Colloque G2

Gravimetry for the LNE Watt balance

Sébastien Merlet, Pierre Gillot, Bing Cheng, F. Pereira Dos Santos

LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris

sebastien.merlet@obspm.fr

http://syrte.obspm.fr/tfc/capteurs_inertiels/

Lecture

Kilogram in the SI

actual situation and evolution

LNE Watt balance

SYRTE participation: Gravimetry

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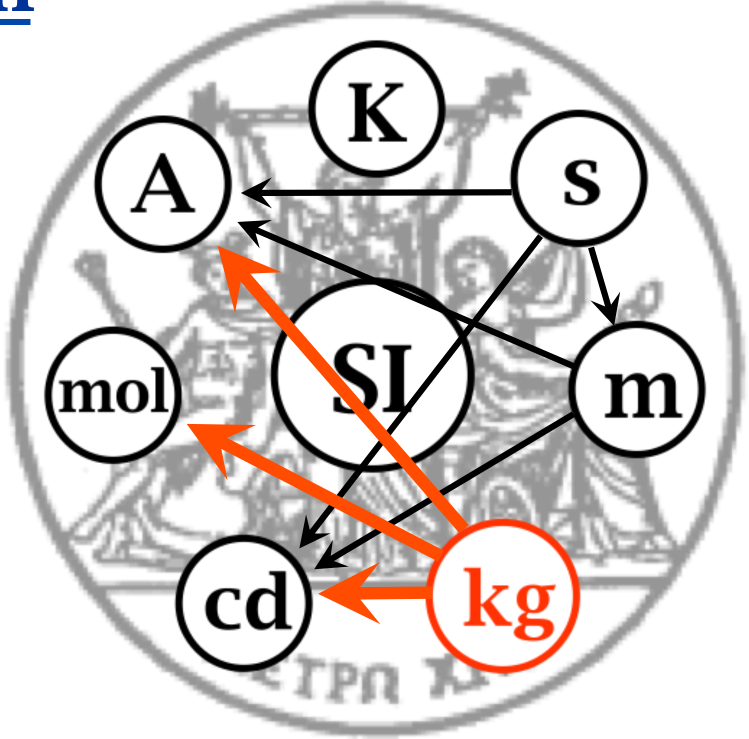
The kilogram

***Le kilogramme est l'unité de masse ;
il est égal à la masse
du prototype international du
kilogramme***

1ère CGPM - 1889 / 3ème CGPM - 1901

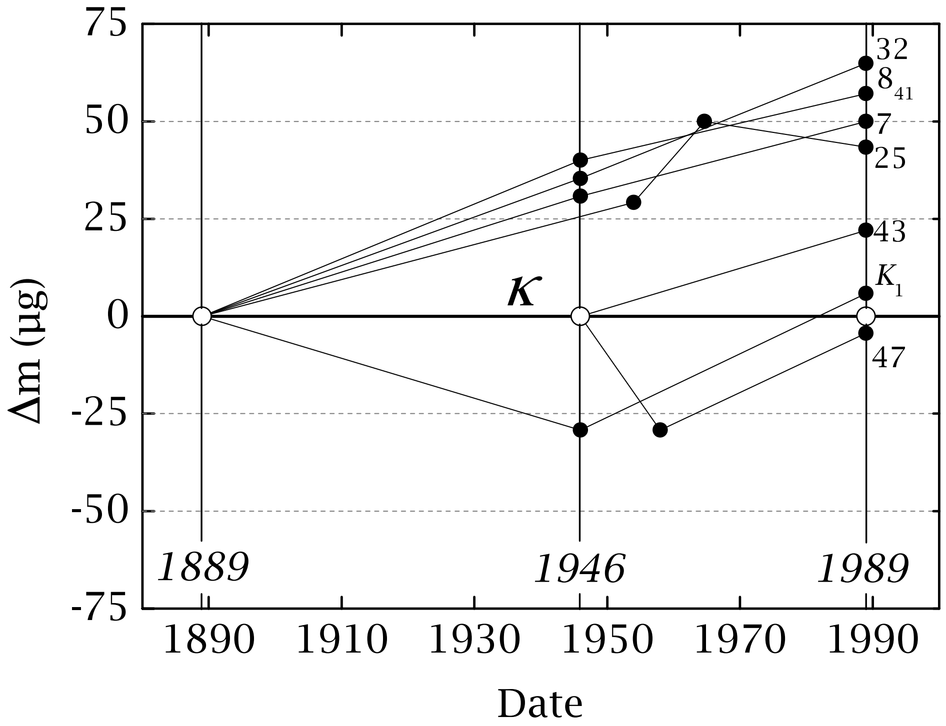
International prototype
of kilogram (**κ**)

→ 1 kg exactly
→ Cylindre PtIr
→ diameter = height



Other units
depends of kg

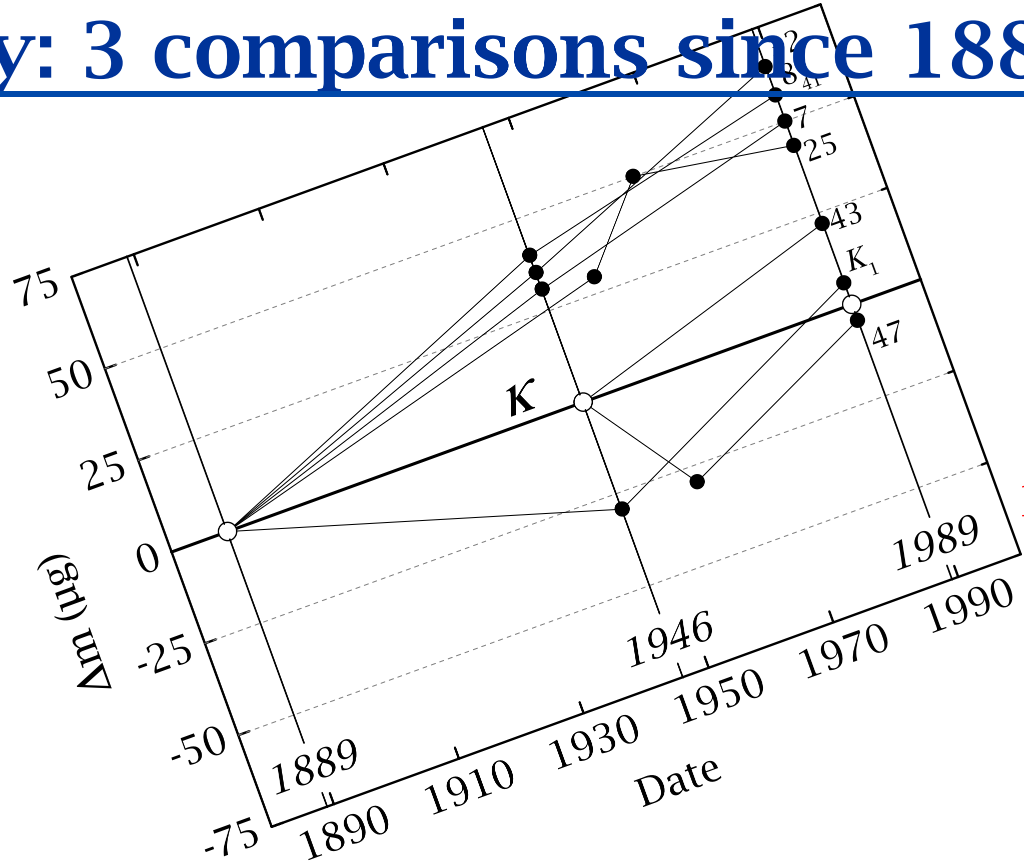
$\mathcal{K}$ stability: 3 comparisons since 1889



Relative dispersion
5×10^{-8}

1×10^{-7} with all the national standards

κ stability: 3 comparisons since 1889



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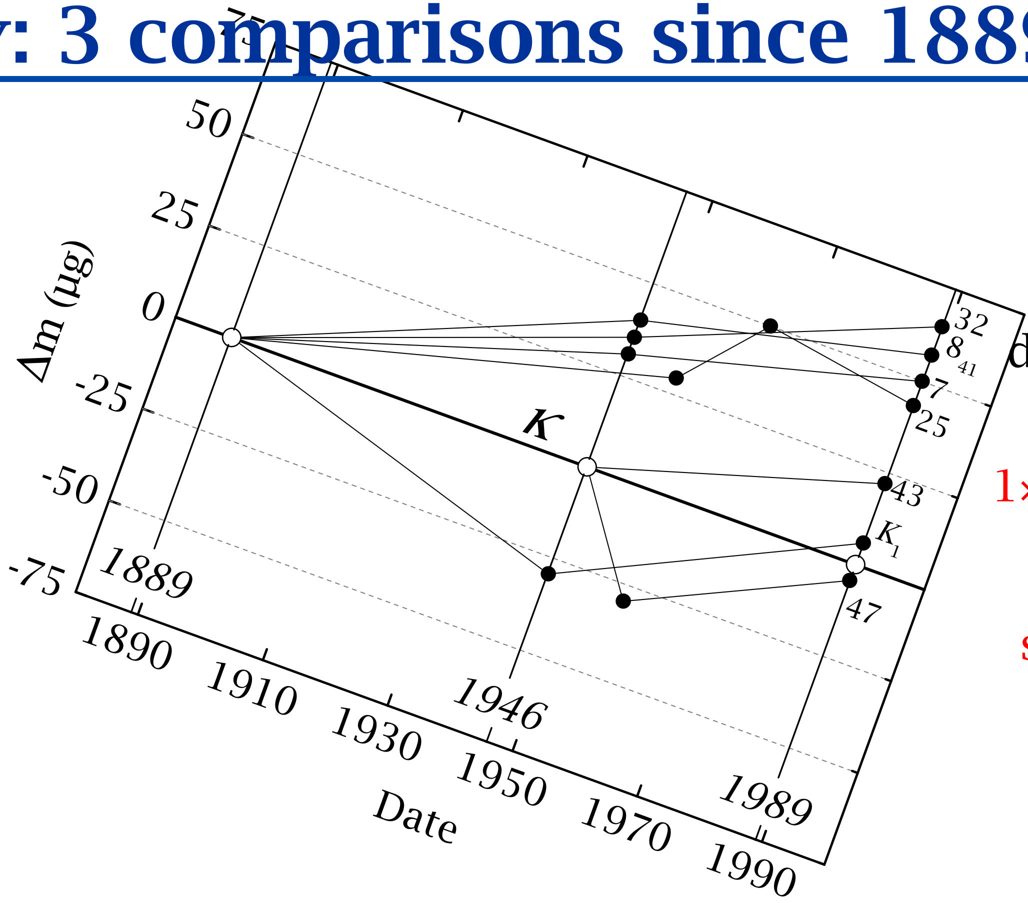

