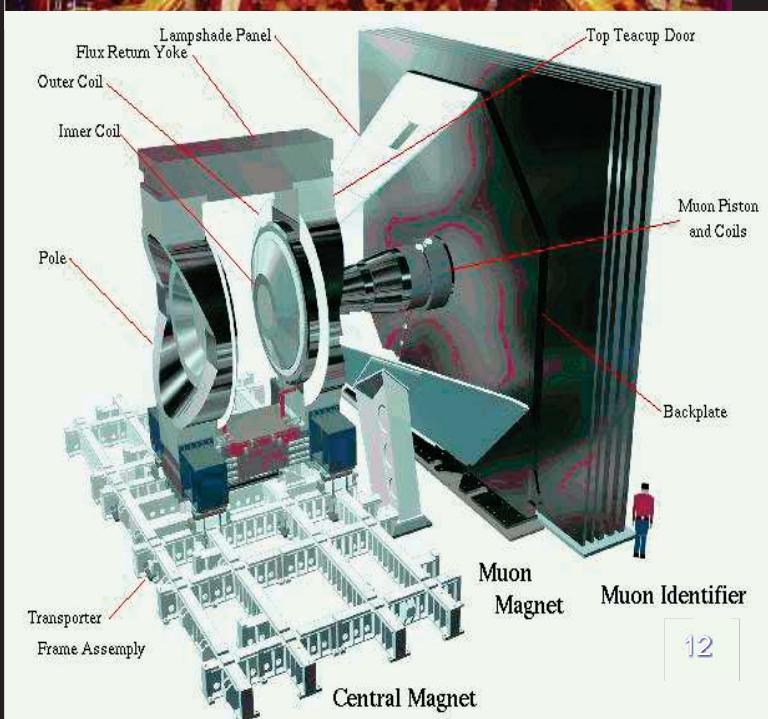
Violation of Newtonian inverse square law is expected at 0.1mm,
assuming unification scale of 1TeV with d = 2



Prologue : PHENIX exp. at RHIC

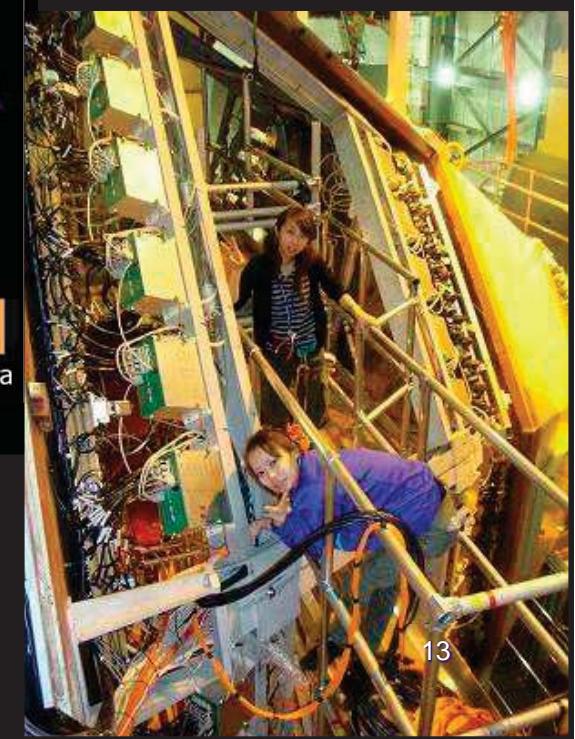
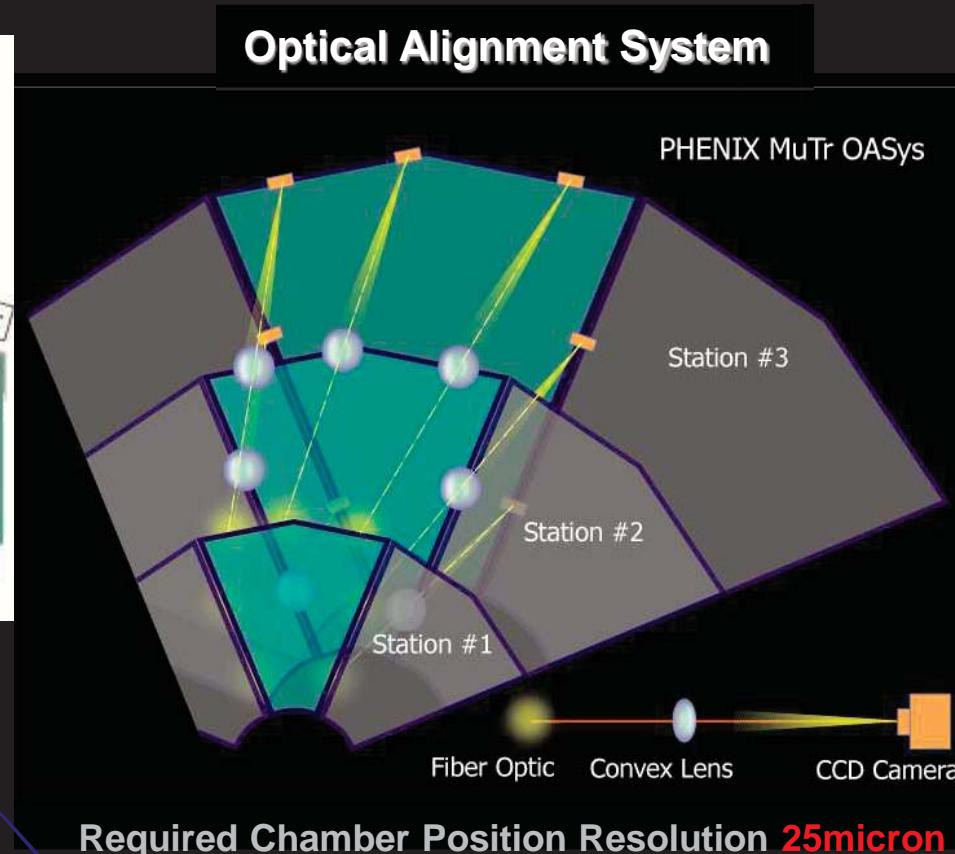
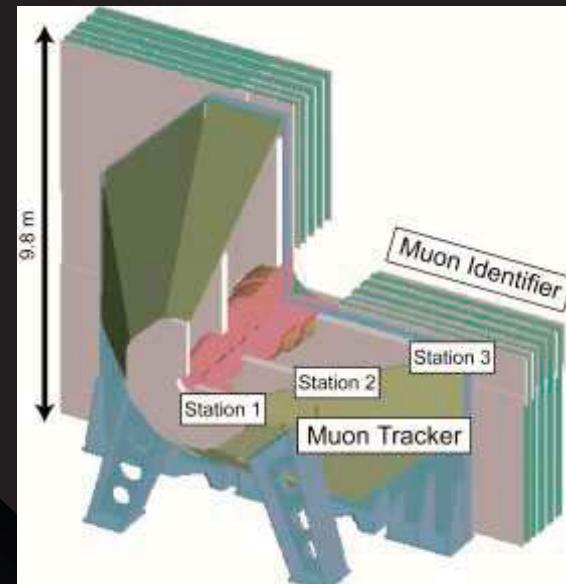


**QCD physics : spin structure of protons
Quark-gluon Plasma**



Prologue : PHENIX Muon Tracking Chamber 1999~2001

Three Stations of Cathode Strip Chambers





RHIC-PHENIX Optical Alignment System to Pico precision Displacement Sensor



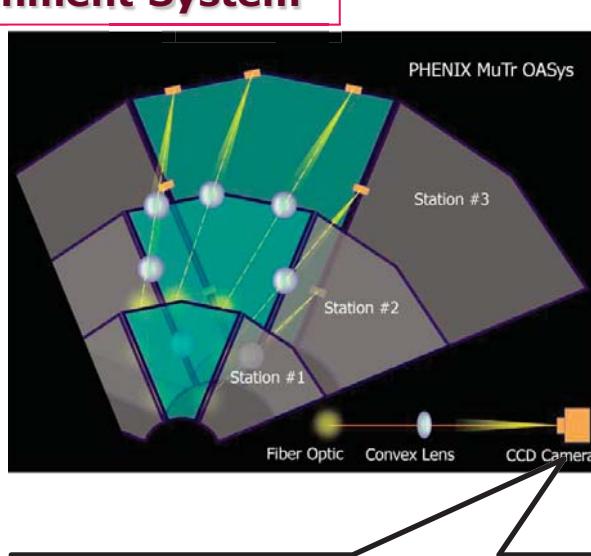
PHENIX-OASys Optical Alignment System



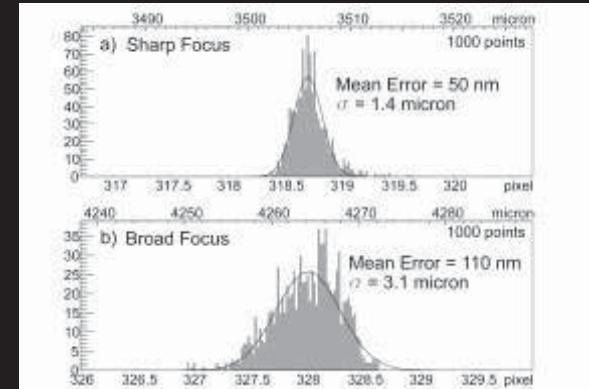
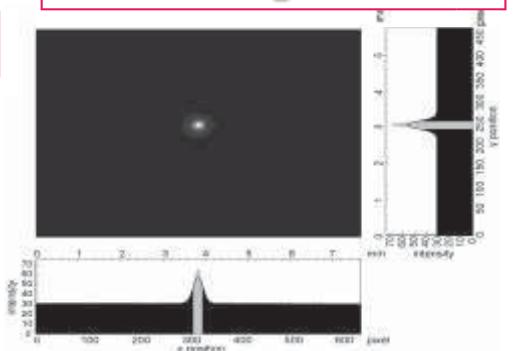
Muon Momentum Resolution

PHENIX Muon Tracker
 $\sim 5\text{m}$ size chambers

Monitoring thermal
Deformation $< 25\mu\text{m}$



Focal Image on CCD



$\sim 50\text{nm}$ resolution



Applicable to Short Range Gravity Exp. ?

Under-G Student Experiment at Rikkyo University

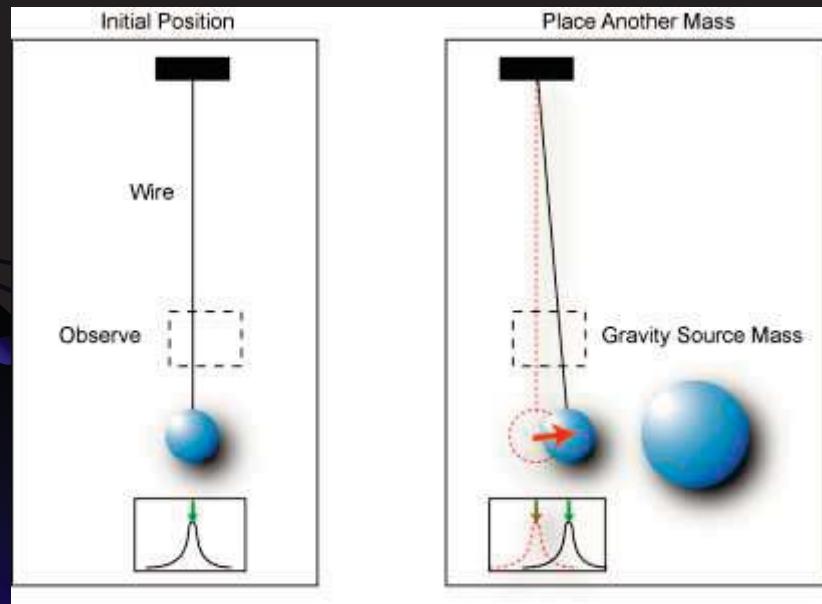
patent pending !

Starting Point of the Rikkyo-Newton exp. 2003

Wide Dynamic Range, Precision Position Measurement



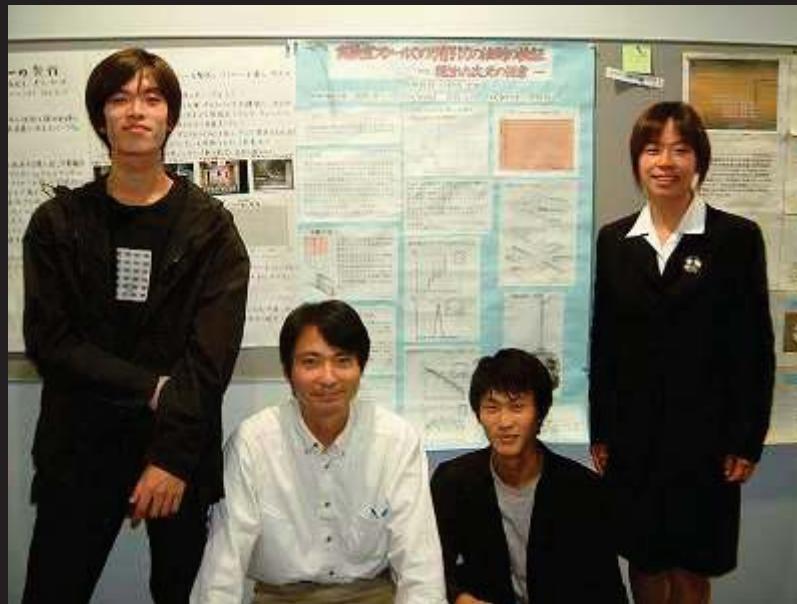
Extremely weak force measurement, by observing displacement



In cm scale,
Gravitational Force $\sim 10\text{nN}$
Displacement $\sim 1\text{nm}$ (1m pendulum)

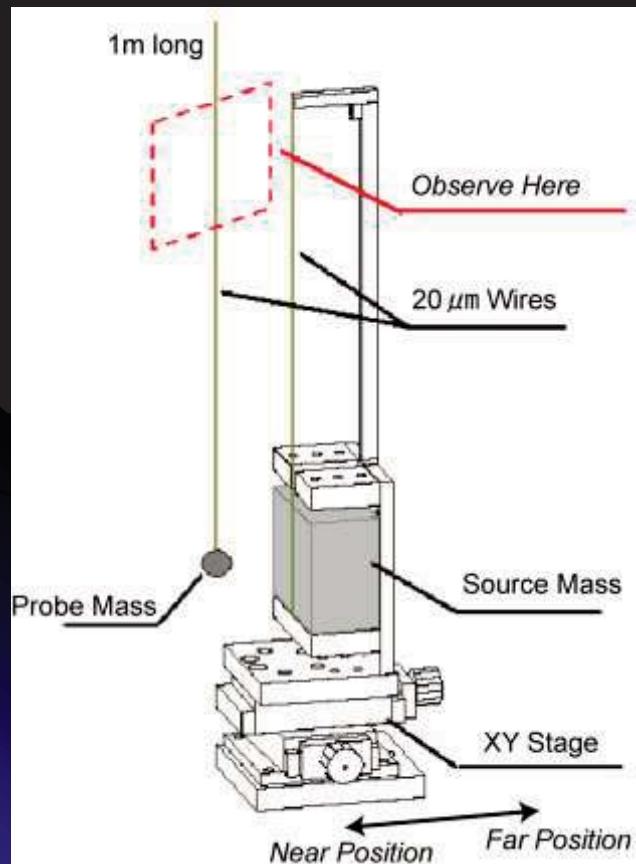


1nm > Resolution !

