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# Analysis of BIPM mass data focusing on the period 2010-2016

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CCM

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# Scope of the work

- Check the stability of BIPM mass references
- Confirm/prove wrong that the wear of the standards has stopped
- Confirm/ prove wrong hat the current mass hierarchy scheme in place is the optimal one
- Find the mathematical model that best describes/predicts mass behavior

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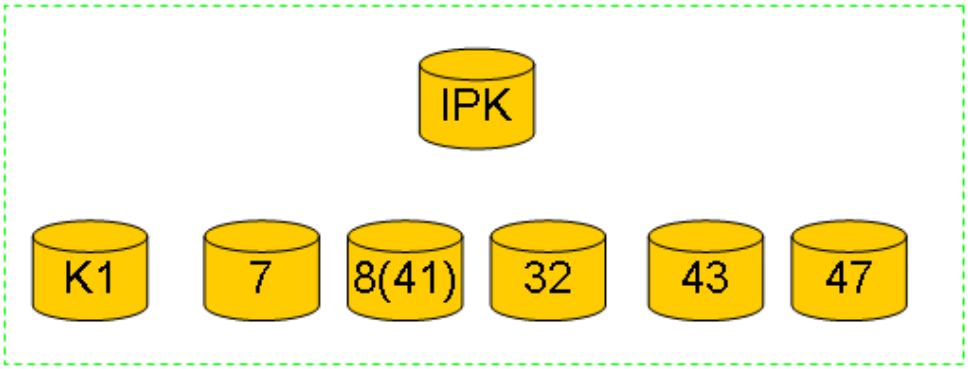
# Methodology

- **Model 3b** has been applied to the data within **1992-2016**
- **Model 3b** has been applied to the data within **2010-2016** (no HK1000)
- **Model 3b** has been applied to the data within **2014-2016**
- Other models with a reduced number of parameters have been tested
  - Model 5: one wear parameter per comparator, the same for all standards
  - Model 6: one wear parameter per standard, regardless of the comparator.
  - Model 1: one drift parameter per standard, no wear.

# Hierarchy within the BIPM PtIr mass standards starting after the Extraordinary Calibrations in 2014




International prototype of the kilogram: $\frac{\text{1 weighing}}{\text{30 - 50 years}}$

official copies: $\frac{\text{1 weighing of 2 copies}}{\text{10 years}}$

To be measured in 2019 → 25, 73, 91

prototypes for exceptional use: $\frac{\text{1 weighing}}{\text{5 years}}$

Measured in
- March 2015
- March 2016
- March 2017 (not yet)