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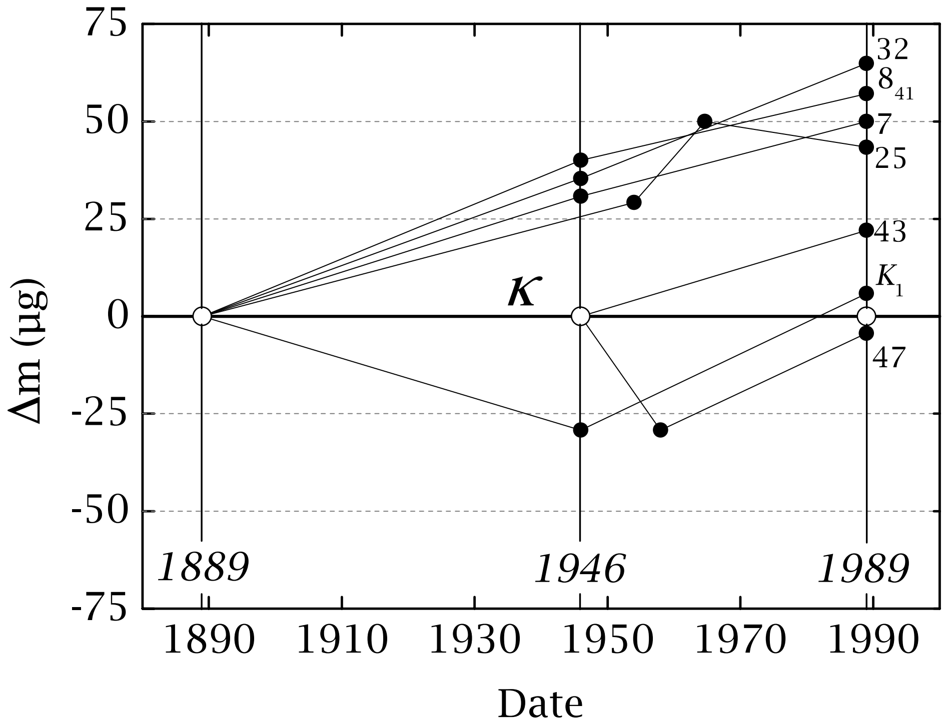


Relative dispersion
5×10^{-8}

1×10^{-7} with all the national standards

→ Requirement: SI have to evoluate, to be improved, especially the kilogram

Many CGPM resolutions encouraging NMI to investigate, study new possibilities

Résolution 5, 20ème CGPM, 1995 | Résolution 12, 23ème CGPM, 2007

Résolution 7, 21ème CGPM, 1999 | Résolution 1, 24ème CGPM, 2011

Avogadro project, N_A

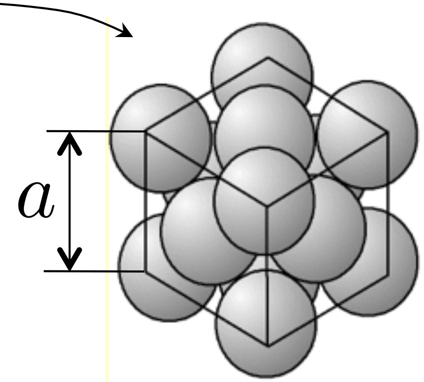
Mesure the mass of a microscopic, macroscopic particule ?

Link to the macroscopic domain ?

Realisation of a massive object of know atoms

N_A realisation which define the mole

Determine the number of atoms in a 1 kg silicium

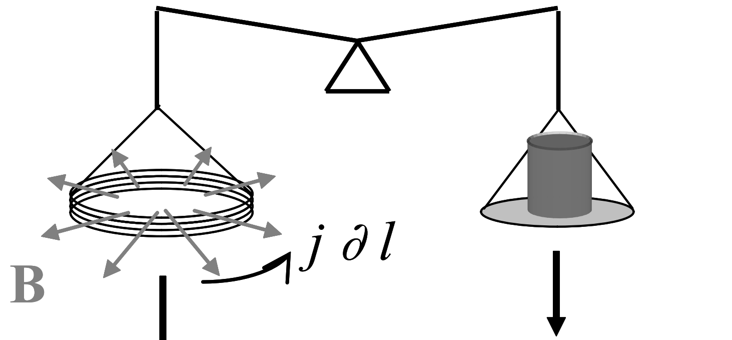


$$\rho = \frac{M}{V} = \frac{n\ m_{\mathrm{Si}}}{a^3\ N_A}$$

Watt balance

Principle proposed by Brian Kibble in 1975

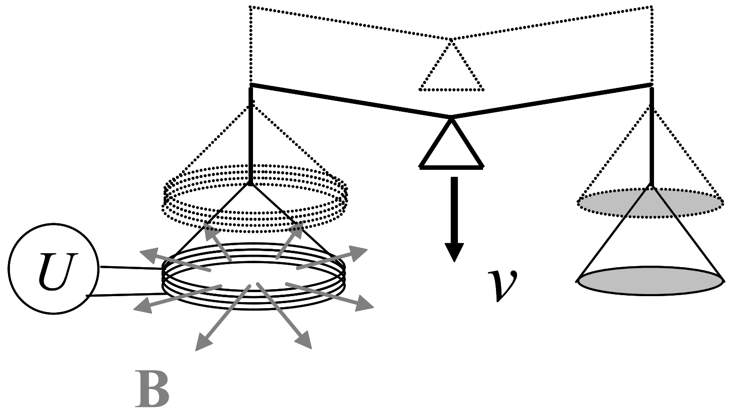
Static phase



$\mathbf{F}_{\mathbf{Laplace}} = B \cdot l \cdot I$ $\quad \mathbf{F}_{\mathbf{g}} = m \cdot \boldsymbol{g}$

$$F_z = mg = Bli$$

Dynamic phase



$$\epsilon = -Blv$$

$$mgv = \epsilon i = \epsilon V/R$$

Electrical measurements: Josephson E ($K_{\mathrm{J}} = 2e/h$) and Q Hall E ($R_{\mathrm{K}} = h/e^2$)

$R = kR_{\mathrm{K}}/i$ $\quad V = n_1 f_1/K_{\mathrm{J}}$ $\quad \epsilon = n_2 f_2/K_{\mathrm{J}}$

$$A = \frac{n_1 f_1 n_2 f_2 i}{k} \qquad mgv = \frac{A}{K_{\mathrm{J}}^2 R_{\mathrm{K}}}$$

$$\frac{m}{h} = \frac{A}{4gv}$$

Absolute value of g needed

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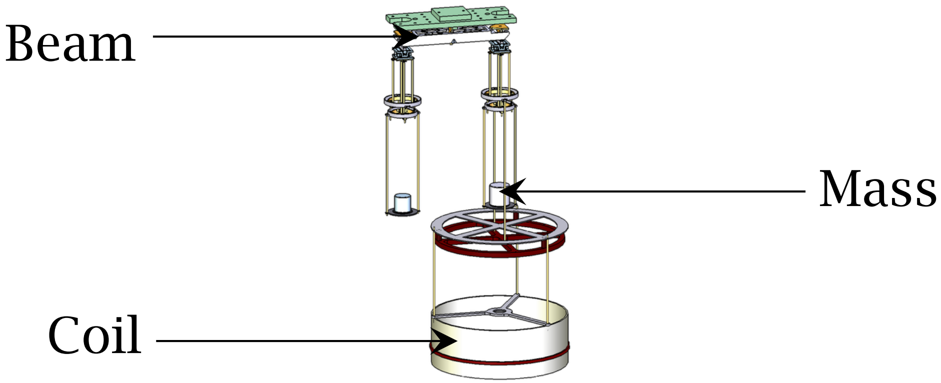
LNE Watt balance

SYRTE participation: Gravimetry

M. Thomas[1], P. Espel[1], D. Ziane[1], P. Pinot[2], P. Juncar[2], F. Piquemal[1] and G. Genevès[1]

[1]LNE, [2]LNE-LCM/Cnam

Parts of the LNE Watt balance



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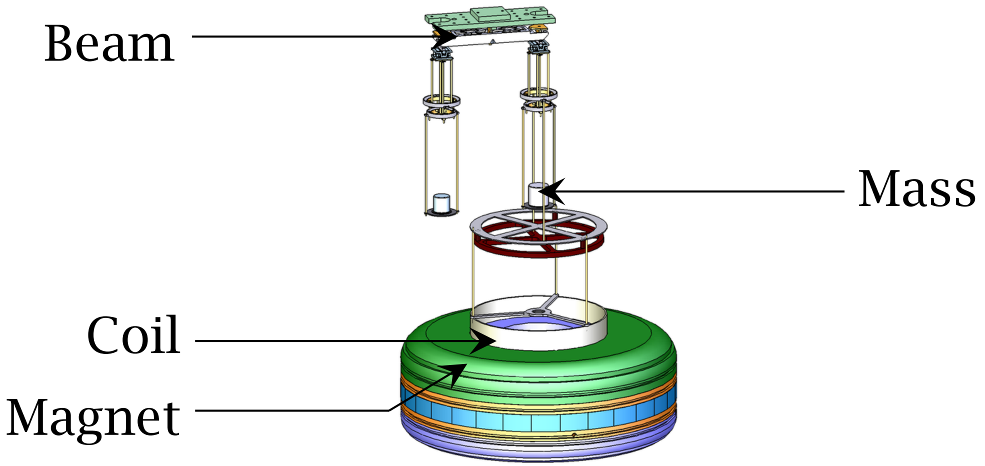

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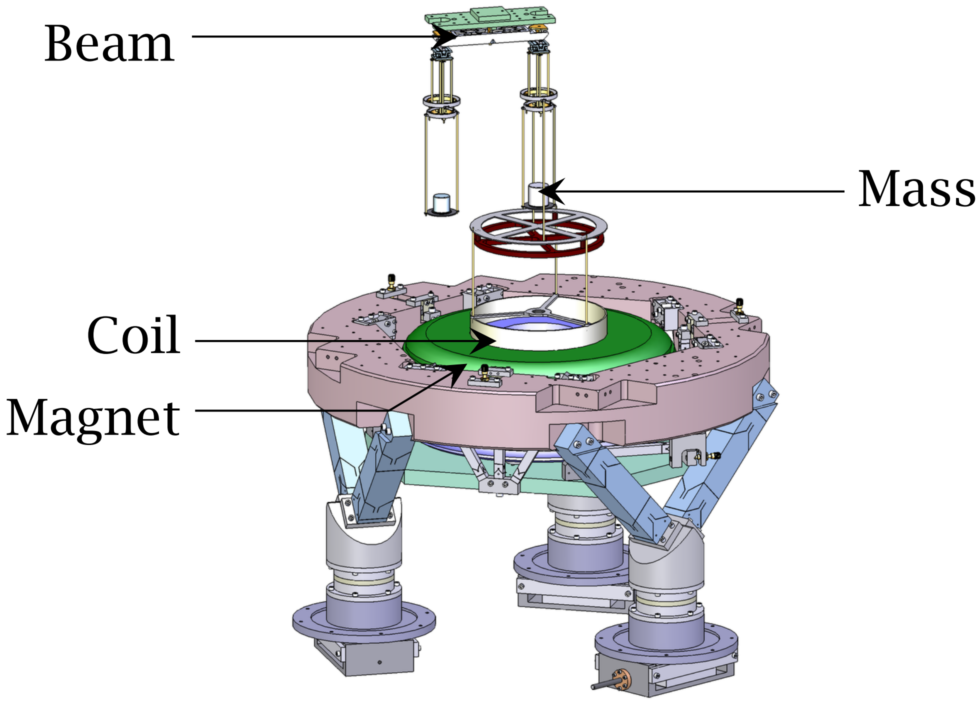

