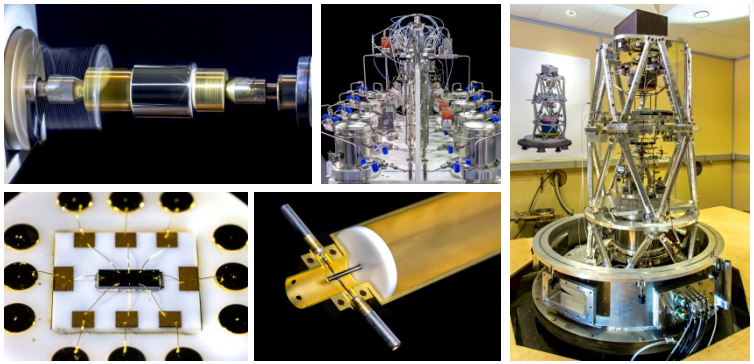
Report from the BIPM mass laboratories

Michael Stock

CCM 18-19 May 2017



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Activities in Mass

Present kilogram definition

- provision of 1 kg Pt-Ir prototypes to Member States
- mass calibrations (Pt-Ir, stainless steel) for NMIs (incl. volume / density)

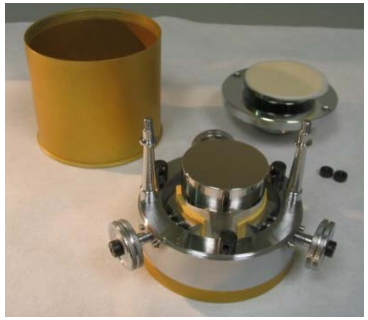
Preparations for the new SI

- extraordinary calibrations with respect to the IPK ✅
- CCM pilot study of primary kg realizations ✅
- development of a watt balance for future realization of kilogram → H. Fang
- creation of an ensemble of 1 kg mass standards stored in inert atmospheres (ERMS) to facilitate dissemination of new kg and for ongoing key comparisons → E. de Mirandés
- coordination activities (CCM, CCU, RMO TCs,...)

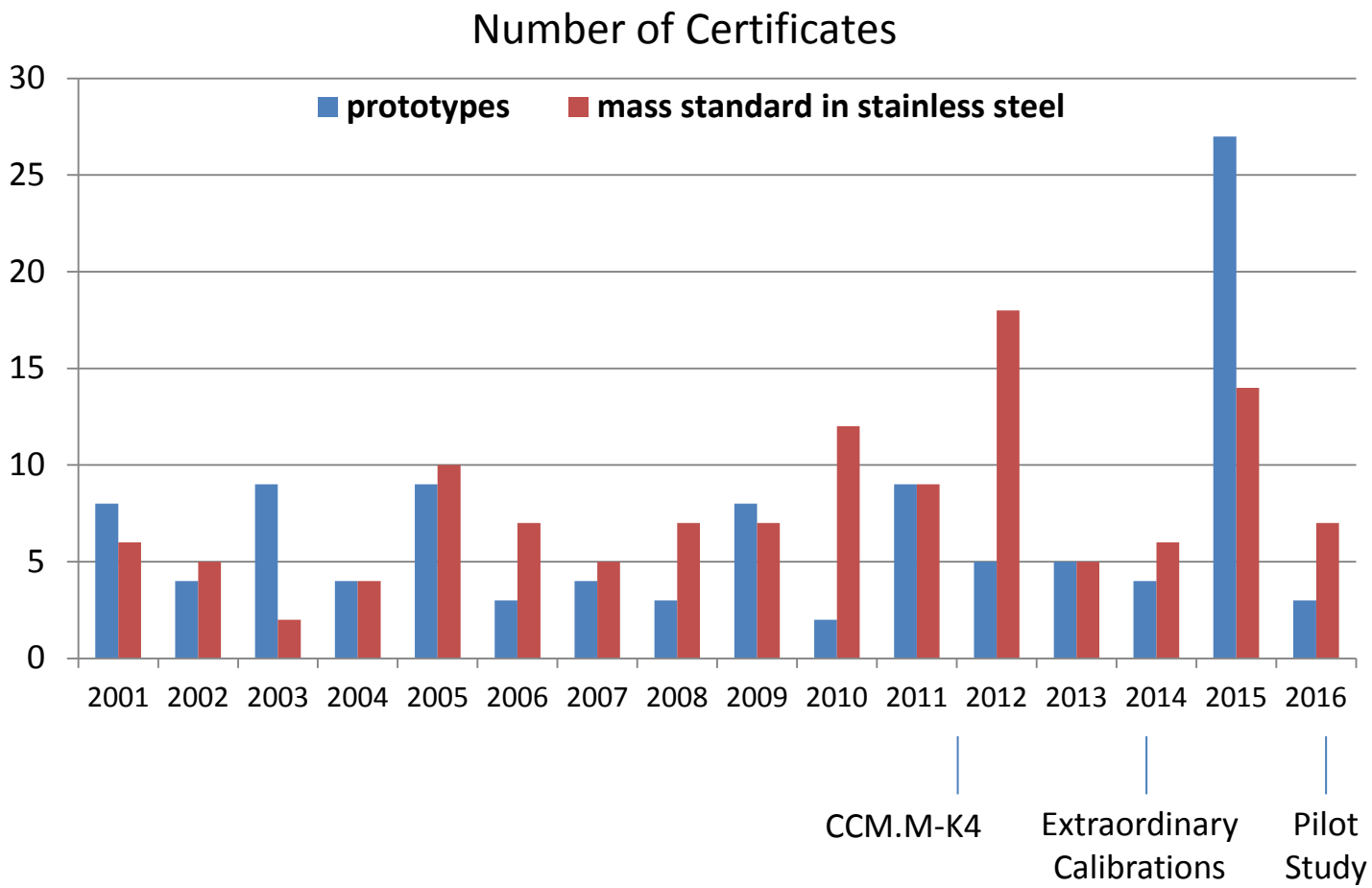
Fabrication of new prototypes and stacks 2015-2016

SASO (Saudi Arabia):	no. 93
NRC (Canada):	no. 106
Reserved for **Pakistan:**	no. 107
INM (Colombia):	no. 108
PTB (Germany):	no. 109
NIM (China):	no. 110
KRISS (Rep. of Korea):	no. 111 finished, to be calibrated

NPL (UK): 1 Pt-Ir stack, from material provided by NPL



Number of mass calibrations per year



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Guiding principles to ensure a stable BIPM mass unit

- BIPM working standards calibrated against IPK in 2014
- hierarchical system of mass standards with significantly different level of usage
- significant reduction of the total number of weighings
- use of statistical techniques to follow the mass evolution of the working standards
- use of subset of official copies for periodical verifications (10 years)
- regular report of status to CCM

Hierarchy of BIPM Pt-Ir prototypes and working standards, introduced in 2015

under authority of CIPM

IPK | K1 | 7 | 8(41) | 32 | 43 | 47

IPK & official copies: $\frac{\textit{1use of 2 copies}}{\textit{10 years}}$

25 | 73 | 91

prototypes for exceptional use:
(to be cleaned before use)

$\frac{\textit{1use}}{\textit{5 years}}$

9 | 31 | 650

standards for limited use:

$\frac{\textit{1use}}{\textit{year}}$

42' | 63 | 77 | 88 | 97 | 103

standards for current use:

$\frac{\textit{4 - 10 uses}}{\textit{year}}$

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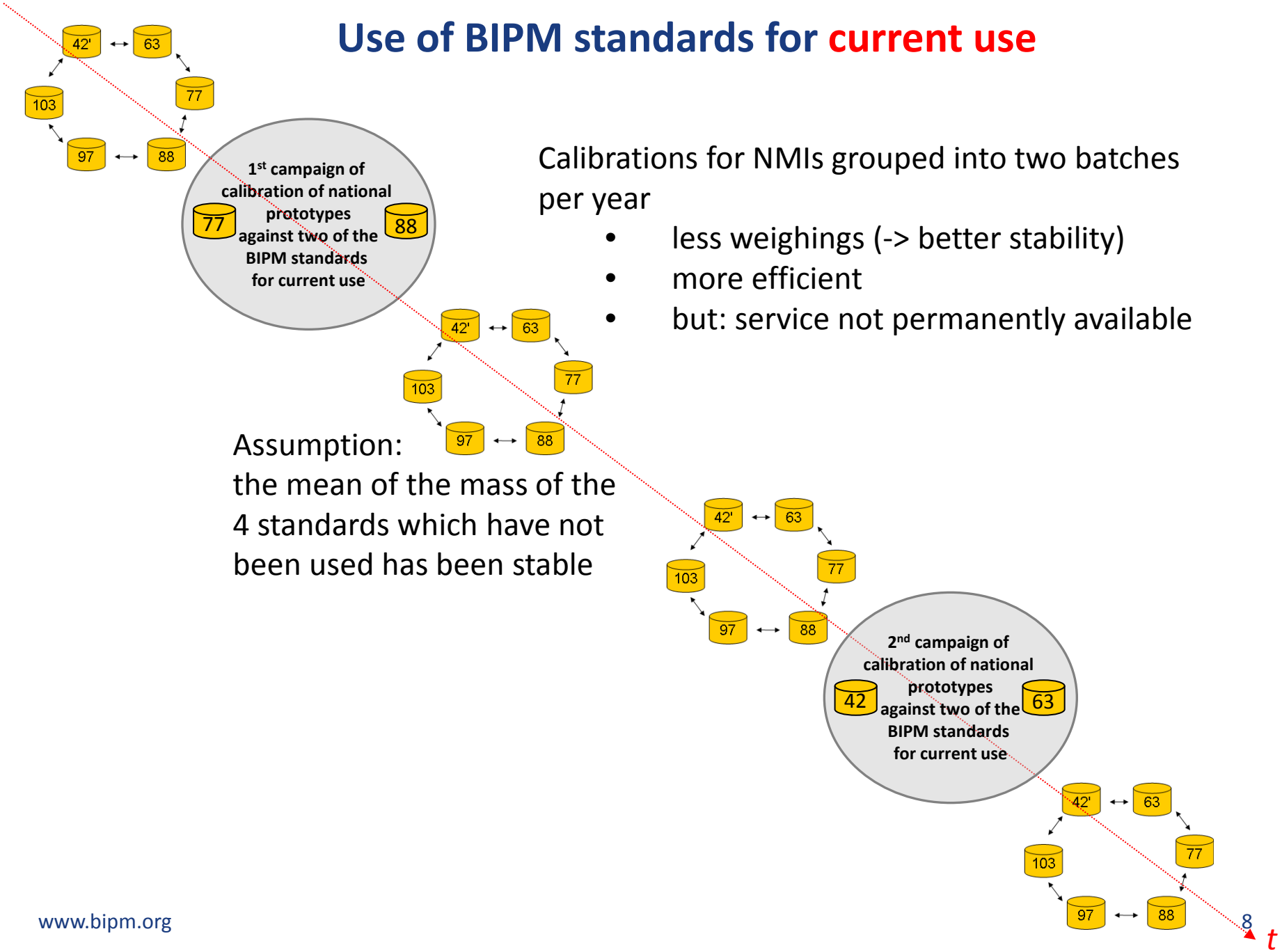
Use of BIPM standards for current use

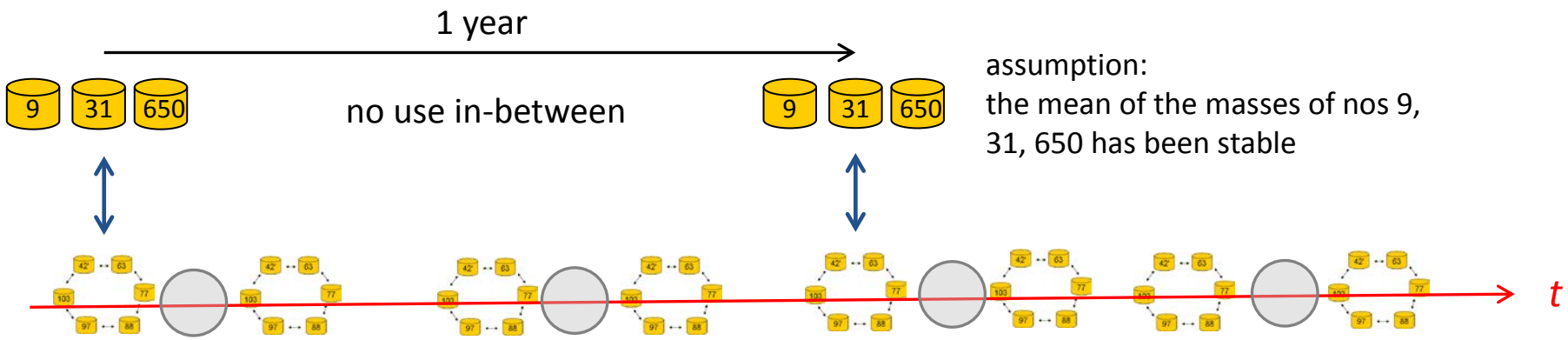


Calibrations for NMIs grouped into two batches per year

- less weighings (-> better stability)
- more efficient
- but: service not permanently available

Assumption:
the mean of the mass of the 4 standards which have not been used has been stable

Use of BIPM standards for limited use



assumption:
the mean of the masses of nos 9, 31, 650 has been stable

during 1 year, mass evolution of standards for current use derived from mass differences using two types of models:

- least-squares adjustment based on assumption that standards not used are stable (treating each campaign separately)
- deterministic models (using data accumulated since 2010)
- and comparing the results

if results are model dependent -> investigation of the situation, if necessary searching advice from CCM