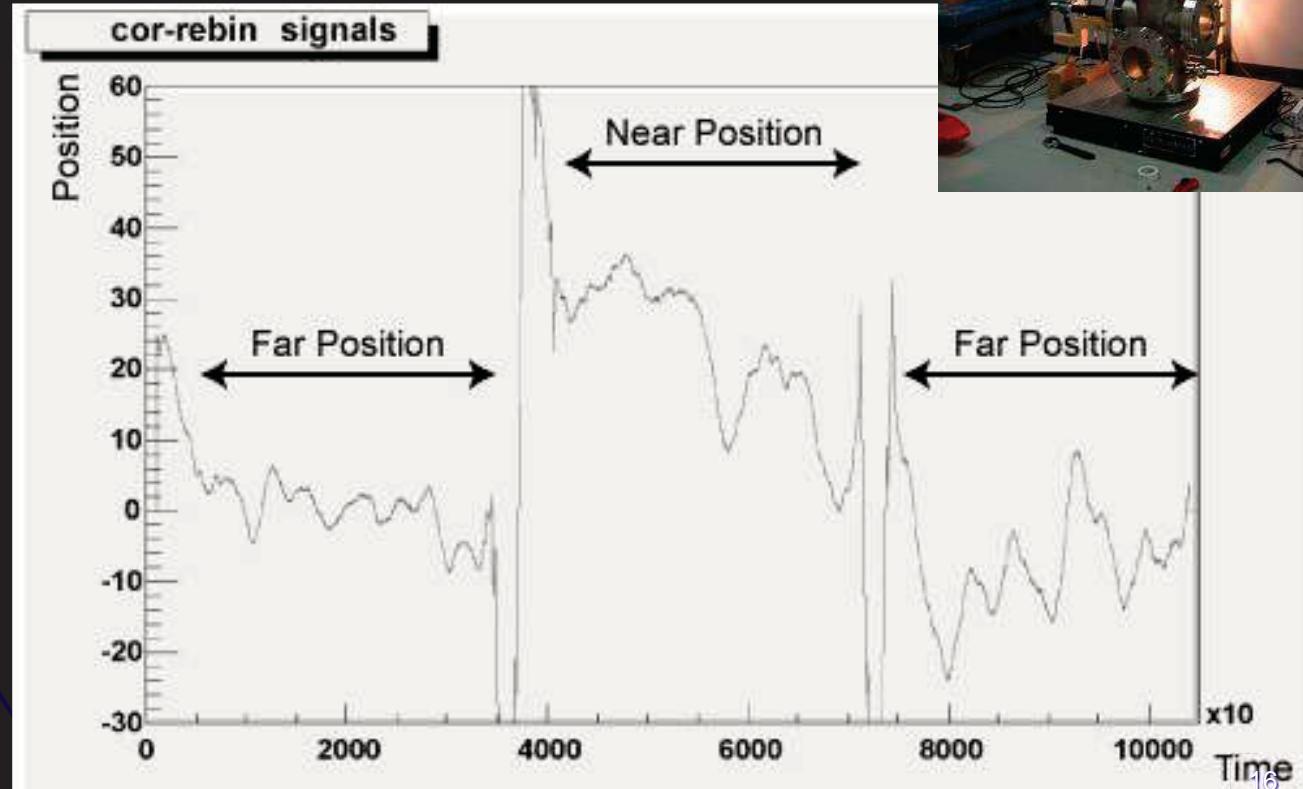


Takahashi, Miyano, Tsuneno 2003

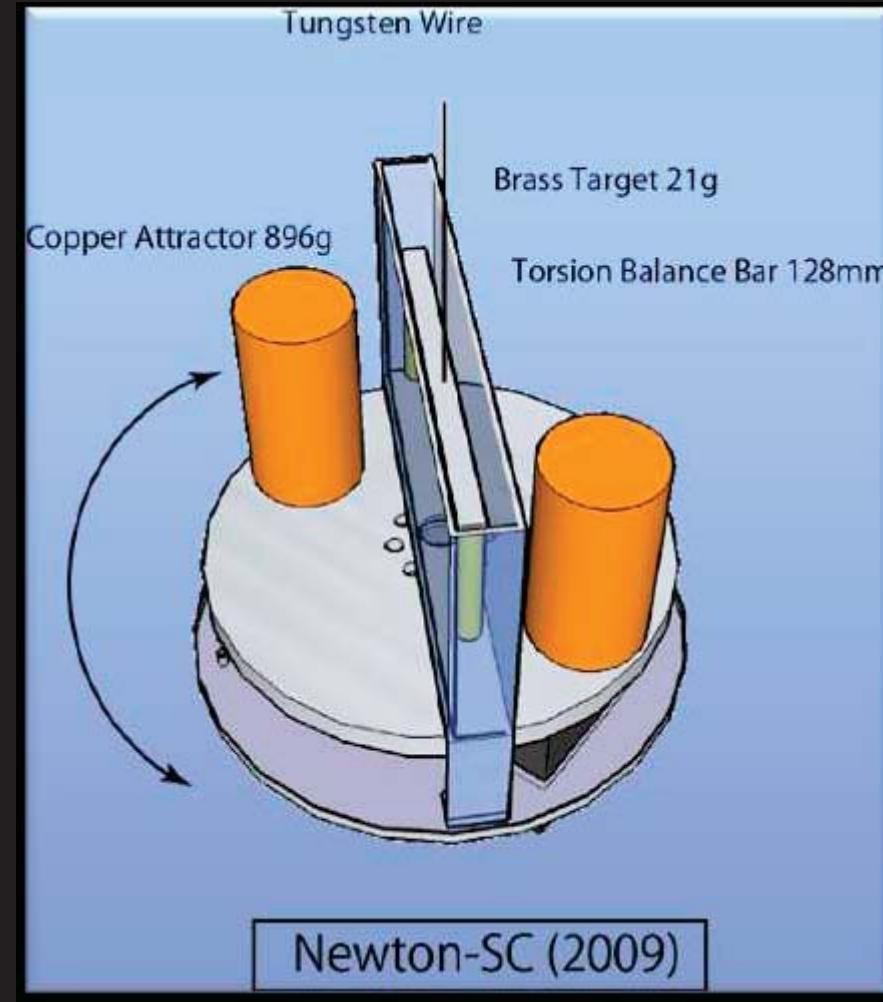
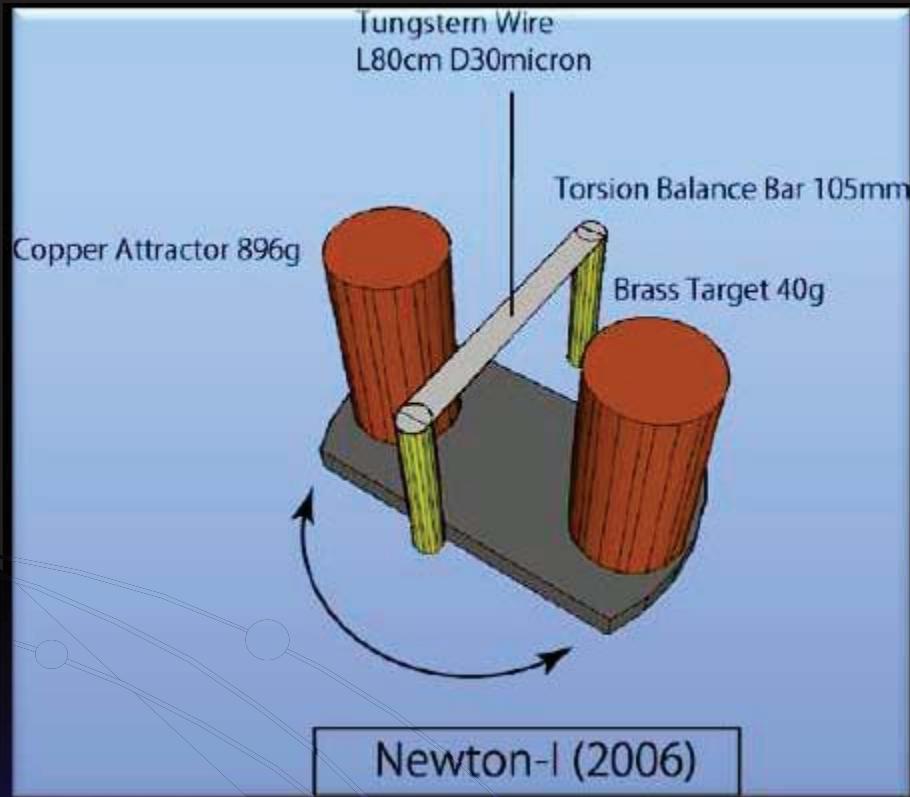
Newton-0 exp. 2003

1st Step Exp. Using 1m long Pendulum

Measured Result



Gravity Signal ? -> maybe tilting ...



Movie File

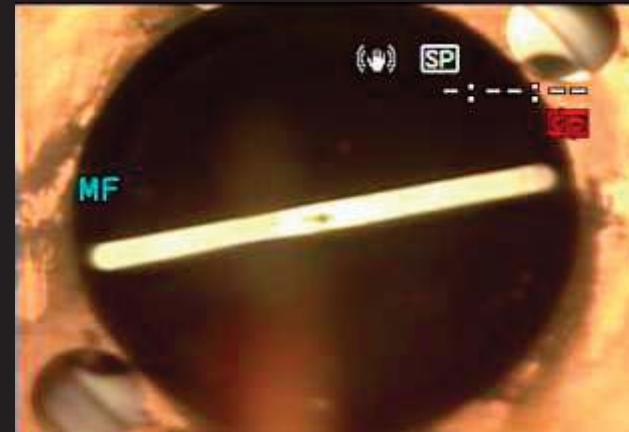
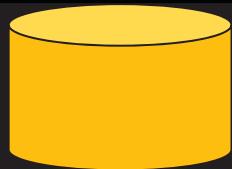
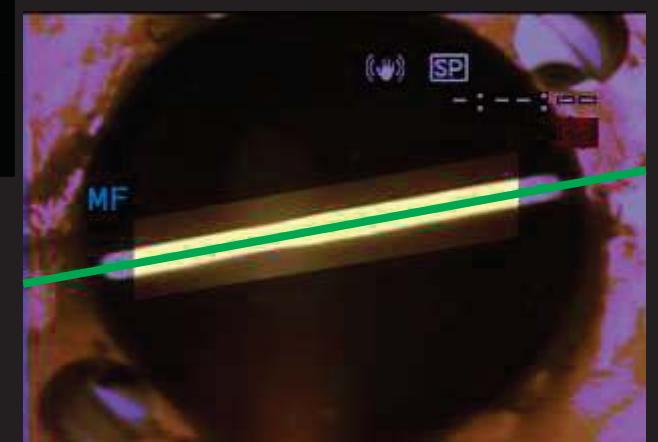
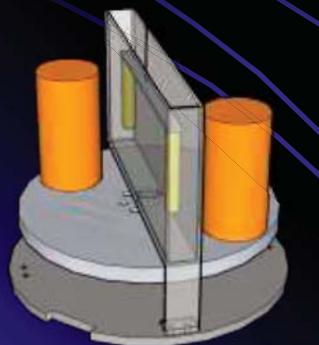