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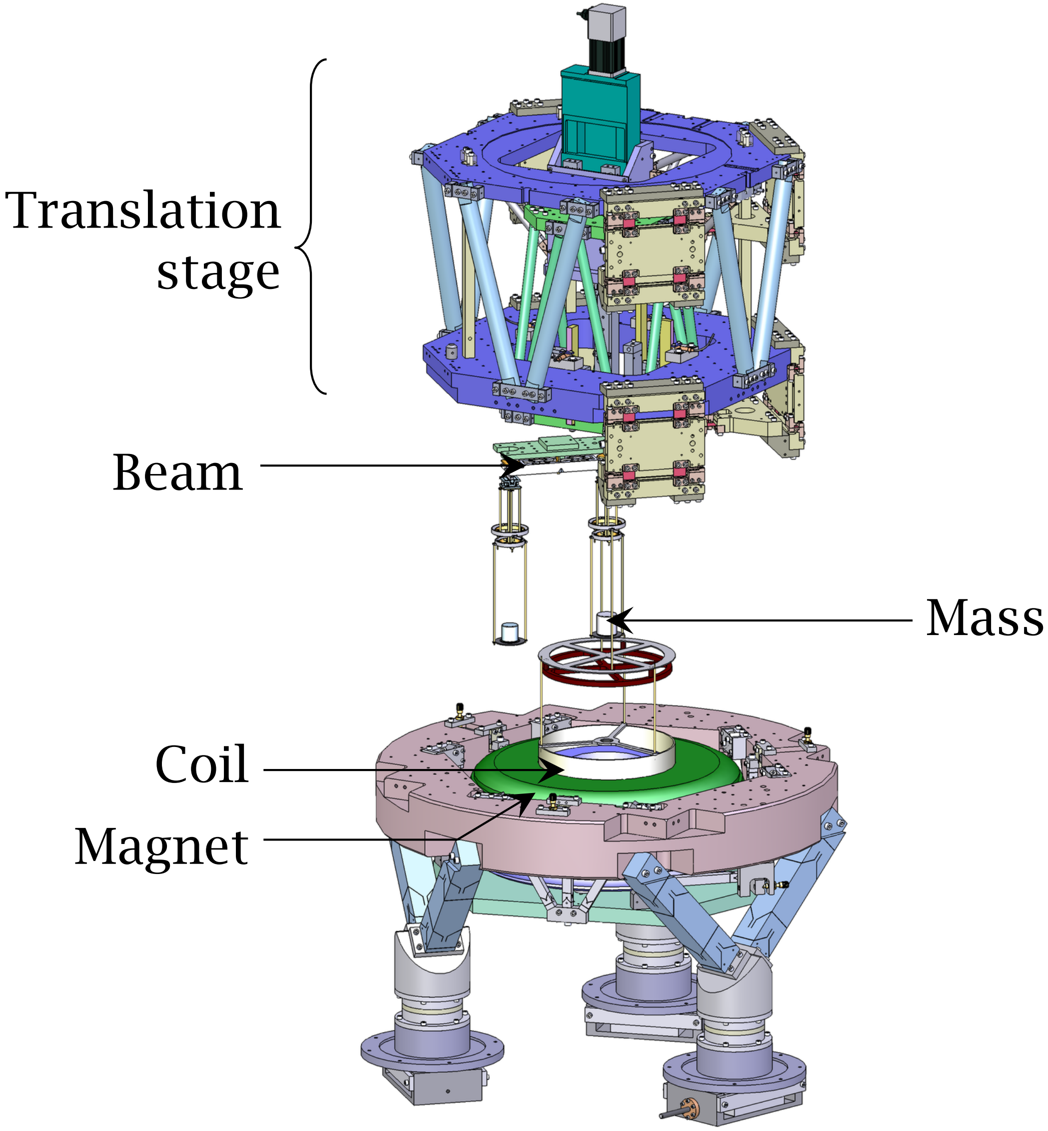

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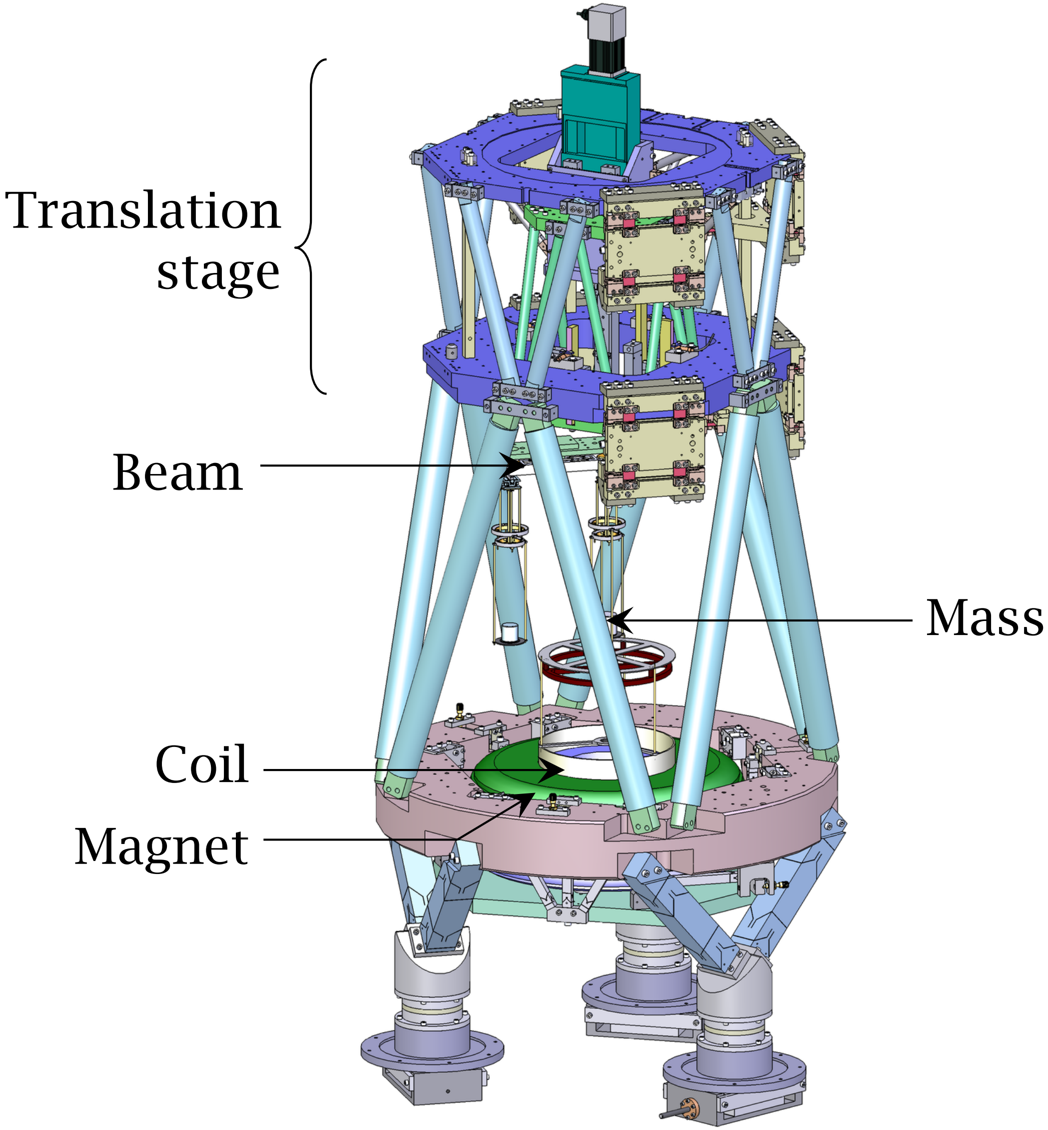
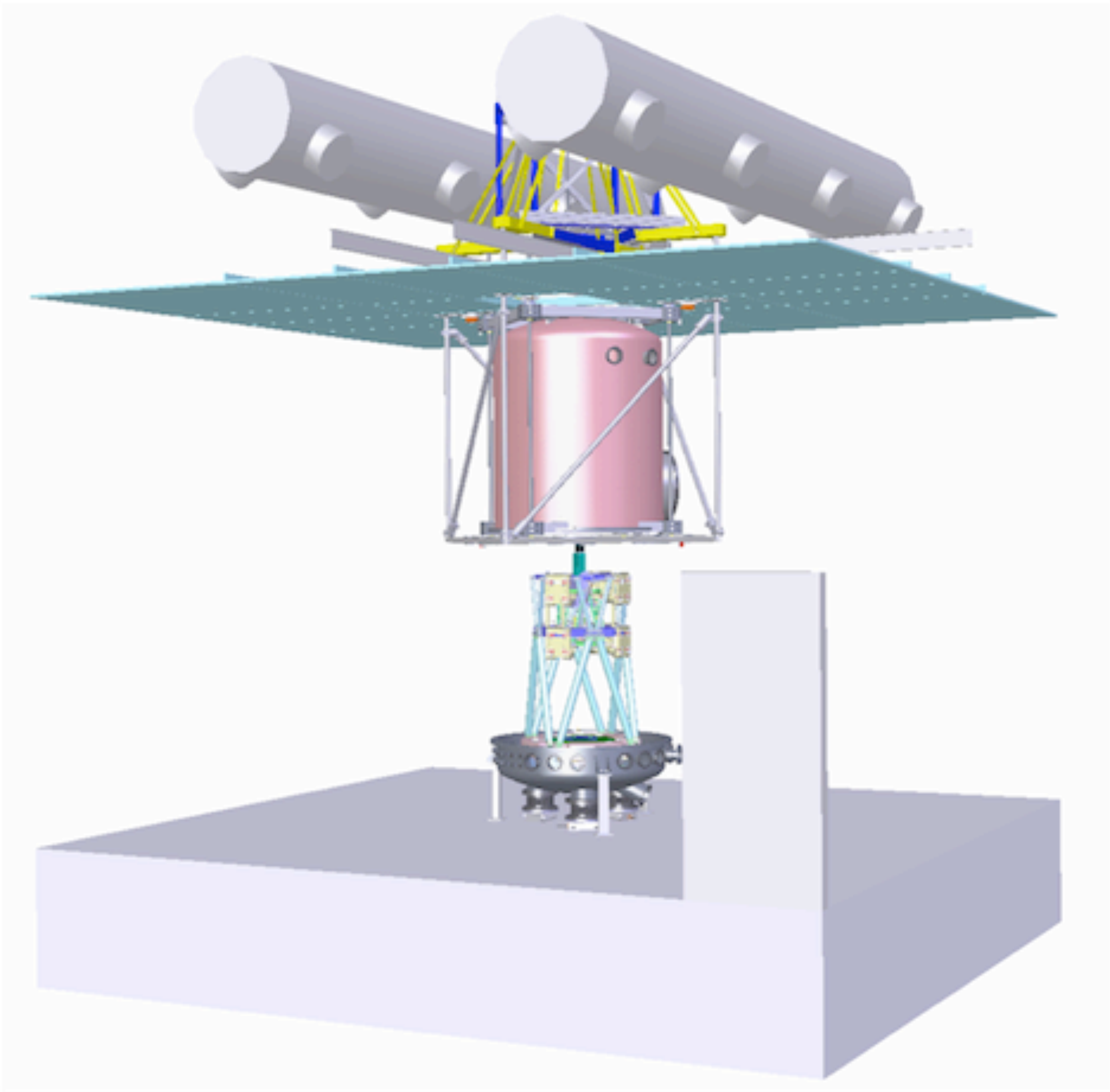
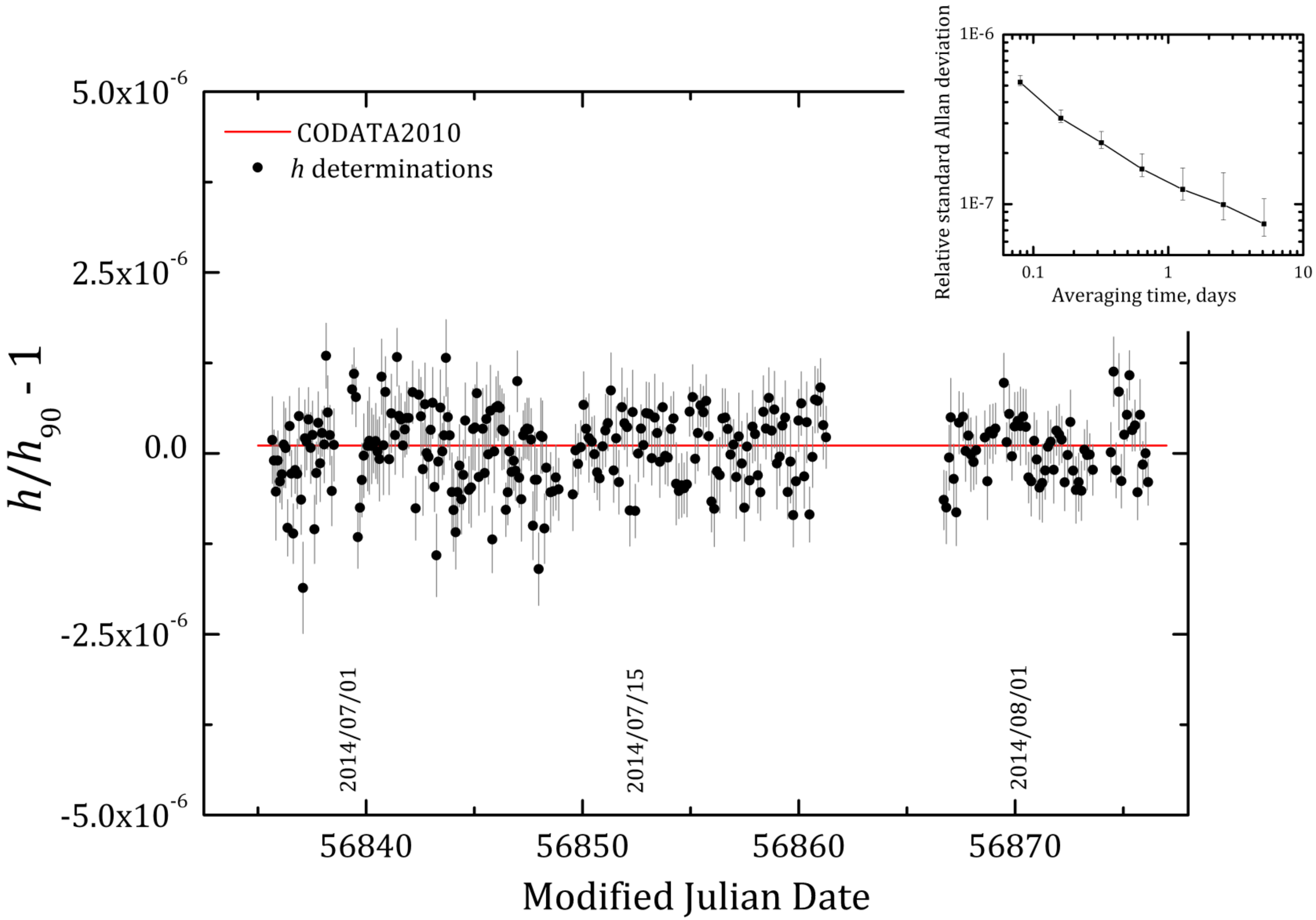