→ 9, 31, 650

standards for limited use: $\frac{\text{1 weighing}}{\text{1 year}}$

42', 63, 77, 88, 97, 103

standards for current use: $\frac{\text{4 - 10 weighings}}{\text{1 year}}$

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# Number of weighings

| | Model 3b (3rd PV-2016) | | | | Model 3b (2010-2016) | | | Model 3b (2014-2016) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| standard | HK1000 | Metrotec | Mone | CCL1007 | Metrotec | Mone | CCL1007 | Metrotec | Mone | CCL1007 |
| IPK | 0 | 0 | 55 | 0 | 0 | 54 | 0 | 0 | 54 | 0 |
| K1 | 0 | 0 | 55 | 0 | 0 | 54 | 0 | 0 | 54 | 0 |
| 7 | 0 | 0 | 93 | 0 | 0 | 92 | 0 | 0 | 92 | 0 |
| 8(41) | 0 | 0 | 53 | 0 | 0 | 52 | 0 | 0 | 52 | 0 |
| 32 | 0 | 0 | 63 | 0 | 0 | 62 | 0 | 0 | 62 | 0 |
| 43 | 0 | 0 | 88 | 0 | 0 | 87 | 0 | 0 | 87 | 0 |
| 47 | 0 | 0 | 88 | 0 | 0 | 87 | 0 | 0 | 87 | 0 |
| 9 | 21 | 241 | 43 | 0 | 137 | 40 | 0 | 0 | 40 | 0 |
| 25 | 110 | 94 | 61 | 0 | 76 | 59 | 0 | 0 | 56 | 0 |
| 31 | 25 | 235 | 56 | 0 | 133 | 54 | 0 | 0 | 51 | 0 |
| 42 | 436 | 1142 | 184 | 0 | 348 | 182 | 0 | 41 | 146 | 0 |
| 63 | 467 | 1129 | 302 | 0 | 625 | 301 | 0 | 71 | 249 | 0 |
| 73 | 114 | 88 | 62 | 0 | 69 | 60 | 0 | 0 | 57 | 0 |
| 77 | 109 | 398 | 178 | 402 | 232 | 175 | 270 | 0 | 111 | 120 |
| 88 | 410 | 1215 | 338 | 0 | 674 | 336 | 0 | 71 | 254 | 0 |
| 91 | 181 | 560 | 361 | 0 | 399 | 359 | 0 | 0 | 300 | 0 |
| 650 | 341 | 1151 | 435 | 0 | 476 | 433 | 0 | 0 | 315 | 0 |
| 97 | 0 | 145 | 90 | 77 | 143 | 87 | 76 | 17 | 51 | 28 |
| 103 | 0 | 28 | 48 | 7 | 77 | 46 | 5 | 27 | 46 | 5 |

# Comparison of model 3b (1992-2016) with model 3b (2010-2016) and model 3b (2014-2016)

One wear parameter per comparator and per standard

$$m_i(t) = m_{0_i} + \gamma_i \sqrt{t - t_{NL}} + \sum_{comparator} \omega_{i,comp} N_{i,comp}$$

- Data (1992 - 2016)
  **HK1000, Metrotec, Mone and Sartorius**

$$18m_0 + 17\gamma + 10\omega_{HK} + 11\omega_{Met} + 19\omega_{Mone} + 2\omega_{CCL} = 77p$$

**(770 equations)**

- Data (2010 - 2016)
  **Metrotec, Mone and Sartorius**

$$18m_0 + 11\gamma + 19\omega_{Mone} + 11\omega_{Met} + 2\omega_{CCL} = 61p$$

**(467 equations)**

- Data (2014 - 2016)
  **Metrotec, Mone and Sartorius**

$$18m_0 + 11\gamma + 19\omega_{Mone} + 4\omega_{Met} + 2\omega_{CCL} = 54p$$

**(323 equations)**

Standards 9, 31 42, 63, 77, 88, 91 and 650 have not been cleaned-washed within 2010-2016, therefore for models 3b (2010-2016) and 3b (2014-2016) it has been imposed $\gamma_9 = \gamma_{31} = \gamma_{42} = \gamma_{63} = \gamma_{77} = \gamma_{88} = \gamma_{91} = \gamma_{650} = 0$.

Standards 97 and 103 have been given a lower weigh due to their very recent incorporation to the group and therefore their very few data.

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# Standard deviation of the models

| | (3rd PV-2016) | (2010-2016) | (2014-2016) |
|---|---|---|---|
| Fit residuals | 3.4 µg | 2.7 µg | 1.0 µg |

