Intercomparison of a dense meter-scale network of superconducting gravimeters at the J9 gravimetric observatory of Strasbourg, France

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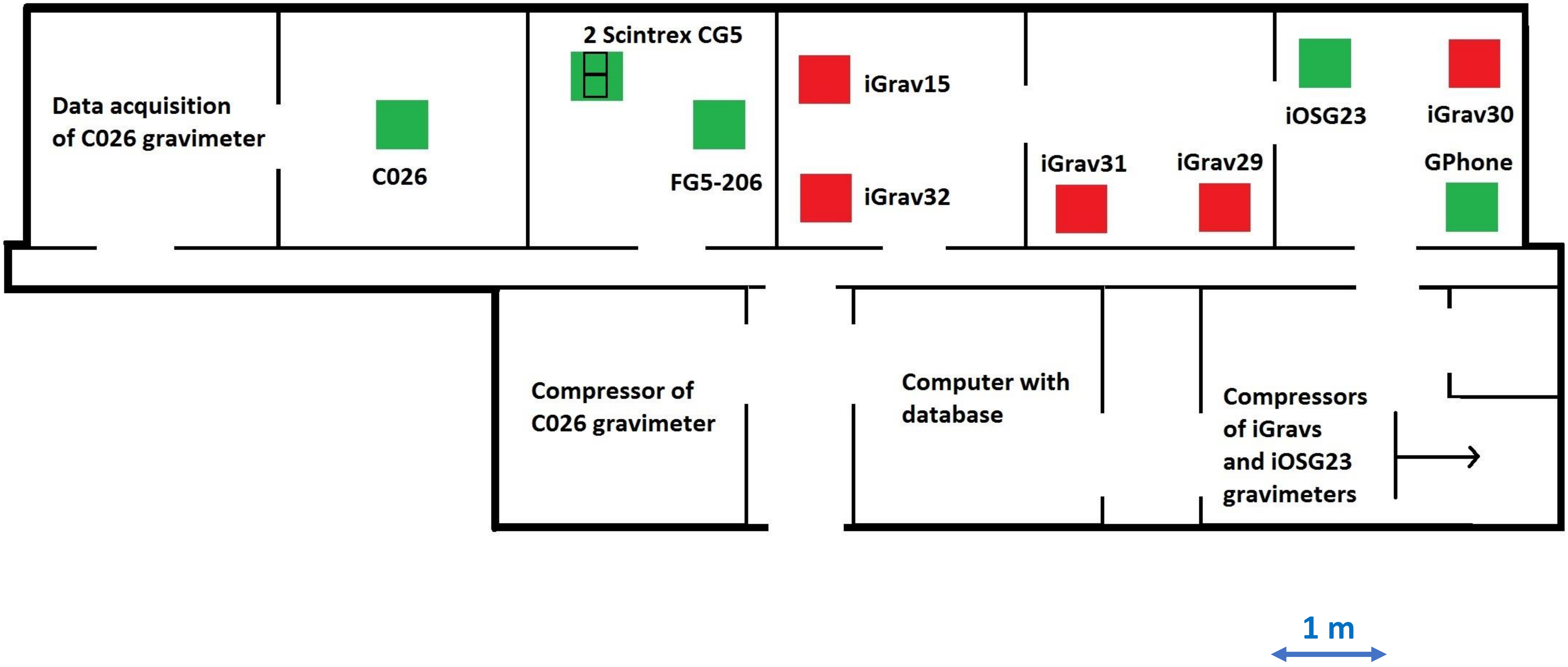
Outline

- Introduction (site, data sets)
- Calibration (absolute and relative)
- Time delay (time cross-correlation, tidal analysis, step experiments)
- Initial drift after installation
- Noise levels
- Conclusion

Strasbourg Gravimetric Observatory (J9)

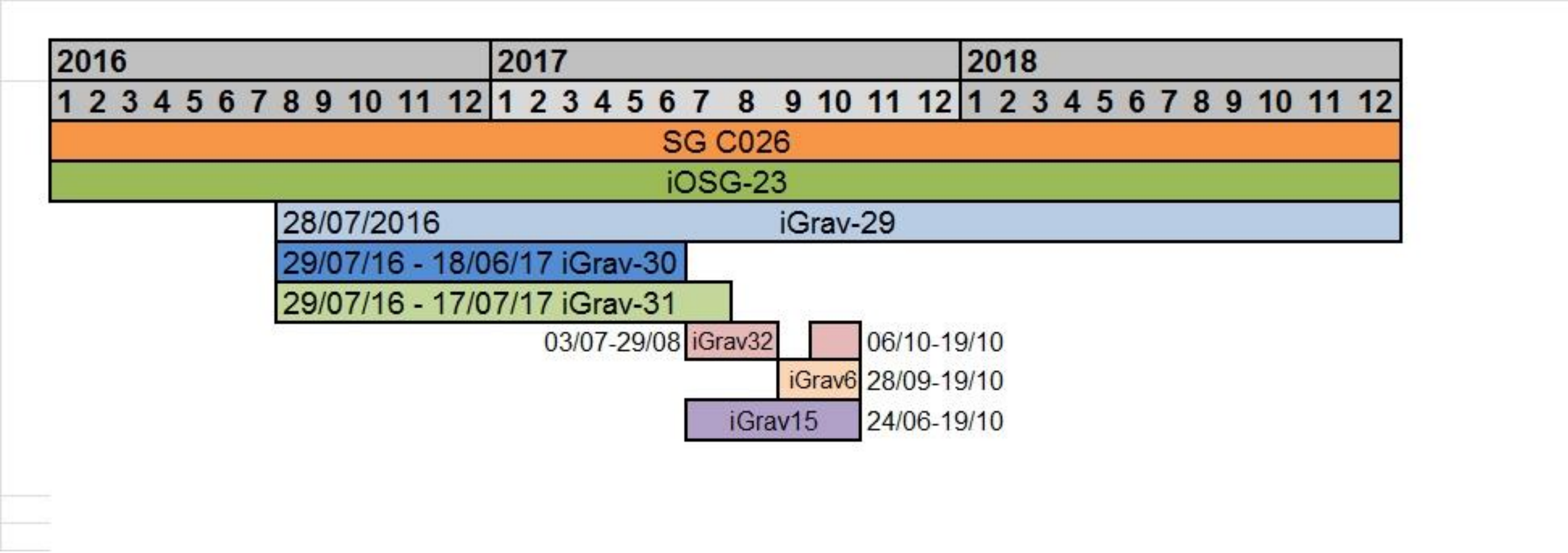


iOSG23

C026

iGrav30

Time table of SG observations at J9



A maximum of **7 different SGs** in operation in STJ9 but only:

6 simultaneous SGs in July 2017: iGrav15, iGrav32, iGrav29, iGrav30, iGrav31, iOSG23, C026

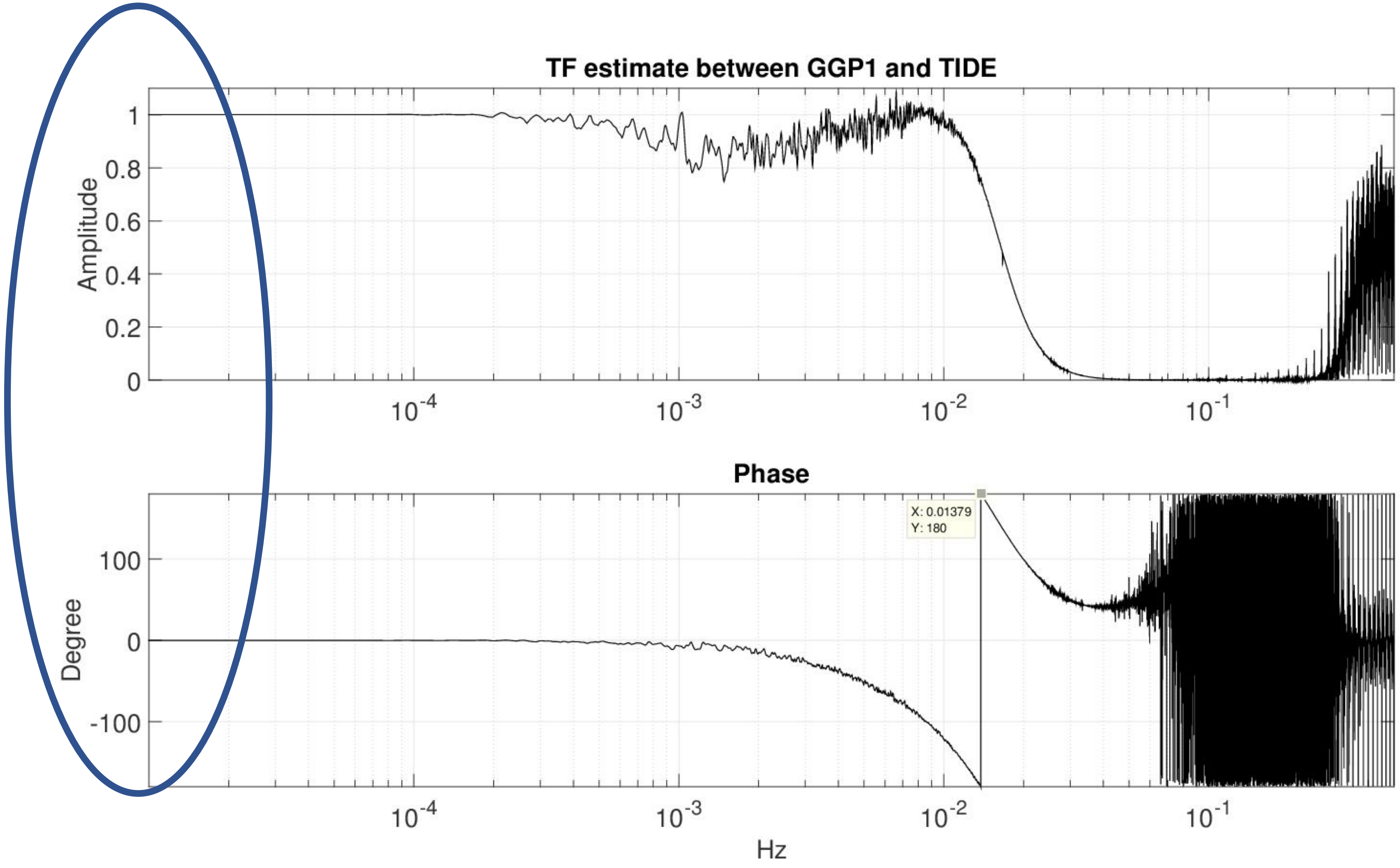
6 simultaneous SGs in October 2017: iGrav6, iGrav15, iGrav32, iGrav29, iGrav30, iOSG23, C026

