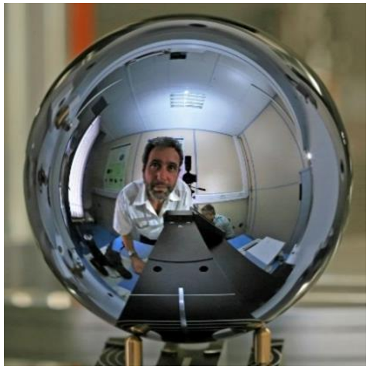
Kilogram redefinition

Isabel Spohr, TC-M Chair
Bucharest, 29 May 2018

Mass and Related Quantities

The (SI) Unit of Mass

- **History**
- **Problems**
- **Solutions**
- **The Future**



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Mass and Related Quantities

A brief history of mass metrology

- Mesopotamian weights made from haematite (2000 BC)
- Roman Empire 2 pan balance (1st century BC)
- TIME FOR A CHANGE

- Scientist have been looking for a “natural” way to define the unit of mass for a long time

Mass and Related Quantities

The SI unit of mass – kilogram

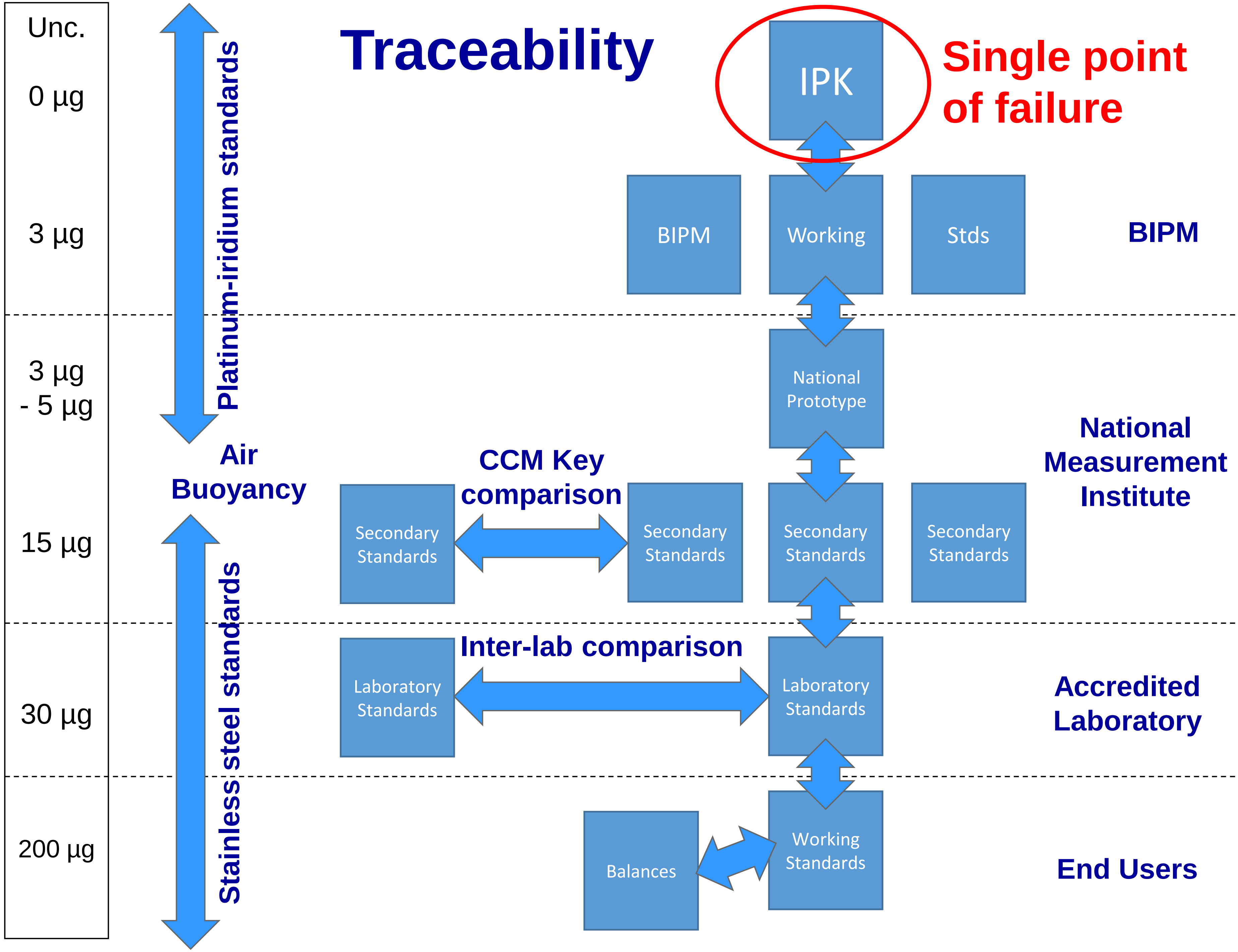
"The kilogram is the unit of mass; it is equal to the mass of the International Prototype of the Kilogram"

