On the drift-free SG time series and comparisons of absolute gravimeters

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Combination of AG and SG

Superconducting Gravimeter (SG)

- relative values
- precision < 0.1 nm/s^2
- continuous registration
- high temporal resolution

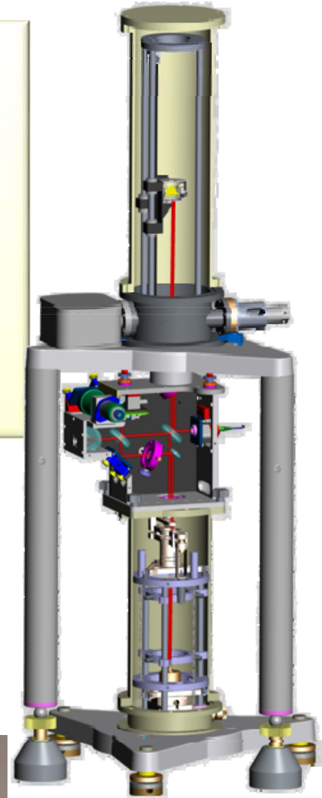
Absolute Gravimeter (AG)

- based upon physical standards
- no drift
- uncertainty: ± 25 nm/s^2
- observation epochs

Combination includes:

- SG drift determination
- Calibration
- AG: Test for offsets

➔**Gravity reference function** with highest resolution *and* long-term stability



Requirements:

- consistent AG data

- no instrumental artefacts in SG data

Strategy paper of CCM and IAG

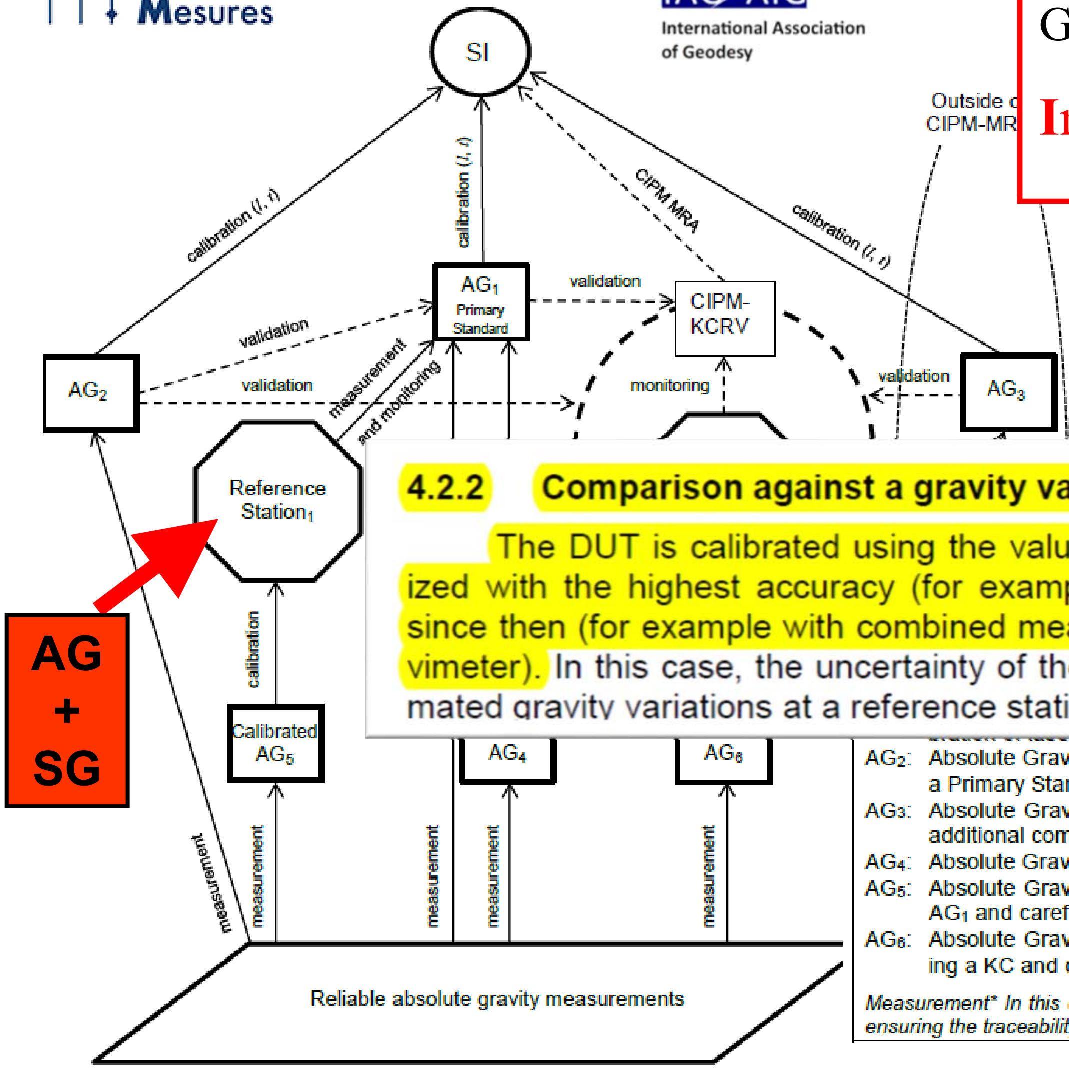
Bureau International des Poids et Mesures

International Association of Geodesy

Referred in 2016 by IAG Resolution (No. 2): Establishment of a Global Absolute Gravity Reference System ⇒

International Gravity Reference Frame

Reference stations can be used also for calibrations of AGs



4.2.2 Comparison against a gravity value of a reference station

The DUT is calibrated using the value of a reference station that has been characterized with the highest accuracy (for example during a KC) and that is carefully monitored since then (for example with combined measurements of absolute and superconducting gravimeter). In this case, the uncertainty of the DUT has to include also the uncertainty of estimated gravity variations at a reference station.

AG_2: Absolute Gravimeter with independent traceability to SI units (§4.1) validated in comparison with a Primary Standard Absolute Gravimeter or with the CIPM-KCRV (§4.1.1 - §4.1.3).

AG_3: Absolute Gravimeter with independent traceability to SI units (§4.1) validated with KCRV of an additional comparison outside the scope of CIPM MRA (§4.1.4).

AG_4: Absolute Gravimeter calibrated against a reference gravimeter (AG_1) (§4.2.1).

AG_5: Absolute Gravimeter calibrated against a gravity value of the Reference $Station_1$ (measured by AG_1 and carefully monitored) (§4.2.2).