Transfer function between two SG time series

Low frequency limit

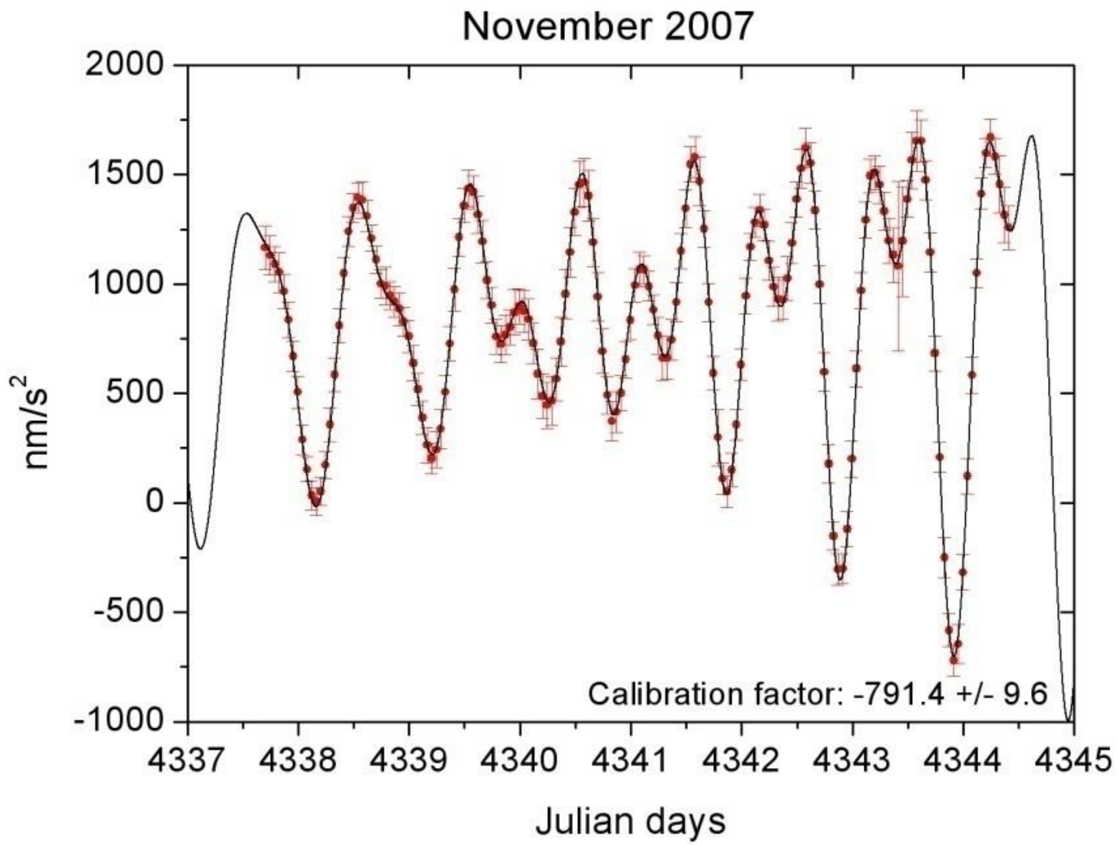
Calibration

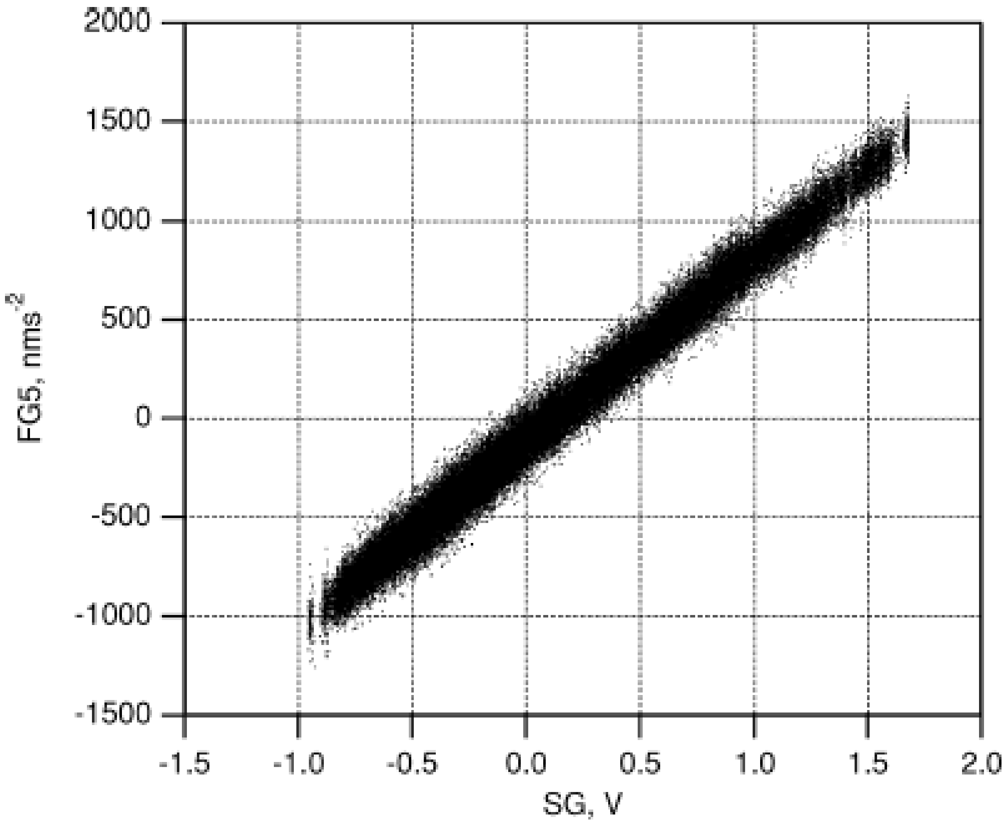
Time delay



Calibration

Absolute calibration: use of AG gravity values in parallel with SG voltages





Imanishi et al. 2002

Determination of scale factor in nm s^{-2}/volt

Absolute calibration

Two AG/SG calibration experiments:

- September 2016: 149 hours = 6.2 days
  iGrav29, iGrav30, iGrav31, iOSG23

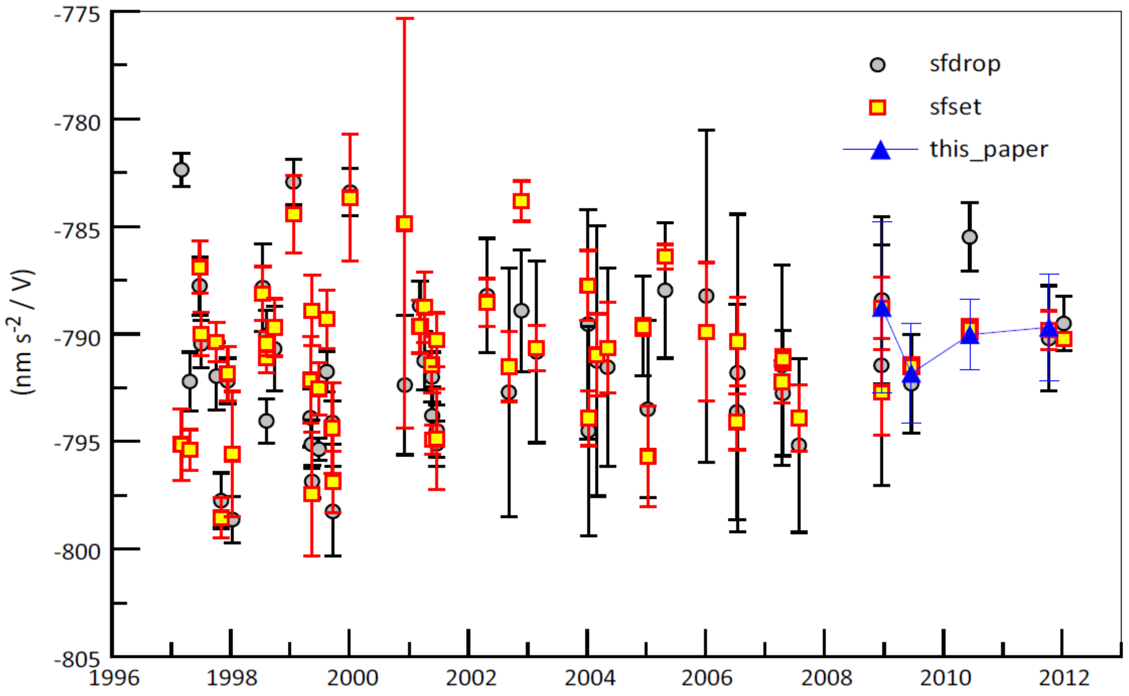
- July 2017: 170 hours = 7.1 days
  iGrav15, iGrav32