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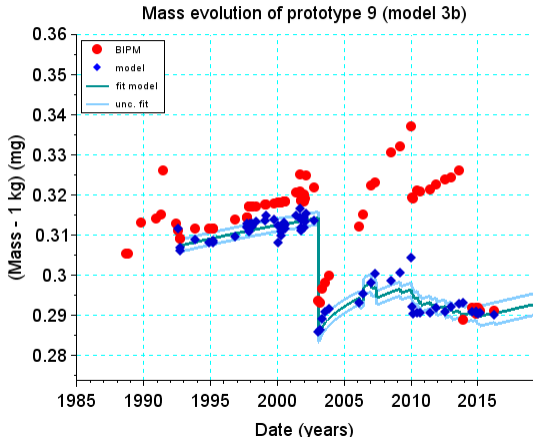
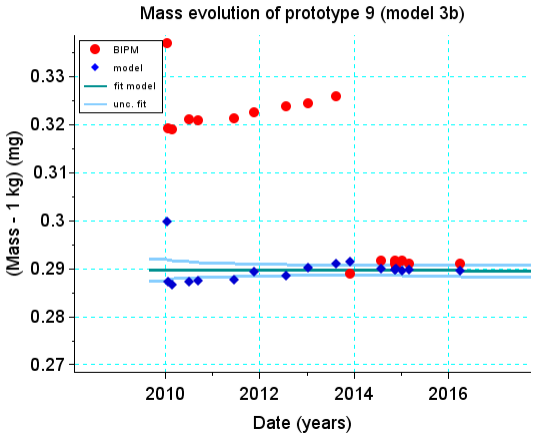
# Standard number 9

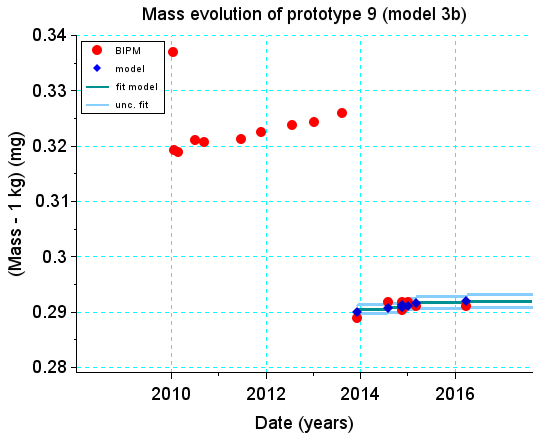
## Model 3b (1992-2016)



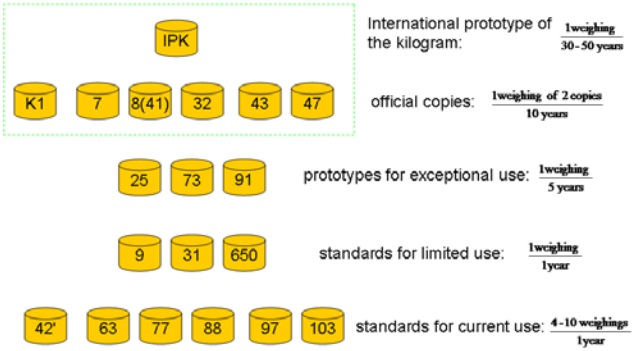

## Model 3b (2010-2016)




## Model 3b (2014-2016)




- The three models agree on the stability of standard 9 in the period 2010-2016



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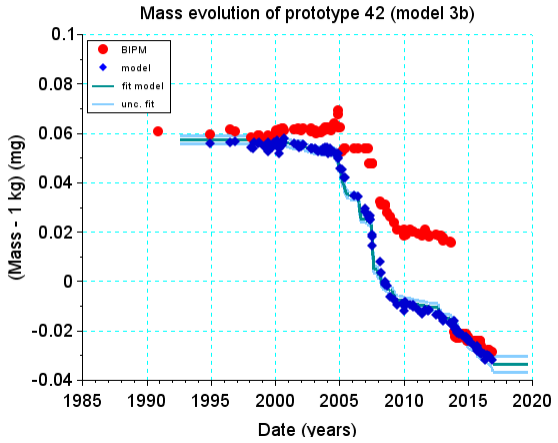
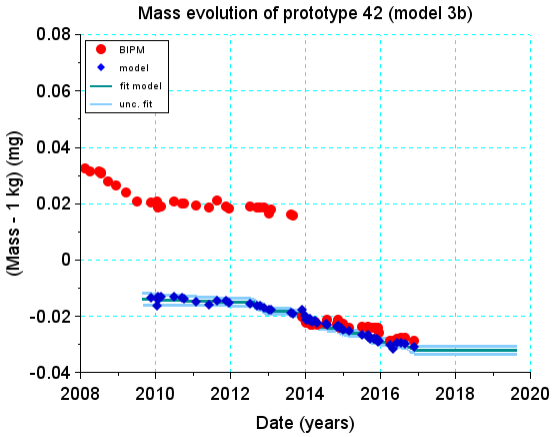
# Standard number 42’