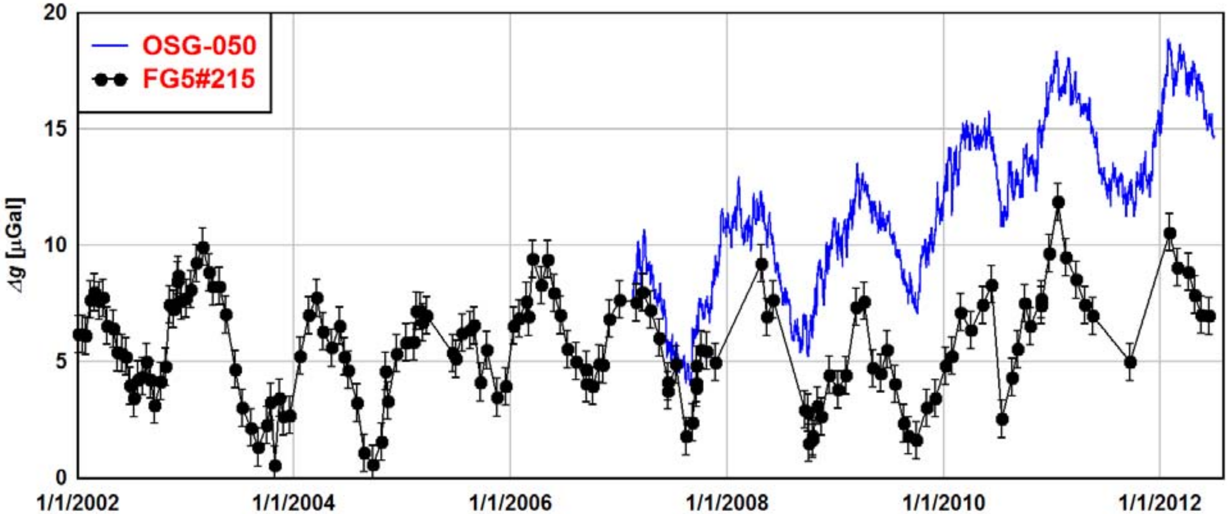
AG_6: Absolute Gravimeter calibrated against a gravity value of a Reference $Station_2$ (measured during a KC and carefully monitored) (§4.2.2).

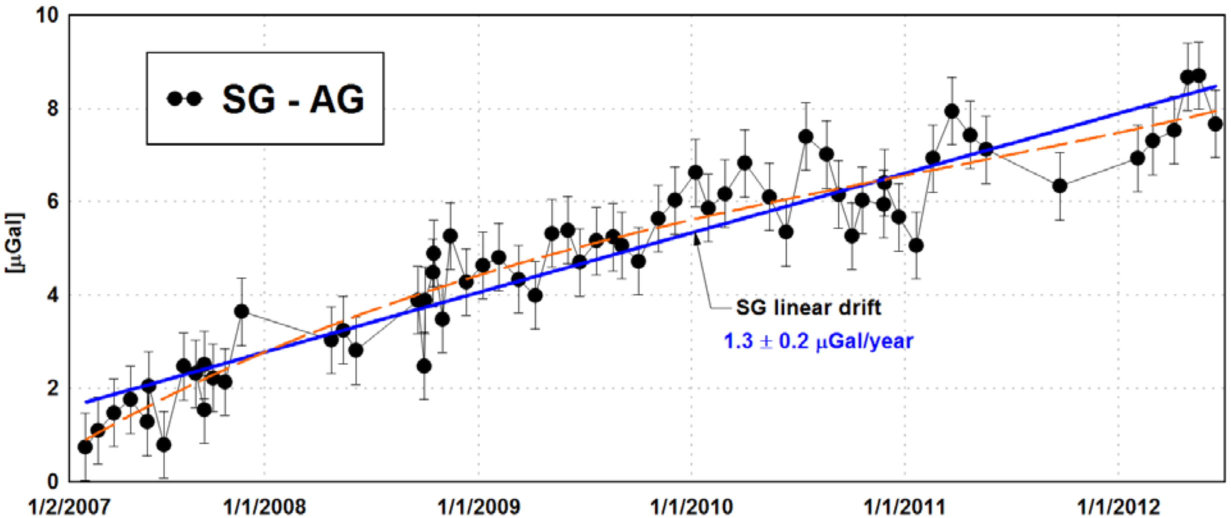
Measurement In this case, measurements carried out by AG_3 cannot establish any measurement certificate for ensuring the traceability to the SI.*

Figure 1: Scheme of the traceability chain in gravimetry, according to §§4.1 – 4.2.

AG vs. SG: Pecný

To distinguish between SG instrumental drift and the real trend of the gravity reference function, repeatedAG measurements are needed.





Example: repeated measurements with one AG only.

Requirements:

- consistent treatment of AG data since different instrumental corrections are applied over longer time span (e.g. self attraction, diffraction, fringe size etc.)
- apply same gradients and transfer heights for all data.

Are these requirements sufficient?

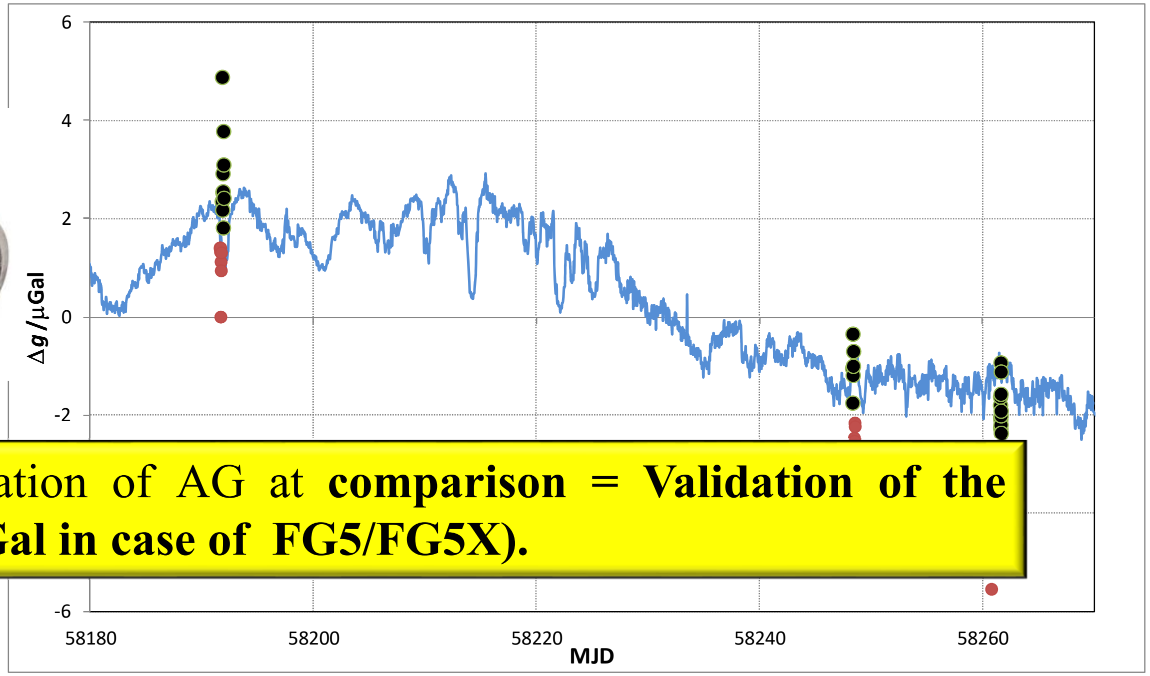
Variable systematic errors

NO! Additional parameters have to be validated/determinated, since **systematic errors of an AG** are not perfectly stable in time:

- **FG5 standard maintenance** ⇒ Coriolis effect (± 1 µGal), rotation of the corner cube (± 1 µGal)
- **laser alignment:** change of the diffraction correction (± 2 µGal), electronic effects (± 2 µGal)

From this point of view: **It is hard to ensure that a particular AG is providing consistent measurements (at the level of it's repeatability** ± 1.5 µGal**) over 10-20 years.**

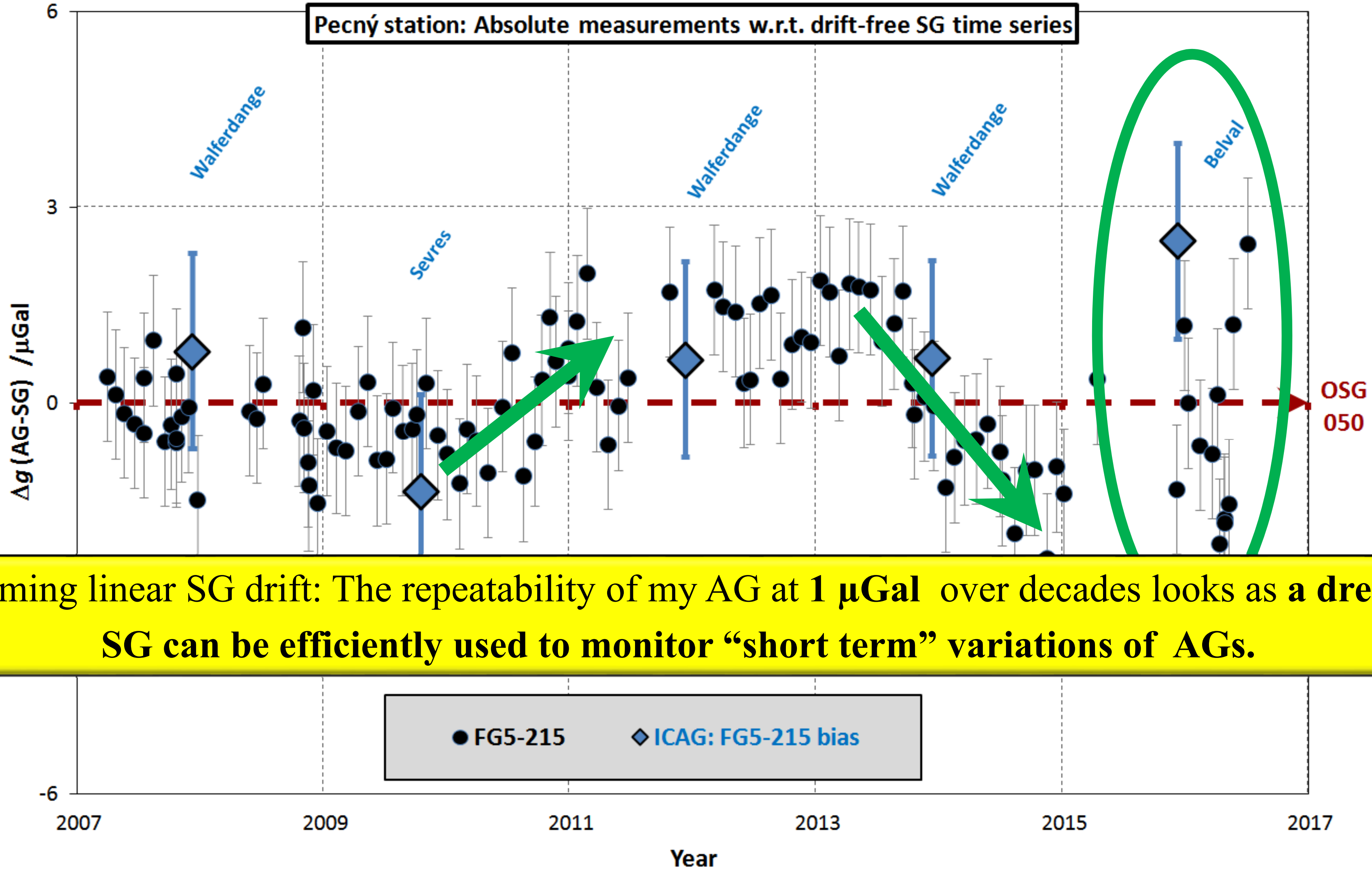
An effect due to two different collimators ≈ *2 µGal* ***(change of the diffraction effect)***



Very important is the participation of AG at **comparison = Validation of the declared uncertainty (± 2.5 µGal in case of FG5/FG5X).**

AG-SG differences: Pecný

Repeatability of my meter is excellent ± **0.8 µGal.** Thus, I will use **only one AG for drift determination (1.5 µGal / year):**



Assuming linear SG drift: The repeatability of my AG at **1 µGal** over decades looks as **a dream.**

SG can be efficiently used to monitor "short term" variations of AGs.