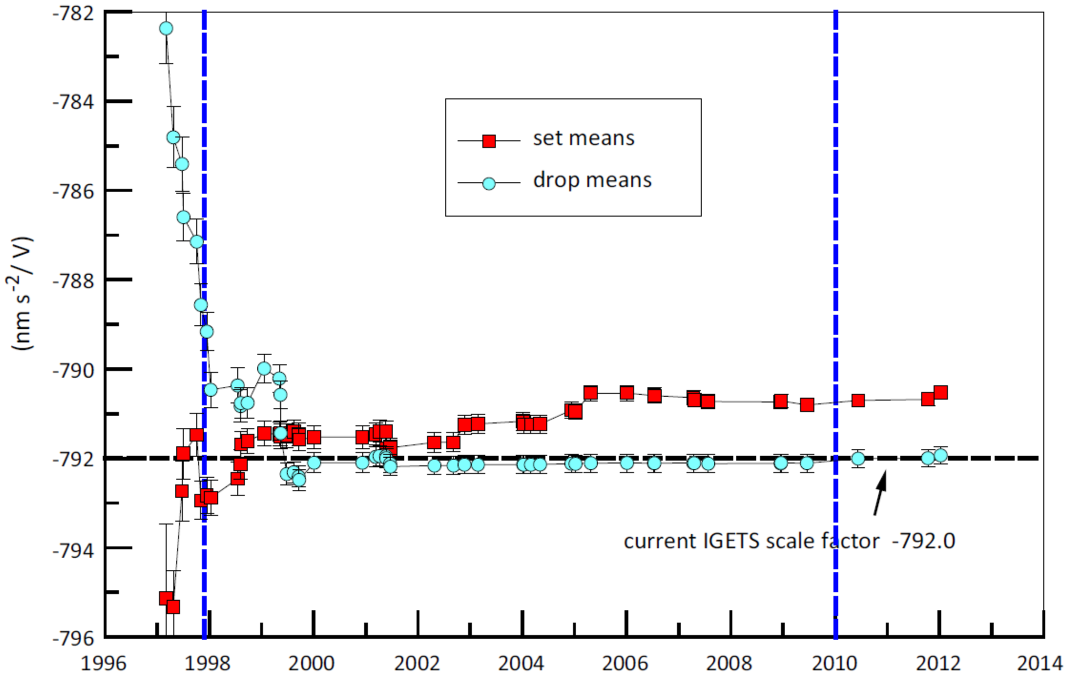
- No absolute calibration for iGrav6

- Numerous calibrations for C026 since 1996

SG name	Duration of calibration experiment	AG Cal and error (nm s^{-2}/V)	Dimensionless Error on AG Cal
C026		-792 ± 1	0.1 %
iOSG023	6.2 days	-451 ± 2	0.4 %
iGrav006	X	X	X
iGrav015	7.1 days	-934 ± 3	0.3 %
iGrav029	6.2 days	-940 ± 4	0.4 %
iGrav030	6.2 days	-918 ± 4	0.4 %
iGrav031	6.2 days	-853 ± 4	0.5 %
iGrav032	7.1 days	-898 ± 3	0.3 %

Time changes in AG CAL for C026 (1997-2012)





IGETS database Cal= - 792.0 ± 1.0 nm s^{-2}/V (0.1%)

2012 conflated drop mean Cal = - 791.93 ± 0.19

2012 conflated set mean Cal = - 790.53 ± 0.11

Crossley et al. 2018 PAGEOPH

Relative calibration

Time regression of gravimeter voltages to a reference gravity signal (previously calibrated at the same site)

An example of multilinear regression

(iGrav30 /iOSG23 in May 2017)

RED: linear drift

GREEN: residual signal (Sigma = 0.7 nm s^{-2})

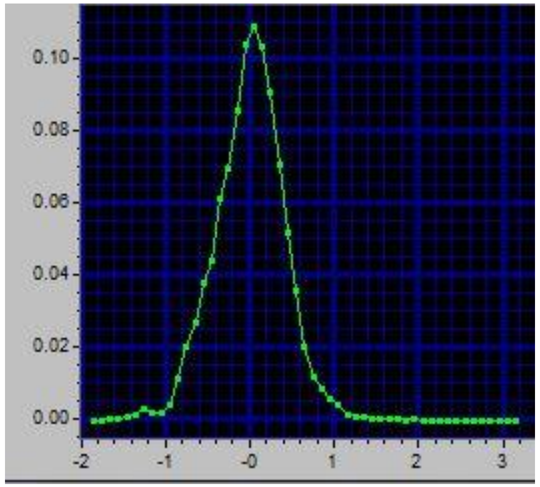
Text output

File

```
============================================
   iGrav30 |     -9.1764e+002 err     5.7951e-003
Poly(t)  0 |      1.6061e+003 err     9.4059e-003
Poly(t)  1 |     -6.6255e-005 err     2.5971e-007
Residual standard deviation:       0.7067241
 +1.000000 -0.893205
 -0.893205 +1.000000
============================================
# of degrees of freedom obj ch#8: 203
# of degrees of freedom comp. ch#2: 203
Correlation:       -0.9999991
t coeff: -10627.766
Student's t probability: %signific.: 100.000
```

relative calibration value + error (in nm s^{-2}/volt)

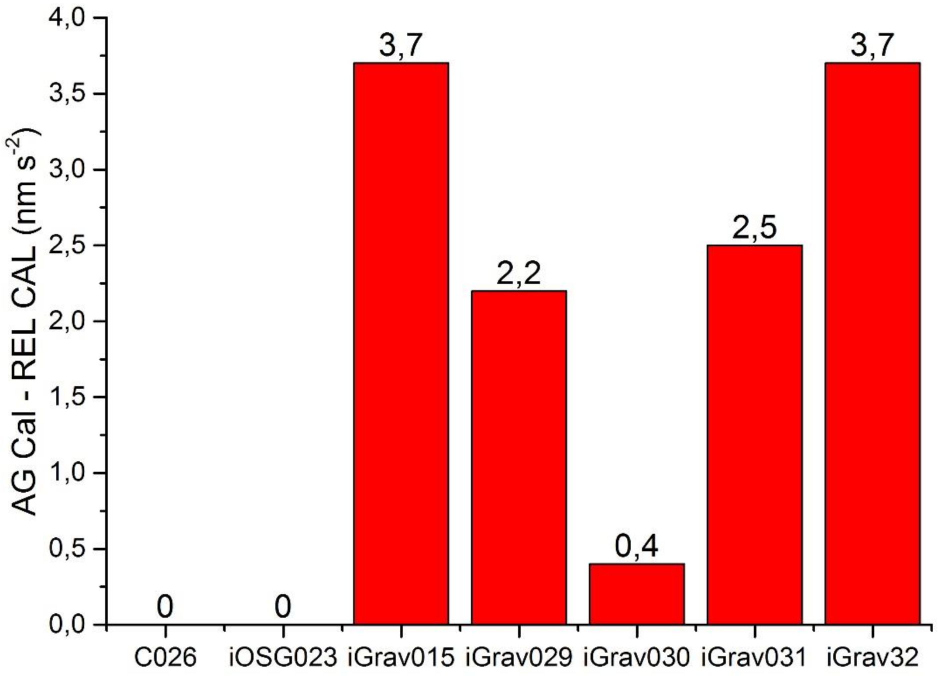
Correlation coefficient



Relative calibration versus absolute calibration

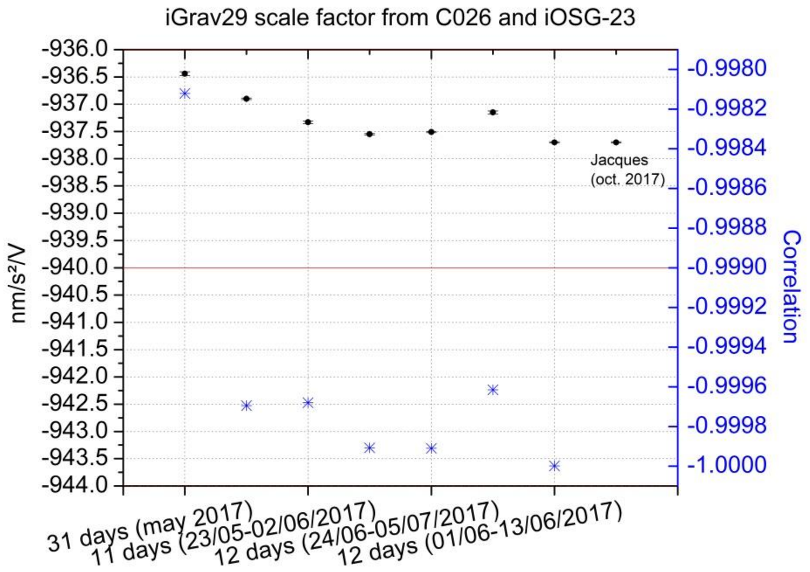
- errors in Rel Cal much smaller than errors in AG Cal in the range 3. 10^{-6} – 5. 10^{-5} according to the length of the comparison
- largest errors for shortest series in the regression analysis
- all correlation factors very high (at least > 0.999)