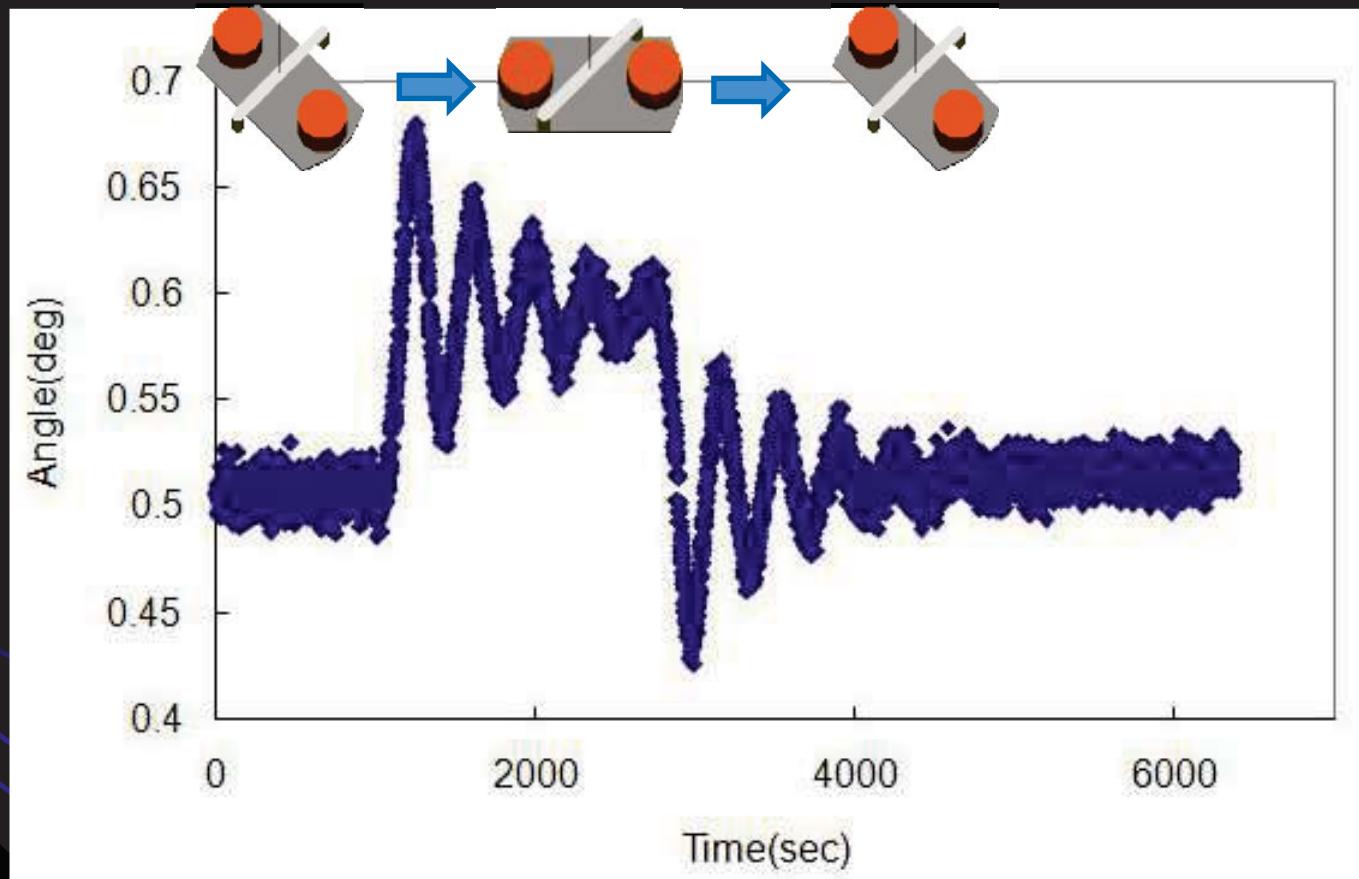
Image Analysis



resolution ~ 1 micro degree

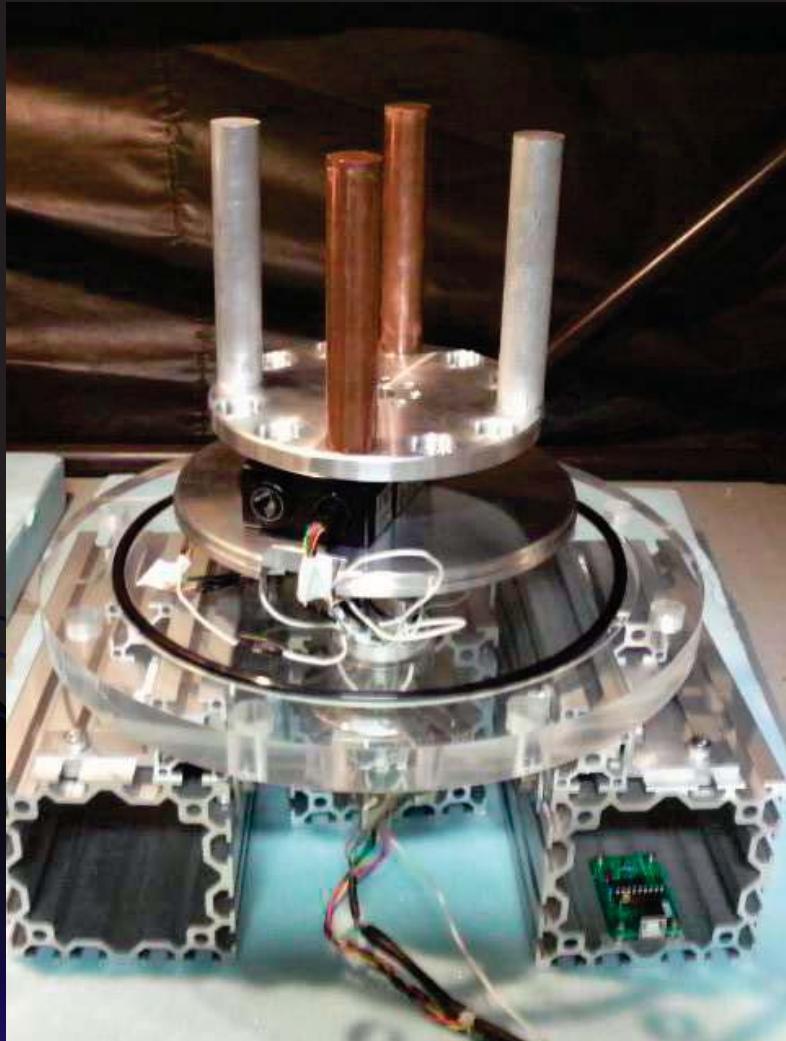


2nd year of Newton-I 2006

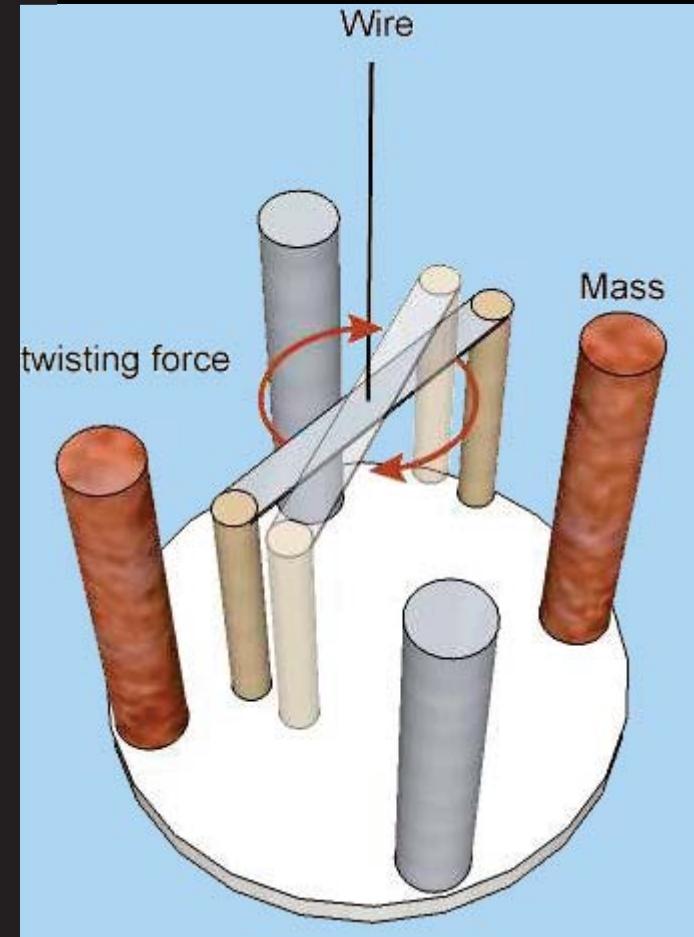


Yazawa, Sato 2005
Hata, J. Phys. CS189 (2009) 012019

**Small Scale, Legacy, but unique and powerful tool:
Torsion Balance Bar**



NEWTON Experiment (2009)