- Based on the density of water at 4 ° C
- Dates from the first meeting of the CGPM (*Conference General des Poids et Mesures*) held in 1889.
- There are about 100 copies of the Kilogram at NMIs worldwide

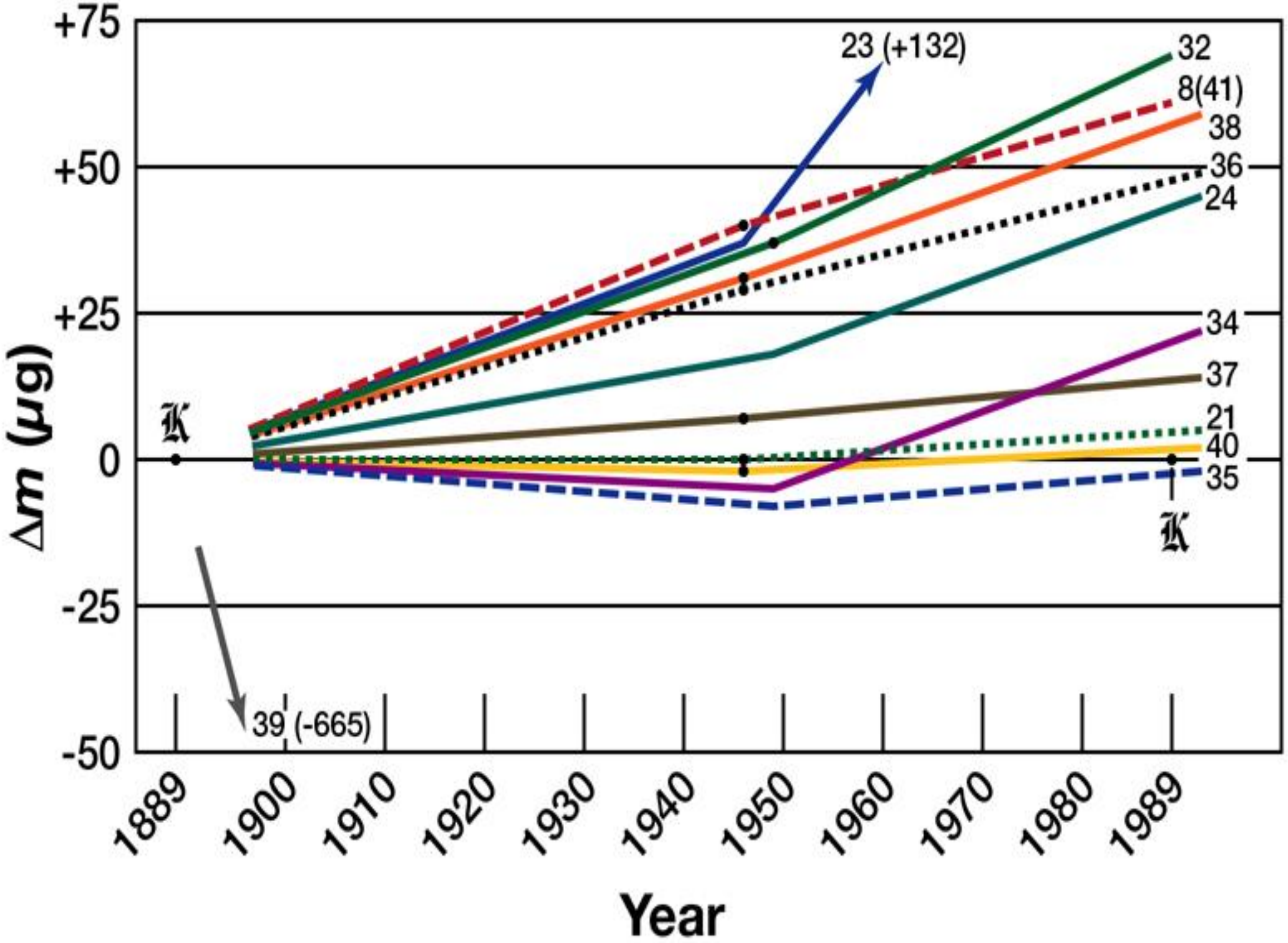
Problems

- **Traceability** – all mass measurements must demonstrate traceability to the IPK (which has only been used 4 times)
- **Stability** – we know an artefact based definition of the kilogram is intrinsically unstable (with time and with usage)