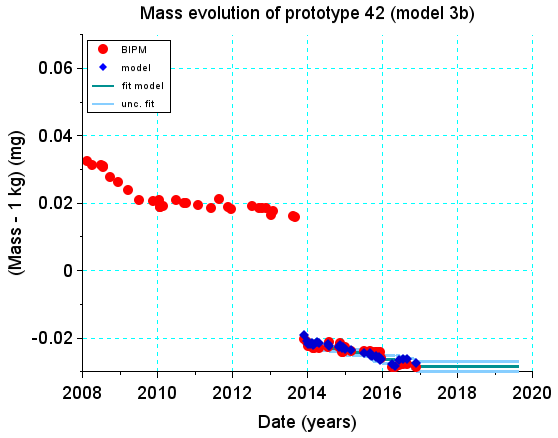
Model 3b (1992-2016)



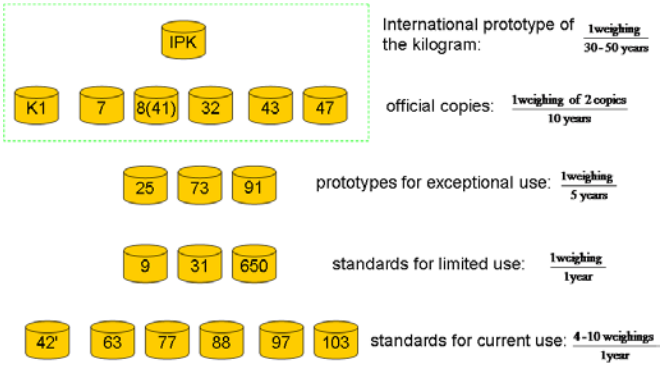

Model 3b (2010-2016)




Model 3b (2014-2016)




- The three models agree that 42’ keeps loosing mass.



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# Mass loss of each standard from 17/2/2014 to 24/11/2016 according to each model

(considering the blue curve)

$\Delta m = m_{24/11/2016} - m_{17/2/2014}$

| standard | (3rd PV-2016) $\Delta m$ (µg) | (2010-2016) $\Delta m$ (µg) | (2014-2016) $\Delta m$ (µg) |
|---|---|---|---|
| 42 | -14.2 (±2.1) | -10.8(±1.1) | -6.9(±1.4) |
| 63 | -9.2 (±2.4) | -6.8(±1.3) | -3.8(±1.4) |
| 77 | -8.7 (±1.6) | -7.1(±0.9) | -1.9(±1.3) |
| 88 | -8.4(±2.4) | -7.2(±1.3) | -2.8(±1.4) |
| 9 | +0.6(±1.9) | -0.1(±0.9) | +1.4(±0.9) |
| 31 | -0.9(±2.2) | -1.6(±1.1) | +1.7(±1.3) |
| 650 | +1.5(±0.8) | +0.8(±0.4) | +2.6(±0.7) |