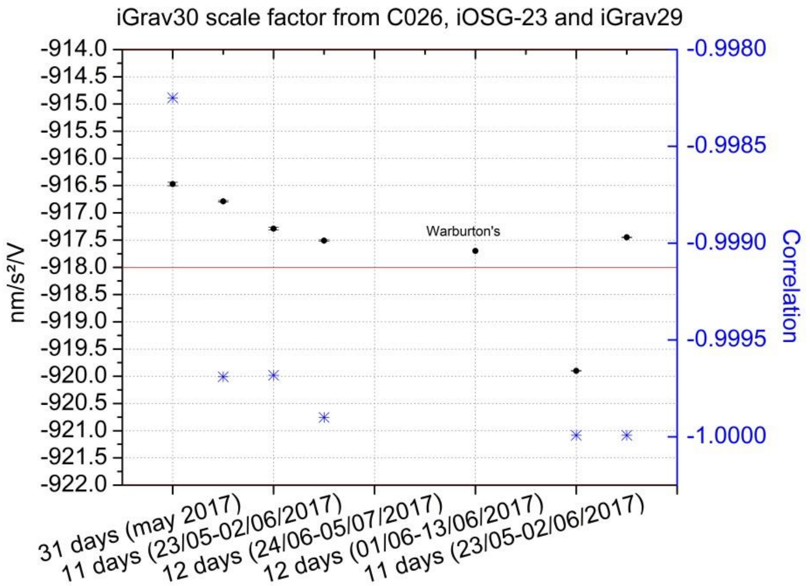
SG name	Duration	Rel Cal and error (nm s^{-2}/V)	dimensionless error on Rel Cal	AG Cal and error (nm s^{-2}/V)	Difference in Rel Cal–AG Cal (nm s^{-2}/V)
C026	31 days 10/17	-792.0 ± 0.02	3. 10^{-5}	-792 ± 1	0
REFERENCE iOSG023	31 days 10/17	-451	x	-451 ± 2	0
iGrav006	22 days 01-22/10 /17	-913.9 ± 0.05	5. 10^{-5}	X	X
iGrav015	22 days 01-22/10 /17	-930.3 ± 0.008	9. 10^{-6}	-934 ± 3	3.7
iGrav029	31 days 10/17	-937.8 ± 0.003	3. 10^{-6}	-940 ± 4	2.2
iGrav030	31 days 05/17	-917.6 ± 0.006	7. 10^{-6}	-918 ± 4	0.4
iGrav031	31 days 05/17	-850.5 ± 0.003	4. 10^{-6}	-853 ± 4	2.5
iGrav032	10 days 13-22/10 /17	-894.3 ± 0.07	8. 10^{-5}	-898 ± 3	3.7

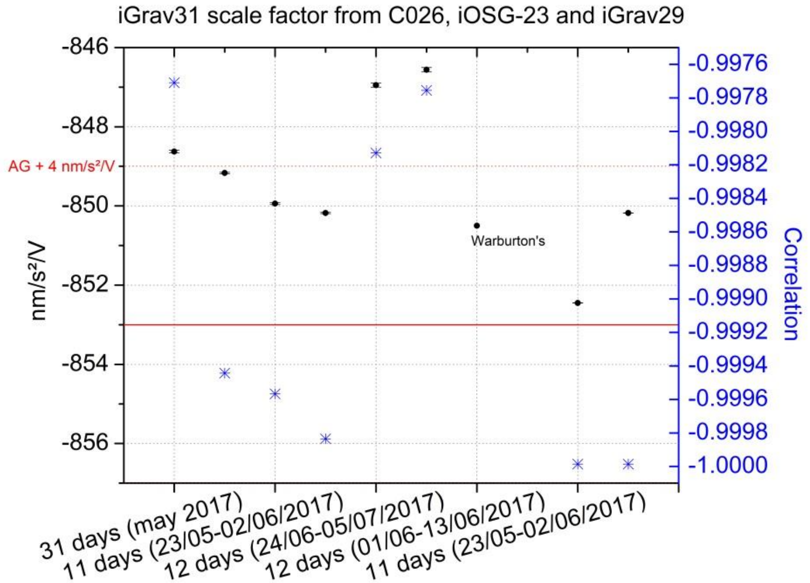


differences between AG Cal and Rel Cal in the range 0.4-3.7 nm s^{-2}/Volt (with calibration factors close to 900 nm s^{-2}/Volt)