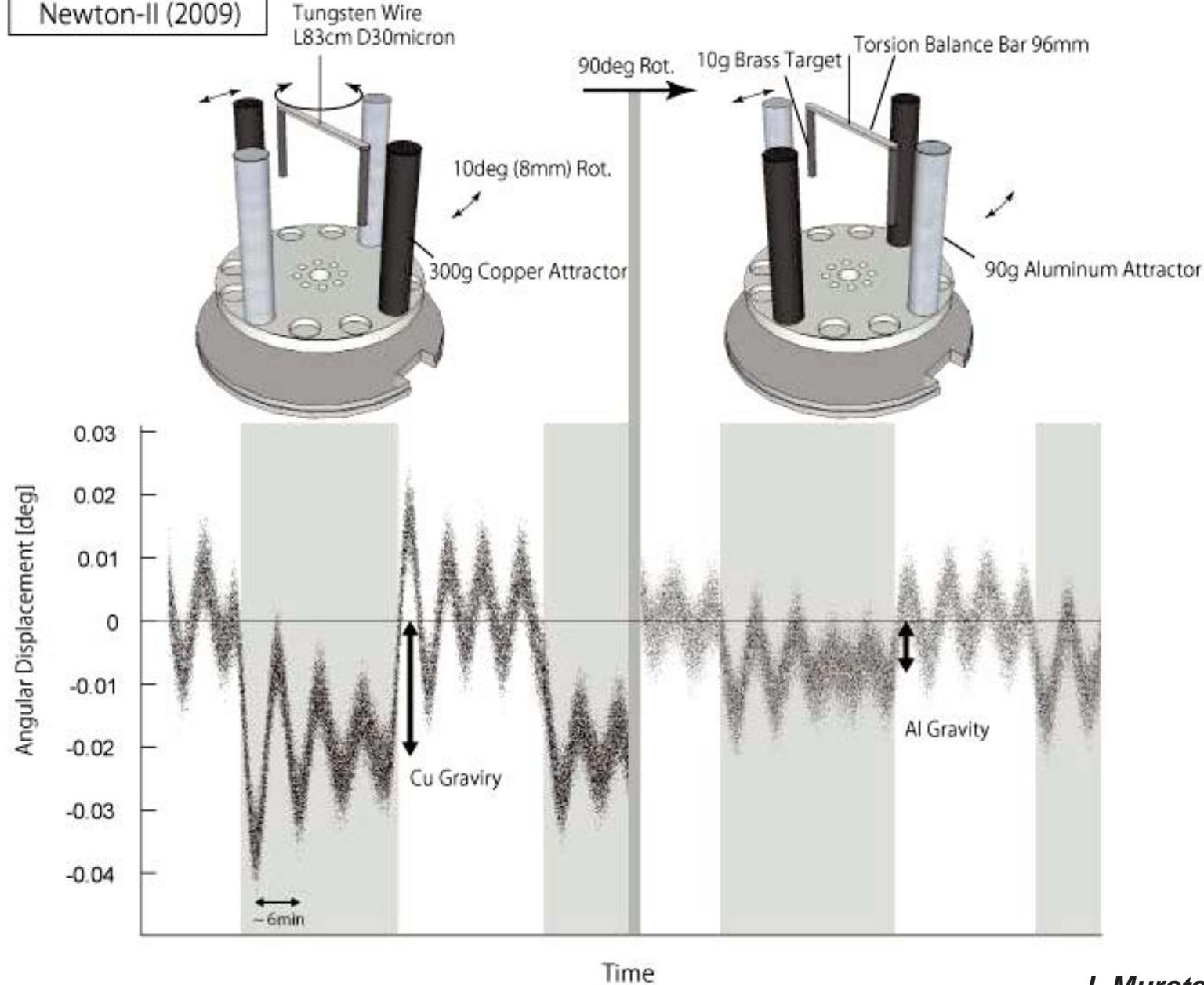


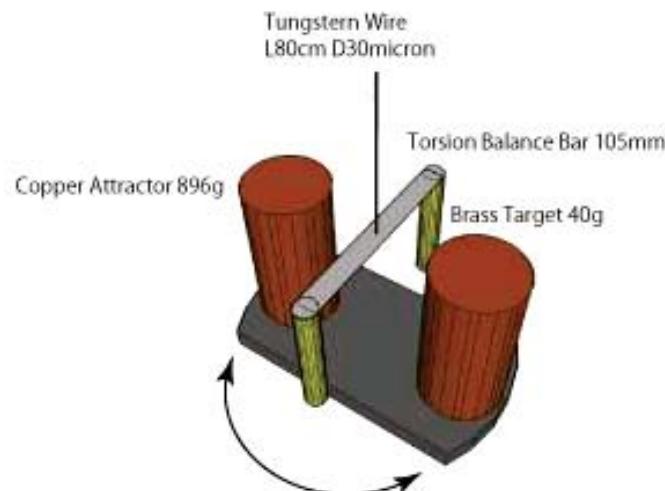
$F \sim 100\text{pN}$



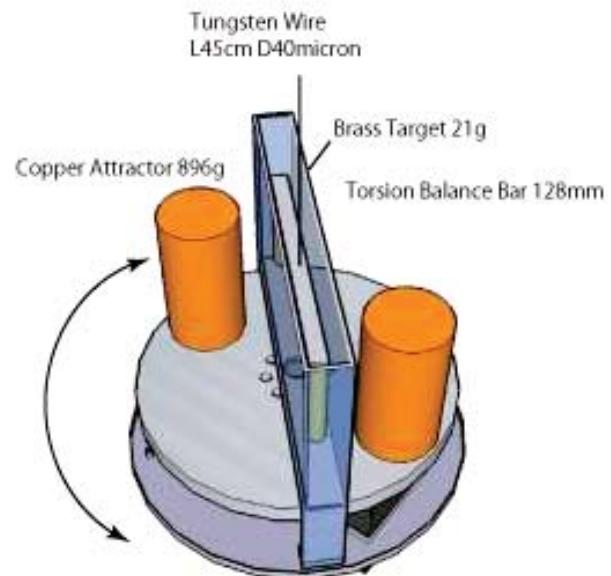
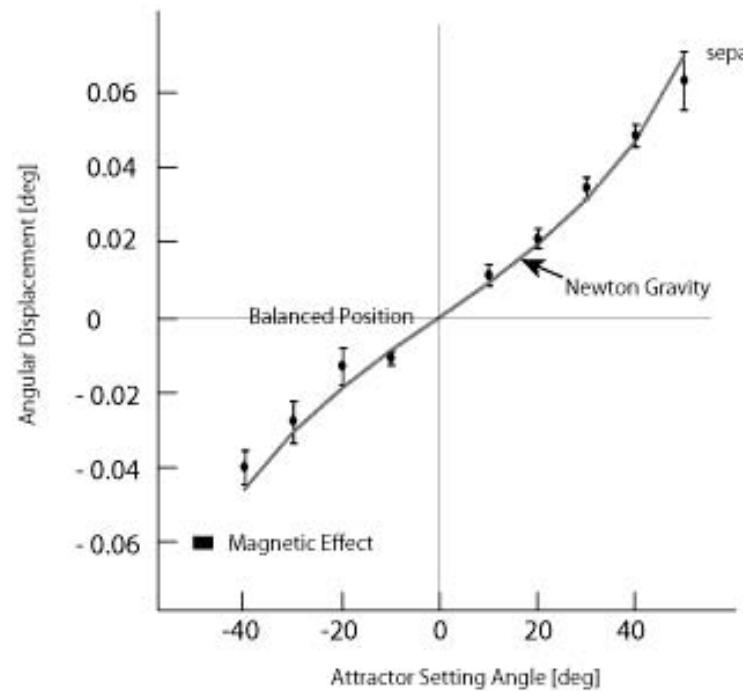
weight of 10um water cubic

Newton-II (2009)

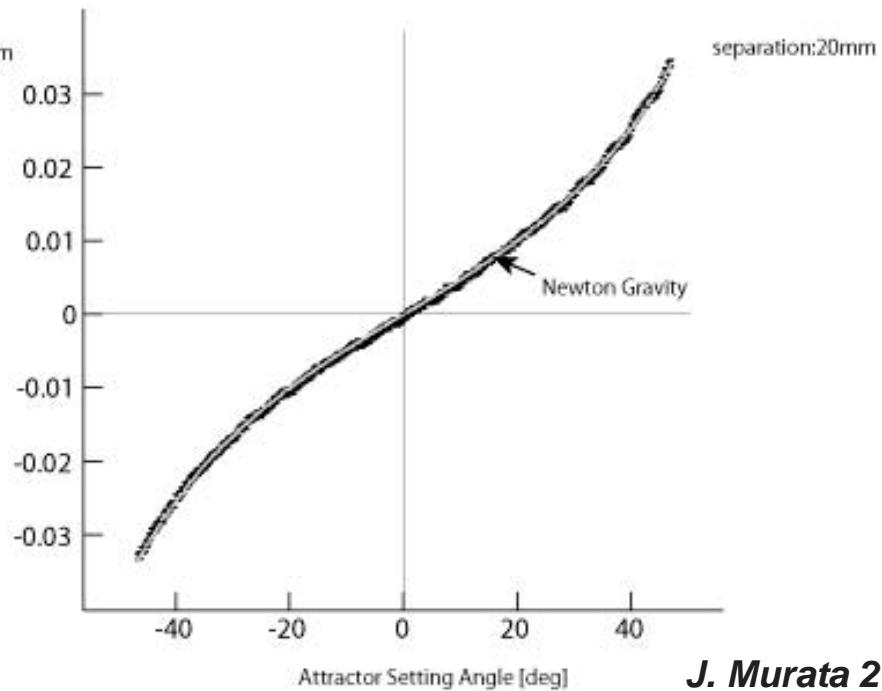


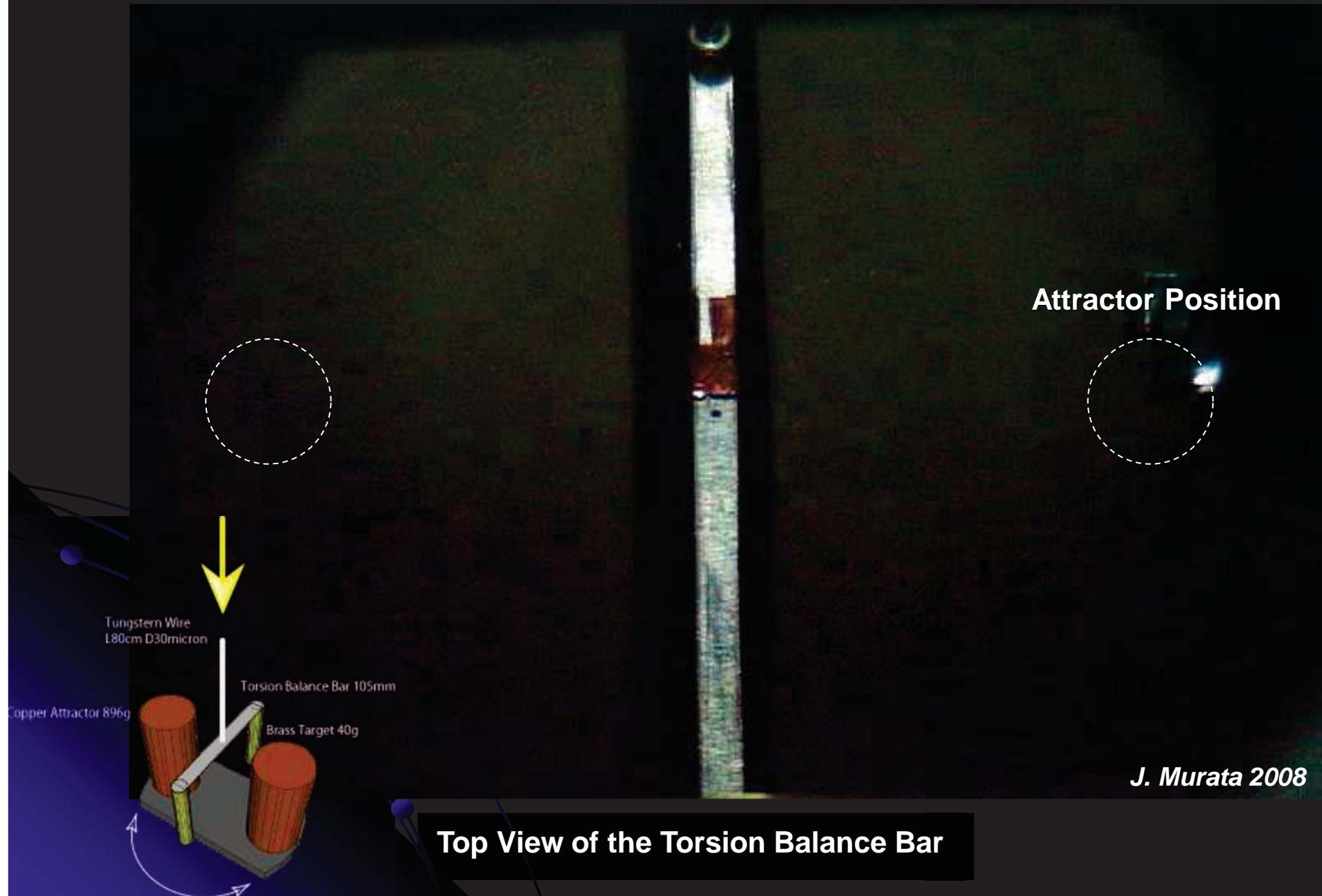


Newton-I (2006)

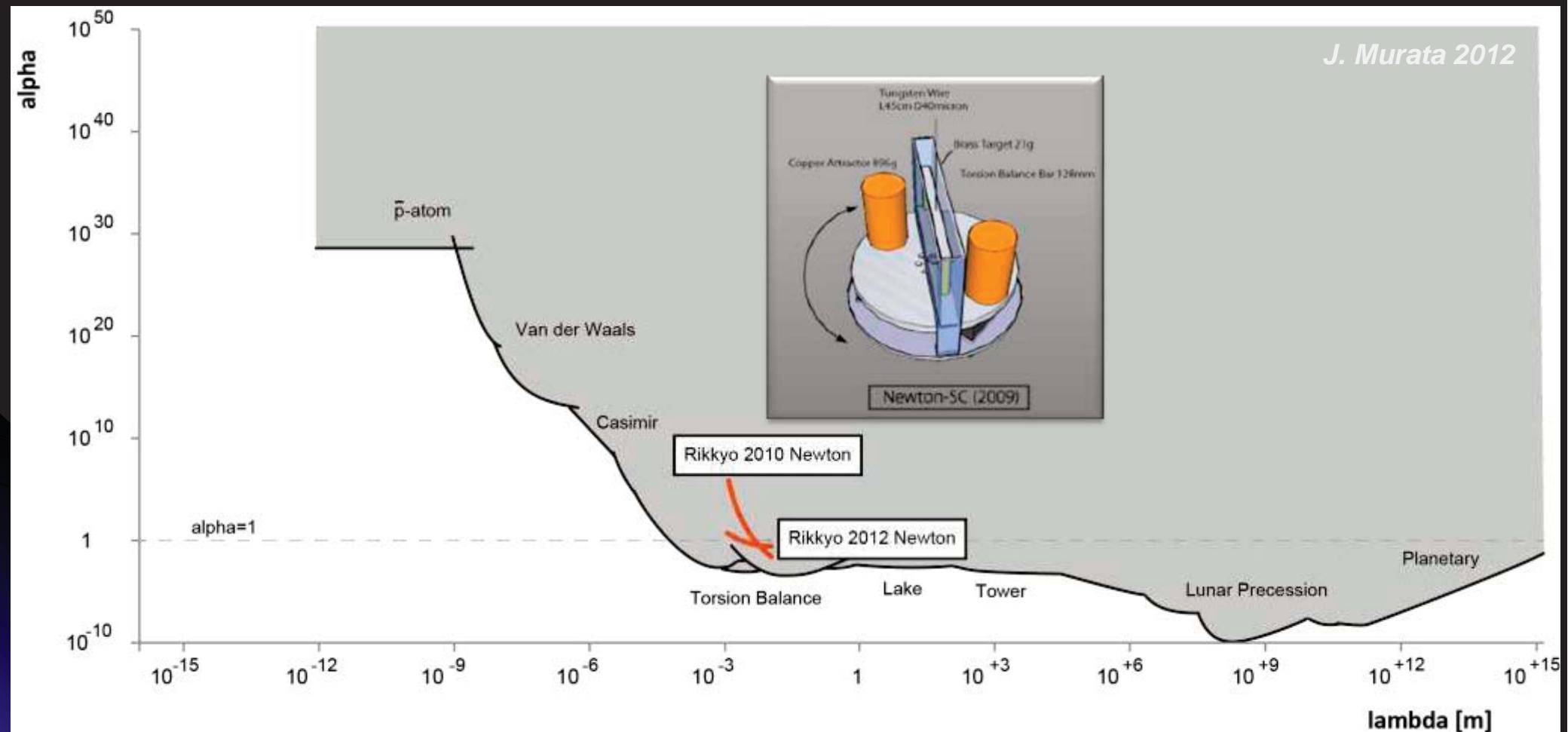


Newton-SC (2009)



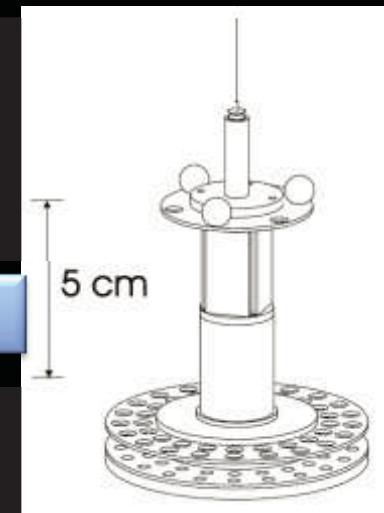
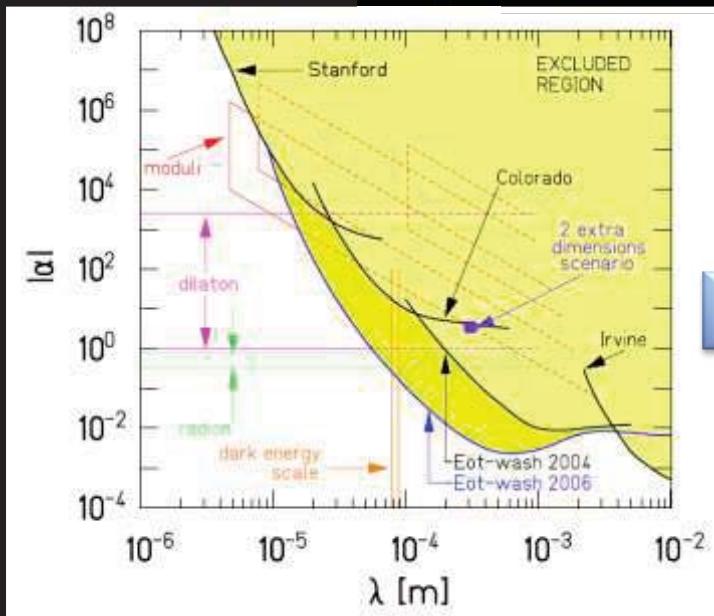