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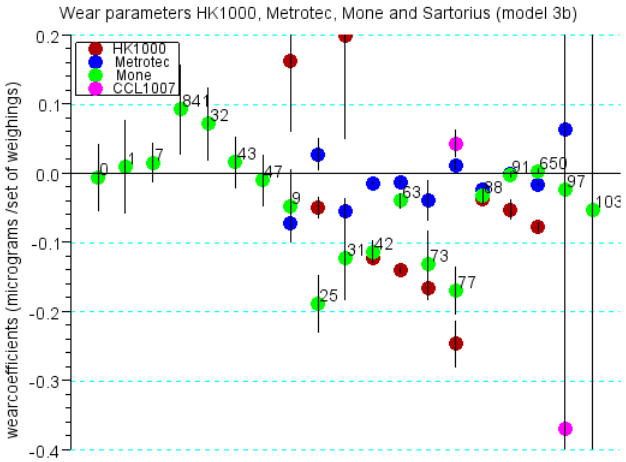
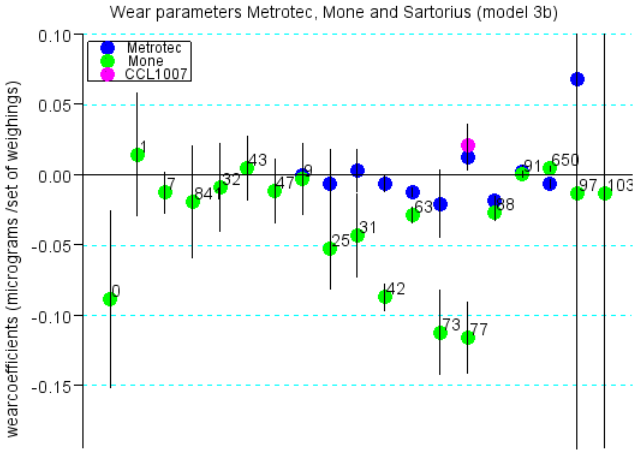
# Wear parameters

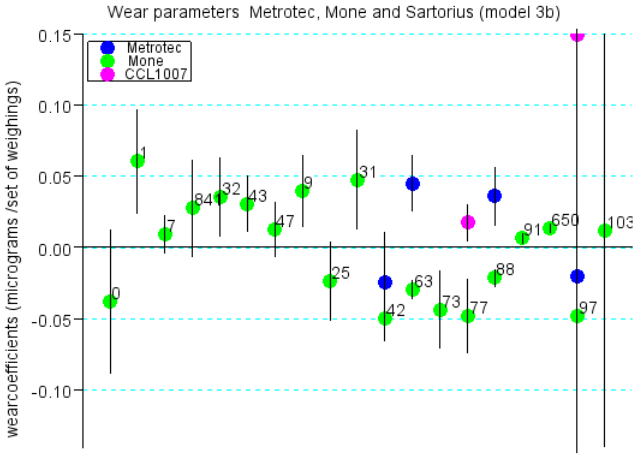
## Model 3b (1992-2016)




## Model 3b (2010-2016)




## Model 3b (2014-2016)




- In model 1992-2016, the wear of IPK is zero. For the other models this is not the case because IPK has been used only once in 2014 and therefore the models cannot determine its wear well.
- The three models agree with the fact that standards 42', 63, 77 and 88 show a well defined wear, atributted mostly to the Mone after 2010. This wear seems of the same order of magnitude than the wear exhibited by the HK1000 comparator prior to 2010.
- The Metrotec comparator seems pretty harmless regardless of the very large number of measurements made with it.

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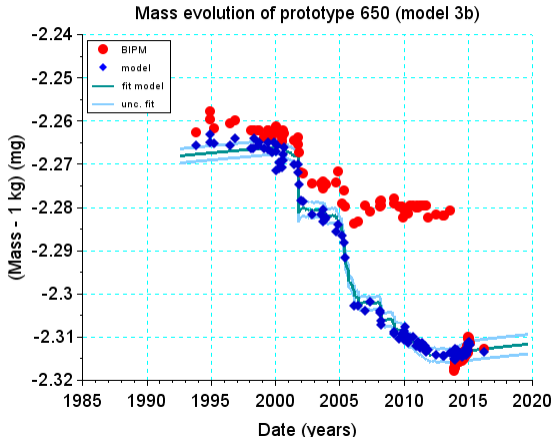
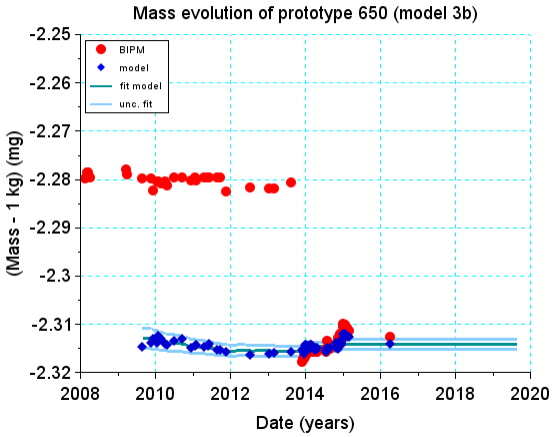
# Standard number 650