Time variability of the Rel Cal







Amplitude of tidal residuals according to calibration factor

iGrav29 -iOSG23   one month of min samples in October 2017

IG29 (-937.4) - IOSG23 GREEN

IG29 (-937.8) - IOSG23 RED   from regression with iOSG23

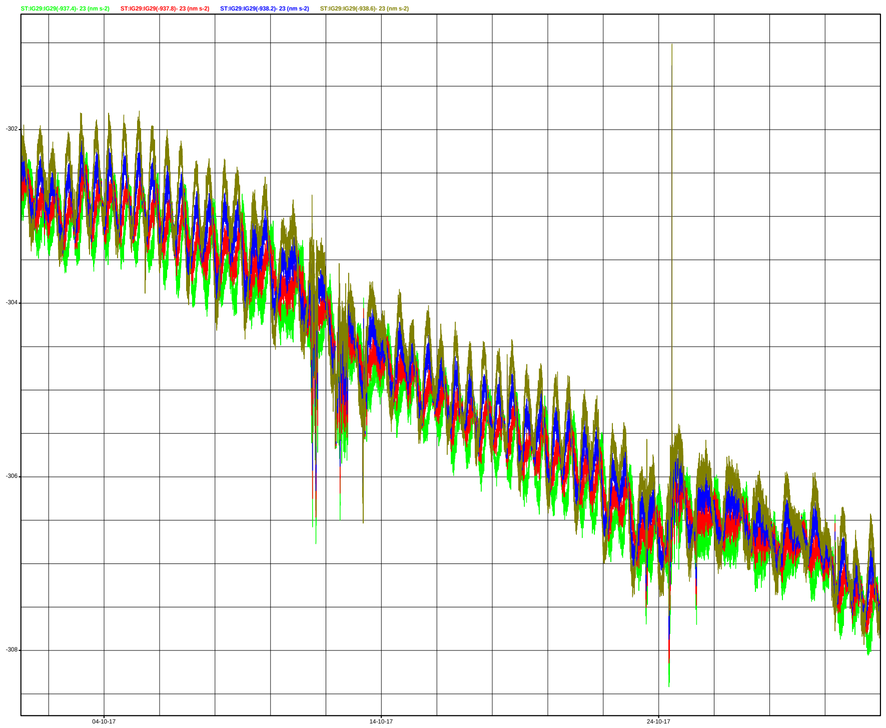
IG29 (-938.2) – IOSG23 BLUE

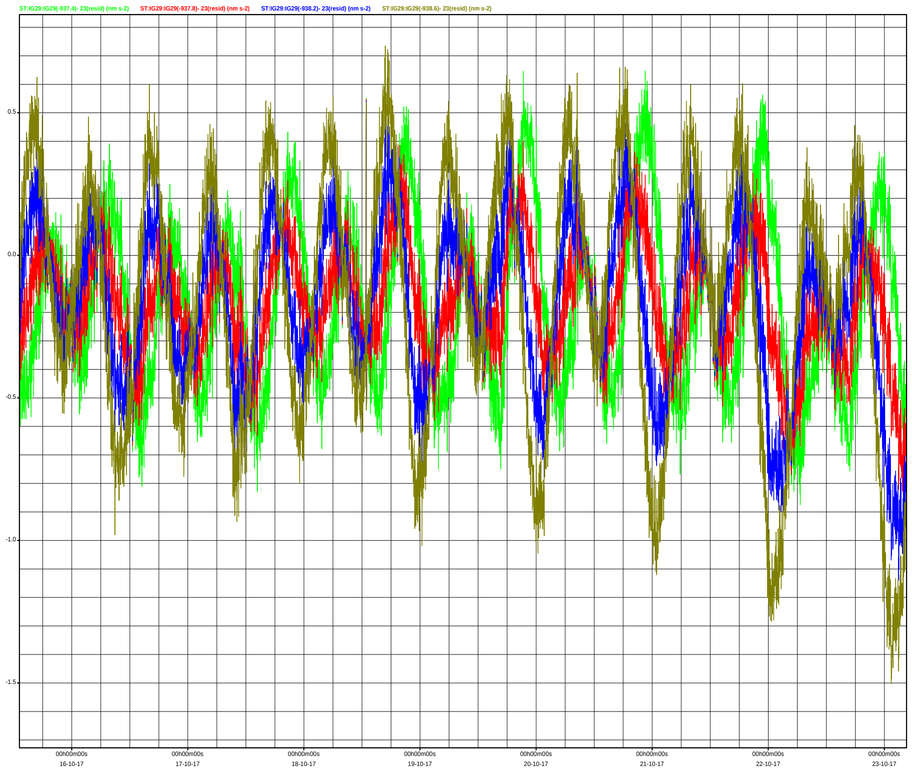
IG29 (-938.6) - IOSG23 BROWN

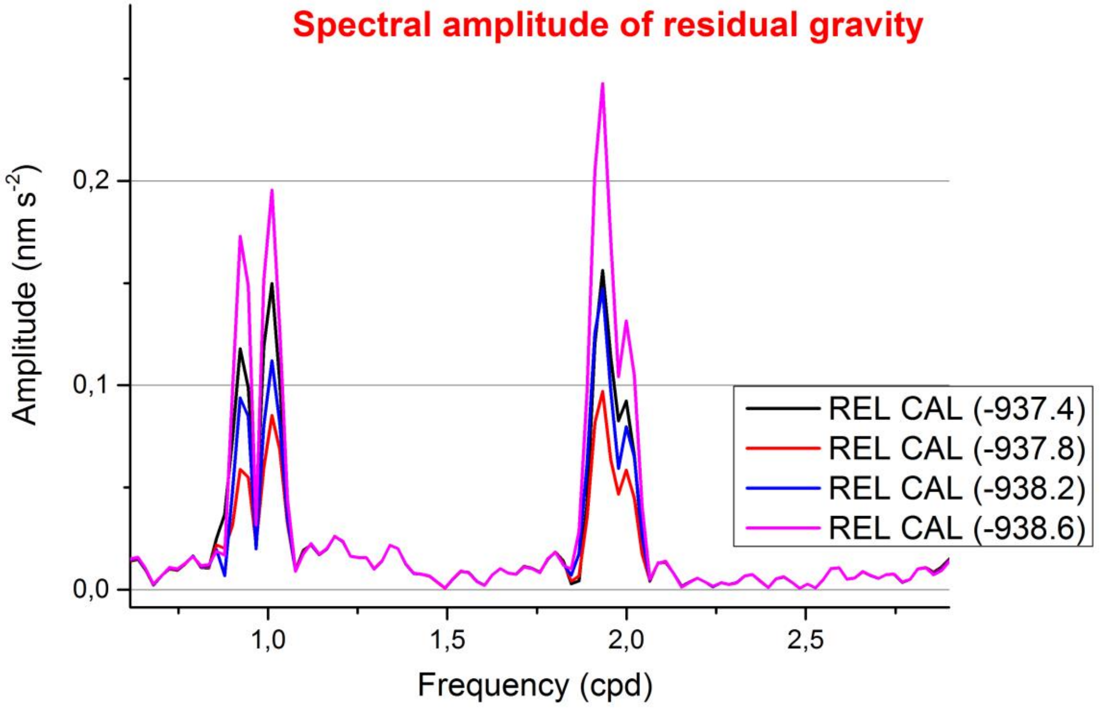
Incremental steps of 0.4 nm s^{-2}/volt

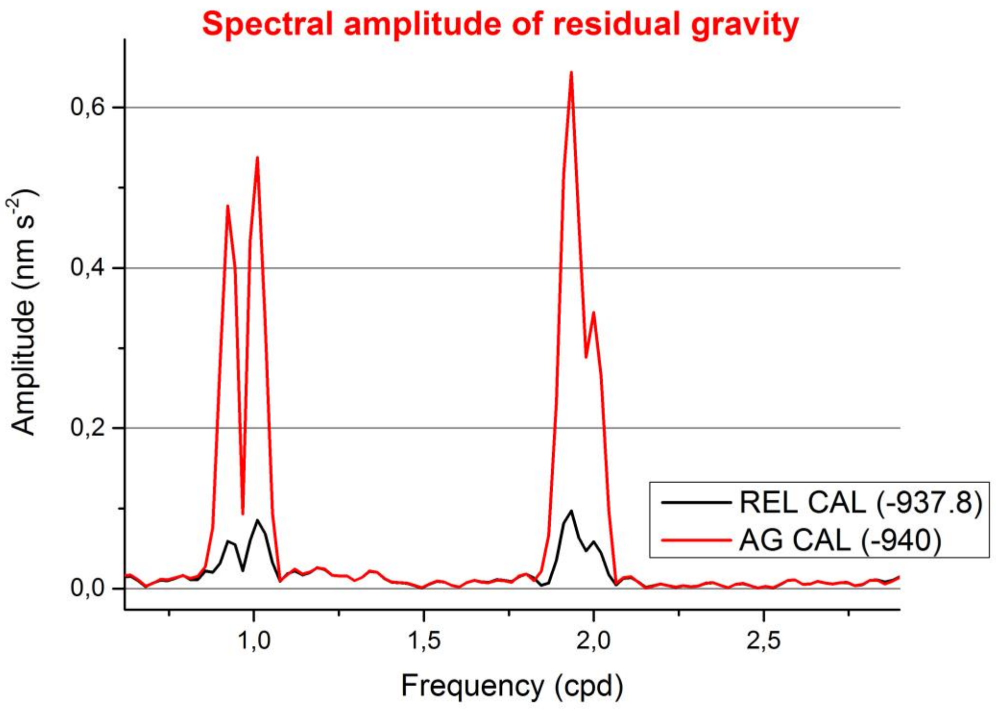
≈ 0.04 %

(compared to 4 nm s^{-2}/volt uncertainty from AG/SG)







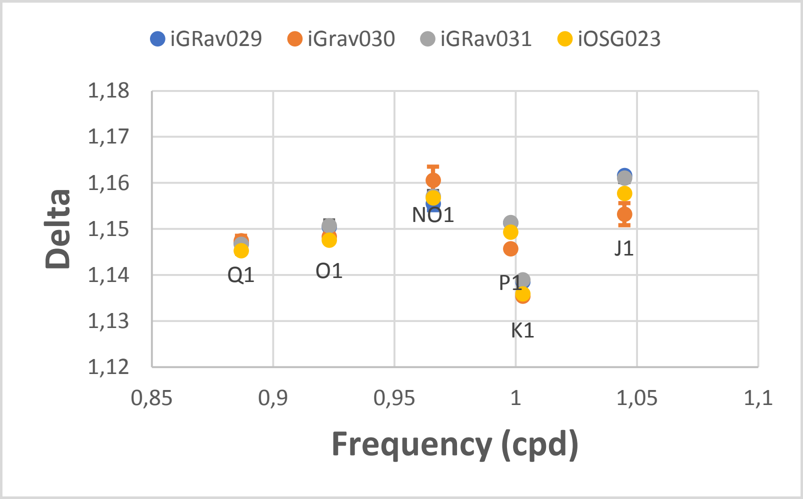


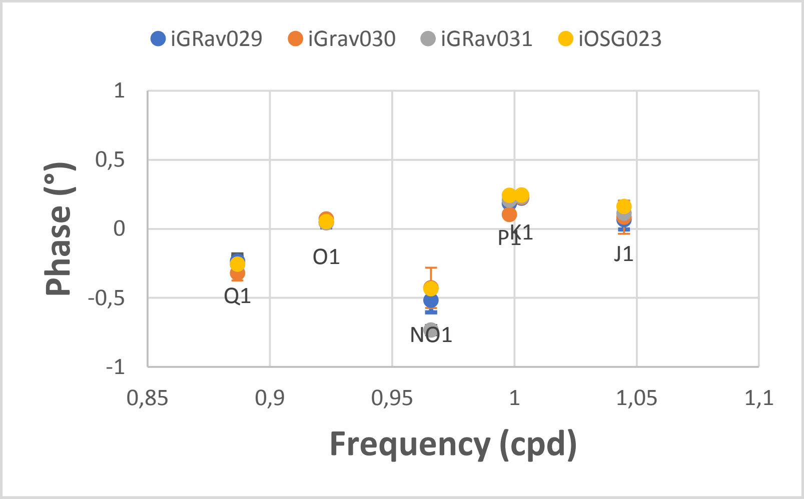
Rel Cal (-937.8) leads to the minimum in tidal residuals (in **RED**)

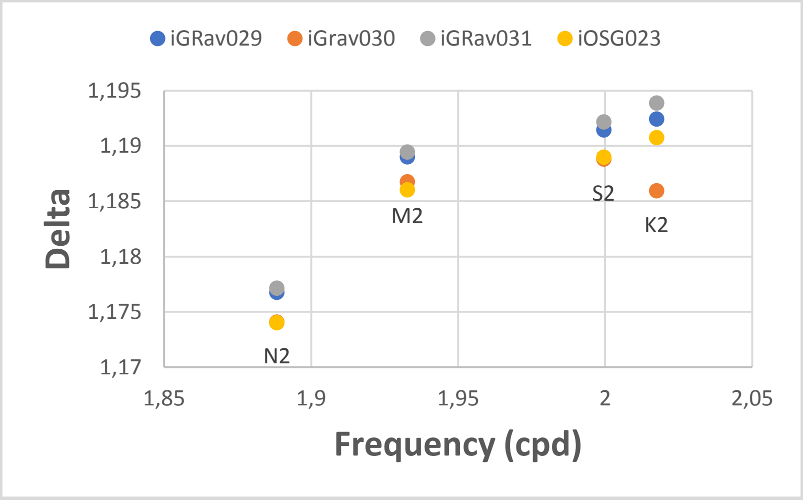
AG Cal (-940 nm s-2/V)) would lead to large tidal residuals…

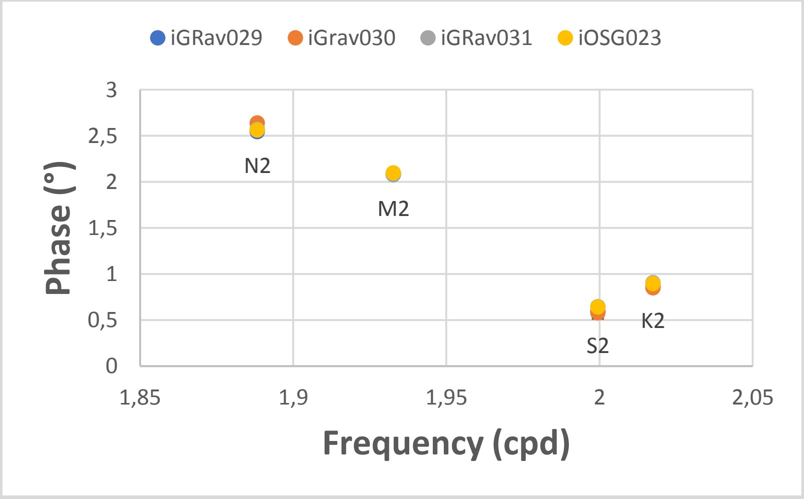
Results from tidal analysis (ET34-ANA-V61A from K. Schüller)