Mass and Related Quantities

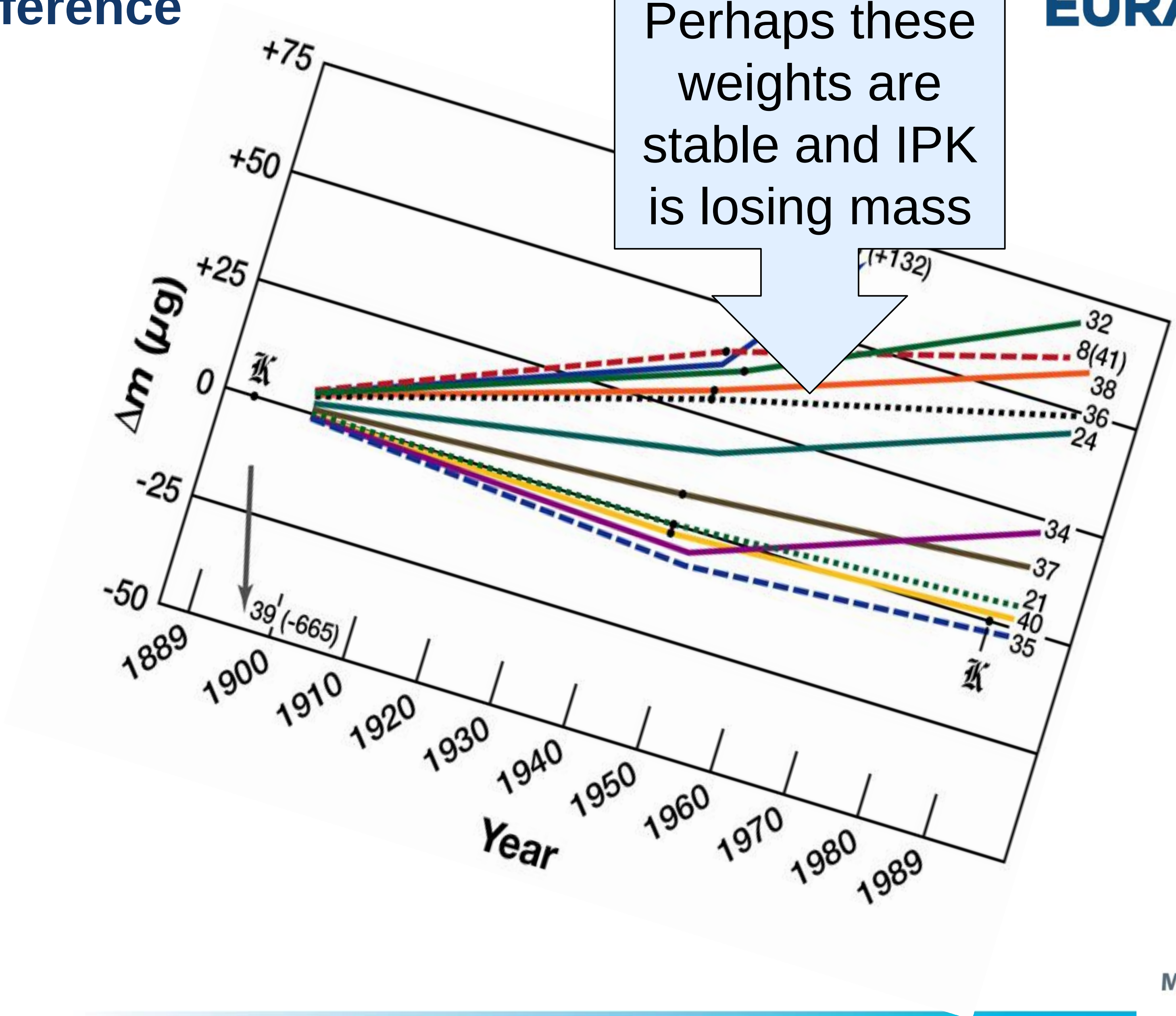

Traceability
Single point of failure
Unc.
0 µg
3 µg
3 µg - 5 µg
15 µg
30 µg
200 µg
Platinum-iridium standards
Air Buoyancy
Stainless steel standards
IPK
BIPM
Working
Stds
BIPM
National Prototype
National Measurement Institute
CCM Key comparison
Secondary Standards
Secondary Standards
Secondary Standards
Secondary Standards
Inter-lab comparison
Laboratory Standards
Laboratory Standards
Accredited Laboratory
Balances
Working Standards
End Users