Parts of the LNE Watt balance

LNE Watt balance in its laboratory



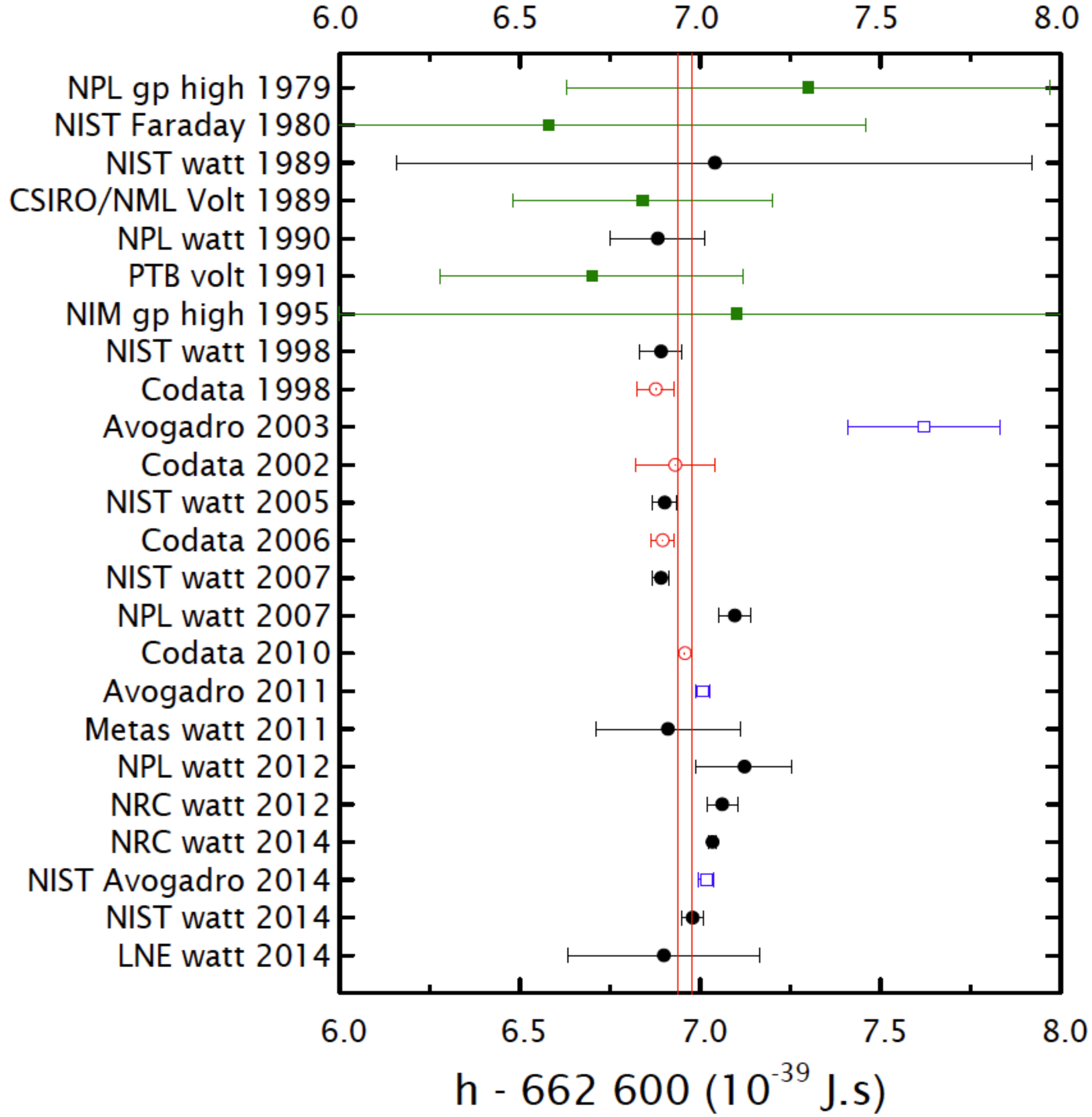
Results summer 2014



Involved Institutes and results

NPL, **NIST**, **METAS**, **LNE**, BIPM,

NIM, MSL, **NRC**



Involved Institutes and results

NPL, **NIST**, **METAS**, **LNE**, BIPM,

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$h_{\text{NIST 2007}}$: 3.6×10^{-8} (**1.2×10^{-8}** for ***g***)

$h_{\text{NPL 2007}}$: 6.6×10^{-8} (**1.5×10^{-8}** for ***g***)

(**0.7×10^{-8}** for ***g***)

$h_{\text{METAS 2011}}$: 25×10^{-8} (**0.25×10^{-8}** for ***g***)

$h_{\text{NRC 2012}}$: 4.3×10^{-8} (**?** for ***g***)

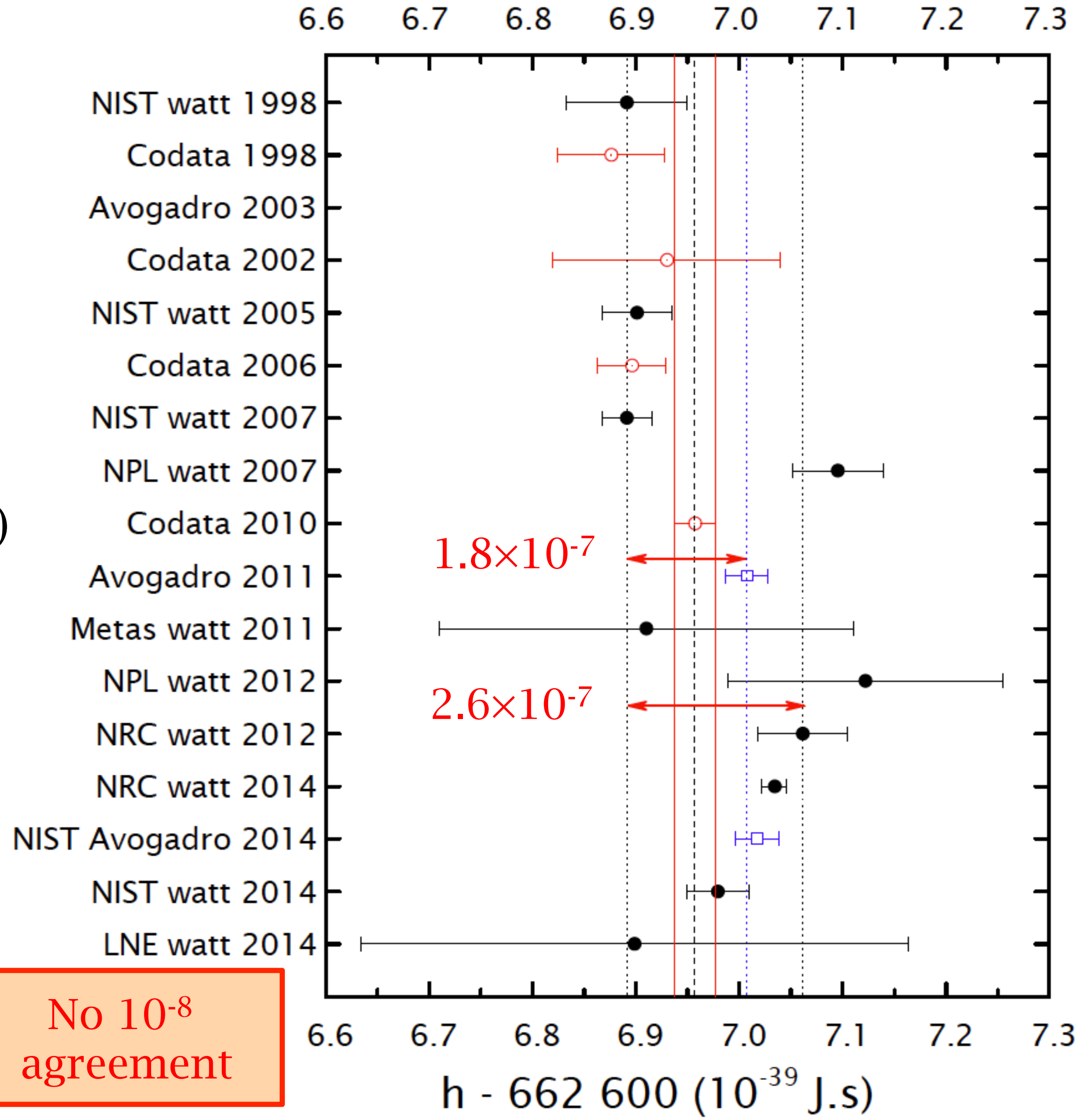
$h_{\text{NRC 2014}}$: 1.8×10^{-8} (**0.57×10^{-8}** for ***g***)