AG vs. SG: Wettzell OLD lab

Wettzell: SG029 - old gravity lab: 2012 -2017 - observations

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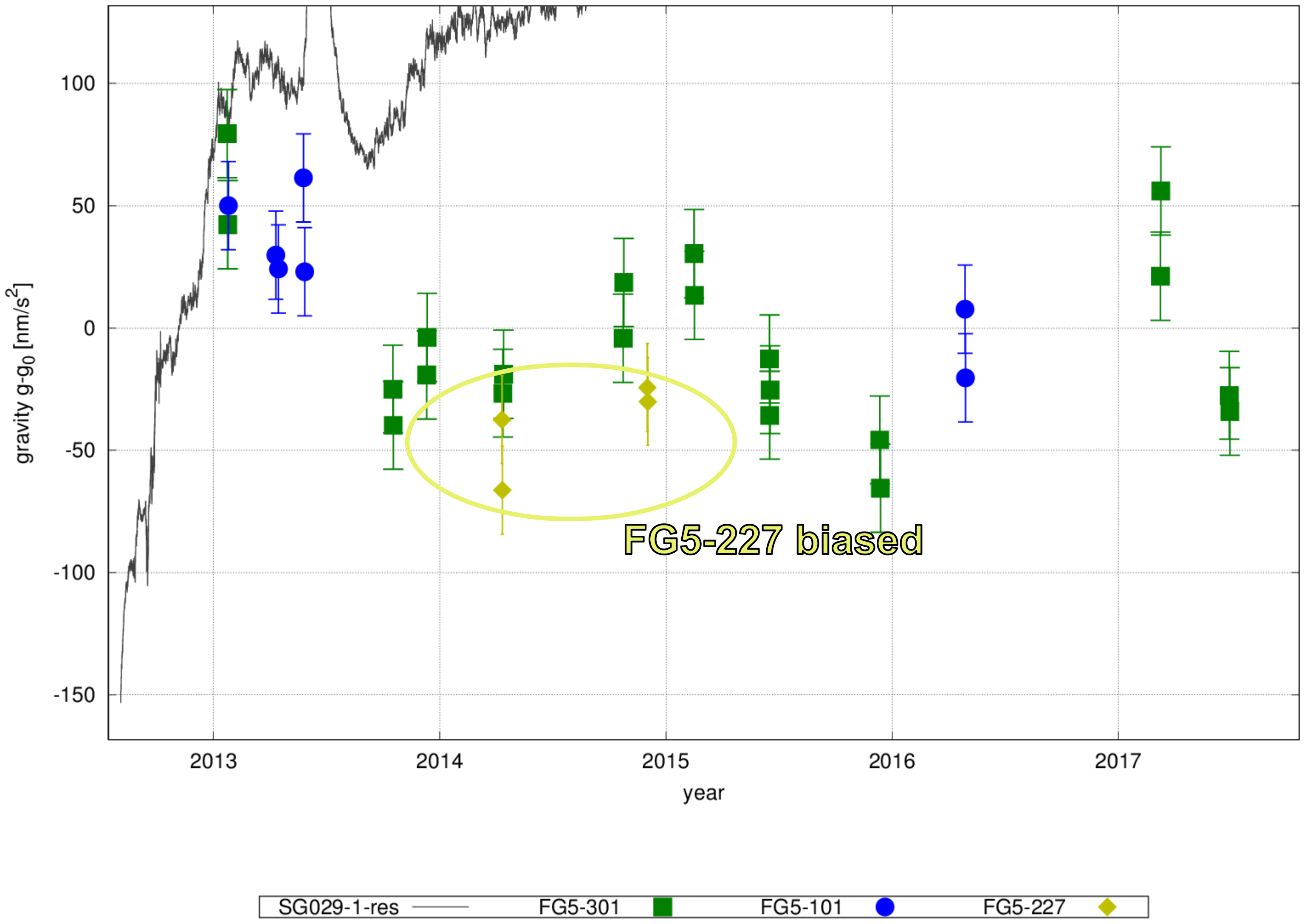