Stability of some official copies with reference to the IPK



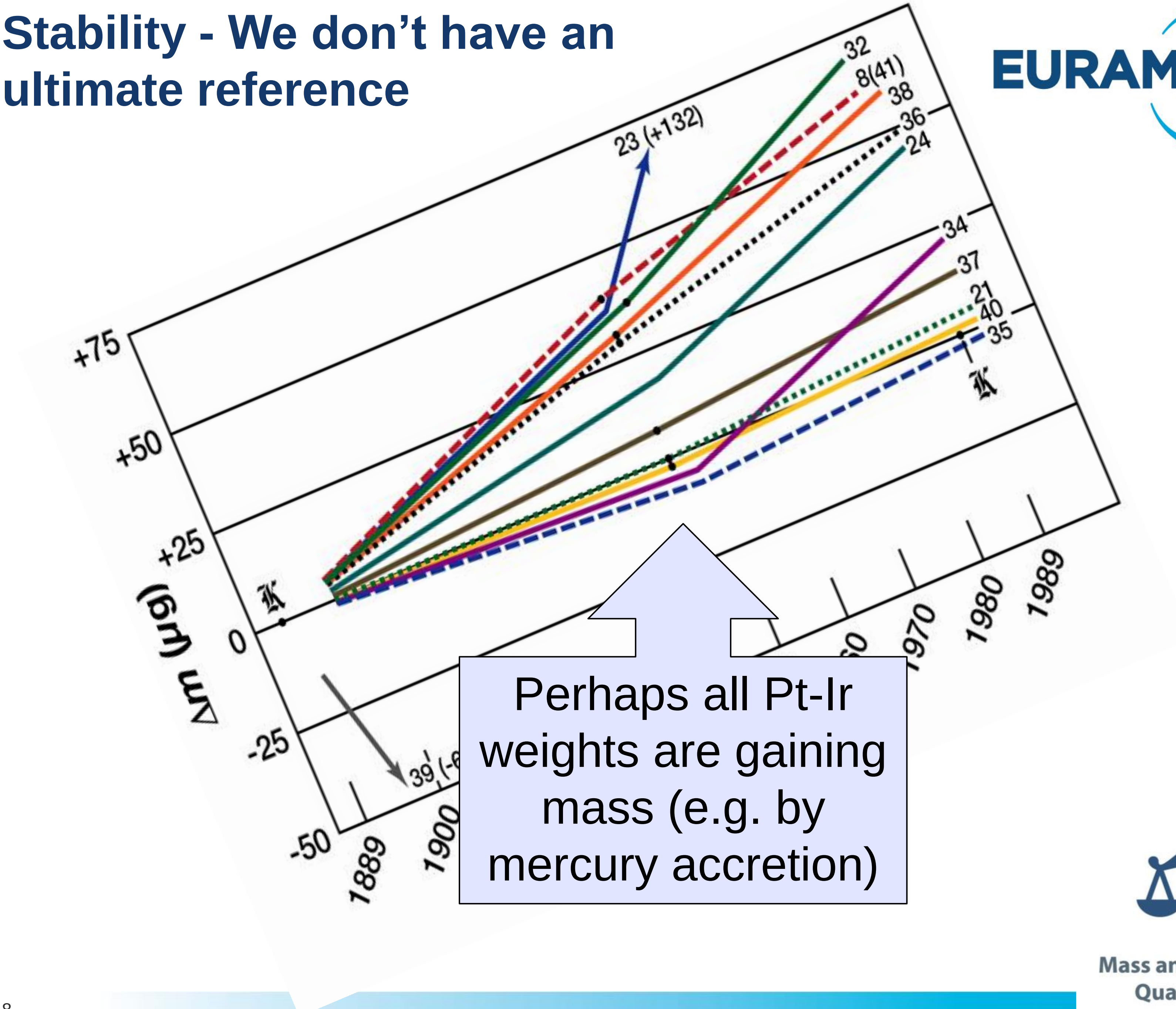
Mass and Related Quantities

Stability - We don't have an ultimate reference



Perhaps these weights are stable and IPK is losing mass

Stability - We don't have an ultimate reference

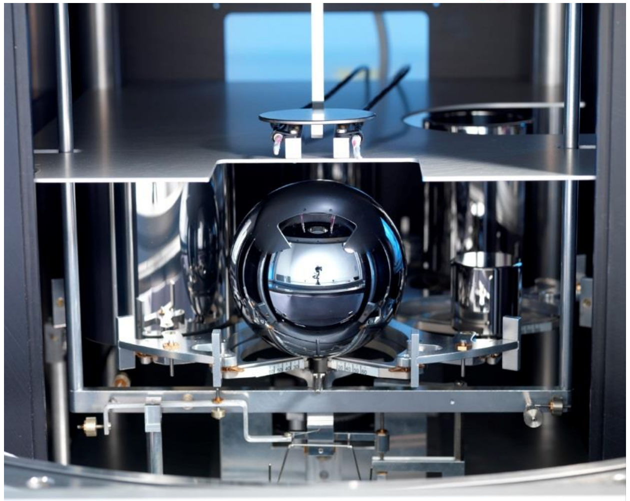


Perhaps all Pt-Ir weights are gaining mass (e.g. by mercury accretion)

Mass and Related Quantities

The “new” kilogram(s) – solving the problems?