Murakami, JGRG22 (2013) submitted

Eot-wash experiment : University of Washington (2006)



Kapner, PRL 98, 021101 (2007)



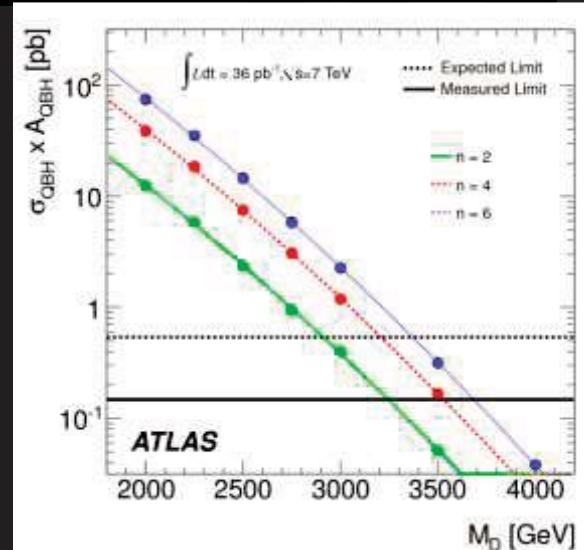
J. Murata 2010



J. Murata 2010



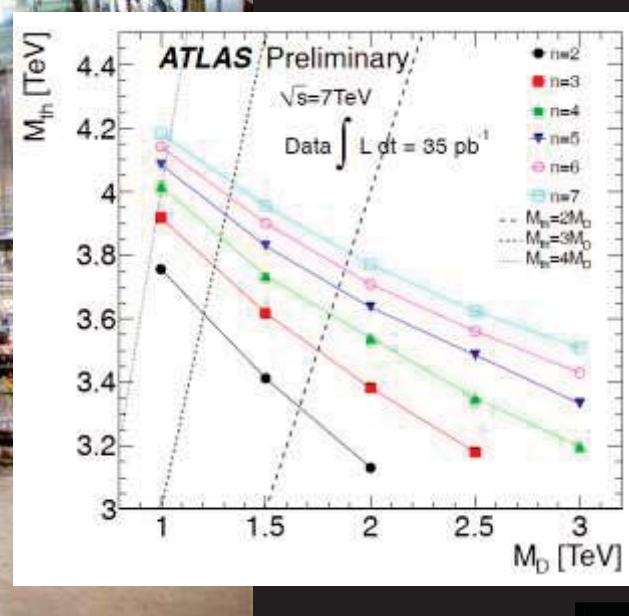
Gravity Signal Search at LHC-ATLAS



Quantum Black Holes

arXiv:1103.3864

$M_D > 3.67 \text{ TeV}$

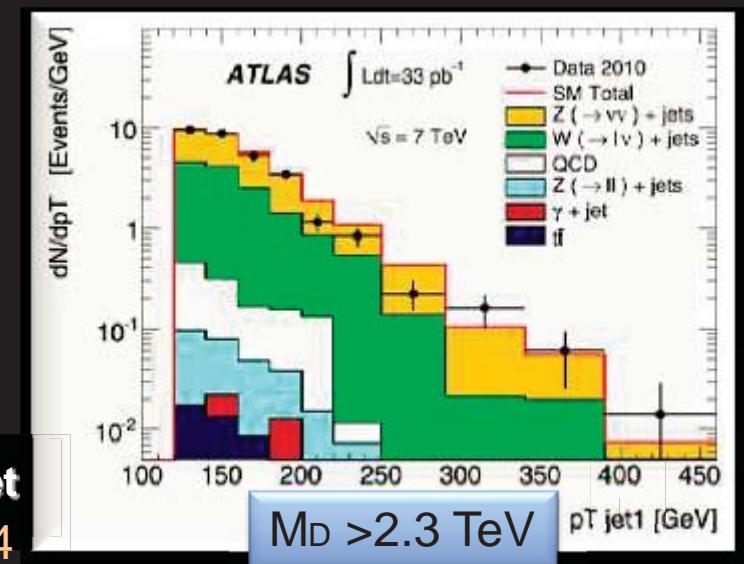


Micro Black Holes

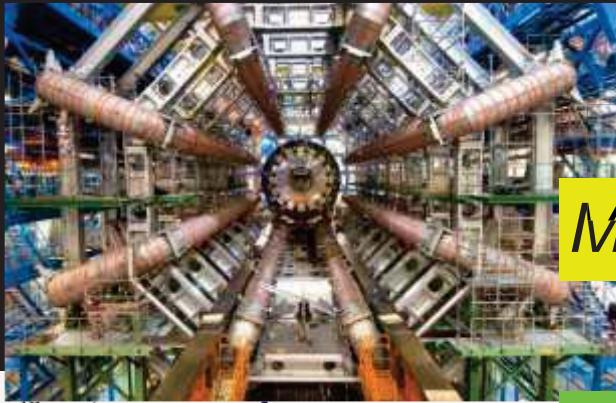
ATLAS-CONF-2011-068

$M_D > 1.37 \text{ TeV}$

Monojet
PLB 705 (2011) 294



$M_D > 2.3 \text{ TeV}$



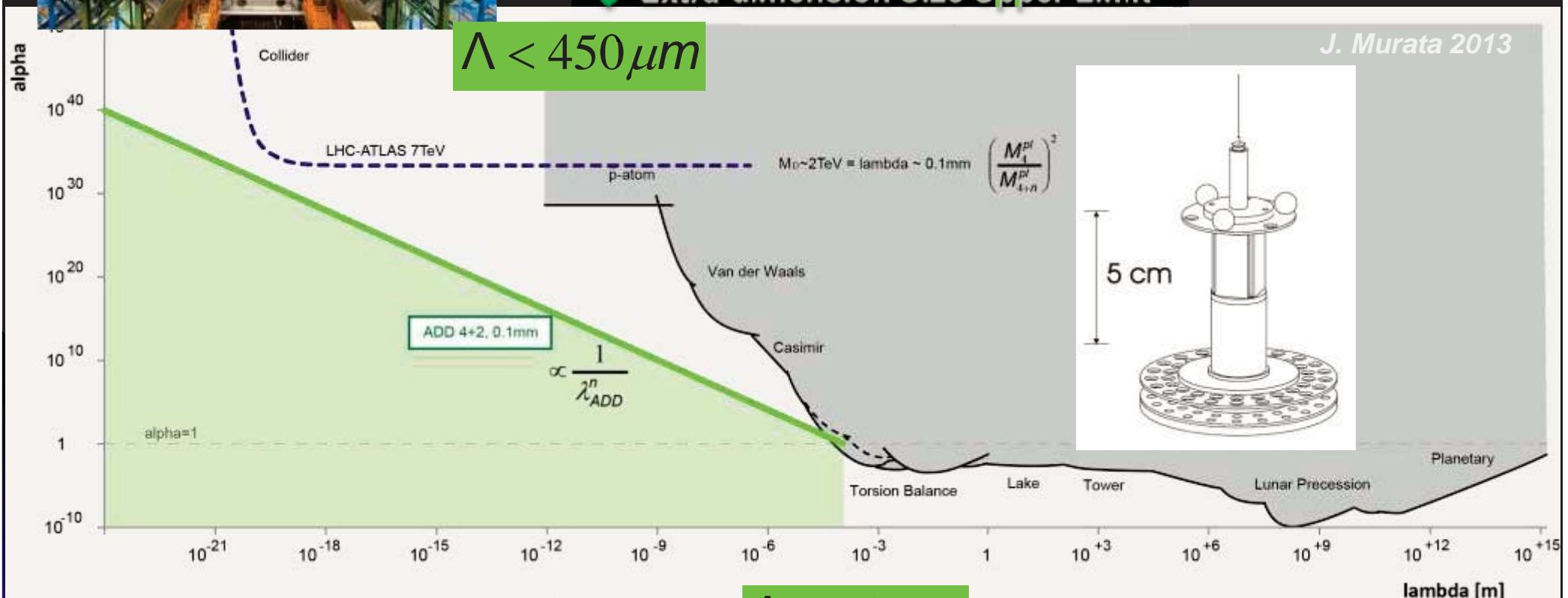
Collider vs Laboratory Test

Planck Energy Lower Limit

$$M_D > 2.3 \text{ TeV}$$

LHC Limit : Max. $M_D \sim 14/3 \text{ TeV} = 5 \text{ TeV}$

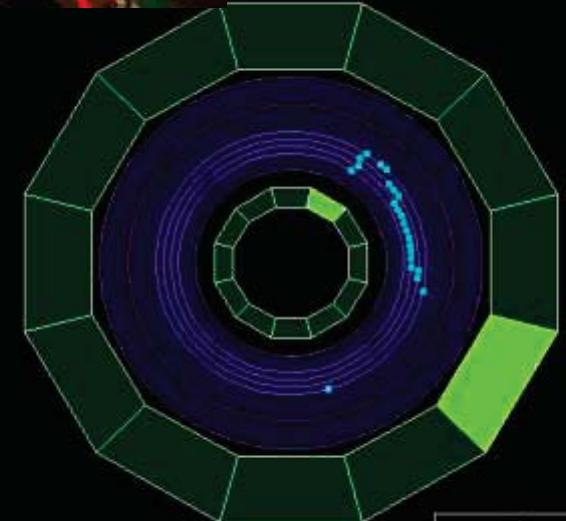
Extra-dimension Size Upper Limit



Searching Large T-Violation at TRIUMF, Canada



Run-IV 2012



**Searching T-Violating Electron Transverse Polarization
T-Violation < 0.1%**

Murata, J. Phys. CS312 (2011) 102011

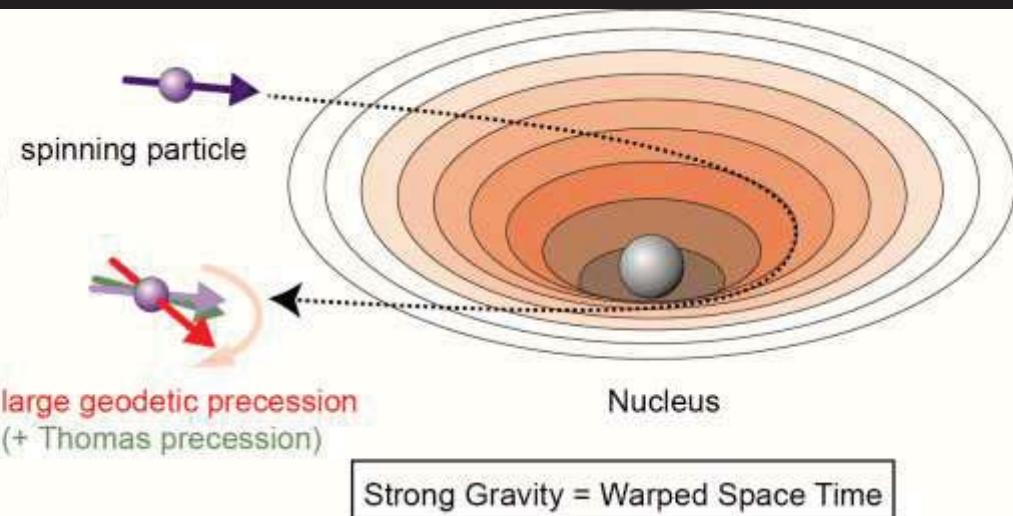
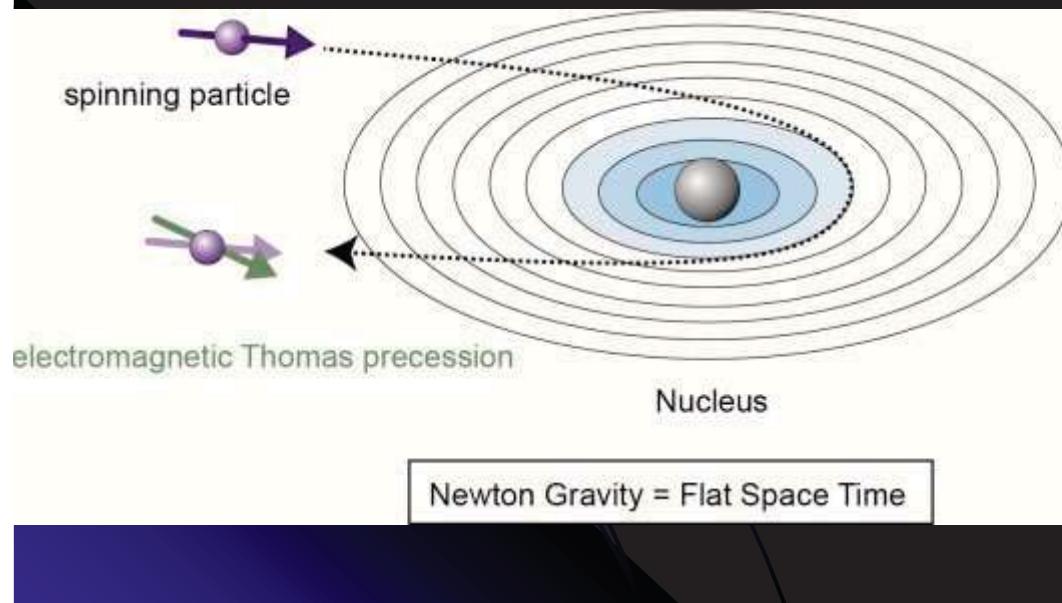
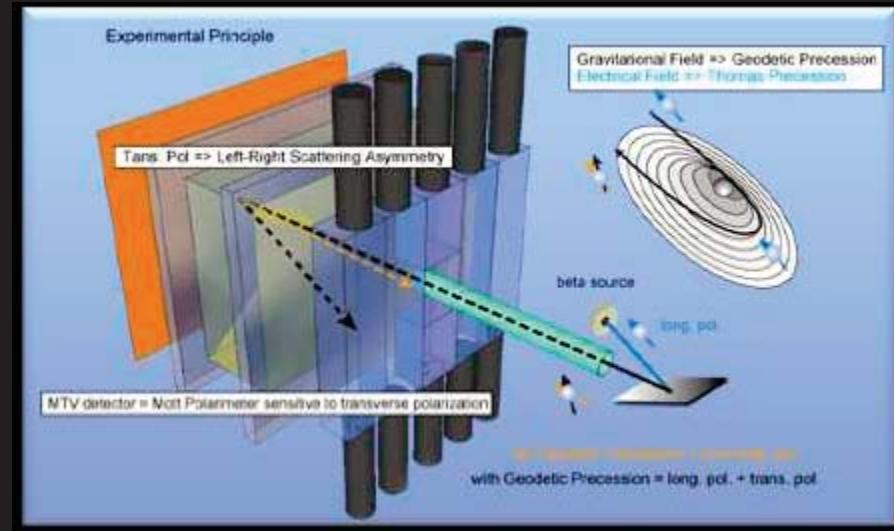
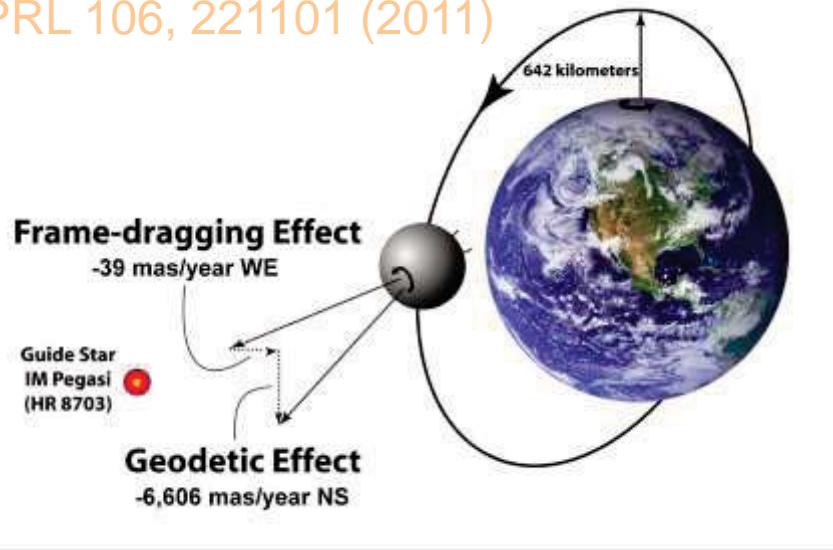
event #20
run #20123064