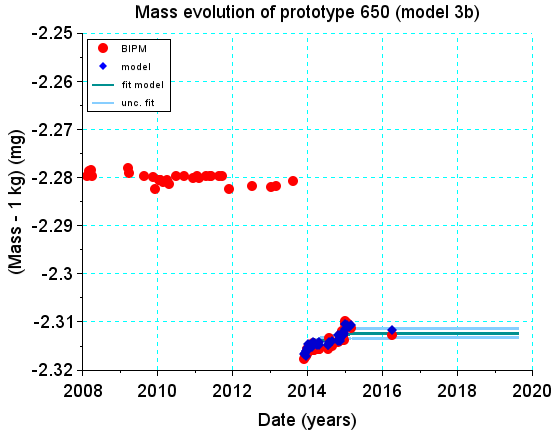
## Model 3b (1992-2016)




## Model 3b (2010-2016)




## Model 3b (2014-2016)




- Standards 91 and 650 show wear from 2010 to 2014.
- During the extraordinary verification in 2014 both have been used together and extensively. During this period they both seem to show a similar mass behavior with a slight increase. This could be attributed to a particular methodology during the verification ¿?
- Standard 650 has been measured in 2016. The mass increase phenomenon seem to have stopped.

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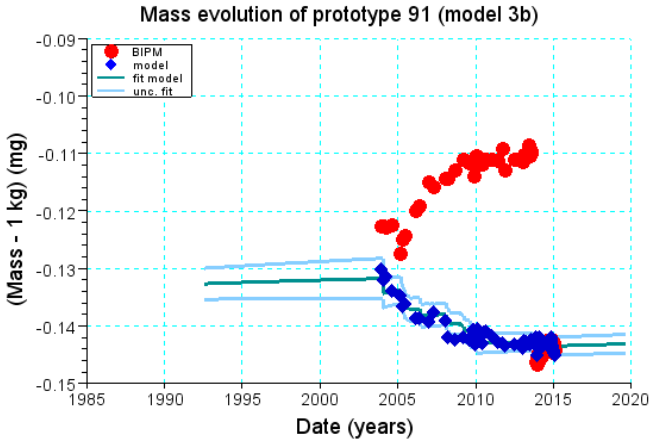
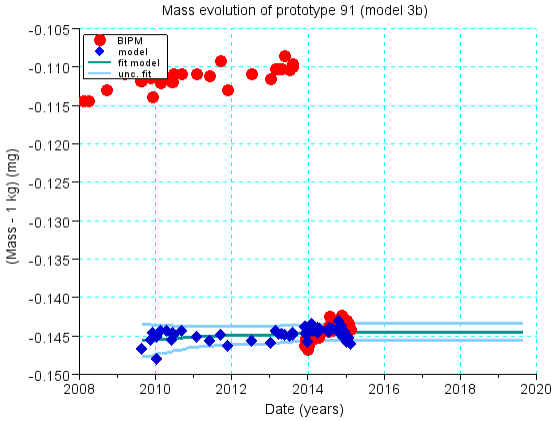
# 91