$h_{\text{NIST 2014}}$: 4.5×10^{-8} (**0.7×10^{-8}** for ***g***)

$h_{\text{LNE 2014}}$: 40×10^{-8} (**0.5×10^{-8}** for ***g***)

Last part of the talk

No 10^{-8} agreement



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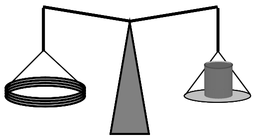
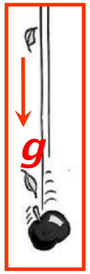
LNE Watt balance objective



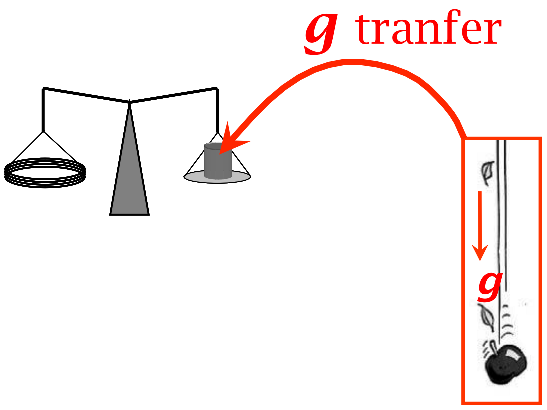


$$\frac{m}{h} = \frac{A}{4gv}$$

Determine *h* with a relative uncertainty of

2×10^{-8}

LNE-SYRTE objective



$$\frac{m}{h} = \frac{A}{4gv}$$

Determine h with a relative uncertainty of

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Determine g with an uncertainty of 10 nm.s^{-2} (1 µGal ~ 10^{-9} g)

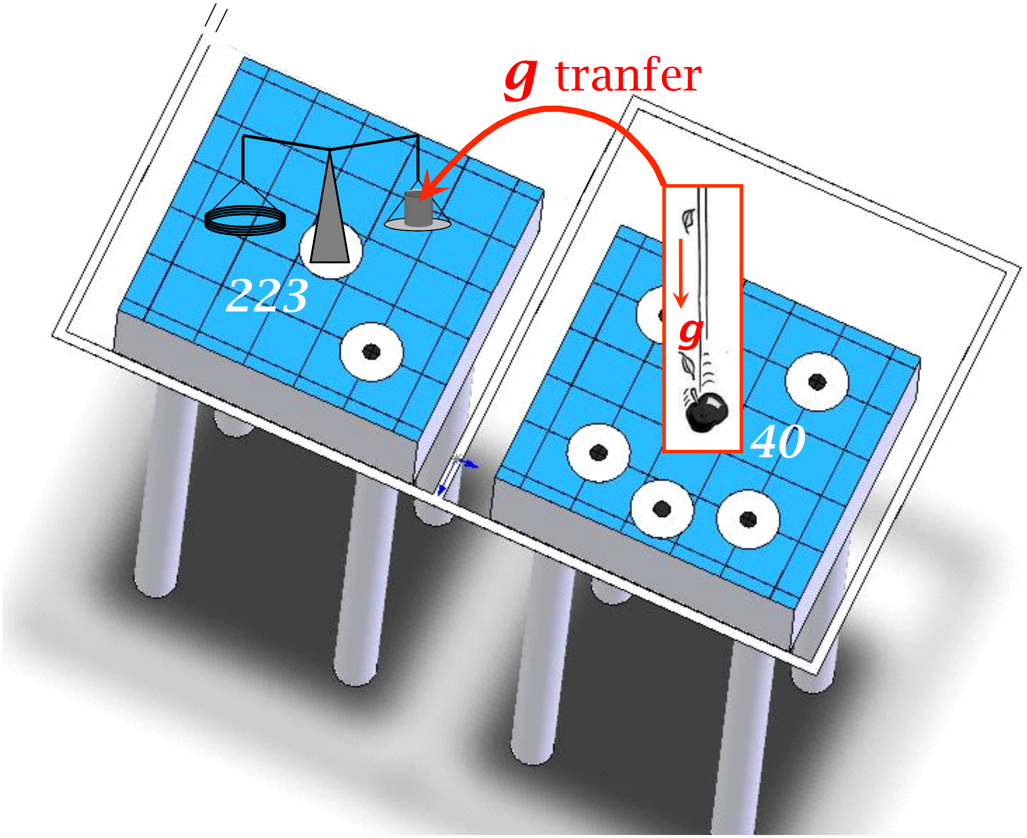
1×10^{-9}

Two tasks:

→ determine g

→ insure the g tranfer at the gravity center of the involved Watt balance mass

LNE-SYRTE objective



$$\frac{m}{h} = \frac{A}{4gv}$$

Determine h with a relative uncertainty of

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Determine g with an uncertainty of 10 nm.s^{-2} (1 µGal ~ 10^{-9} g)

1×10^{-9}

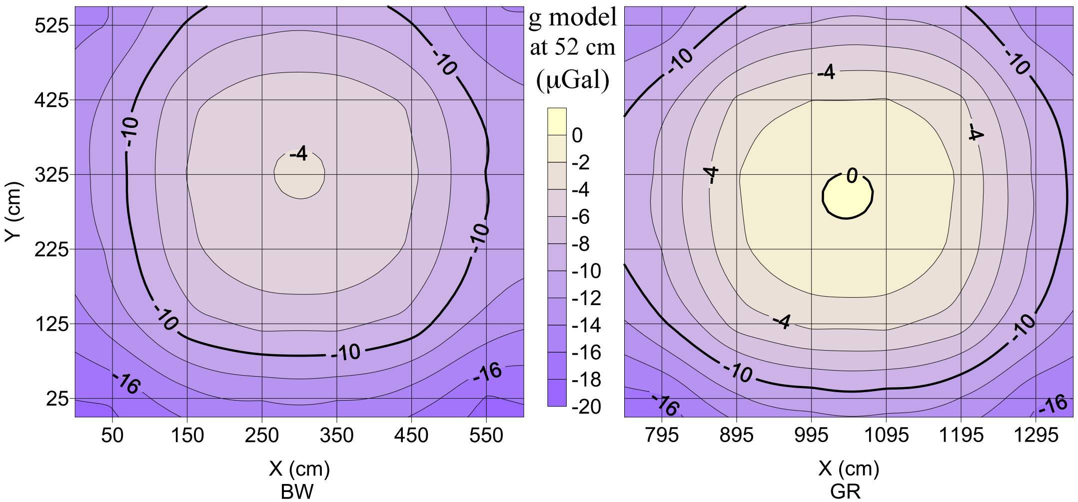
Two tasks:

→ determine g ⇒ absolute gravimeter

→ insure the g tranfer at the gravity center of the involved Watt balance mass ⇒ laboratory gravity mapping

Model, *g* transfer

- *Laboratories*



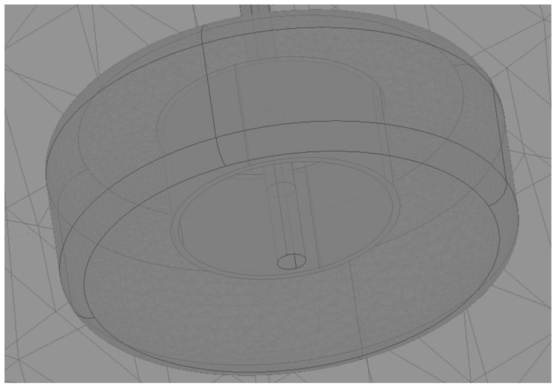
U_{model} < 3 μGal in a 50 m^3 volume

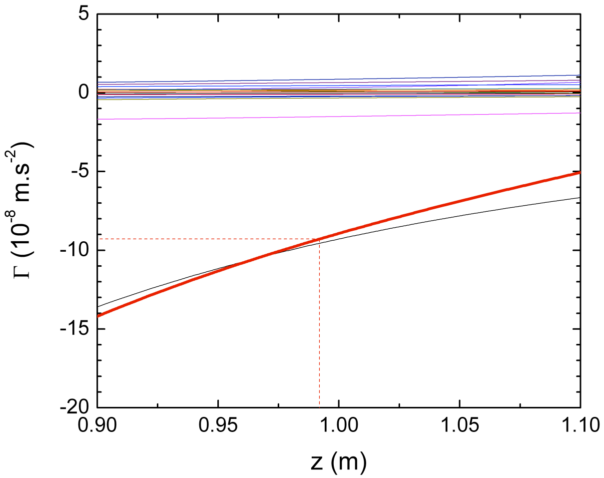
$U_{centres}$ = 1.0 μGal ⇒ ***g*** transfer in the Watt balance uncertainty budget : 10^{-9}

S. Merlet et al.Metrologia **45** (2008) 265-274

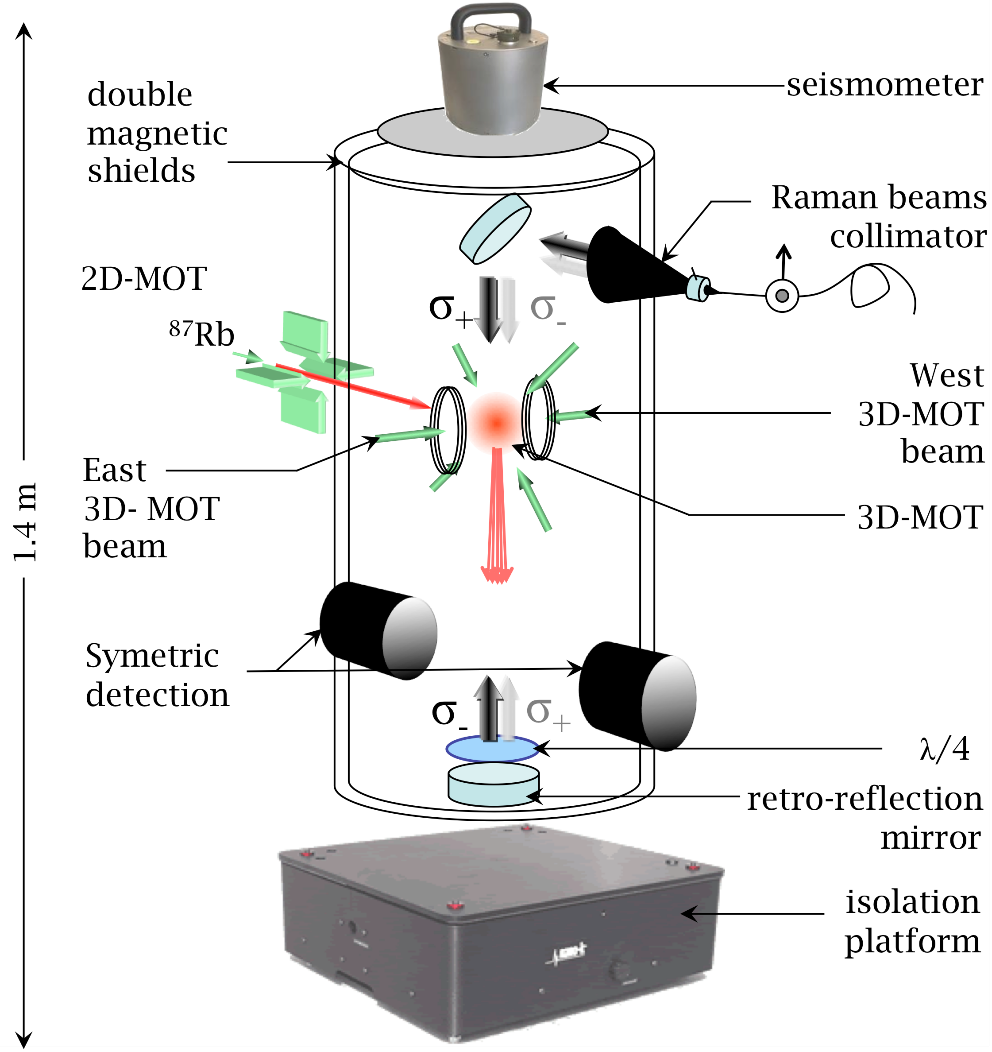
- *Balance (self gravity effect)*

Calculation based on the one developped to determine the CAG SGE :
FEM
G. D'Agostino et al *Metrologia* 48 (2011)