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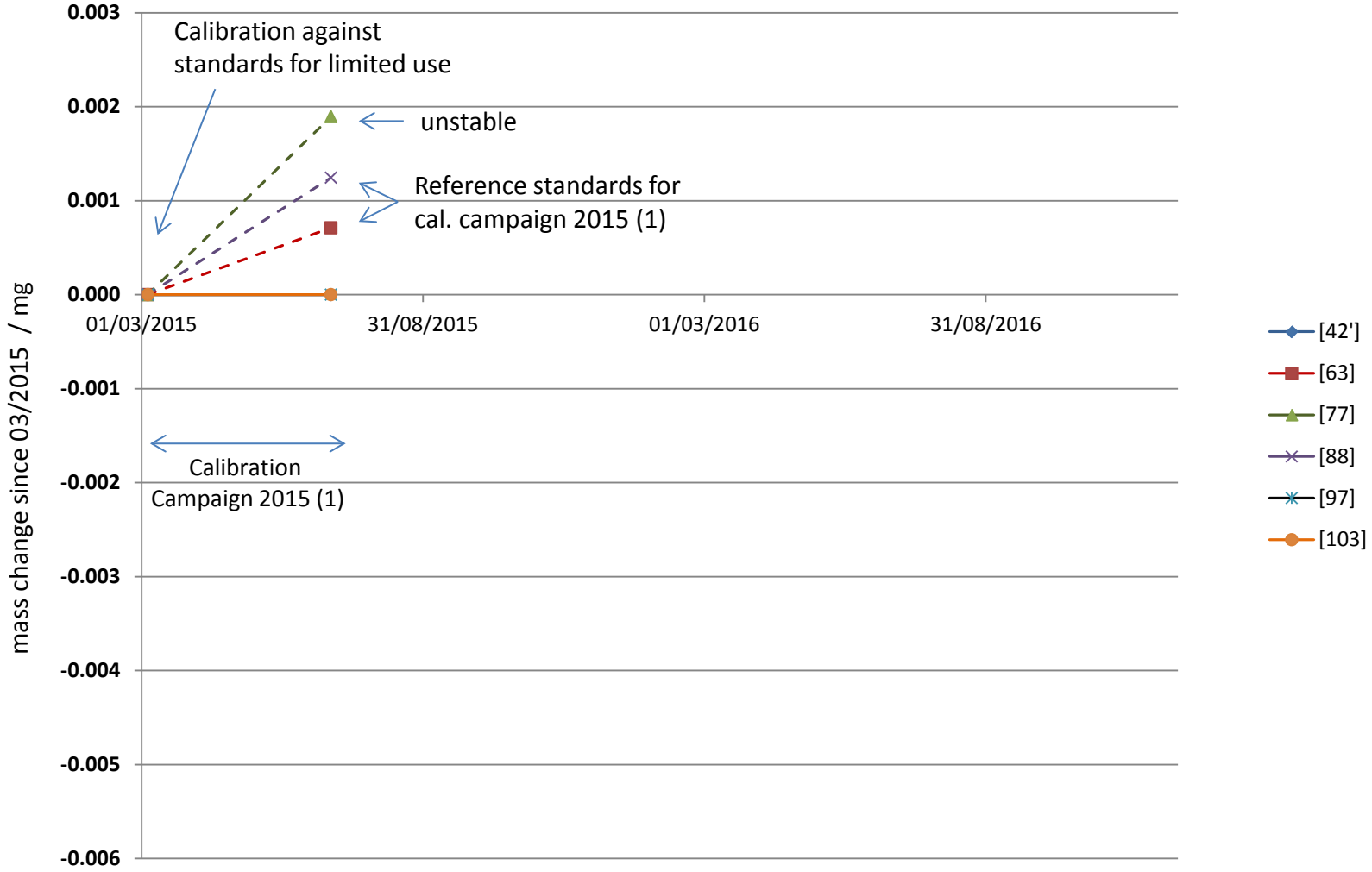
Calibration campaign 2015 (1)



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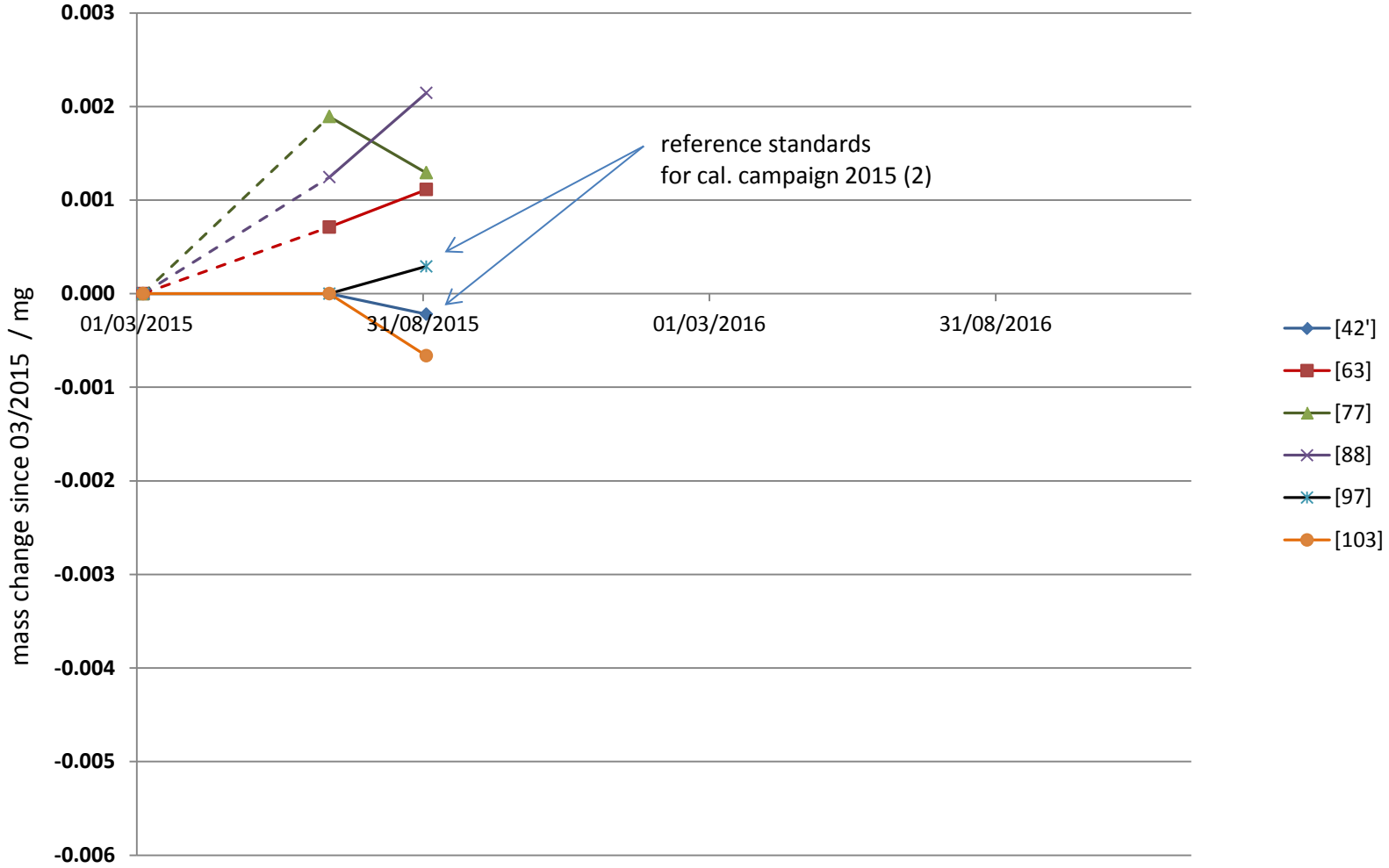
Before calibration campaign 2015 (2)