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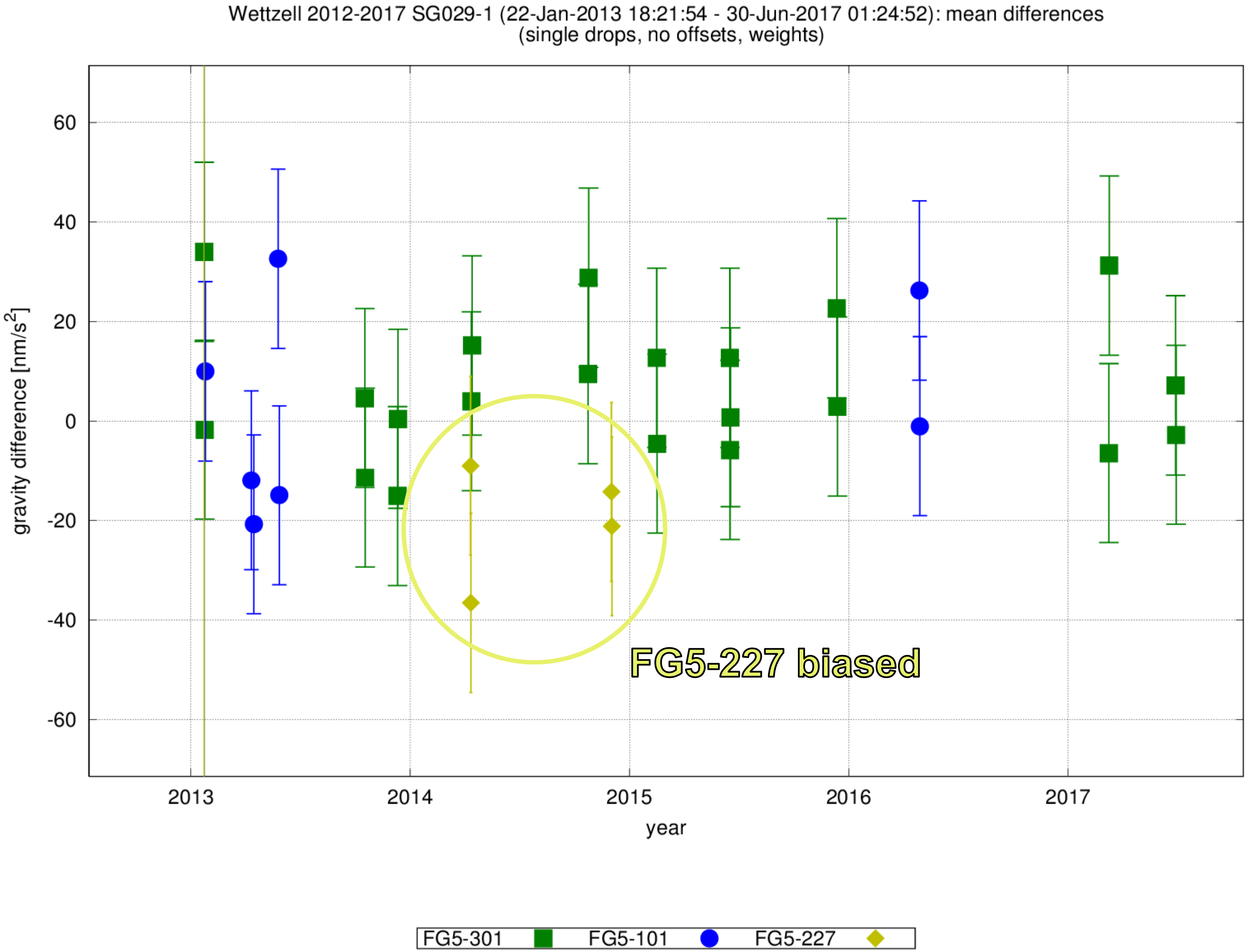
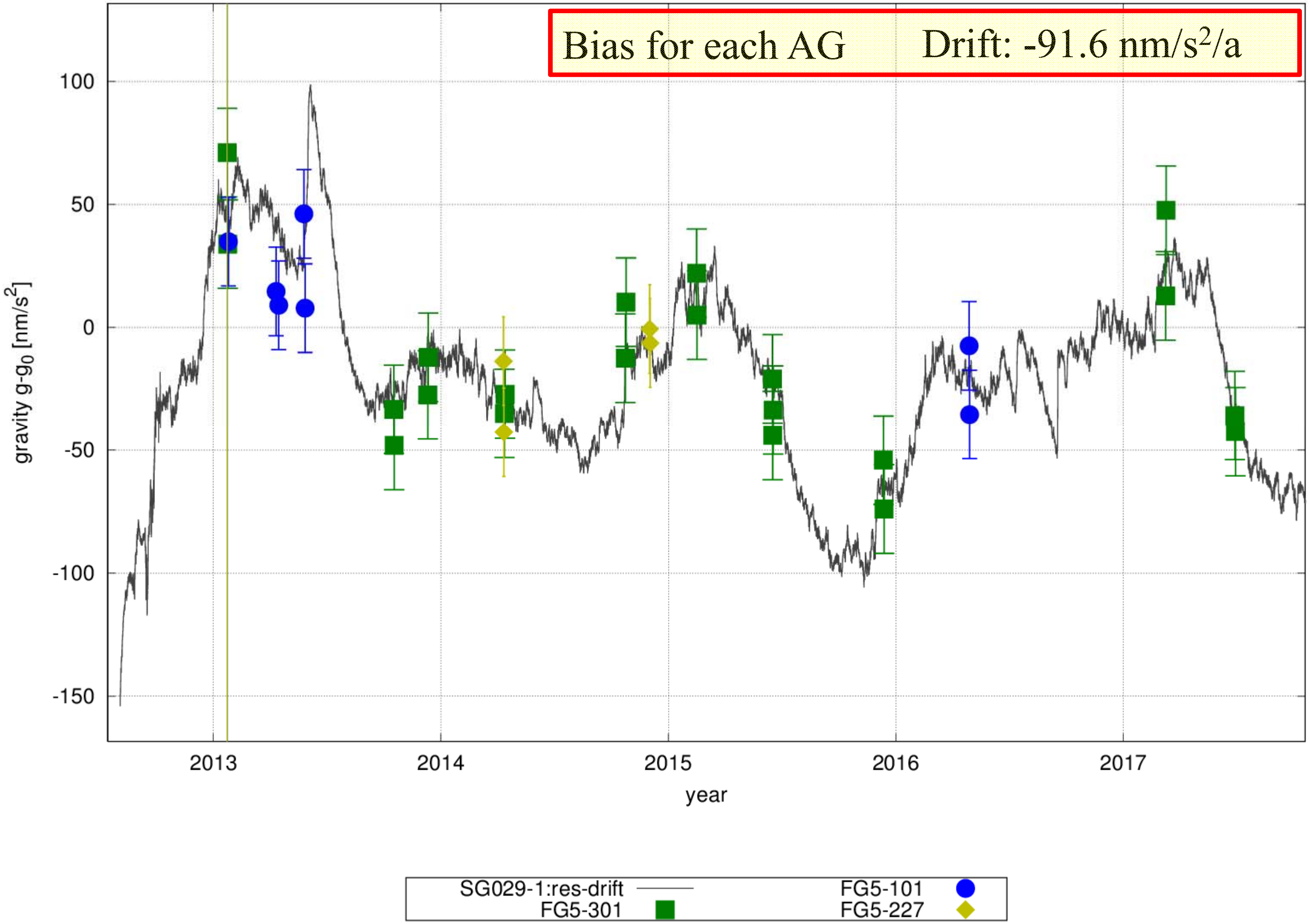