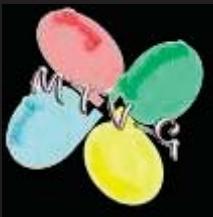


MTV-G exp. : Searching Large Geodetic Precession

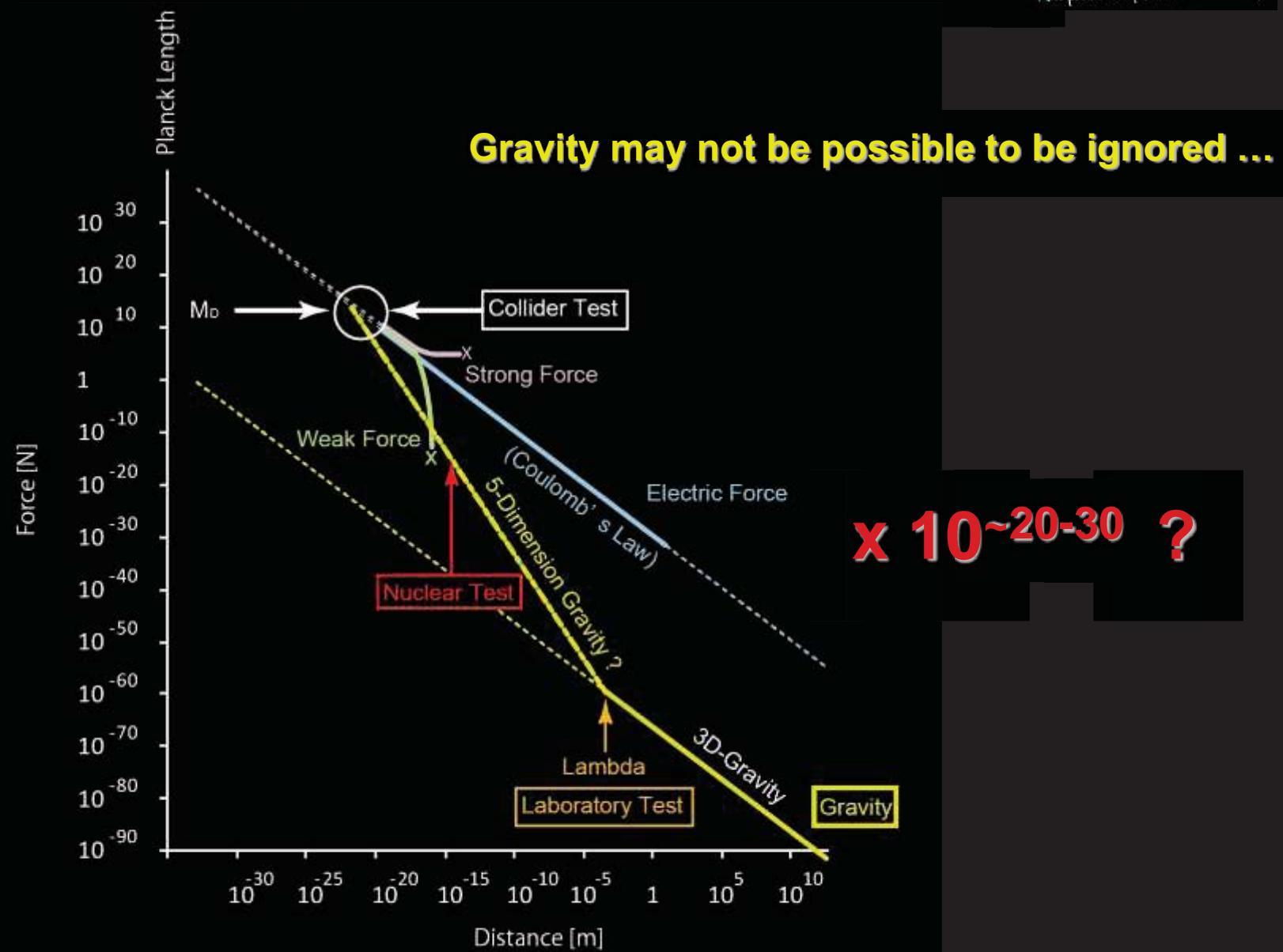


PRL 106, 221101 (2011)

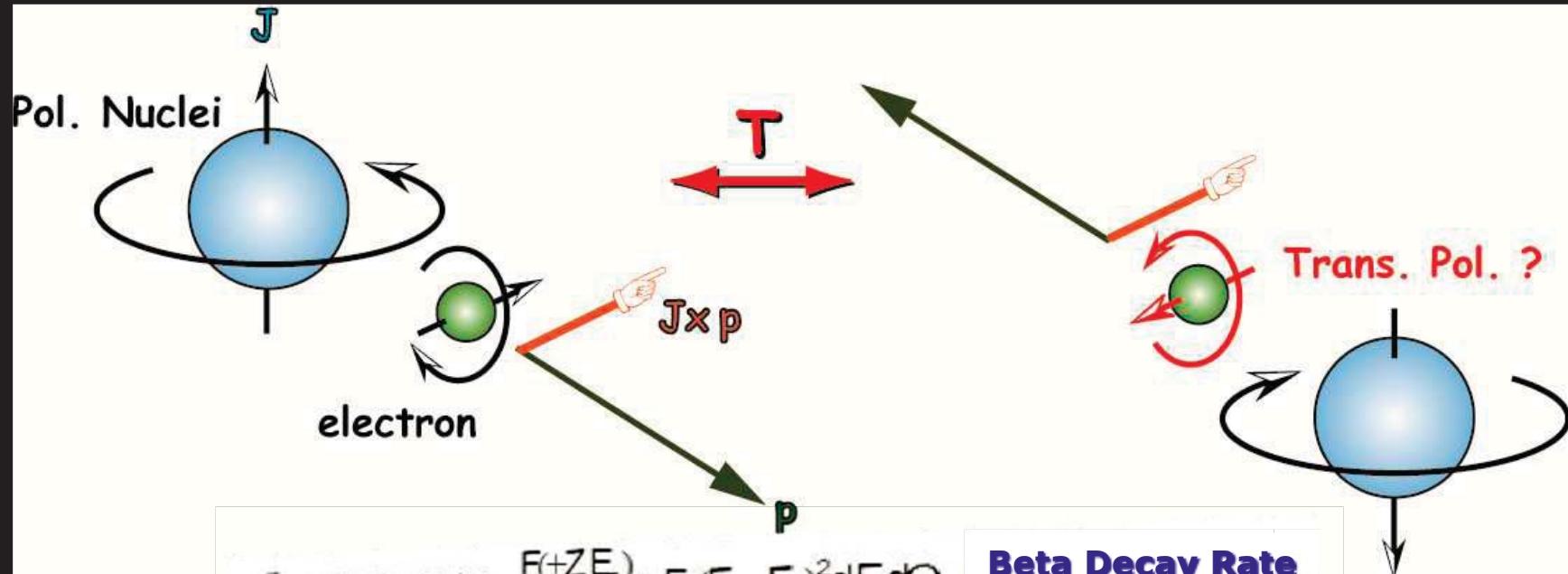




MTV-G exp. : Strong Gravity Search at Nuclear Scale



Measurement = R -Correlation Search of P-odd & T-odd New Interaction



$$\omega \langle \bar{J} \rangle \sigma(E_e, \Omega_e) dE_e d\Omega_e = \frac{F(+Z E_e)}{(2\pi)^4} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e$$

Beta Decay Rate

$$\times \left[1 + b \frac{m}{E_e} + \frac{\bar{p}_e}{E_e} \cdot \left(A \langle \bar{J} \rangle + G \bar{J} \right) \right] + \bar{\sigma} \left[N \frac{\langle \bar{J} \rangle}{J} + Q \frac{\bar{p}_e}{E_e + m} \left(\frac{\langle \bar{J} \rangle \bar{p}_e}{J E_e} \right) \right] + R \frac{\langle \bar{J} \rangle}{J} \times \frac{\bar{p}_e}{E_e}$$

Required Components

Production

Pol. Nuclei

Measurement

Electron Momentum

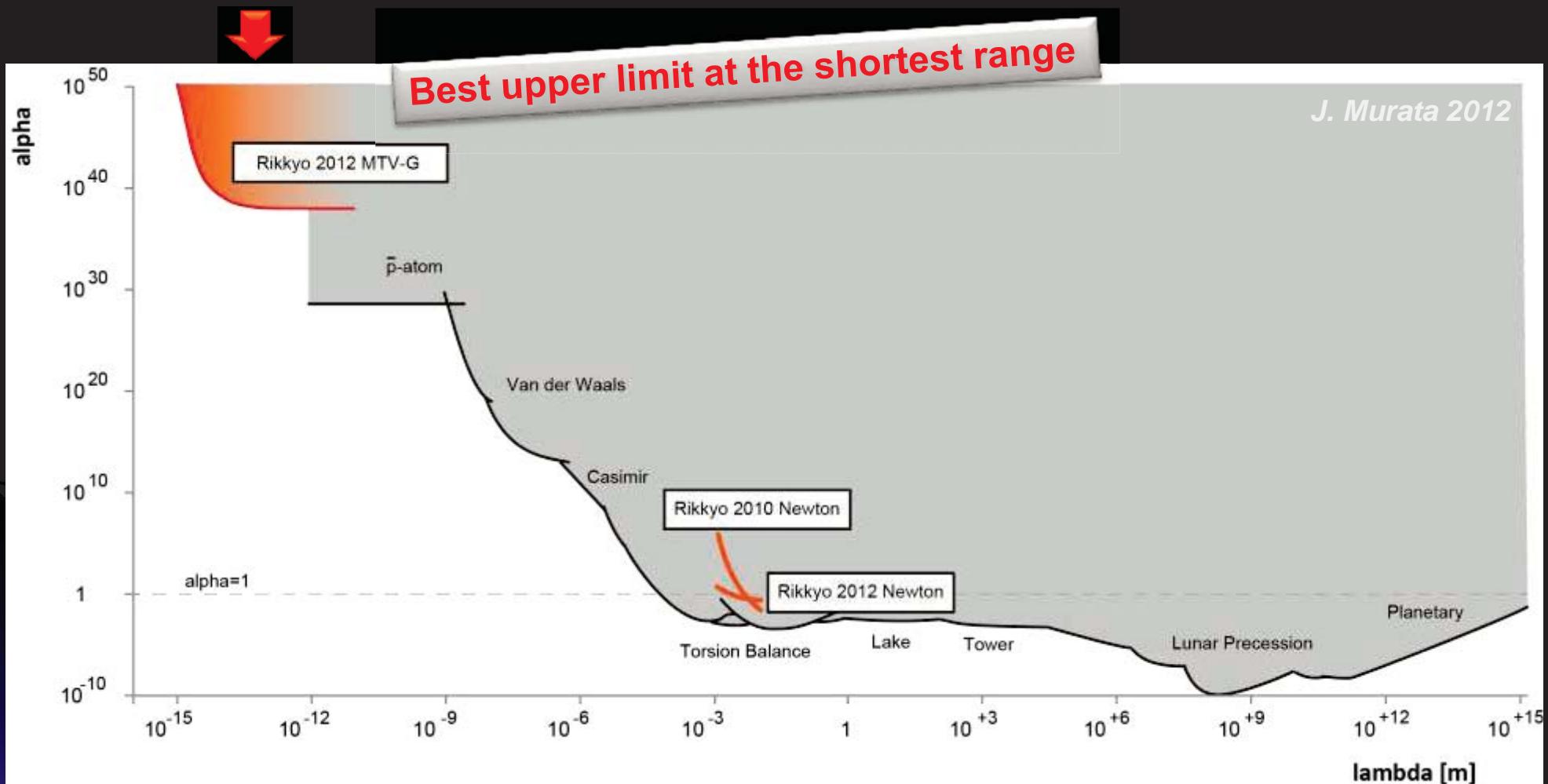
Measurement

Electron Trans. Pol.