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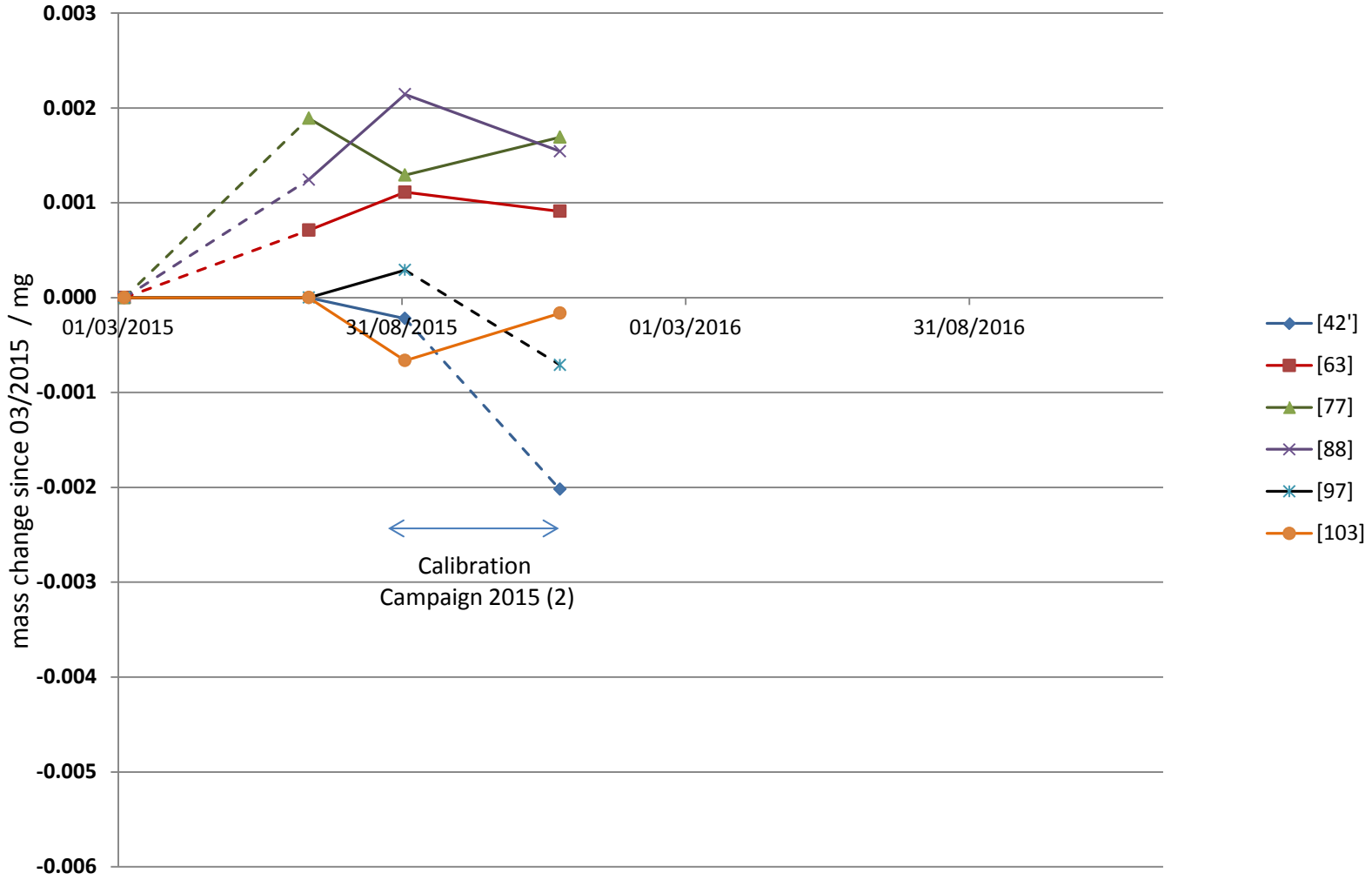

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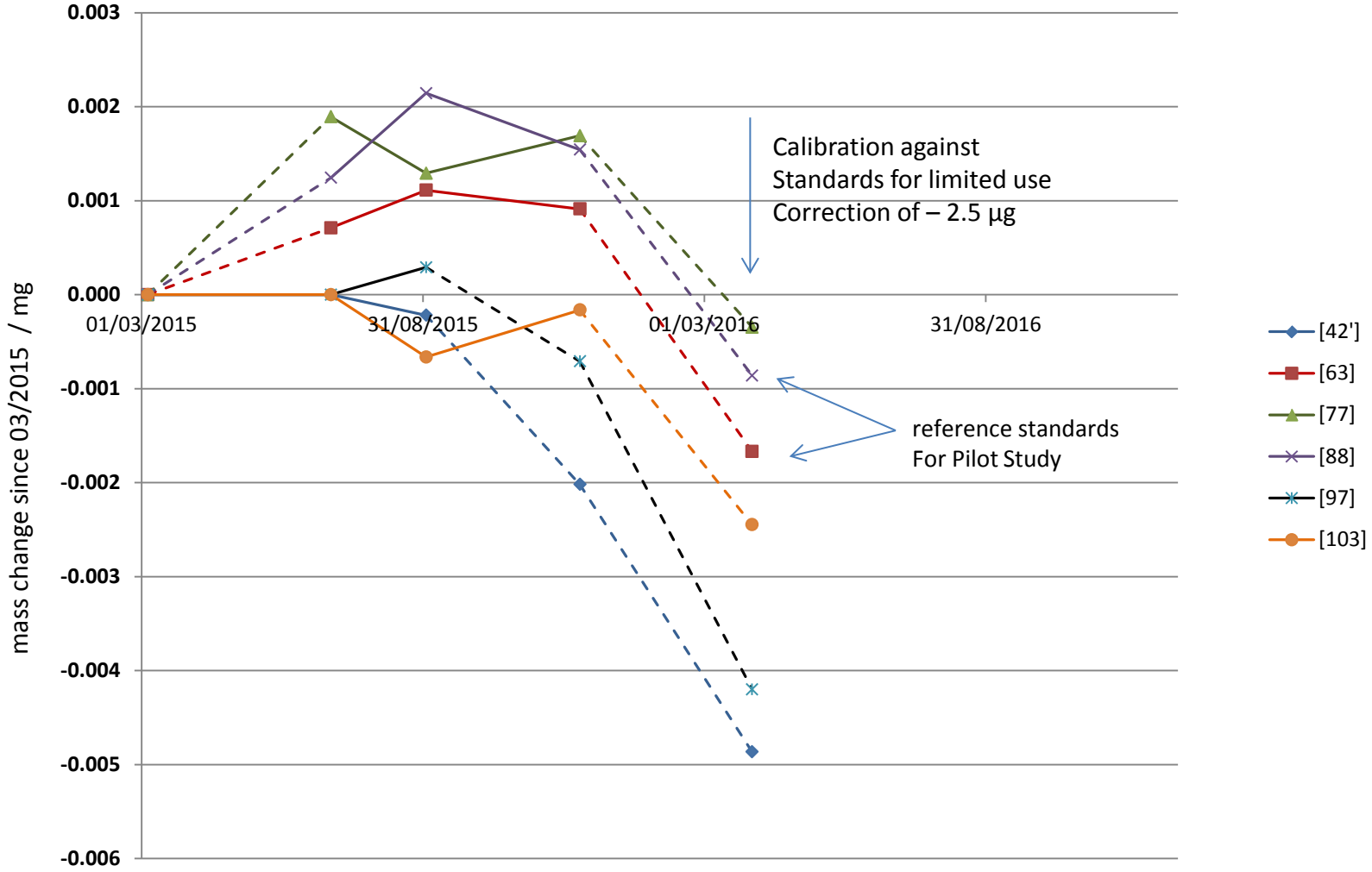
Comparison with standards for limited use Before CCM Pilot Study 2016