AG vs. SG: Wettzell OLD lab

Wettzell: SG029 - old gravity lab: 2012 -2017 - fit



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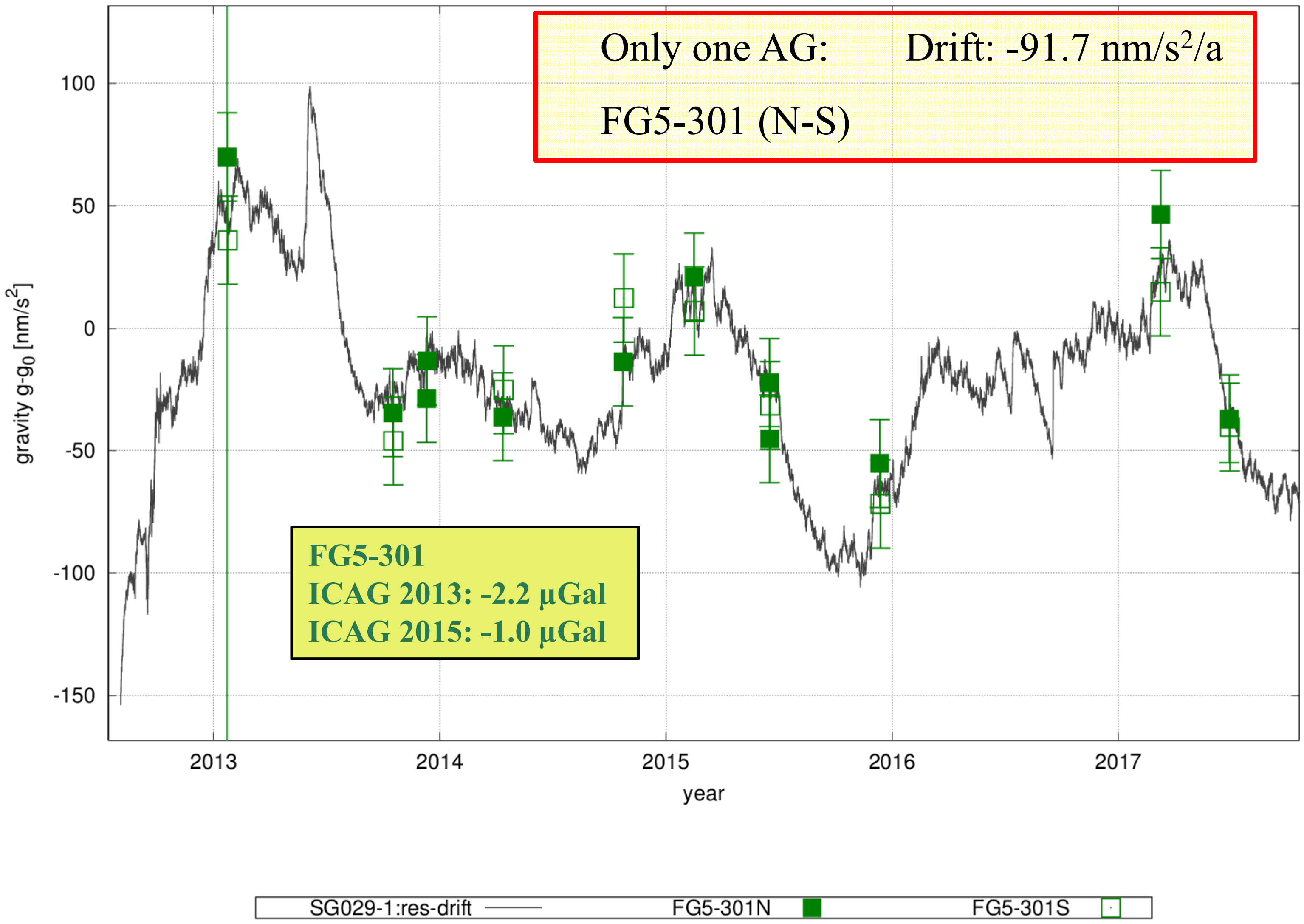
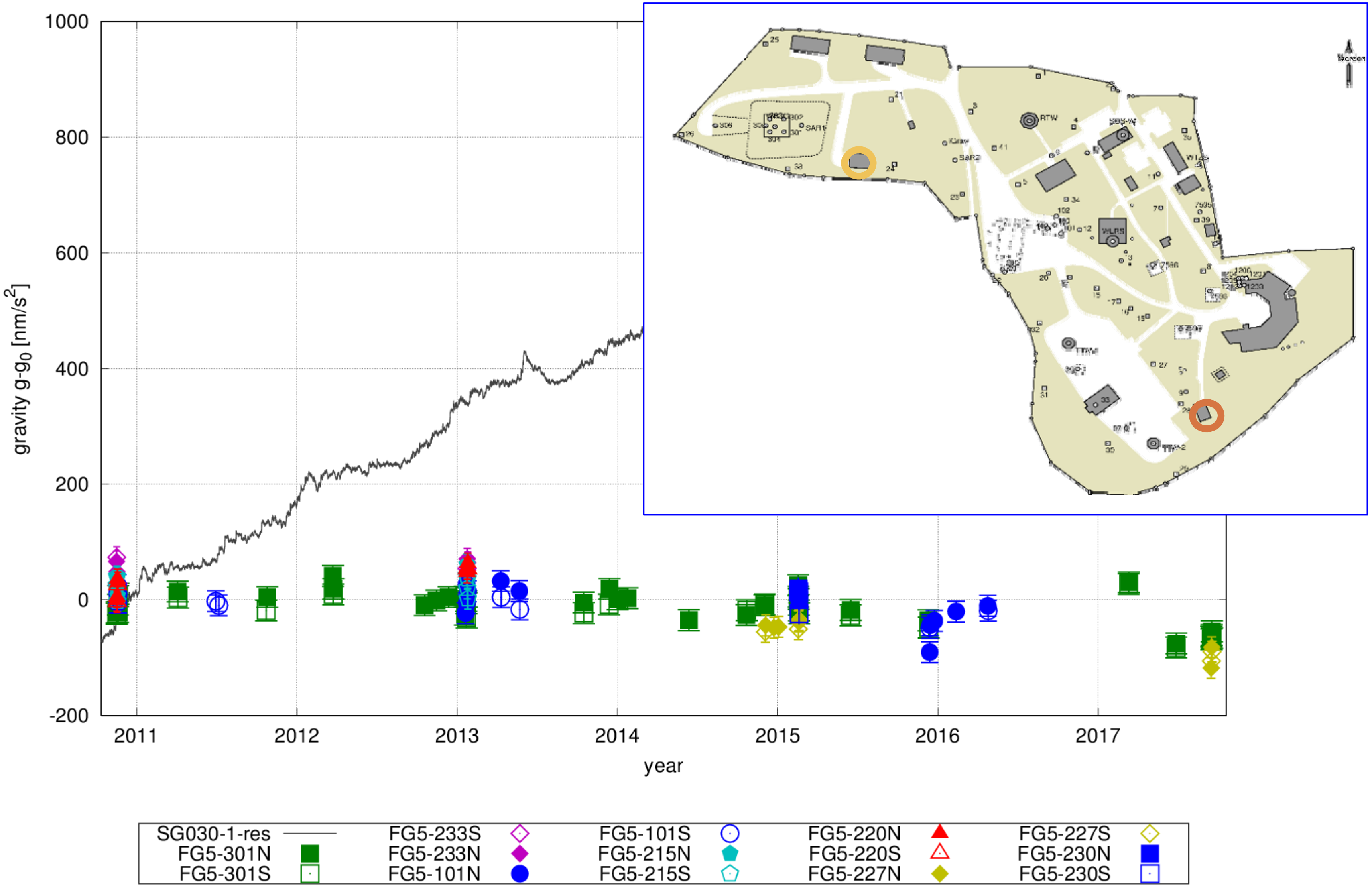