Absolute gravimeter

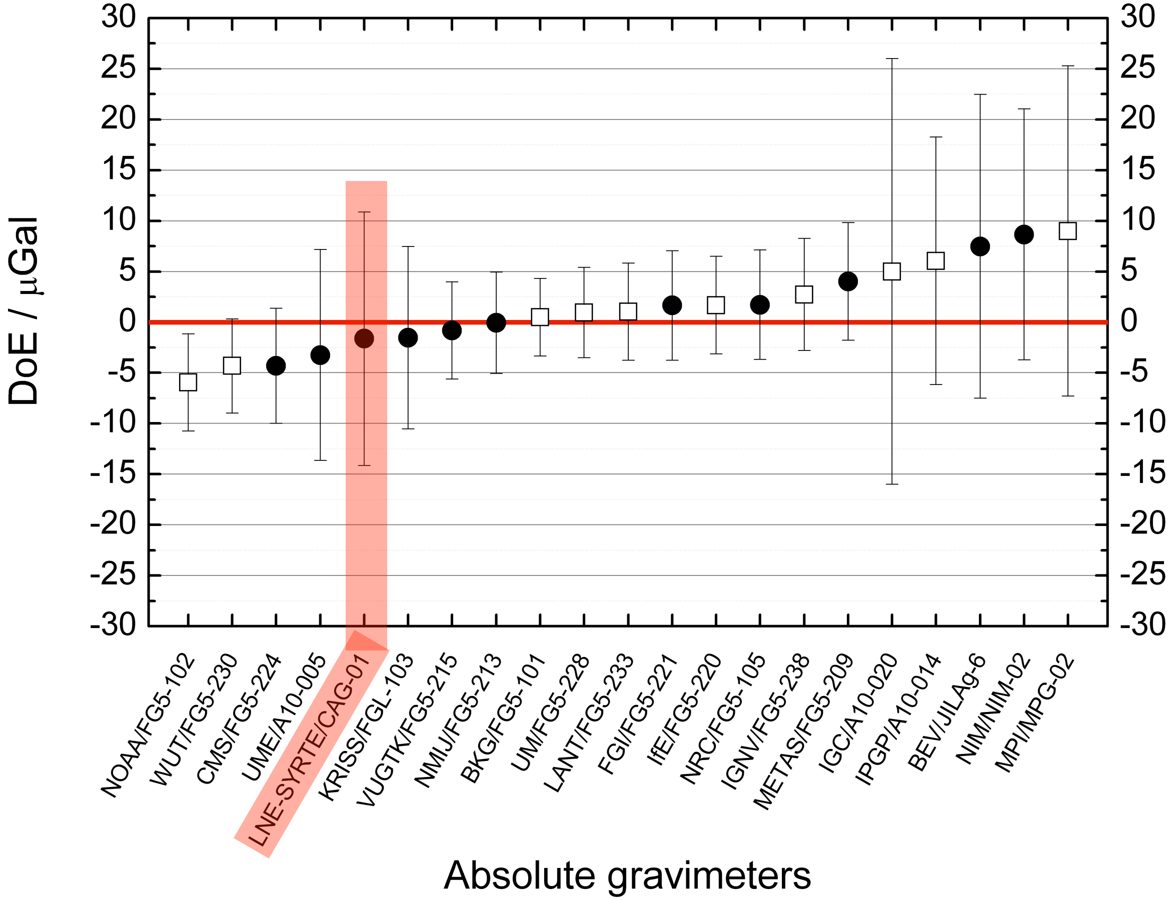


Movable set up

- Participation to international key comparisons: ICAG'09 (BIPM), ECAG'11(Lux), ICAG'13(Lux)

8 comparisons: 4 @ LNE; 7 with CAG

ICAG'09 (BIPM)



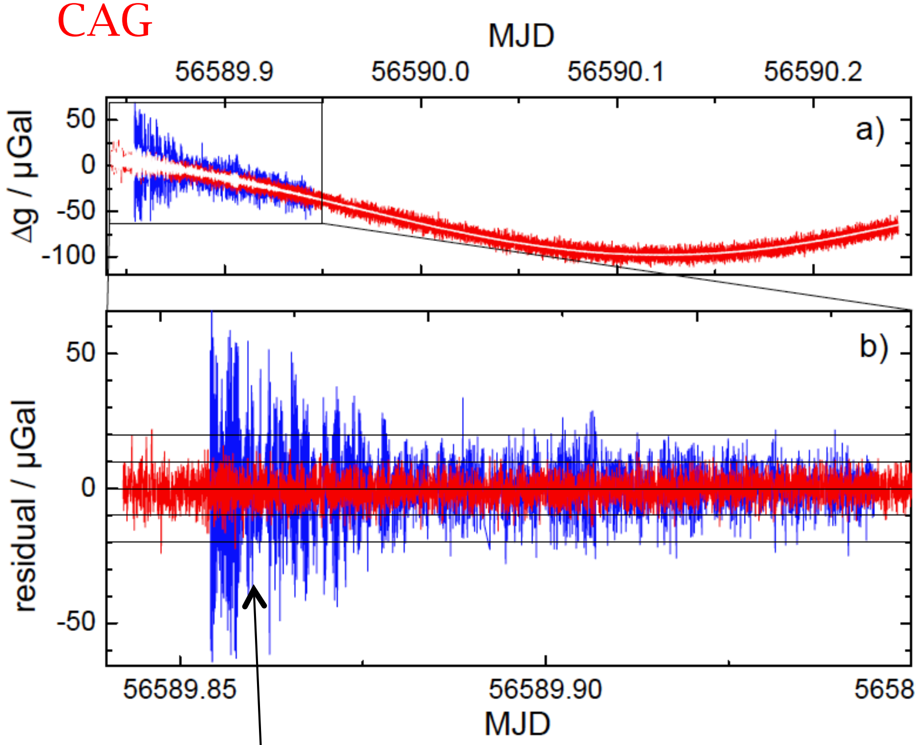
Z. Jiang et al *Metrologia* **49** (2012)
S. Merlet et al *Metrologia* **47** (2010)
A. Chauvet-Louchet et al *IEEE Trans. Instrum. Meas.* **60** (2011)
0. Francis et al *Metrologia* **50** (2013)
P. Gillot et al Metrologia **51** (2014)

ECAG'11 (Walferdange Lux)

Effect	Bias µGal	u µGal
Alignments	2.4	0.5
Frequency reference	-4.6	<0.1
RF phase shift	0.0	<0.1
vgg	-10.3	<0.1
Self gravity effect	-1.3	0.1
Coriolis	1.3	0.8
Wavefront aberrations	0.0	4.0
LS1	0.0	<0.1
Zeeman	0.0	<0.1
LS2	-7.7	0.5
Detection offset	0.0	0.5
Optical power	0.0	1.0
Cloud indice	0.4	<0.1
Cold collisions	<0.1	<0.1
TOTAL	**-19.8**	**4.3**