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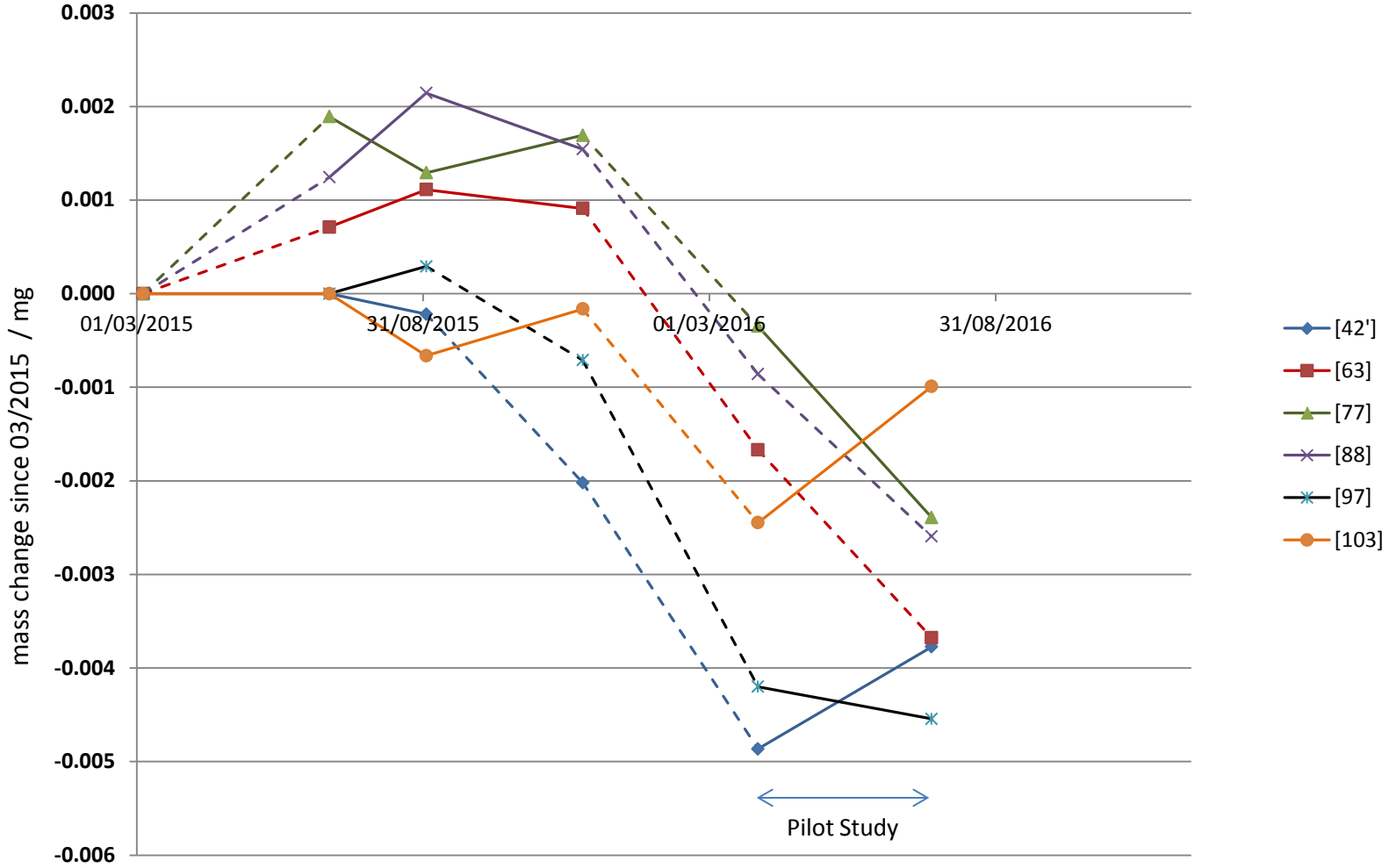
After CCM Pilot Study 2016



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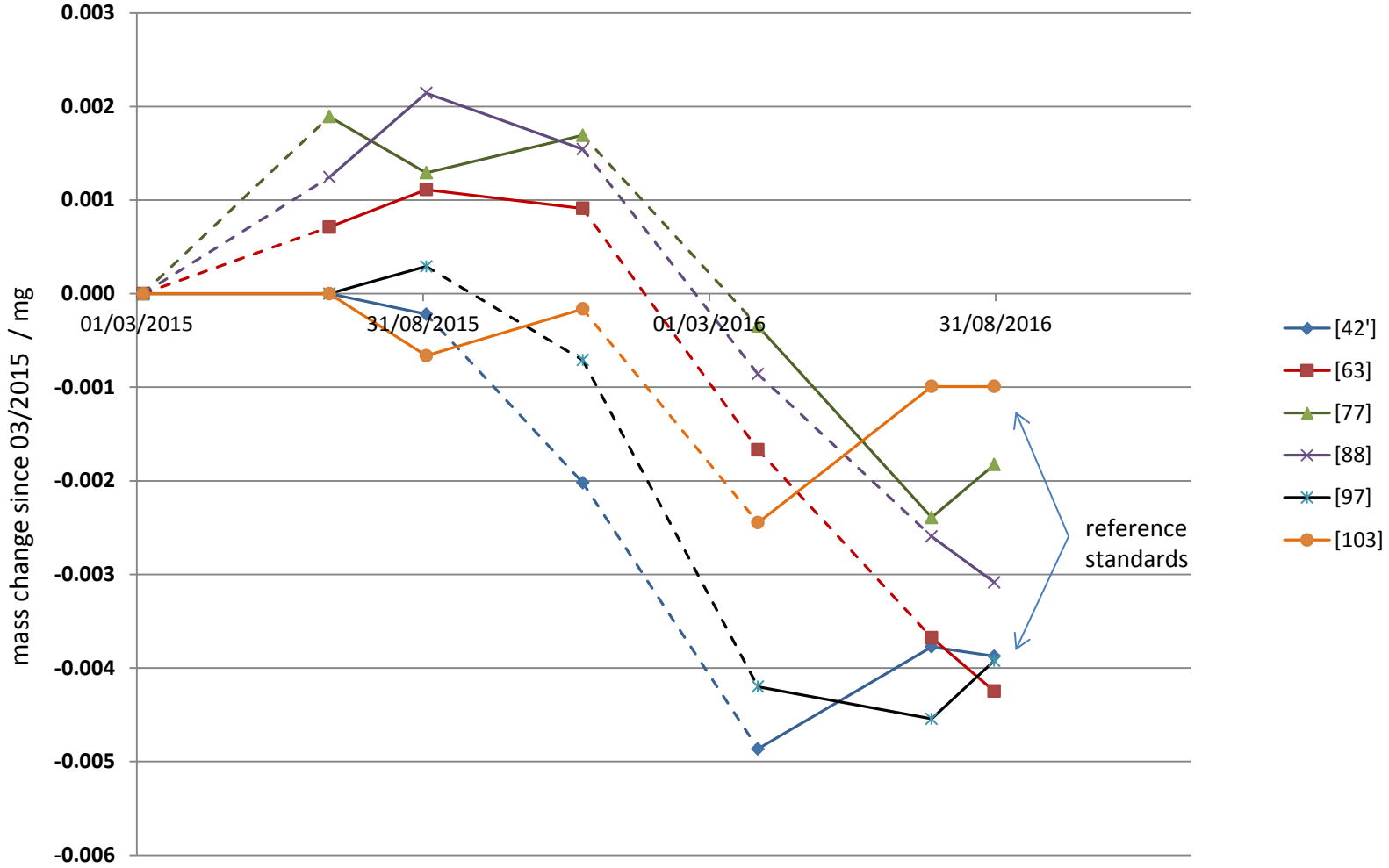
Before calibration campaign 2016 (2)