- Problems (with the current definition)
  - ➢ Single point of traceability/failure
  - ➢ Lack of long-term stability
  - ➢ Only available at one value (1 kg)
- Solution
  - ❑ Relation to a fundamental constant
  - ❑ Uncertainty of < 2 in 10^8 required
- Implementation
  - ✓ International Avogadro project - fixes Avogadro constant N_A
  - ✓ Kibble (watt) balance - fixes the Planck constant h

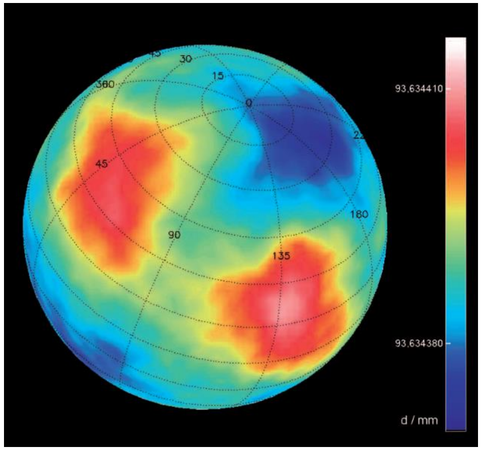


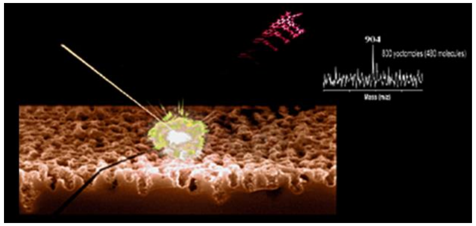
Mass and Related Quantities

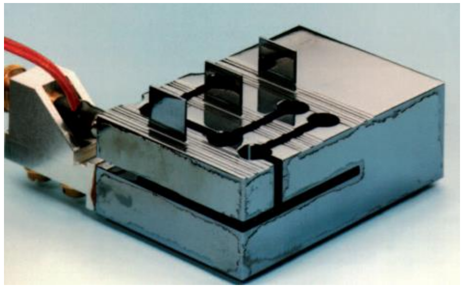
Implementation -Avogadro kilogram

$$N_A = \frac{n.M_m}{\rho.a^3}$$

- Realisation via a 93.6 mm diameter sphere pure single-crystal silicon (X-ray crystal density experiment)
- Measure:
  - Sphere volume and mass
    - Out of roundness of sphere is about 10 nm
  - Isotopic composition
    - Difficult, so we use enriched ^{28}Si
  - Lattice spacing
    - X-ray/optical interferometry
  - Surface chemistry
    - To determine oxide thickness and carbonaceous overlayers