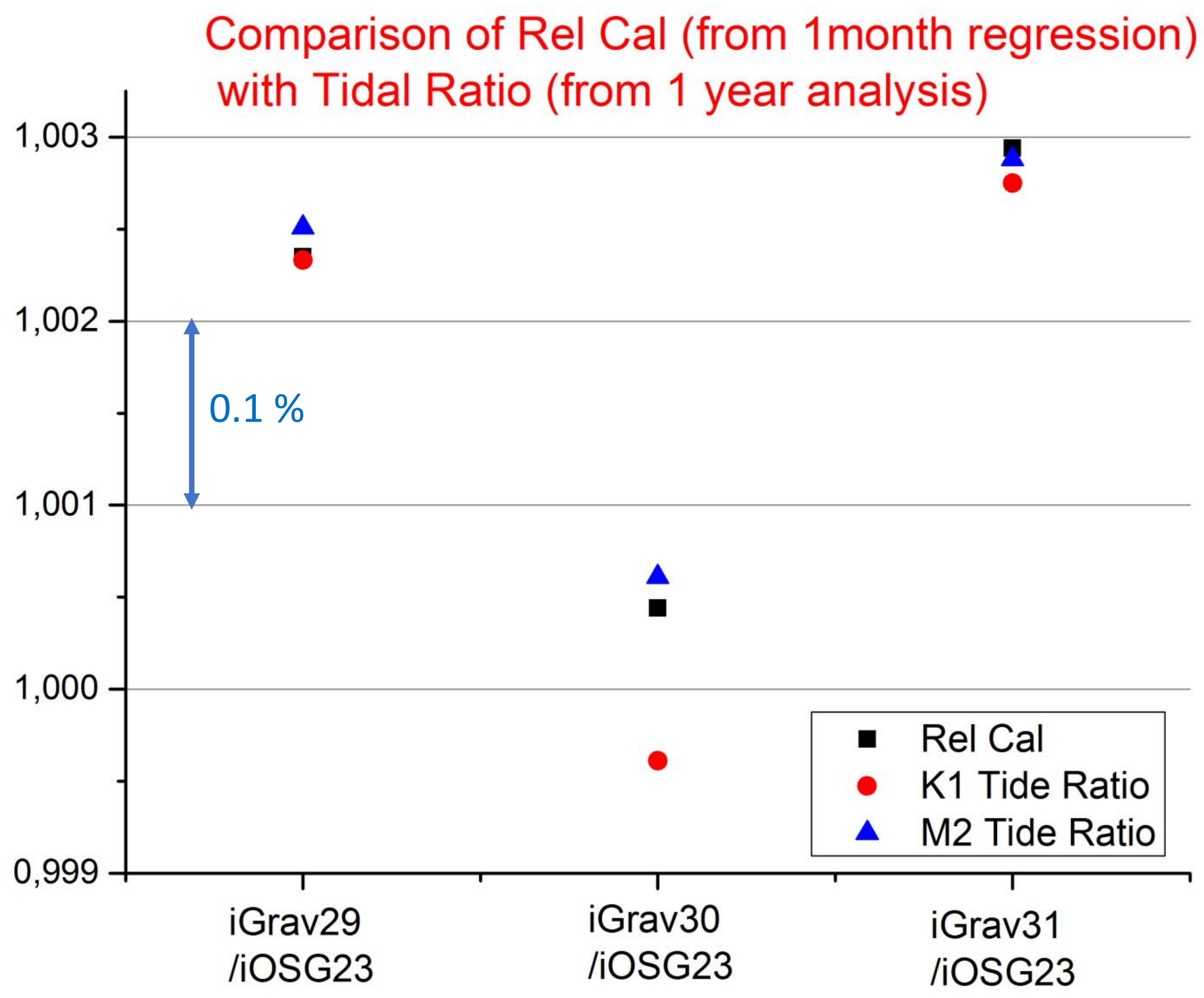
longest common period (LCP) of iGrav 29,30,31 and iOSG23
04/08/2016 - 19/06/2017; 321 days (nearly 1 year)
assuming null phase lag and using the AG Cal for each gravimeter









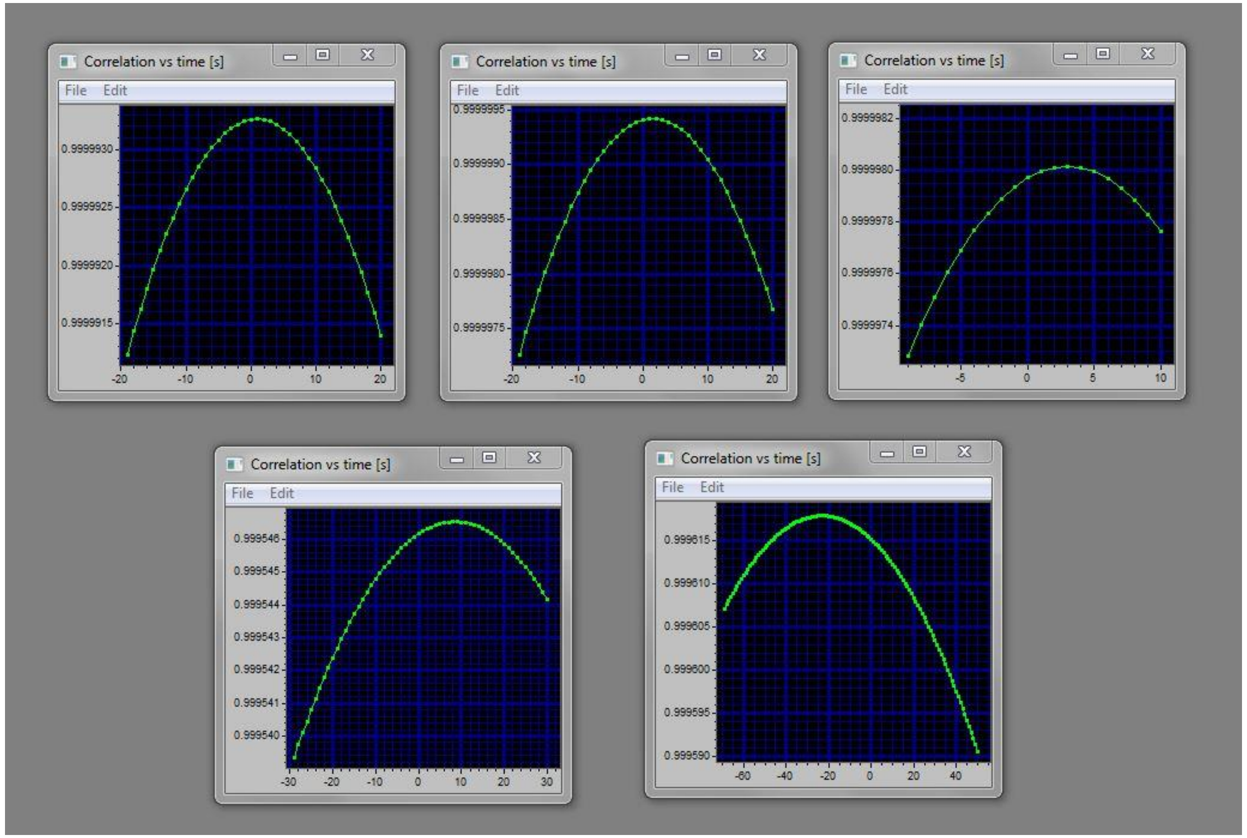

Comparison of Rel Cal (from 1month regression)
with Tidal Ratio (from 1 year analysis)
1,003
1,002
1,001
1,000
0,999
0.1 %
Rel Cal
K1 Tide Ratio
M2 Tide Ratio
iGrav29
/iOSG23
iGrav30
/iOSG23
iGrav31
/iOSG23

Time delay

Time cross-correlation analysis

Uses two by two common time series with identical sampling
e.g. 1 month of 1 min samples (**May 2017**)