AG vs. SG: Wettzell NEW lab

Wettzell: SG030 - new gravity lab: 2010 -2017 - observations



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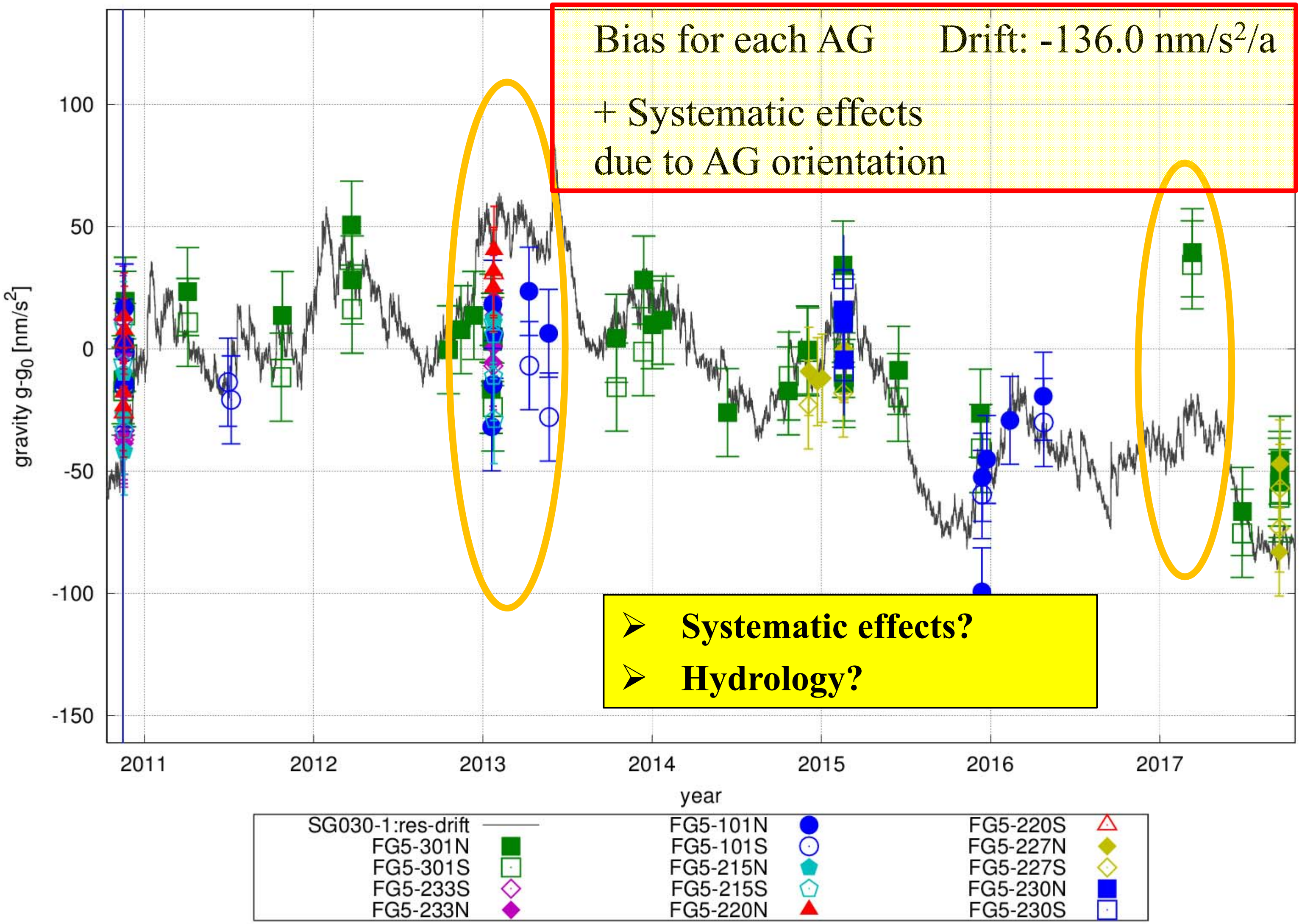

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AG vs. SG: Wettzell OLD lab

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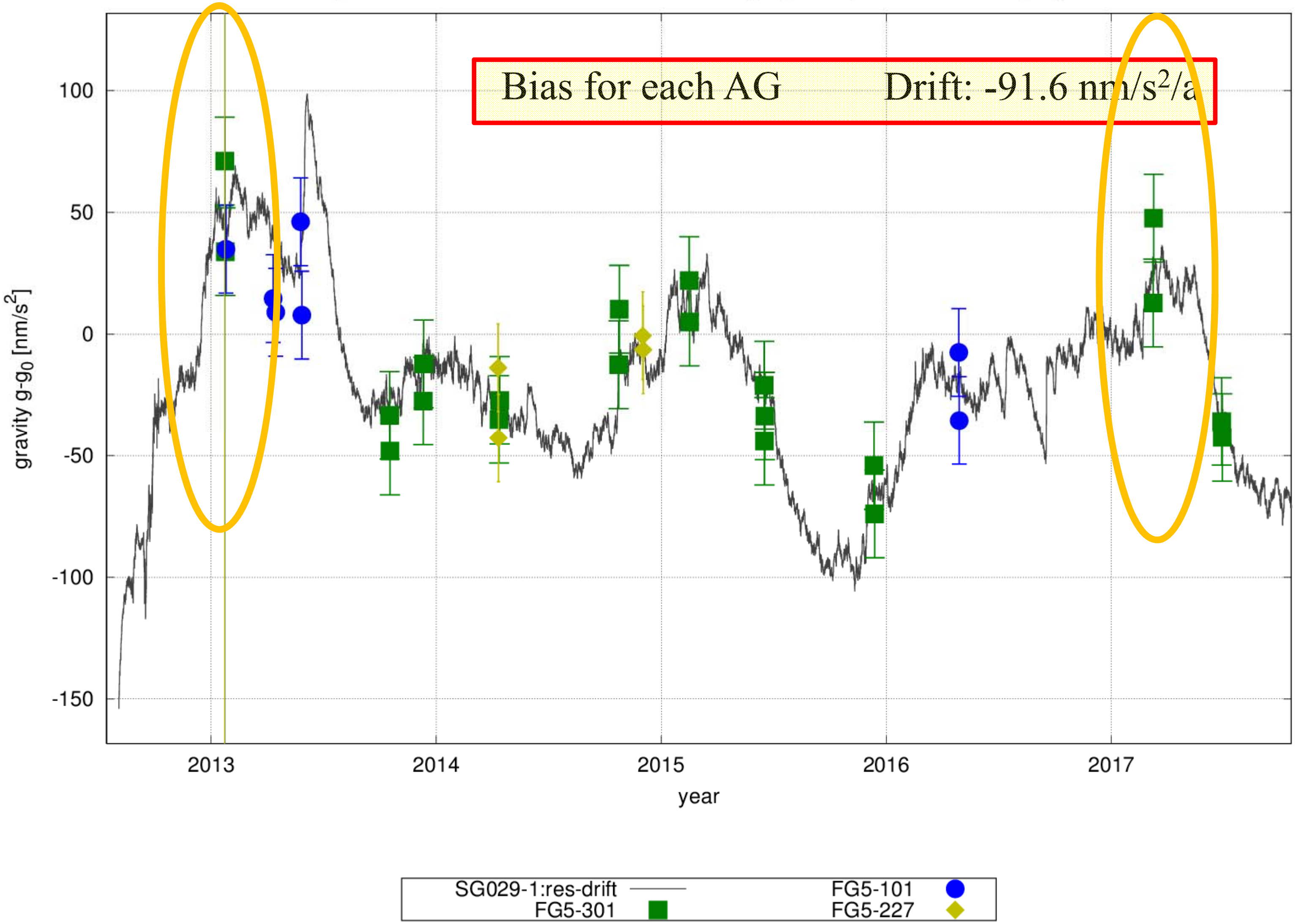