Implementation –
Electrical kilogram, Kibble balance

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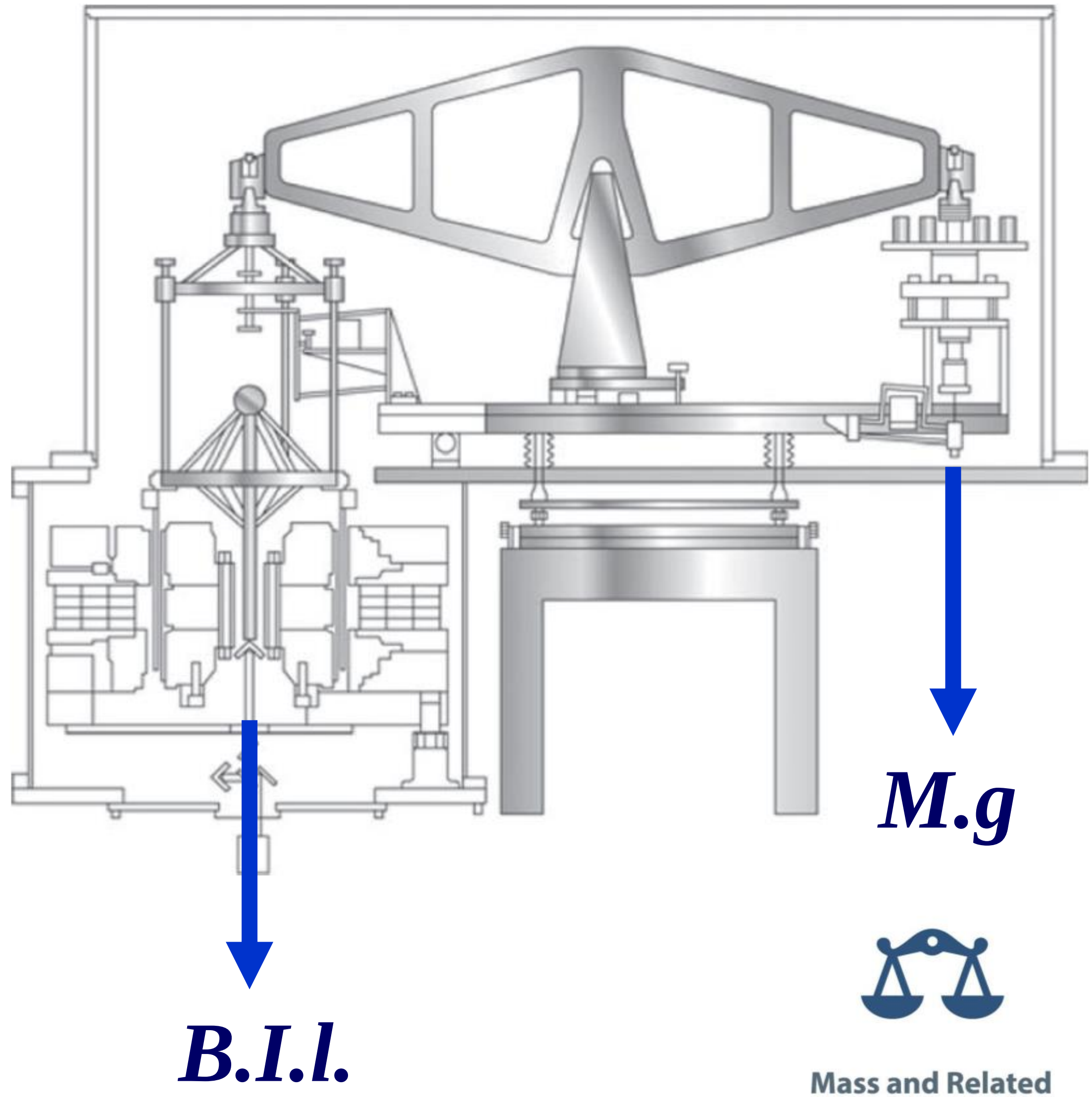
- Balances electrical and mechanical power;

$$B.I.l = M.g$$

- **BUT** field strength (B) and coil length (l) are difficult to measure to the required accuracy
- SO



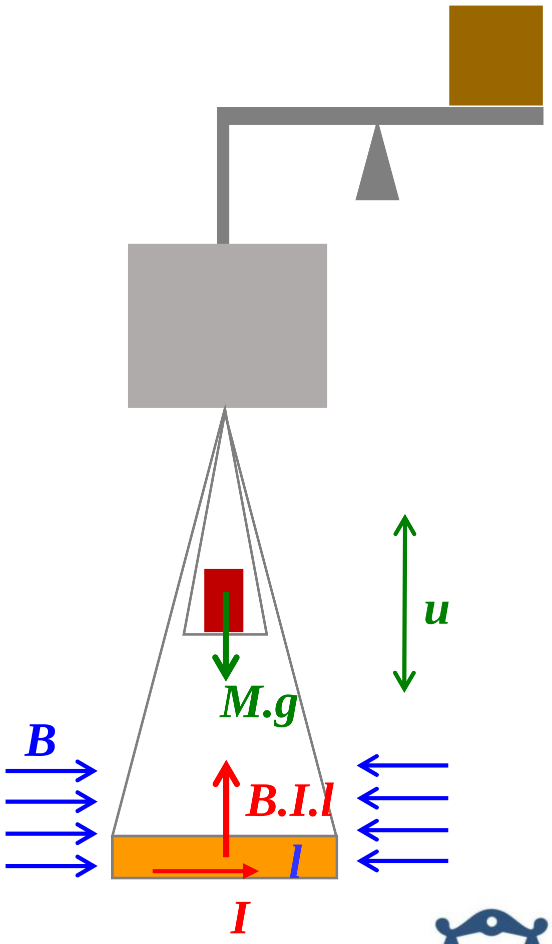
Mass and Related Quantities

Implementation – Electrical kilogram, Kibble balance

- Use a 2-part experiment
  1. Static - coil force balances the weight $(M.g = B.I_s.l)$
  2. Moving - coil goes through the field at a constant velocity, *u* to generate a voltage, V_m $(V_m = B.l.u)$

$$M.g = V_m I_s / u$$

- Quantum electrical units Josephson **voltage** and quantum Hall **resistance** are realised with relation to the Planck constant (h)



Mass and Related Quantities

The “new” kilogram –problems solved?