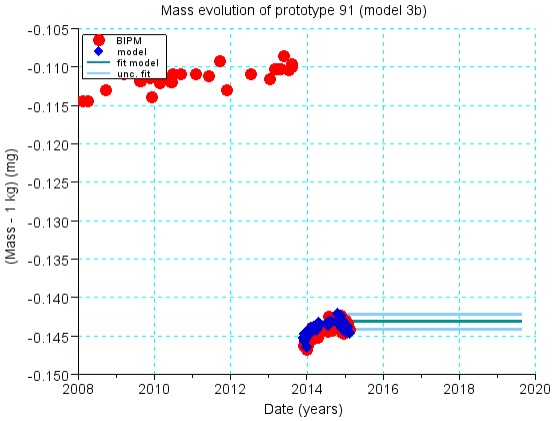
## Model 3b (1992-2016)




## Model 3b (2010-2016)




## Model 3b (2014-2016)



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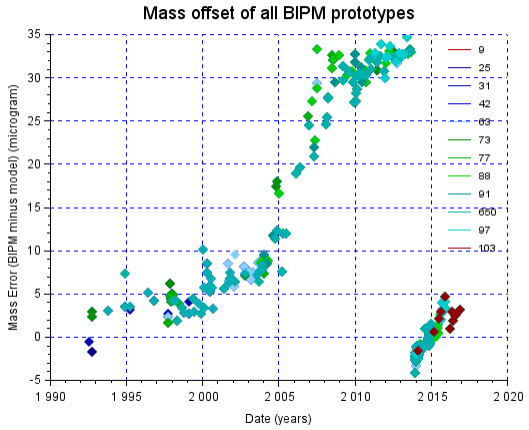
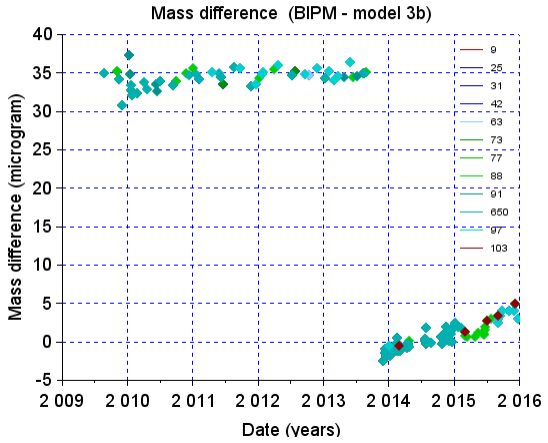
# Differences between the numerical models and the classical BIPM calculations

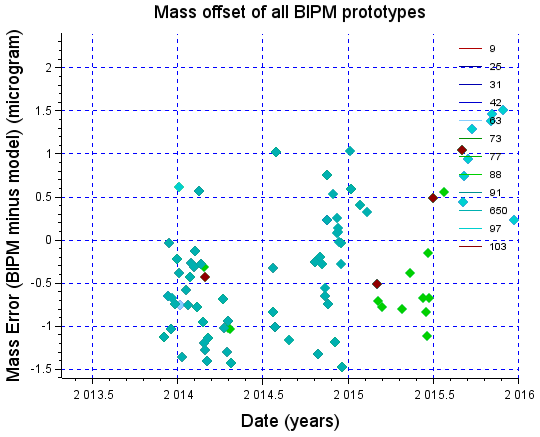
## Model 3b (1992-2016)




## Model 3b (2010-2016)




## Model 3b (2014-2016)



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# Conclusions

- There seems to be still wear in the BIPM mass comparison process. The wear seems to be linked to the balances, and would be higher for the Mone than for the Metrotec.
- Standards 9 and 31 (low measurement frequency) are stable. The present piramidal weighing scheme should be kept.
- Our measurements seem to point to a particular phase of the weighing process as responsible for the wear.
- The numerical model is in good agreement with the traditional BIPM calculations in the assignment of mass values to our standards.