iGrav30/iGrav29 iGrav31/iGrav29 iOSG23/iGrav29



C026 GGP1/iGrav29 C026 TIDE/iGrav29

Reference instrument: iGrav29

Time delay of iGrav30/iGrav29 = -1 ± 1 sec
cor. = 0.9999933

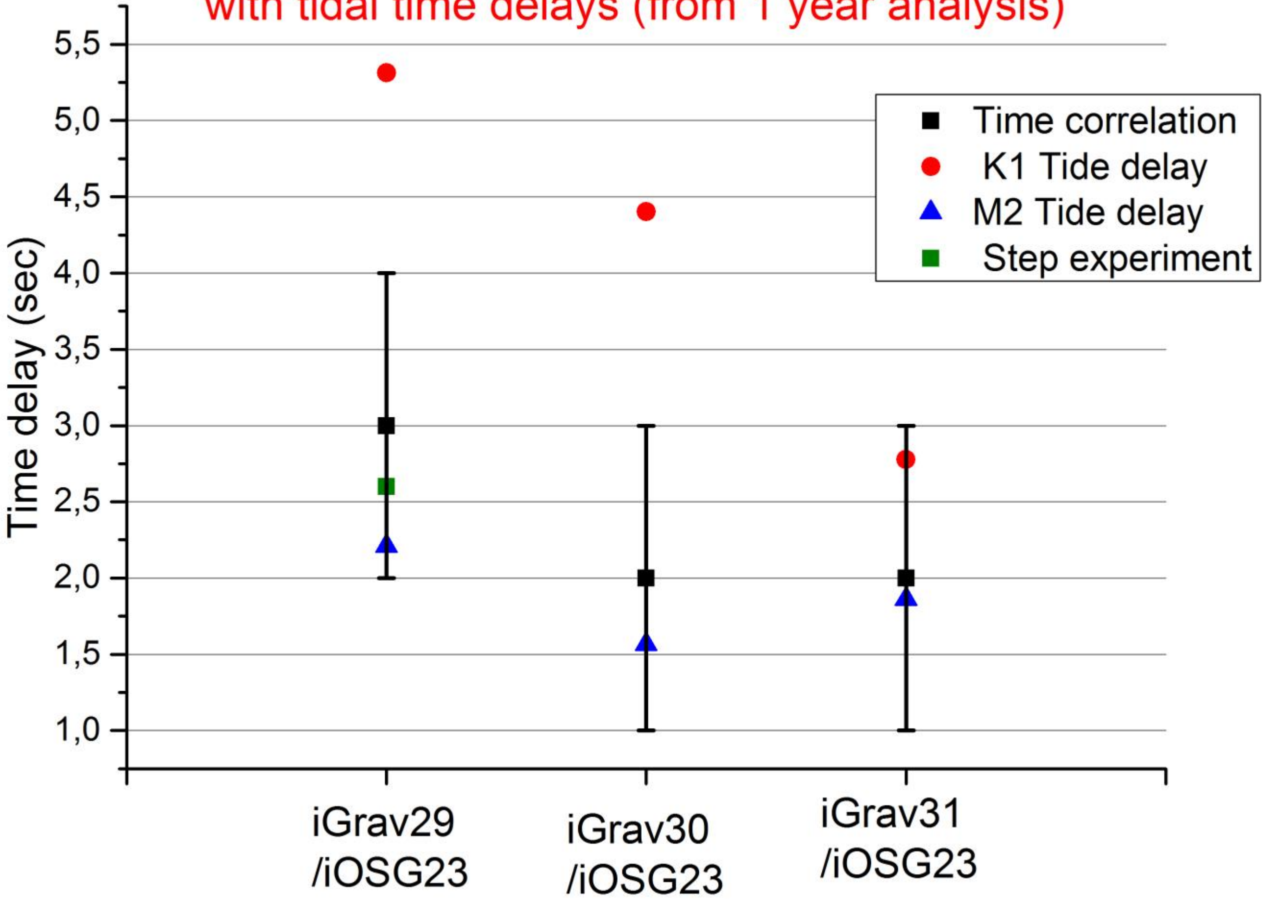
Time delay of iGrav31/iGrav29 = -1 ± 1 sec
cor. = 0.9999994

Time delay of iOSG23/iGrav29 = - 3 ± 1 sec
cor. = 0.9999980

Time delay of C026 (GGP1)/iGrav29 = -8 ± 1 sec
cor. = 0.9995466

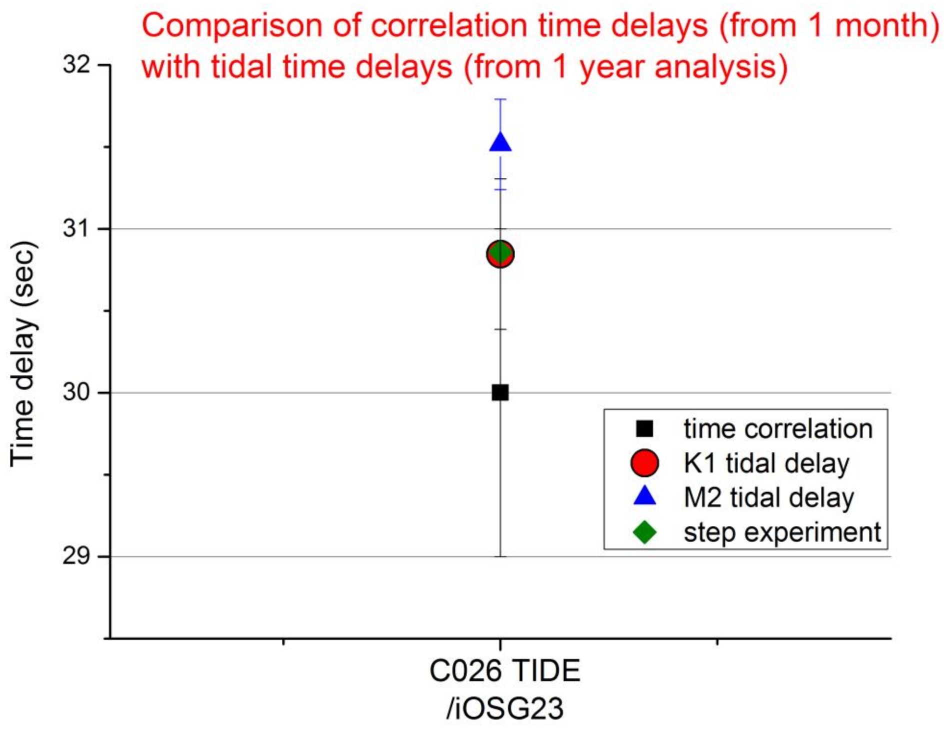
Time delay of C026 (TIDE)/iGrav29 = +23 ± 1 sec
cor. = 0.9996181

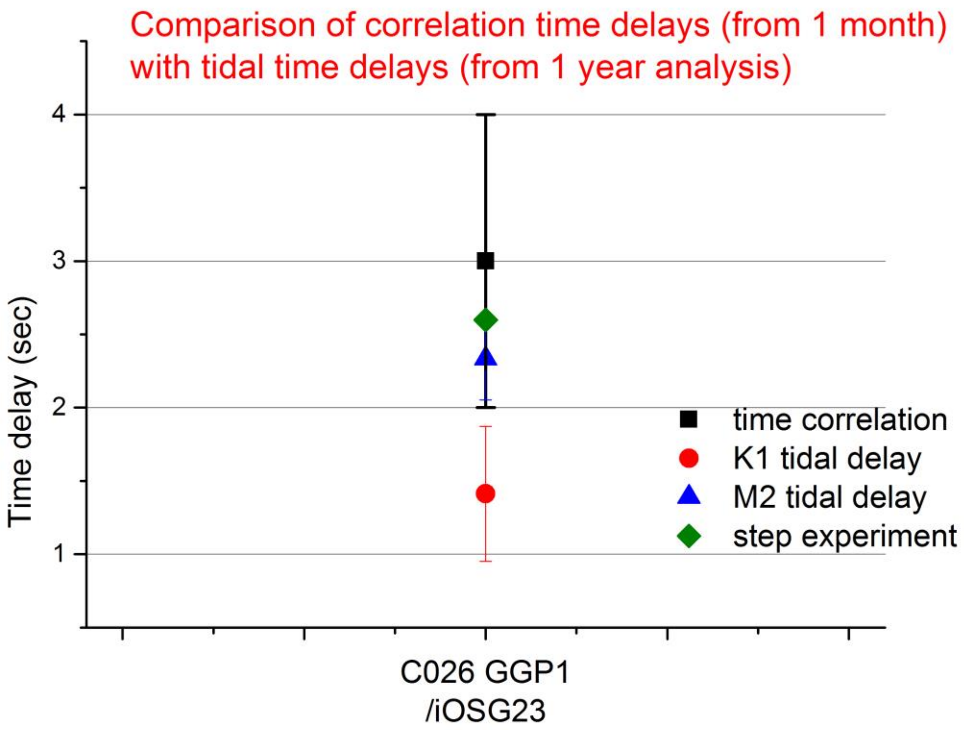
Comparison of correlation time delays (from 1 month) with tidal time delays (from 1 year analysis)



Time cross-correlation: **May 2017** 31 days

Tidal analysis: **303 days** for iGrav29, **321 days** for iGrav30,
300 days for iGrav31, **334 days** for iOSG23





Time cross-correlation: **October 2017** 31 days

Tidal analysis: 2017.06.01 - 2018.04.30 **334.0 days**

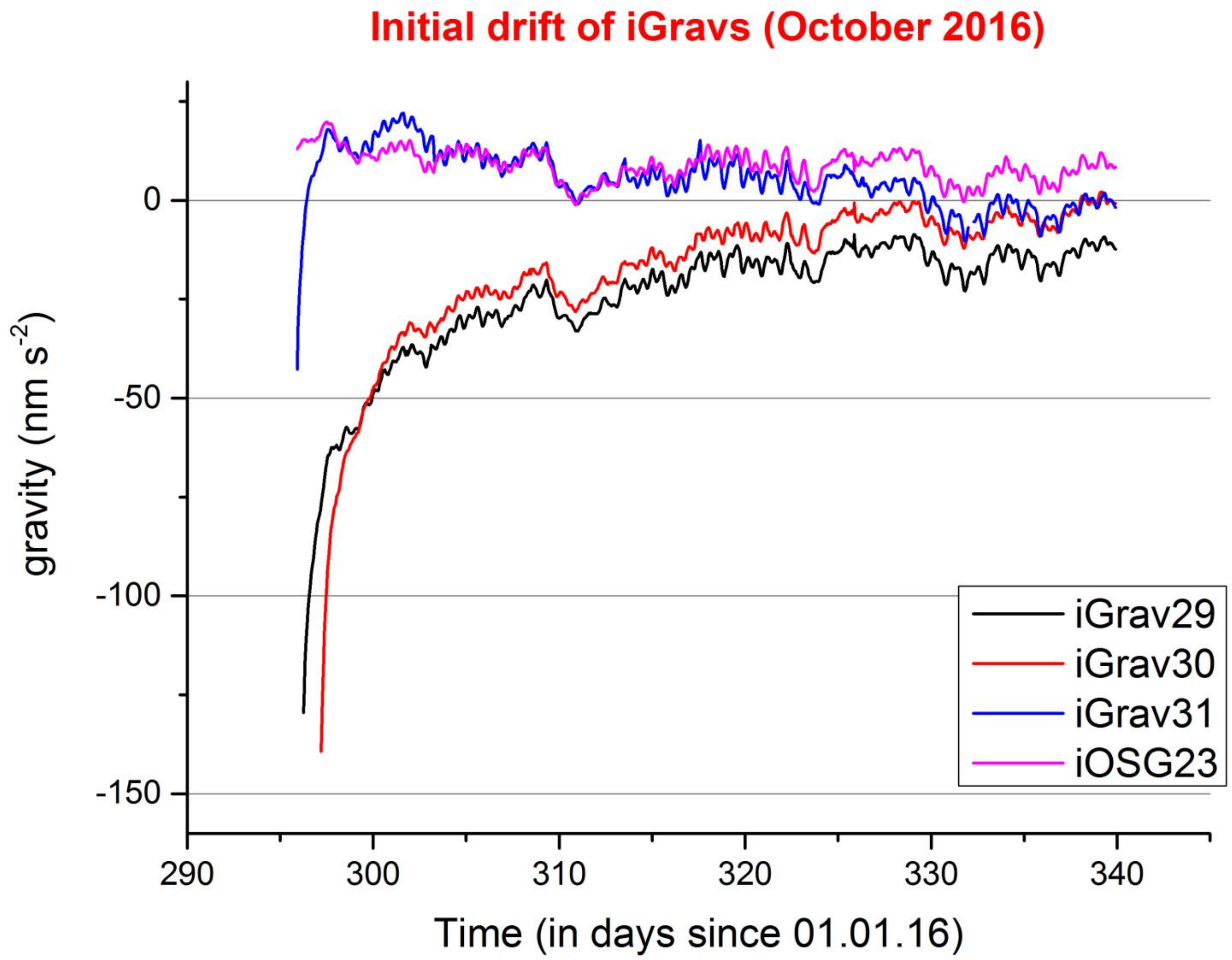
Step experiments for C026 GGP1 in 2012 and C026 TIDE in 1999