- Subject to endorsement by the CGPM we will have a value for the SI unit of mass related to a fundamental constant which will guarantee long-term stability **but**;

- Despite the fact that CODATA have fixed a value for the Planck constant the **currently available realisation experiments are not in agreement**

Mass and Related Quantities

The CODATA 2017 value of *h* for the revision of the SI

D B Newell *et al* 2018 *Metrologia* **55** L13

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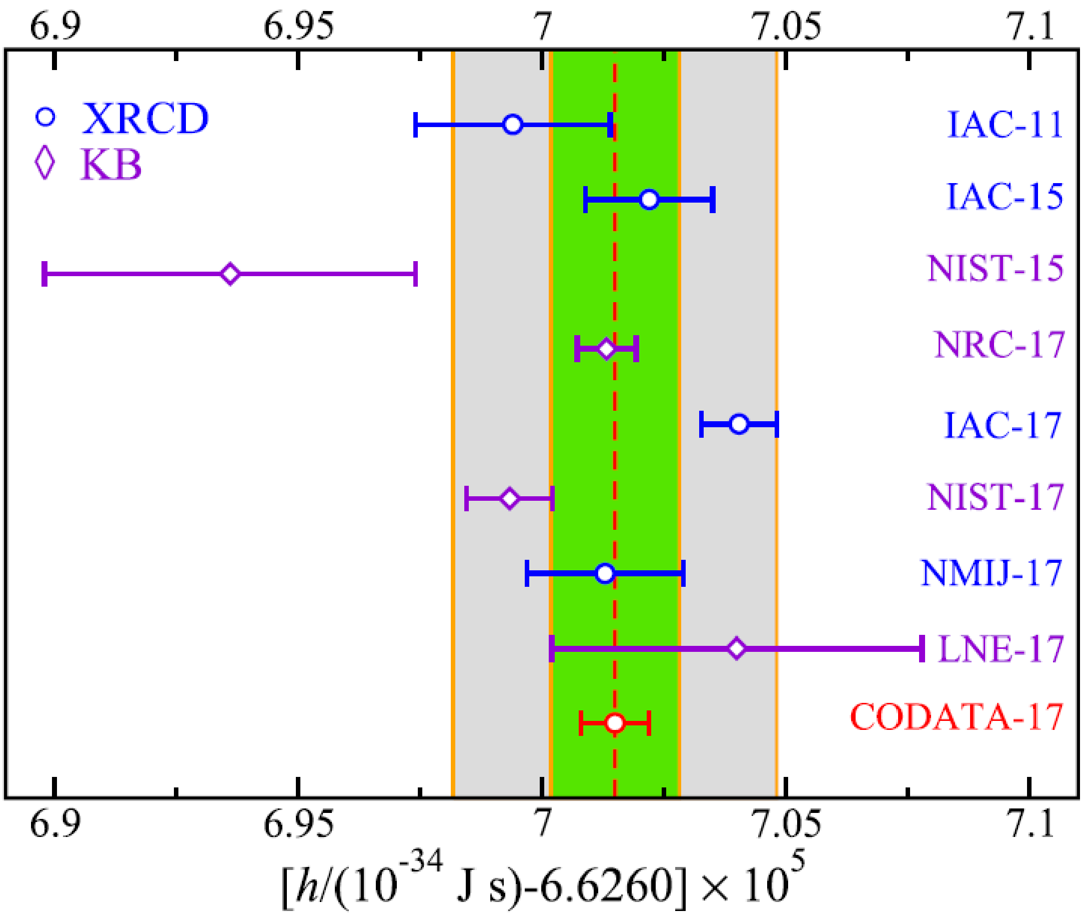

- Contributing values to the CODATA 2017 value for the Planck constant *h*
- XRCD: x-ray-crystal-density
- KB: Kibble balance

➢ The inner green band is ± 20 parts in 10^9

➢ The outer grey band is ± 50 parts in 10^9

CODATA *h* = **6.626 070 150(69) × 10^{-34} J s**

Relative standard uncertainty **± 1.0 × 10^{-8}**

Mass and Related Quantities

The “new” kilogram – problems solved?

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- Subject to endorsement by the CGPM we will have a value for the SI unit of mass related to a fundamental constant which will guarantee long-term stability **but**;

- Despite the fact that CODATA have fixed a value for the Planck constant (CODATA 2017 special adjustment – *Metrologia* 55 (2018)) the currently available realisation experiments are not in agreement **so;**

- Until such a time as the agreement and reliability of the realisations can be demonstrated a **consensus value** for the kilogram, maintained by the BIPM, will be adopted

Mass and Related Quantities

CCM (2017)

CCM Recommendation G1 (2017): For a new definition of the kilogram in 2018

To preserve the international equivalence of calibration certificates:

- NMIs having a realization of the kilogram shall disseminate a consensus value, instead of their own realization
- Consensus value will be determined from an ongoing comparison of kilogram realizations, organized by the BIPM
- Until the dispersion in values becomes compatible with the individual realization uncertainties
- CCM TG (chair: S. Davidson) will define details and prepare a note on dissemination after the redefinition
- CCM reminds Members States not having a realization of the new definition will have access to calibration services of the BIPM
- CCM recommends that the CIPM undertakes the necessary steps to proceed with the planned redefinition

Bureau International des Poids et Mesures

Mass and Related Quantities

The “new” kilogram – problems solved?