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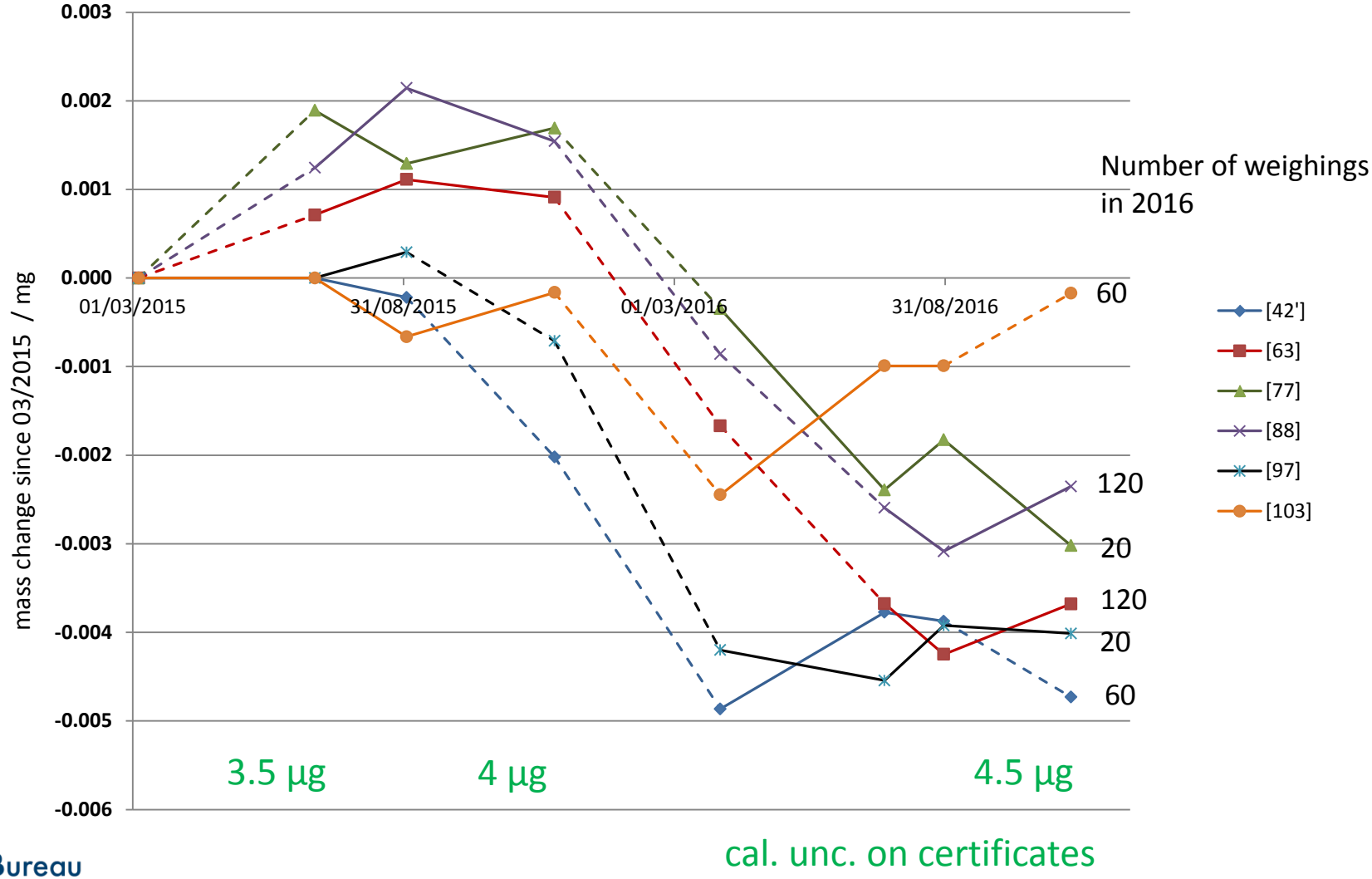
After calibration campaign 2016 (2)



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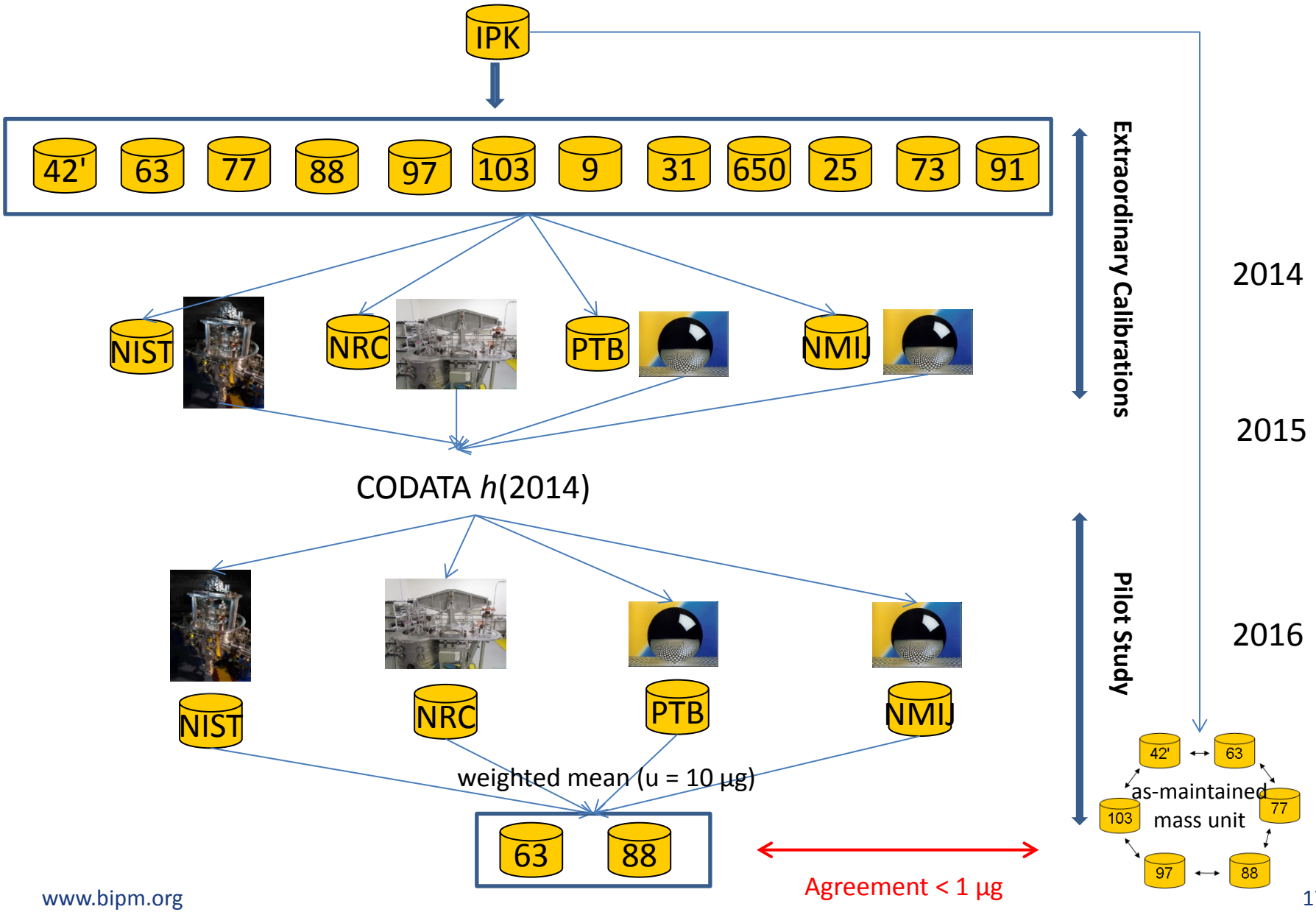
- Results for period 2015-2016 agree within 1 µg with predictions of deterministic model