Zero or Non-Zero ?



MTV-G Result

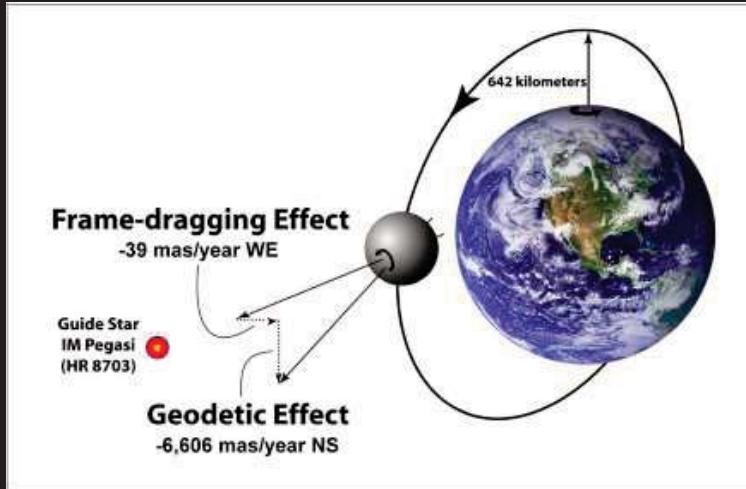


Tanaka, J. Phys. (2013) submitted



MTV-G : Theoretical Challenging

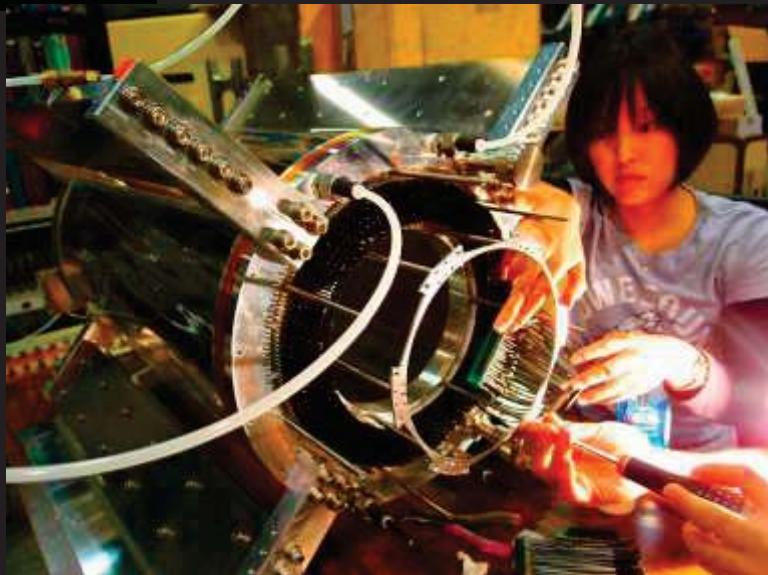
$$\vec{\Omega}_G = \frac{3}{2} \frac{GM}{r_0^3} \vec{r} \times \vec{v}$$



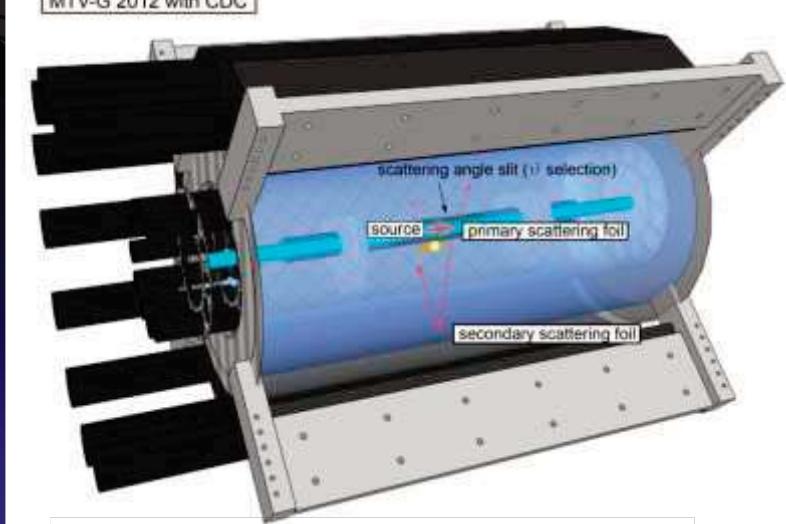
1. Relativistic spinning particle
2. Orbital motion is not gravitational free fall (Coulomb Scattering)
3. Microscopic ($\sim 100\text{fm}$)



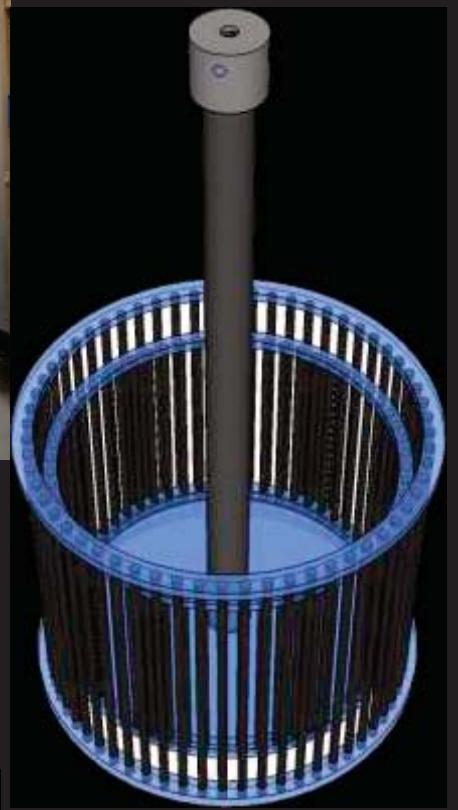
MTV-G : Next Generation Experiment 2012 ~



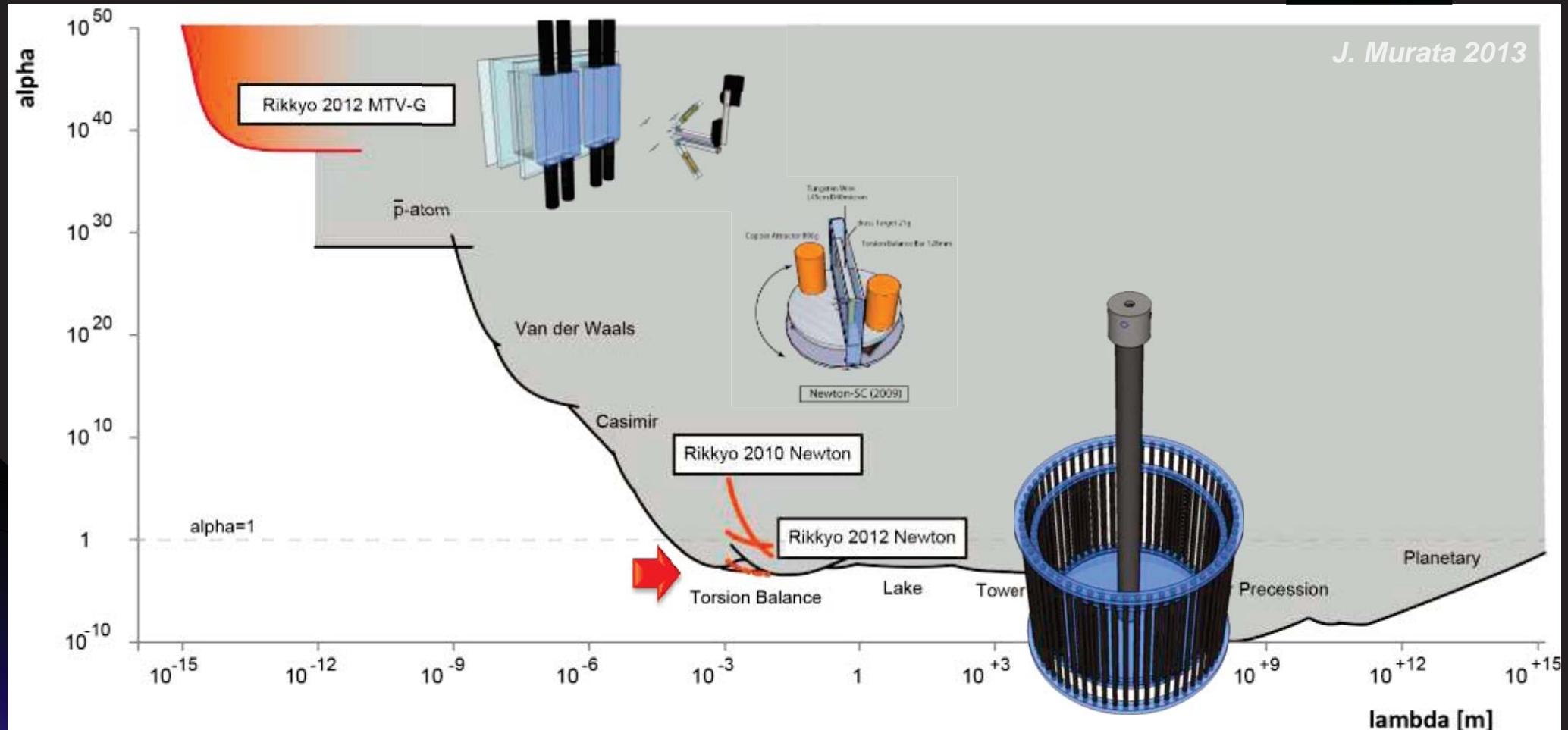
MTV-G 2012 with CDC



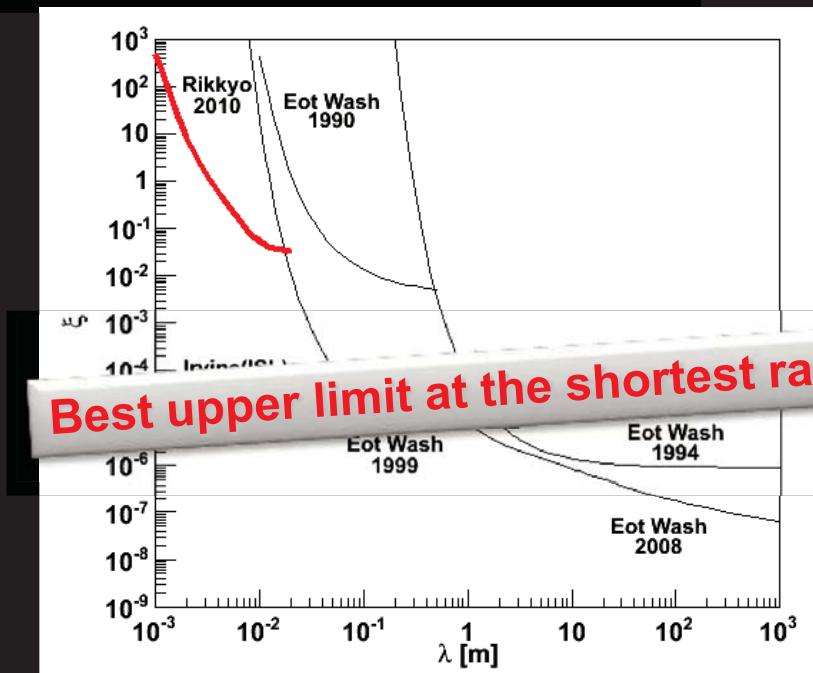
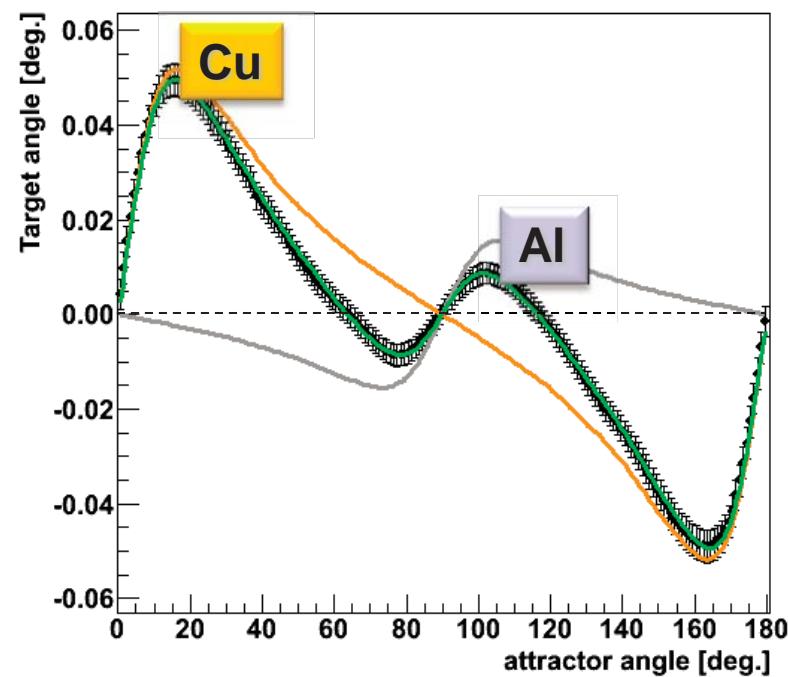
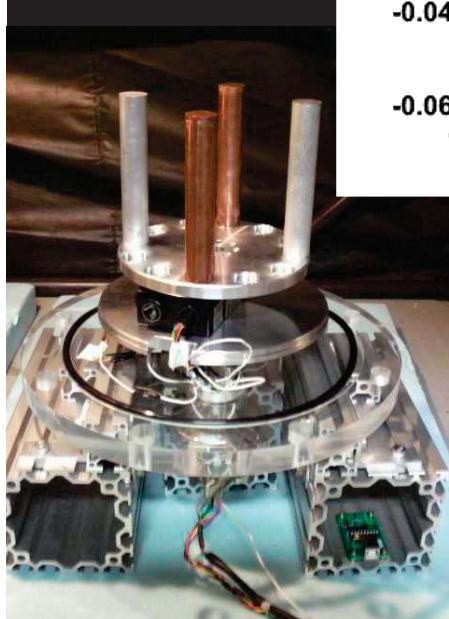
Cylindrical Drift Chamber