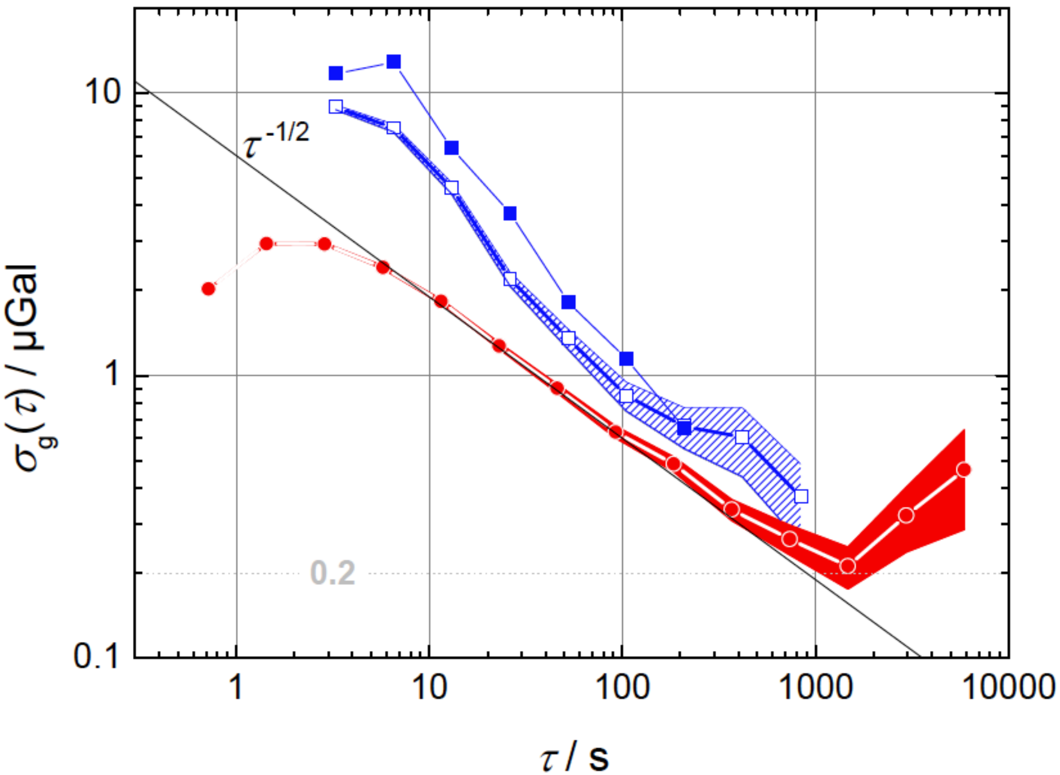
CAG sensitivity

FG5X#216
CAG



Rejection of earthquake effect

P. Gillot et al Metrologia **51** (2014)



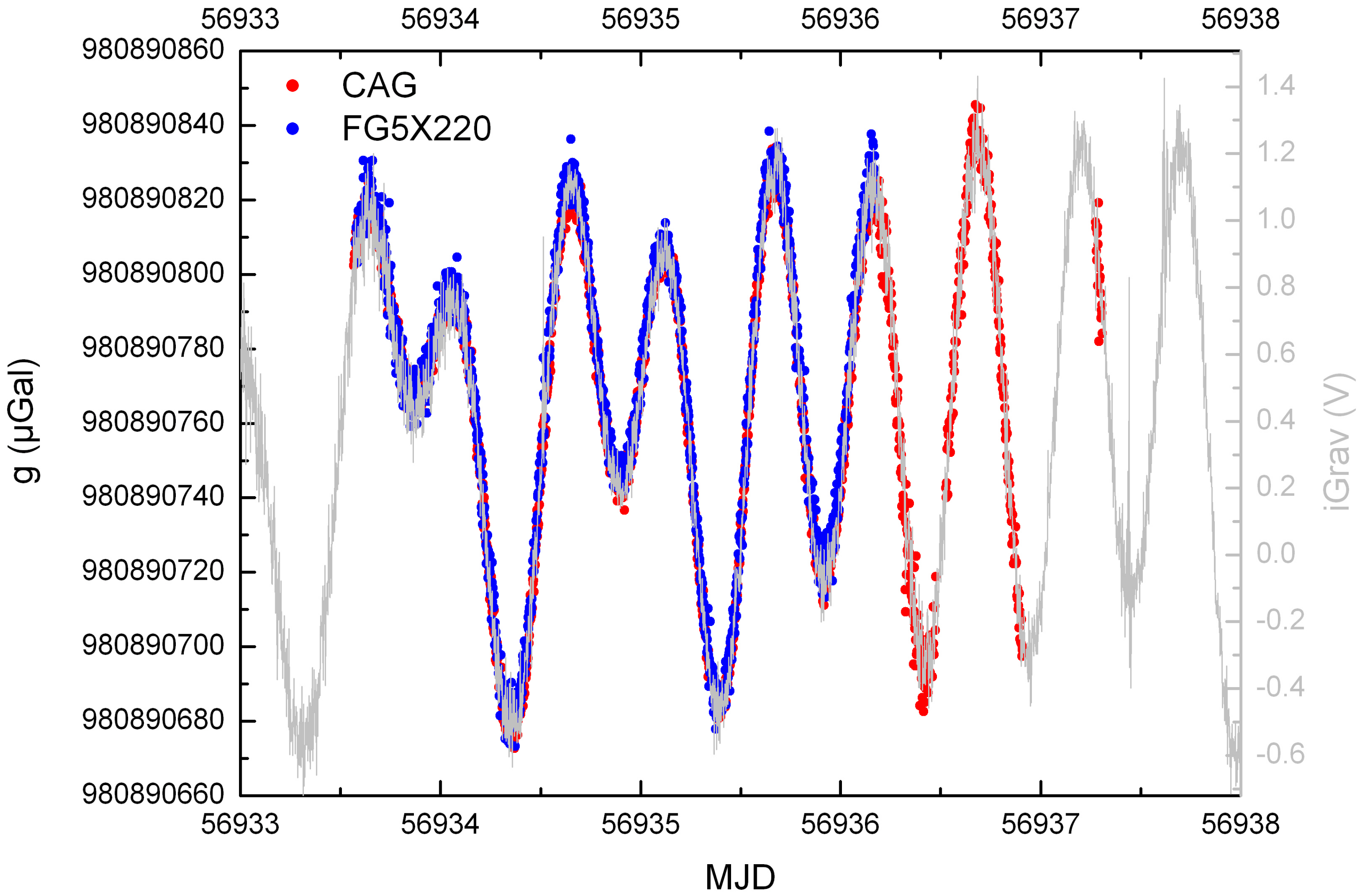
Superconducting gravimeter iGrav-005

Operating since beginning of 2013

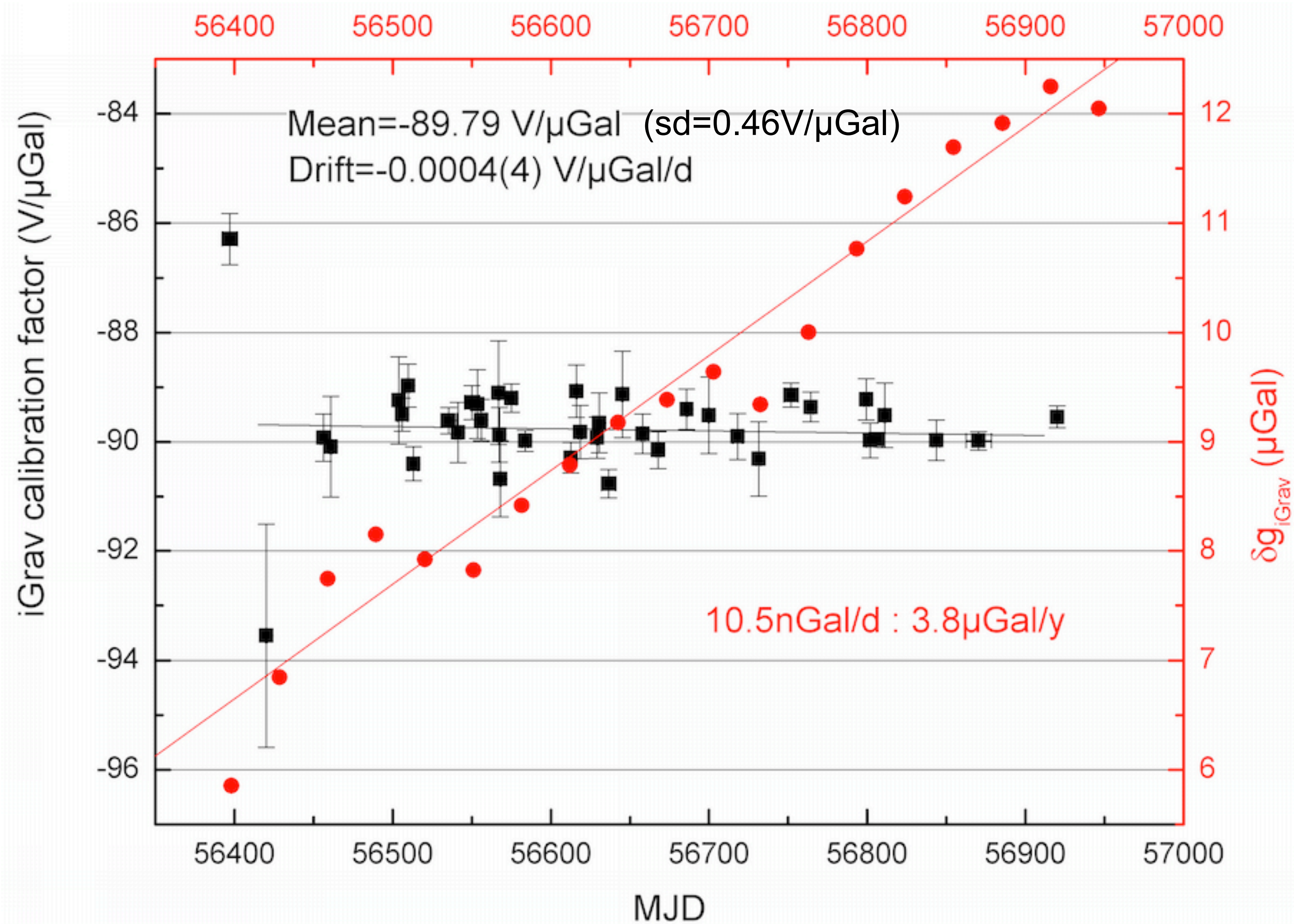
Installed on the same GR pillar than CAG

- *Study of long term stability of CAG*
- *Continuous g recording, back up for CAG*
- *No g variation model needed for WB (tides, pressure, ground watter…)*