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OTHER ISSUES

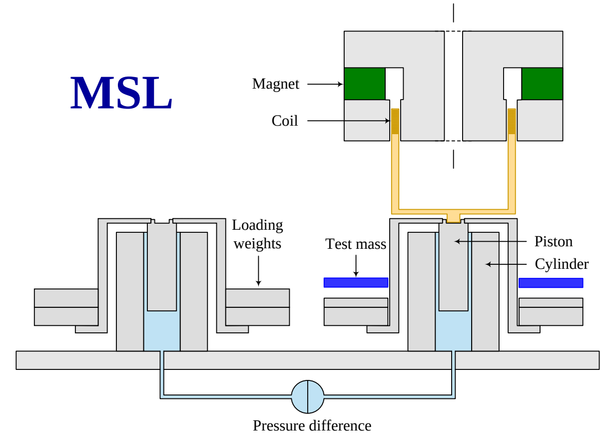
- There are currently only three realisation experiments operating at the 2 in 10^8 level required by the mass community

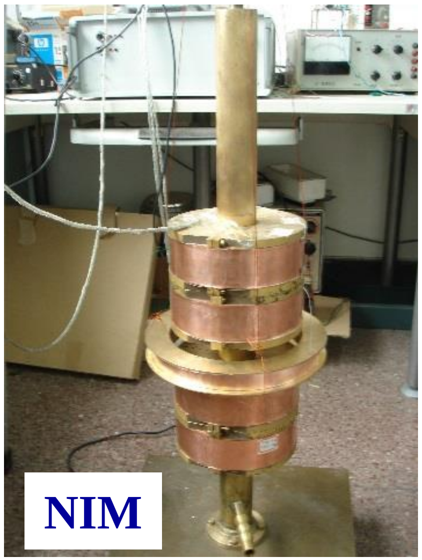
- The cost of developing and running experiments based on current technology does not encourage other NMIs to enter this field (or allow for “factory floor” application of SI traceability)

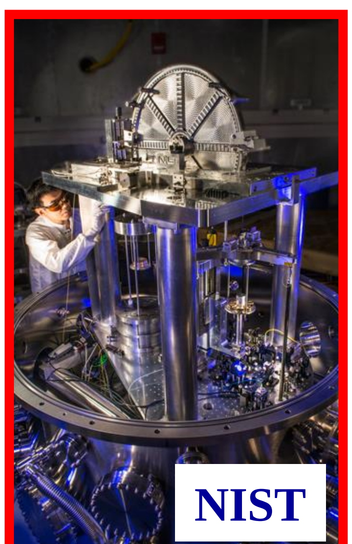
Mass and Related Quantities

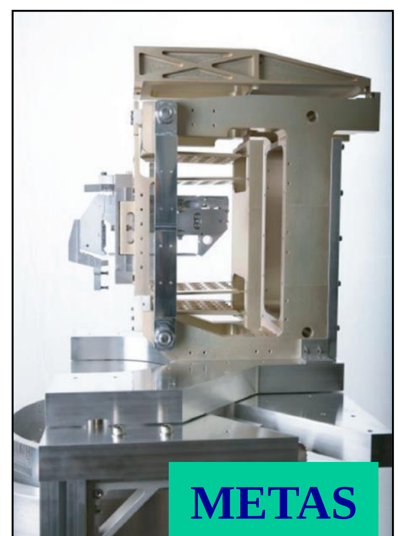
Kilogram realisation experiments worldwide

MSL









The “new” kilogram – Issues for EURAMET

- Three realisation experiments at the 2 in 10^8 level do not constitute a robust way to maintain and disseminate the unit of mass AND
- Only one of the realisation experiments at the 20 µg level involves EURAMET participants
- The aim the revision to the SI is to make the units more directly accessible to end-users. This is not currently possible with the SI unit of mass

SOLUTIONS

- Invest in the development of more practical means of implementing the realisation experiments giving access to more NMIs and to end-users
- Explore the options of realising the SI unit at other mass values (e.g. micro-mass and micro–force standards for pharmaceutical, micro-fabrication and personalised medicine)

Mass and Related Quantities

Thank you for your attention.

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The kilogram new definition

"*The kilogram, kg, is the unit of mass; its magnitude is set by fixing the numerical value of Planck's constant (h) to be equal to exactly 6.626 070 15* $\times 10^{-34}$ *when it is expressed in the unit* $s^{-1}\ m^{2}\ kg$*, which is equal to J s*."

Thanks to Stuart Davidson
SC- Mass Convenor

Mass and Related Quantities