Improving FG5(X)

Another way for improving the accuracy of "gravity reference function" **by decreasing the uncertainty of AG measurements: identification and determination of systematic errors, improving the measurement system**

Křen et al. (2016, 2017, 2018) in Metrologia and Journal of Geodesy

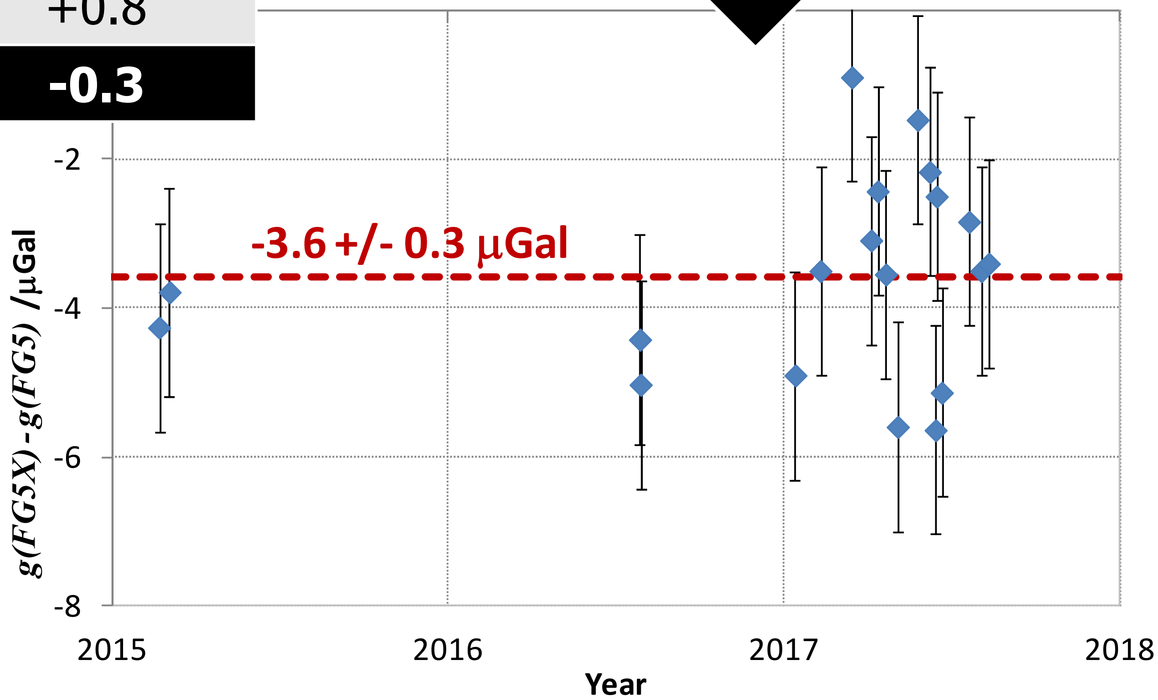
Table 1. Instrumental uncertainty

Influence parameters x_i	Type A s_i	Type B a_i	Units	Variance $u^2(x_i)$	Sensitivity coefficients c_i	Contribution to the variance $u_i^2(g)$	Contribution to the uncert. $u_i(g)$
Laser frequency	1.0E+04		Hz	1.0E+08	2.07E-14	4.3E-20	2.1E-10
Rb-oscillator frequency	1.0E-04		Hz	1.0E-08	1.96E-06	3.8E-20	2.0E-10
Test mass rotation		2.0E-02	rad/s	1.3E-04	6.00E-07	4.8E-17	6.9E-09
Electronic phase shift and timing electronics		7.0E-09	m/s^2	1.6E-17	1.00E+00	1.6E-17	4.0E-09
Vacuum pressure		2.0E-04	Pa	1.3E-08	1.30E-05	2.3E-18	1.5E-09
Glass wedges		3.0E-05	rad	3.0E-10	1.41E-04	6.0E-18	2.4E-09
Air gap modulation		1.0E-08	m/s^2	3.3E-17	1.00E+00	3.3E-17	5.8E-09
Electrostatic effect		2.0E-09	m/s^2	1.3E-18	1.00E+00	1.3E-18	1.2E-09
Magnetic gradient field		1.0E-04	T/m	3.3E-09	4.00E-05	5.3E-18	2.3E-09
Temperature sensitivity	1.0E-09		$m/s^2/°C$	1.0E-18	5.00E+00	2.5E-17	5.0E-09
Coriolis effect	5.0E-05		m/s	2.5E-09	1.00E-04	2.5E-17	5.0E-09
Determination of the reference instr. height		2.0E-03	m	1.3E-06	3.00E-06	1.2E-17	3.5E-09
Perturbation due to non-constant gravity gradient	2.0E-09		m/s^2	4.0E-18	1.00E+00	4.0E-18	2.0E-09
Floor recoil effect		7.0E-09	m/s^2	1.6E-17	1.00E+00	1.6E-17	4.0E-09
Choice of the scaled fringes	8.0E-09		m/s^2	6.4E-17	1.00E+00	6.4E-17	8.0E-09
Impedance mismatch	5.0E-10		m/s^2	2.5E-19	1.00E+00	2.5E-19	5.0E-10
Setup error	8.0E-09		m/s^2	6.4E-17	1.00E+00	6.4E-17	8.0E-09
				Variance, $u^2(g)$		**3.23E-16**	**m^2/s^4**
				Stand. Uncert., $u(g)$		**1.80E-08**	**m/s^2**

New vs. Original systems of FG5(X)

Corrections / µGal	FG5-215 Orig. syst.	FG5X-251 Orig. syst
Self-attraction	-1.7	-1.2
Diffraction	+2.1	+2.1
Distortion	-4.4	-2.2
Cable effect	-0.7	-0.8
Verticality	+0.2	+1.0
Eötvös	+0.4	+0.8
Sum	**-4.1**	**-0.3**

Standardly, the self-attraction and diffraction corrections are applied, then **observations** should show on the **difference of -3.3 µGal between AGs.**



Conclusions

Combination of time series from **SG** with episodic **AG** observations provides long term **stability** and high resolution **continuous gravity series.**

The **compatibility** of the **AG** must be checked at **international comparisons.**

The **combination** allows **SG drift** determination and to monitor **AG stability** or detect systematic errors.

For the **combination in long-term,** comparisons results should be taken into account for **reffering the reference gravity function**. Further analyses are needed.

The SG can provide a **comparison reference function**, also in the frame of metrology: This is an important **contribution of IGETS to the International Gravity Reference Frame (IGRF)**.

Thank you for your attention!