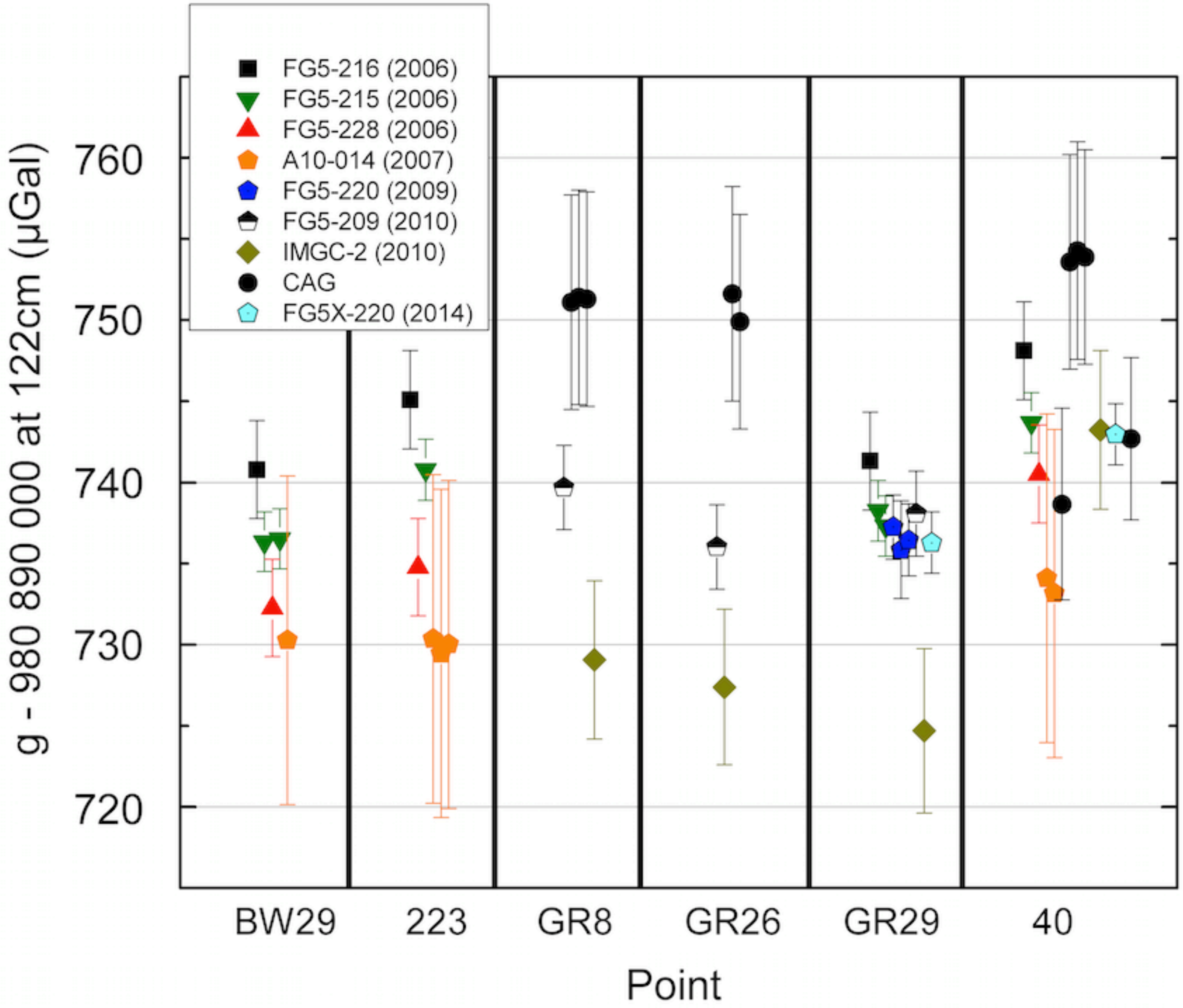
Comparison FG5X#220 and CAG Vs iGrav005



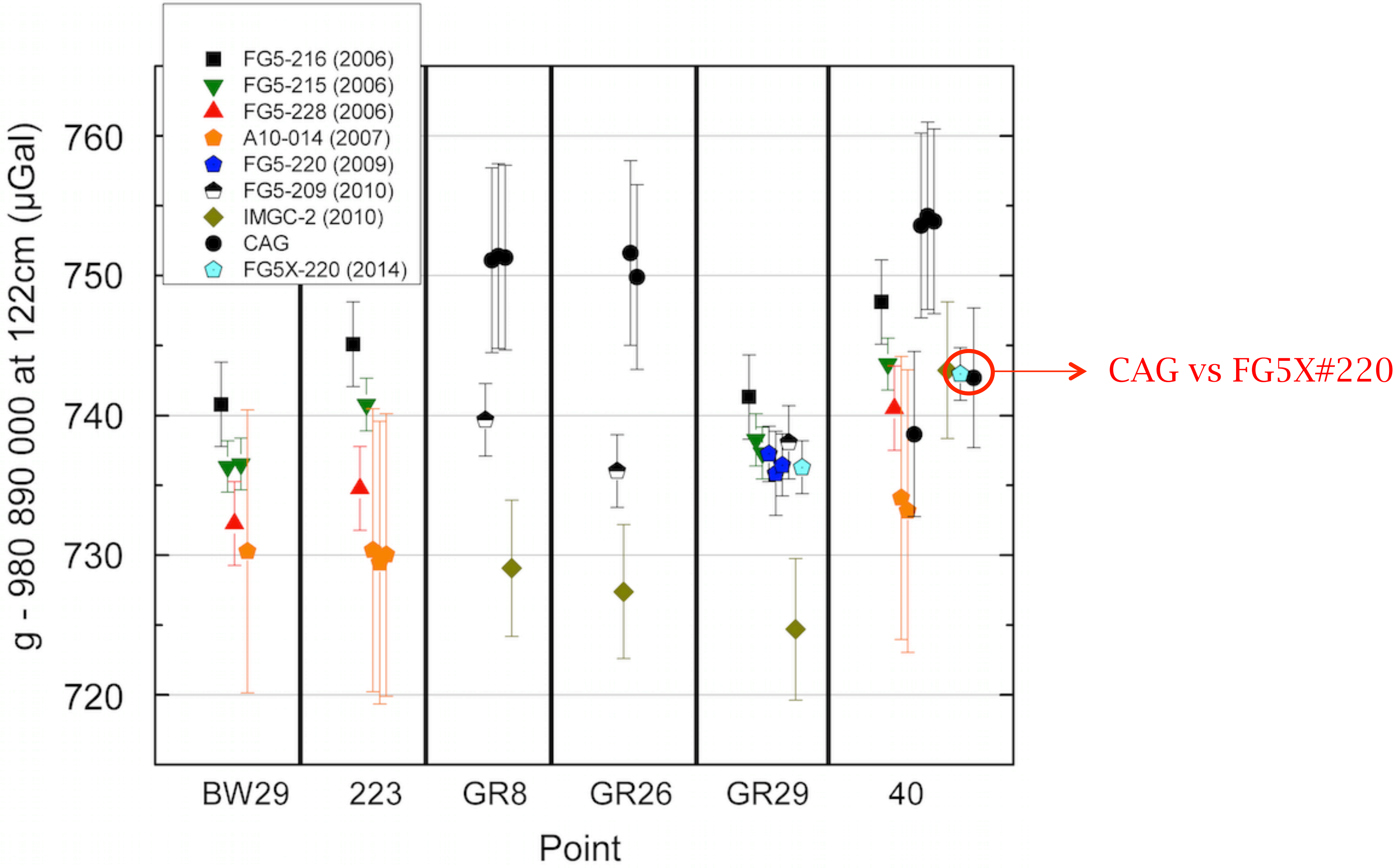
iGrav005 calibration factor and drift



Absolute measurements @ LNE



Absolute measurements @ LNE



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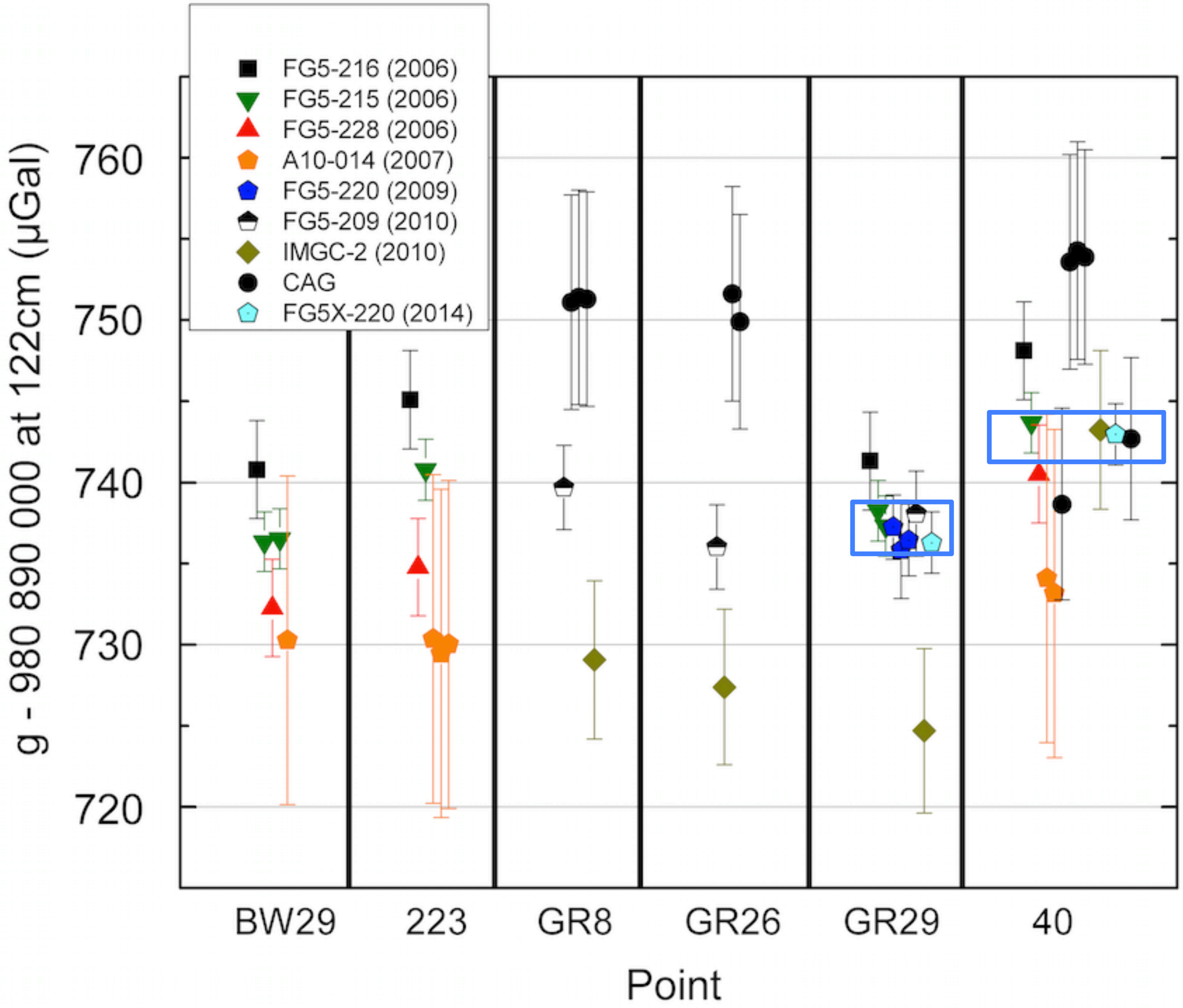
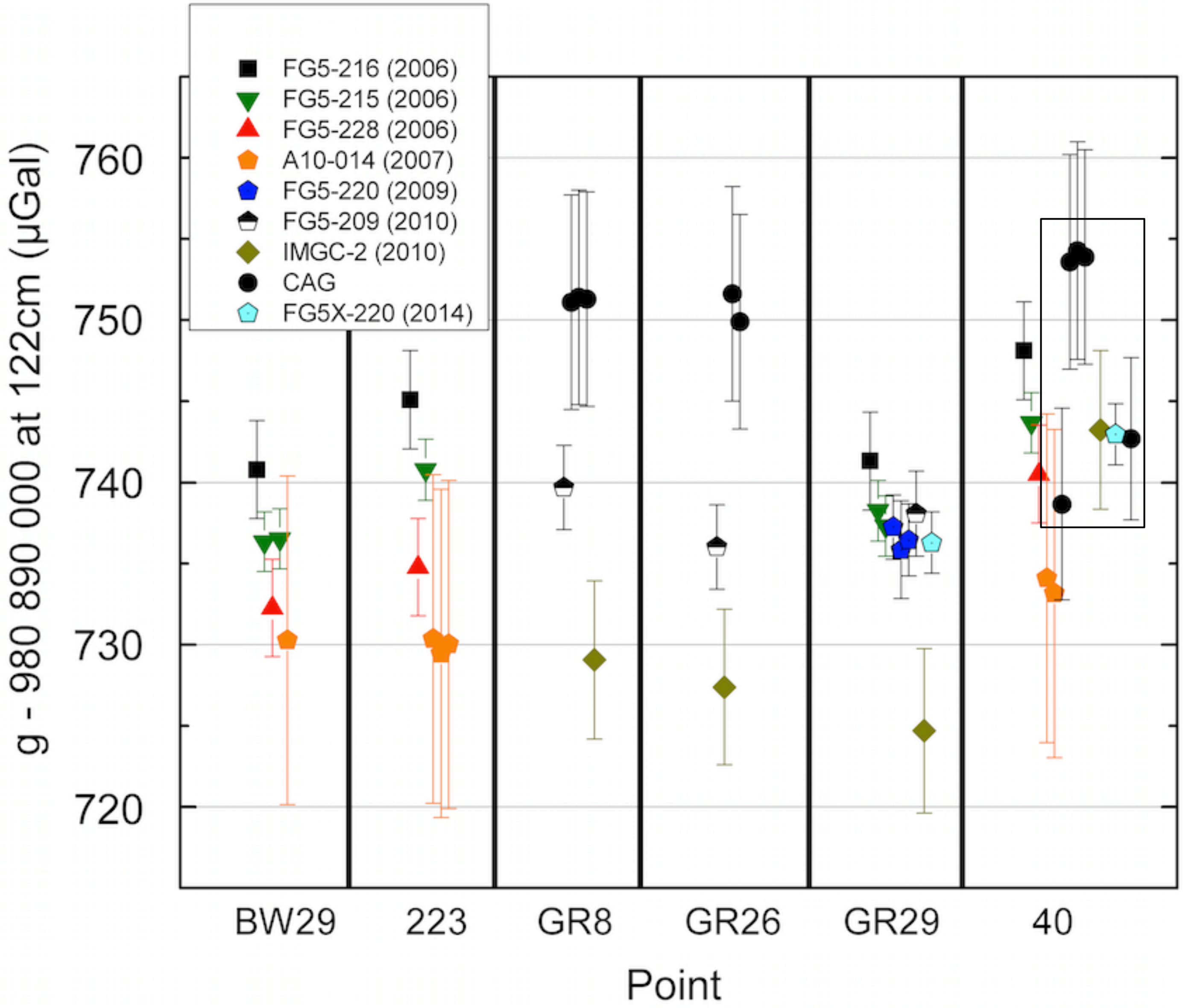


Stability of LNE site

Absolute measurements @ LNE



Improvement of CAG

Prospects

Kilogram: a definition to change, when ? CGPM 2018 ?

h with BW ? with N_A ? With both ? → *solve the discrepensies*

LNE Watt balance → *international comparison with IPK in 2015*

→ *in air : 1×10^{-7} in 2015*

→ *in vaccum : < 1×10^{-7} in 2016-2017*

→ *participation to the kilogram redefinition ?*

CAG improvement: → *decrease uncertainty to 1×10^{-9}g*

→ *improve the sensitivity with the iGrav*

Provide a continous absolute g value for the LNE Planck constant determinations

Continue to compare the CAG with other AG (CC and AI)

Continuous g measurements for years

Thank you for your attention

http://syrte.obspm.fr/tfc/capteurs_inertiels/