IPK
42'
63
77
88
97
103
9
31
650
25
73
91
Extraordinary Calibrations
2014
NIST
NRC
PTB
NMIJ
2015
CODATA h(2014)
Pilot Study
2016
NIST
NRC
PTB
NMIJ
weighted mean (u = 10 µg)
63
88
Agreement < 1 µg
42'
63
77
103
97
88
as-maintained
mass unit

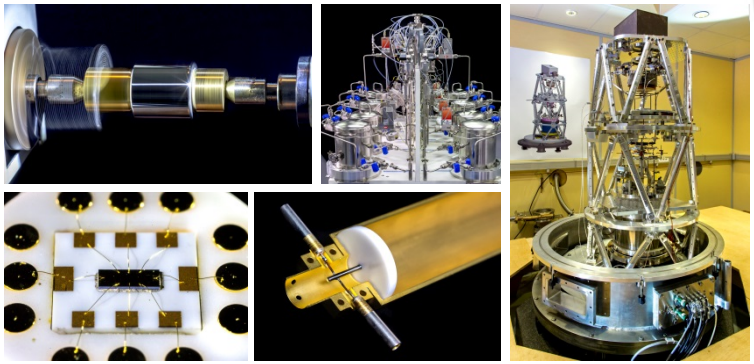
How to continue ?

- Process needs to be continued to collect more information:

  → new comparison with standards for limited use

- Verification of mass comparators
  - Metrotec tested in 2014, no wear found (confirmed by the mathematical modelling of the data 1992 to 2014)
  - CCL 1007 tested in 2016 with Si spheres, no wear found
  - M_One to be tested

Investigations on surface structures on Si spheres



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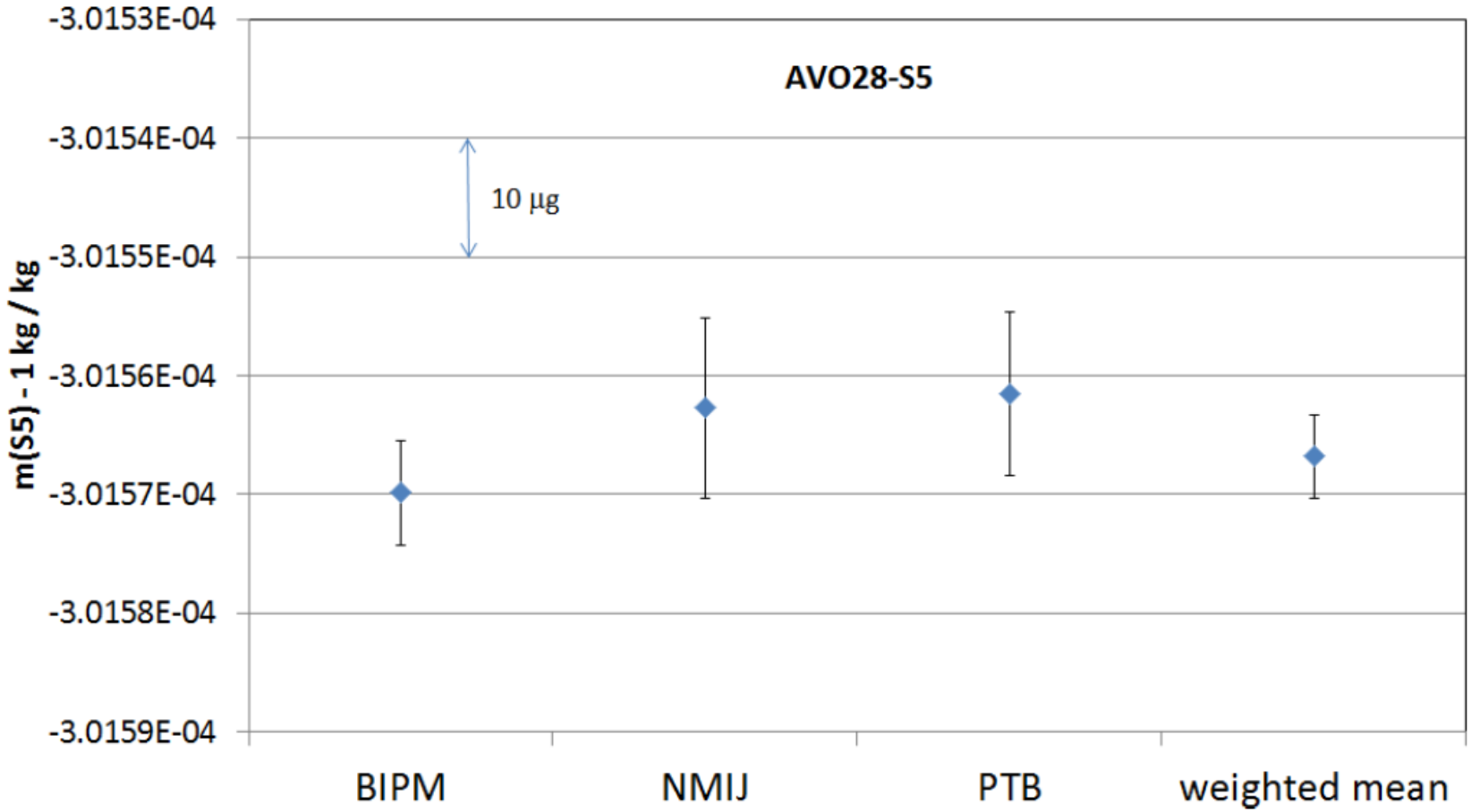
Determination of mass of AVO28-S5 and S8 in 2014



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Typical structure found by NMIJ on AVO28-S5 and S8

AVO28-S5

AVO28-S8

What is the origin of these structures ?