and for iOSG23 in 2018

Instrumental drift

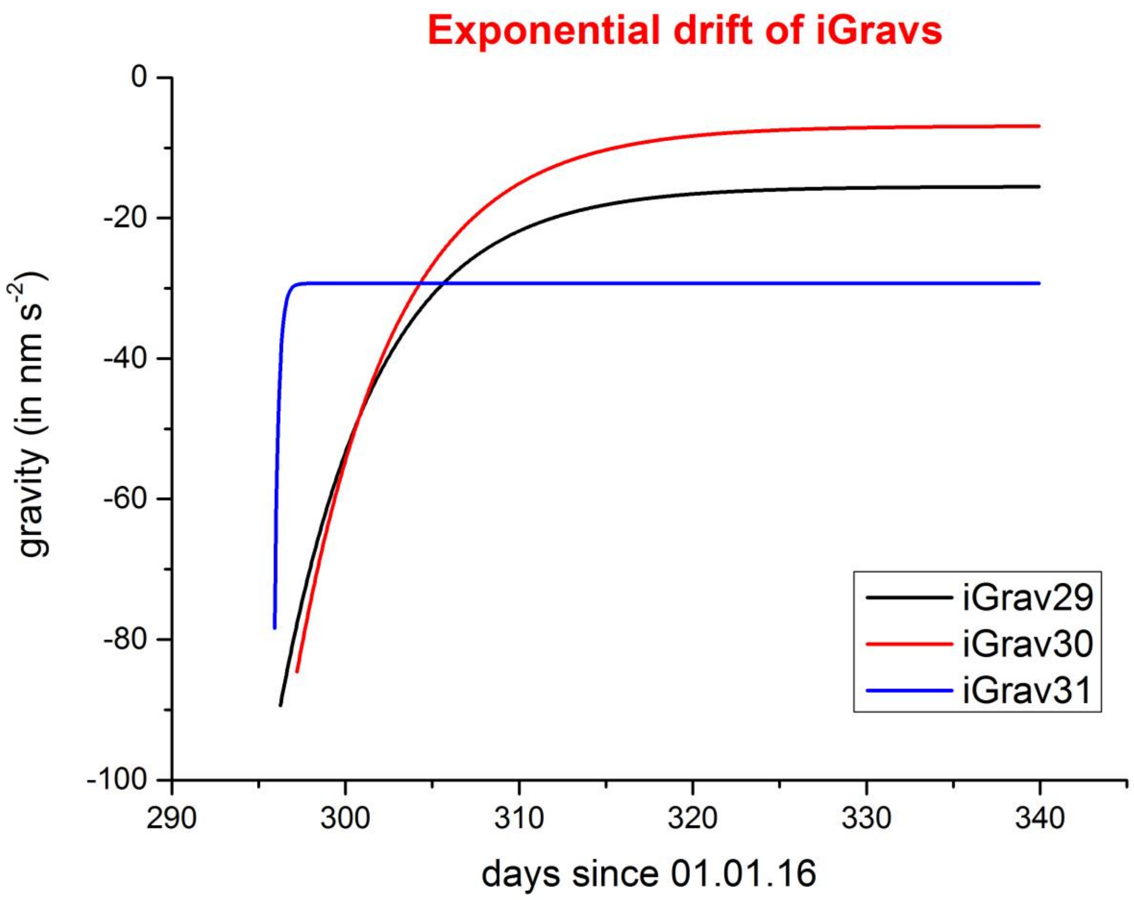
iGrav29, 30, 31:
- installed in July 2016
- relevitated in October 2016

iOSG23 installed in february 2016

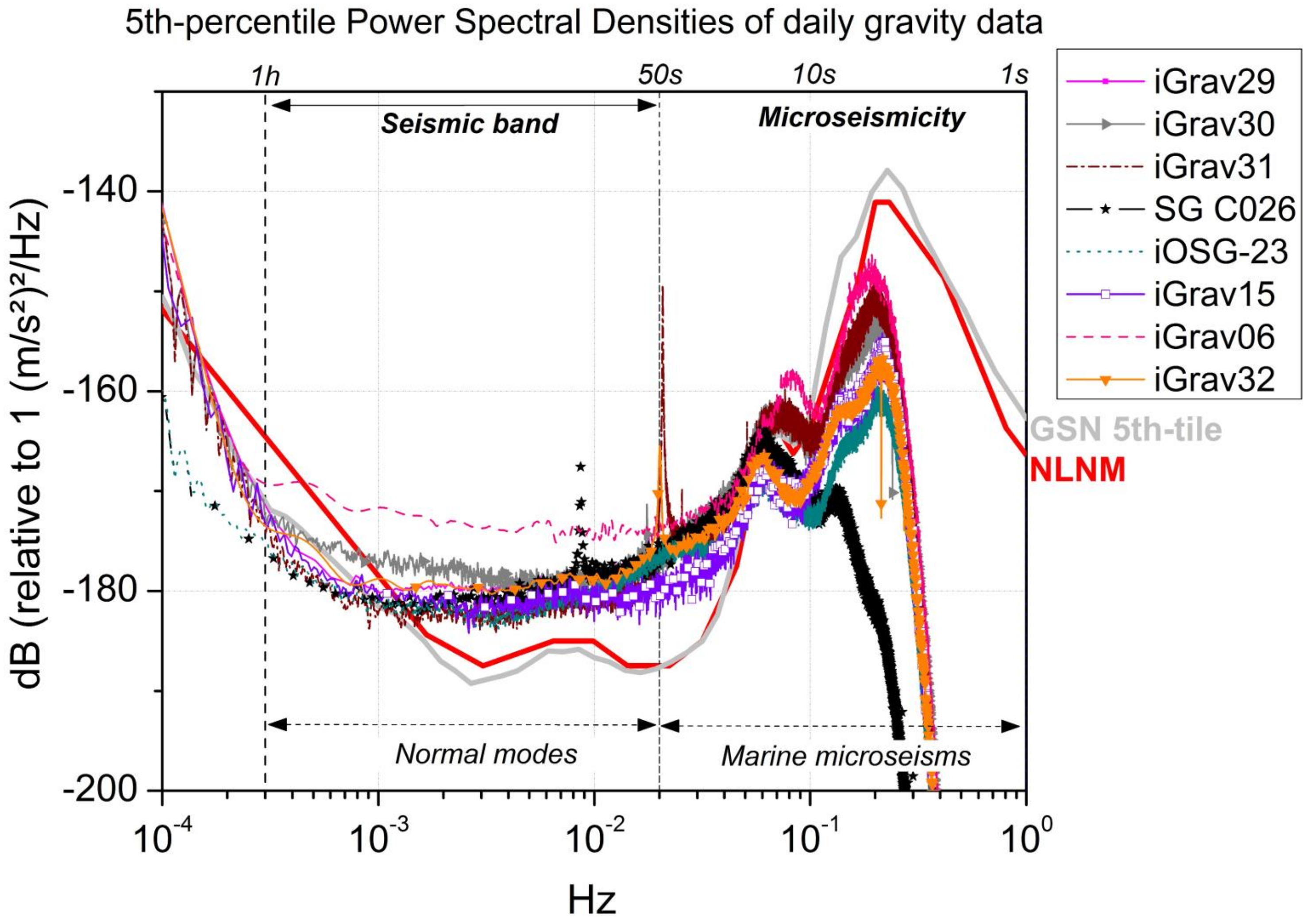


$$y = y_0 + A_1 * \exp(-(x-x_0)/T_1)$$

	iGrav29	iGrav30	iGrav31
A1 (in nm s^{-2})	-73.9	-77.7	-49.1
T1 (in days)	5.6	5.7	0.2



Comparison of the noise levels of all SGs in Strasbourg



Summary

- Relative calibration when different SGs are present on the same site
can be more accurate than absolute calibration from AG/SG parallel records

- Time delays can be retrieved from crosscorrelation between different SG time series,
from tidal analysis or from step experiments

- Initial drift of iGravs is exponential with time constants less than 10 days

To be done

- Stability of calibration factor, time delay and drift when moving a SG from one site to another

Thank you for your attention!

Special thanks for R. Reineman (GWR Instruments) for installing the SGs in J9
and to R. Warburton (GWR Instruments) for numerous discussions on SG properties