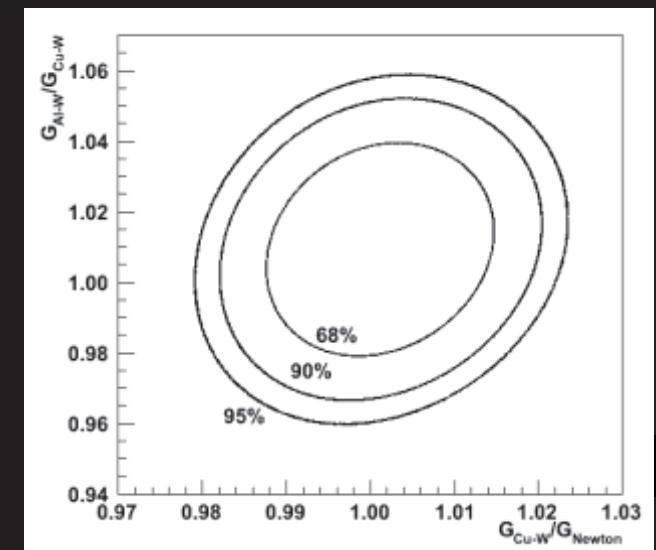
Newton-IV



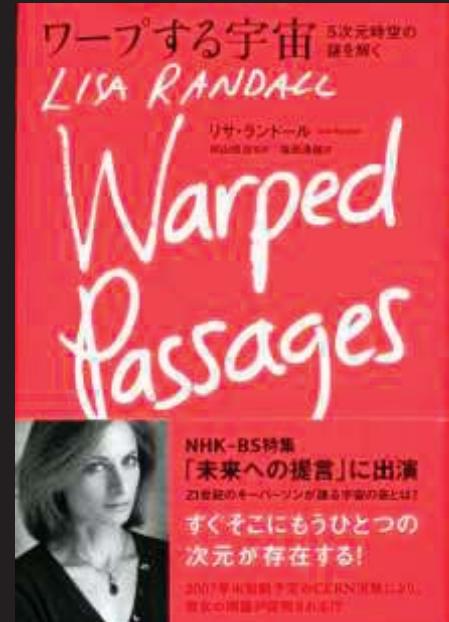
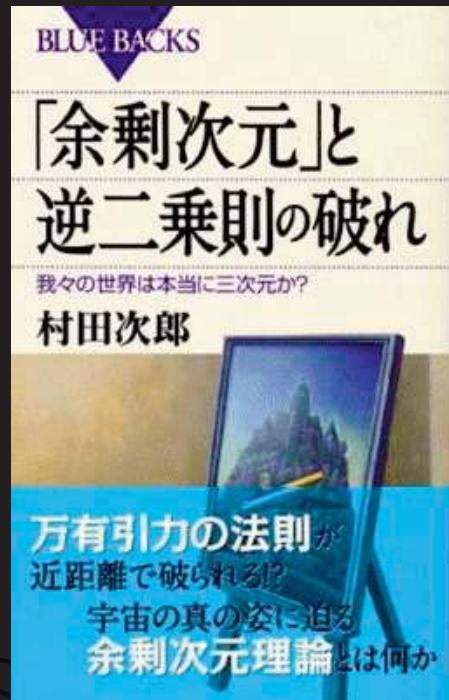
Test of Weak Equivalence Principle : Composition Dependence of G



$$V(r) = G \frac{mM}{r} \left(1 + \xi \frac{B_A B_B}{\mu_A \mu_B} e^{-\frac{r}{\lambda}} \right)$$



Book for General Readers



Warped Passages Lisa Randall, S. Mukohyama, 2007



“Extra-dimension” and Violation of Inverse Square Law
Kodansha, Jiro Murata, 2011

日経サイエンス 01
SCIENTIFIC AMERICAN'日本版
付録 特製カレンダー
パズルの国のアリス

特集 ヒッグス粒子の先へ クォークの中の素粒子 余剰次元を探る

abc予想を証明?
快樂の神経回路
竜脚類繁栄の謎
笑うネズミ
どの生物を守るべきか

特集:世界の科学力
中国は伸び続けるか?
ドイツの強さの秘密
科学のグローバル化
From J
再生紙

http://www.nikkei-science.co.jp/

probing extra-dimension
Nikkei- Science, Jan, 2013

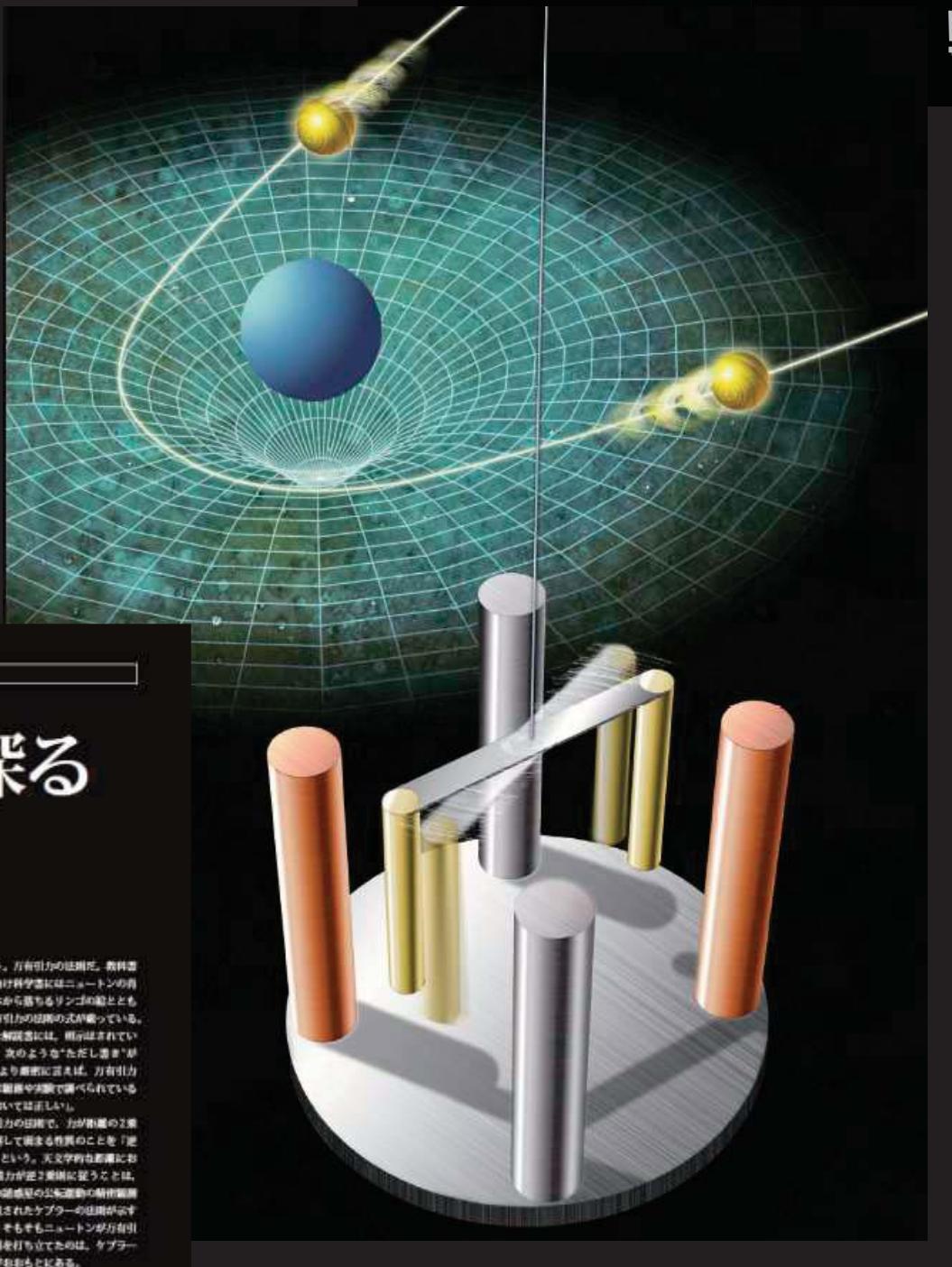
私たちがこの世を3次元の空間に時
間の1次元を加えた4次元座標の世界
としてとらえている。一方、万物を説
明する流動理論の有力候補、超弦理論
(4次元)によれば、宇宙は9次
元の空間と時間からなる10次元时空
だという。最近ではさらに1次元を加
えた11次元时空であるとする説が有
力になっている。この11次元から私
たる空間とはまったく異なるアプロー
チでも企劃が提案されている。世
界で数チームが開拓していて、日本では
筑波大学のグループが活発に活動して
いる。子がかりとなるのは重力。物理
学者の努力の強さを評価する上で、
重力研究の進歩が、それも日本大
学連携をより早く導く可能性があ
るという。

重力は余剰次元とのようなつなが
りがあるのか、余剰次元の存在は假
想論の研究によって1970年代から假
設として指摘されていたが、加速度計
や重力測定で検出できる可能性が浮
かび上かったのは、今から約10年前
の1990年代だ。その後、企劃実行に
關する理論的な研究で大事件が起きた
のだった。そのインパクトの大さきを
理解するには、重力の精緻測定の少ひ

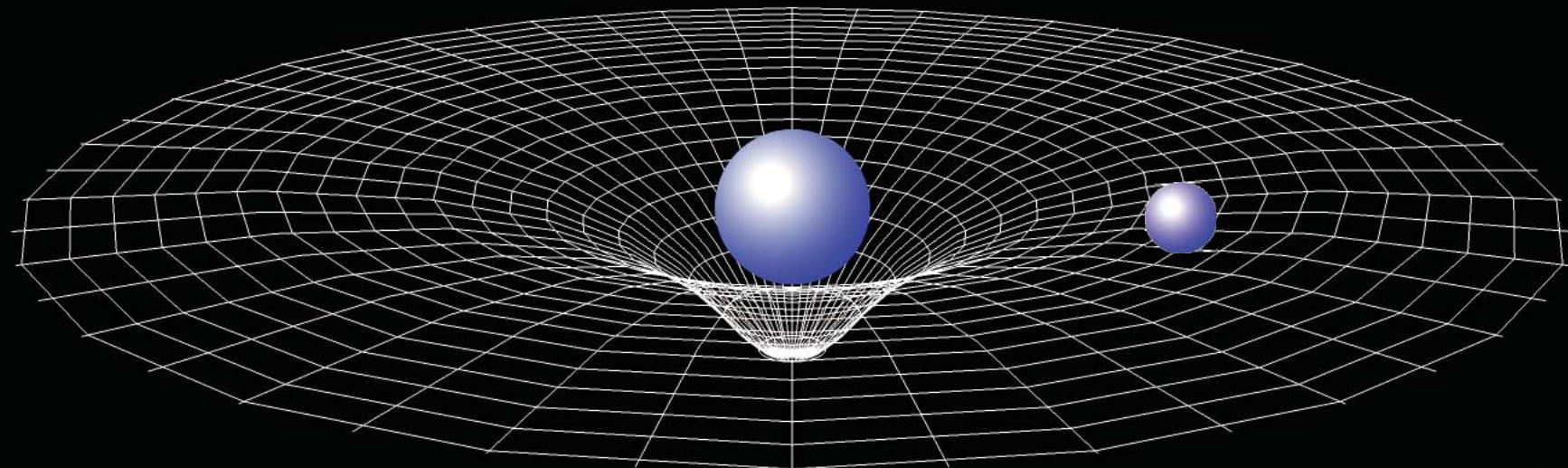
ると音う。万有引力の法則だ。教科書
や一般百科事典にはニュートンの背
後編や木から落ちるリンゴの話とともに
て、万有引力の法則の式が載っている。
そうした教科書には、例が記されてい
ないが、次のようなくだり書き"が
つく。「より厳密に言えば、万有引力
の法則は距離や角度で導かれている
範囲においては近似だ」。

万有引力の法則で、力が距離の2乗
に反比例して弱まる性質のことを「逆
2乗則」という。天文学では距離に依
いて、重力が2次則に従うことは、
太陽系の諸惑星の公転運動の精緻測定
から発見されたケプラーの法則が示す
通りだ。そもそもニュートンが万有引
力の法則を打ち立てたのは、ケプラー
の法則が宇宙に適用してからは、より

ある筑波大学原子核研究機構(CERN)
で世界最初の超対称LHCが本格稼働
し、余剰次元が存在する证据をつかめ



Playing with Gravity is a great fun !



Let's enjoy together !

**Tower Measurement (undergraduate exp.)
at Tokyo Skytree, Jan 2013**