Analysis of surface damage of spheres

The 4 nat Si spheres S2, S3, S4 and S5 for the BIPM Ensemble of Reference Mass Standards were analyzed using a stereoscopic microscope equipped with a USB camera and image treatment software

- Investigation of the sphere surfaces as received
- Investigation of the sphere surfaces before and after measurement in Sartorius CCL 1007 (same meas. sequence as for AVO28-S5 and -S8)

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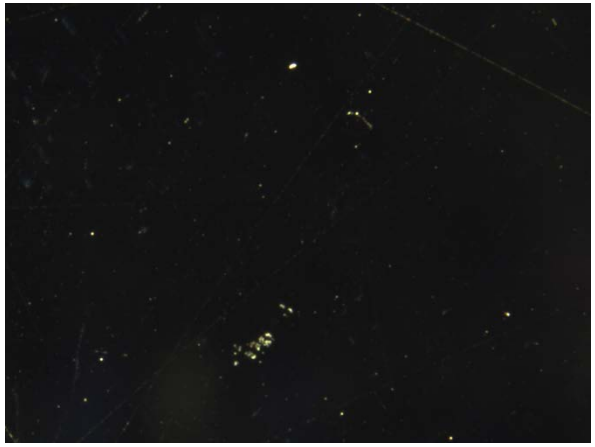
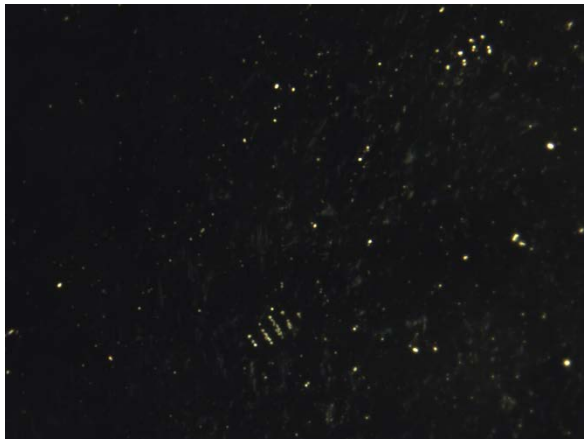
Structures observed on S2 and S4 as received

Before any use in a BIPM mass comparator

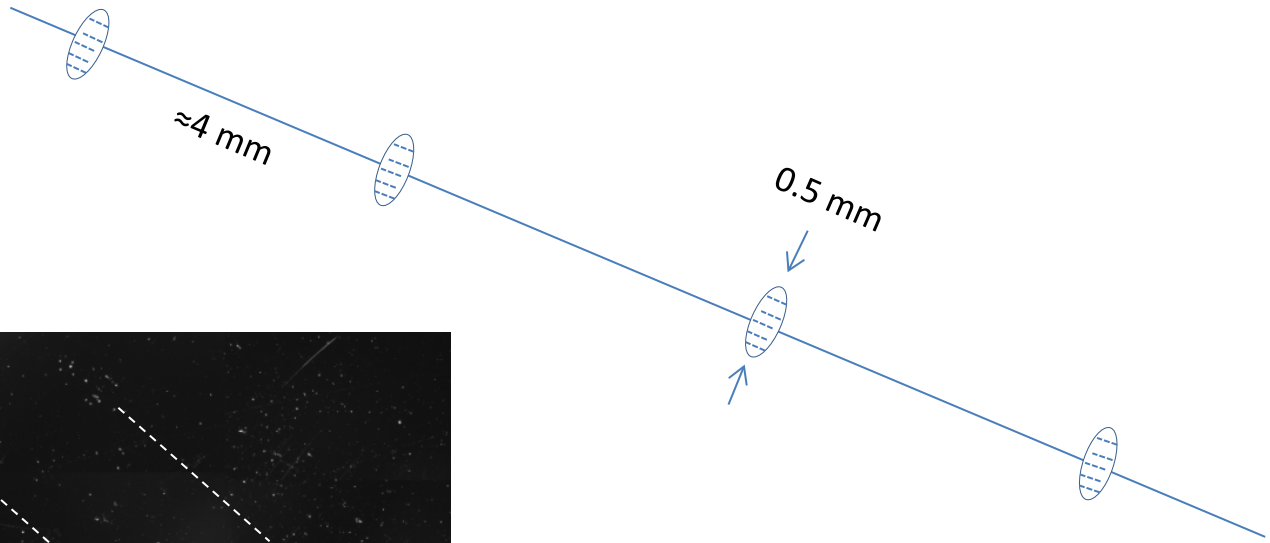


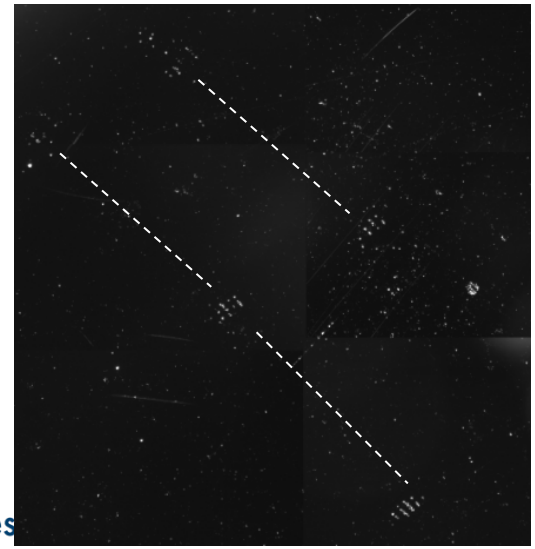


NMIJ photographs (AVO28)

Superstructure of the “clouds”

Several clouds arranged along a straight line, at relatively regular distances





Does this arrangement also exist on AVO28-S5 and -S8?

Test on Sartorius CCL 1007

Complete scan with microscope of annular zones on S2, S4 and S5

S2, S4 and S5 loaded into the CCL 1007 mass comparator, with annular zones in contact with support pins

Same measurement sequence as in 2014 for AVO28-S5 and S8

Scan of annular zones repeated

Result: no additional structures (clouds) found in annular zones

→ No surface damage caused by CCL 1007

Conclusions from sphere analysis

- Surface damage ("clouds") observed on AVO28-S5c and -S8c in April 2014 at NMIJ
- Very similar structures observed on S2 and S4 before use at BIPM
- Structures on AVO28 and BIPM spheres seem to have the same origin
- Structures on AVO28 spheres very likely not caused by BIPM
- BIPM CCL 1007 does not mark Si spheres

- Clouds are regularly arranged on straight lines, distance typically 4 mm
- <u>Possibly</u> caused by a device where they are in contact with a rotating wheel

Outlook 2018 -2019

- provision of 1 kg Pt-Ir prototypes to Member States
- mass calibrations (Pt-Ir, stainless steel) for NMIs
- completion of development of Kibble balance with rel. unc. below 0.1 ppm
- optimization (possibly also simplification) of ERMS as means of providing traceability for 1 kg calibrations with highest accuracy
- possibly late 2019 or 2020 beginning of a key comparison of kilogram realizations (similar to the Pilot Study)

Outlook long-term (2020-2025)

- organization of comparison of realizations of the kilogram, including bilaterals
- maintain the most robust ensemble of reference mass standards for providing tracebility for 1 kg mass calibations and as reference for comparison
- selection and implementation of the most accurate and efficient means of realization of the kilogram, incl. possibility of using AVO28-S5 and/or S8
- mass calibrations (Pt-Ir, stainless steel)
- provision of 1 kg Pt-Ir prototypes
- CB&KT in the field of mass metrology?