

Calibration of a superconducting gravimeter with an absolute atom gravimeter

S. Merlet, P. Gillot, B. Cheng, R. Karcher, A. Imanaliev and F. Pereira Dos Santos

LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Paris, France

L. Timmen

Institute of Geodesy, Leibniz University Hannover, Hannover, Germany

<https://synte.obspm.fr/spip/science/iaci/>

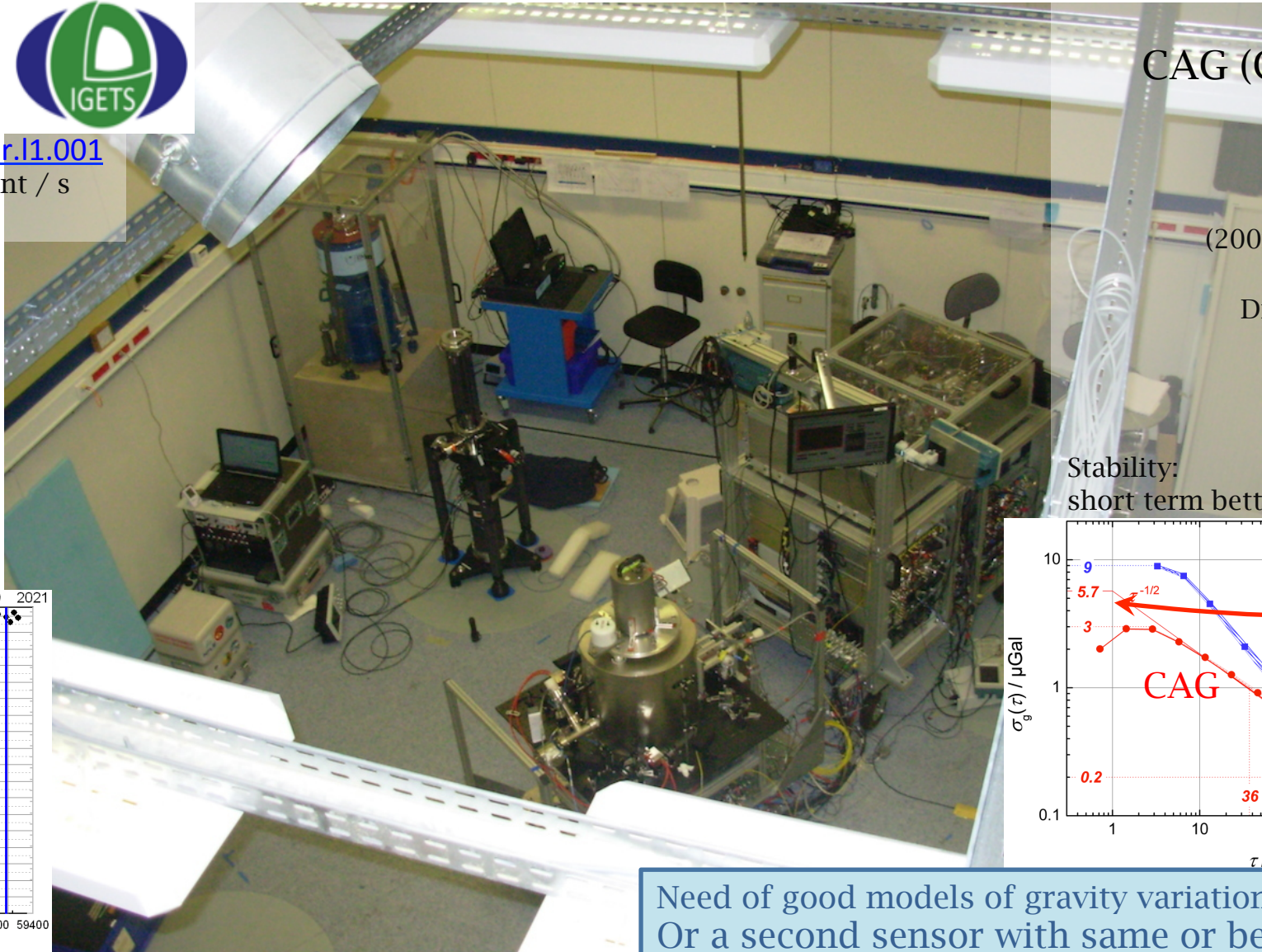
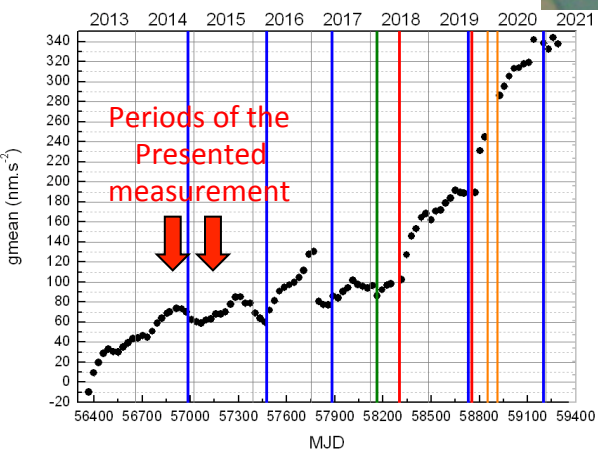
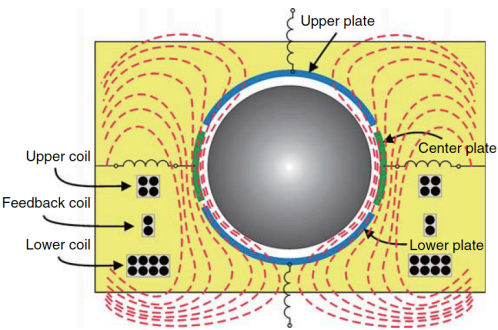
Revisiting a measurement already presented at EGU2016

Relative gravimeter iGrav005 SG

since 2013

<http://doi.org/10.5880/igets.tr.l1.001>

(12Hz „averaged“) 1 gravity point / s
Continuous



Absolute gravimeter CAG (Cold Atom Gravimeter)

since 2009

3 gravity points / s
(here one absolute point / 177 s)

Quasi continuous
(200ms/360ms without measurement)

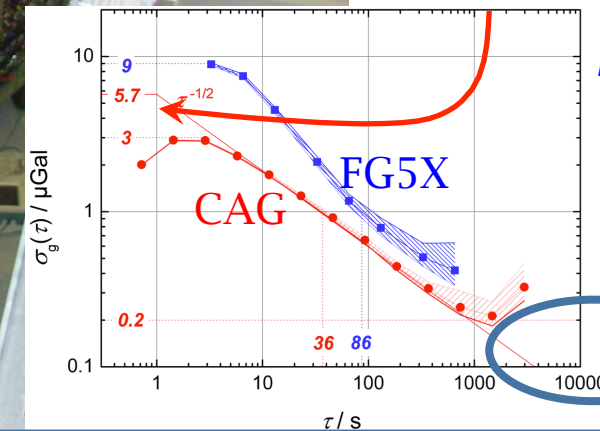
Direct measurement of acceleration

Biases corrected for

ABSOLUTE MEASUREMENT
(in 2015, accuracy 40-50 nm.s⁻²)

Stability:

short term better than 60nm.s⁻² in 1s



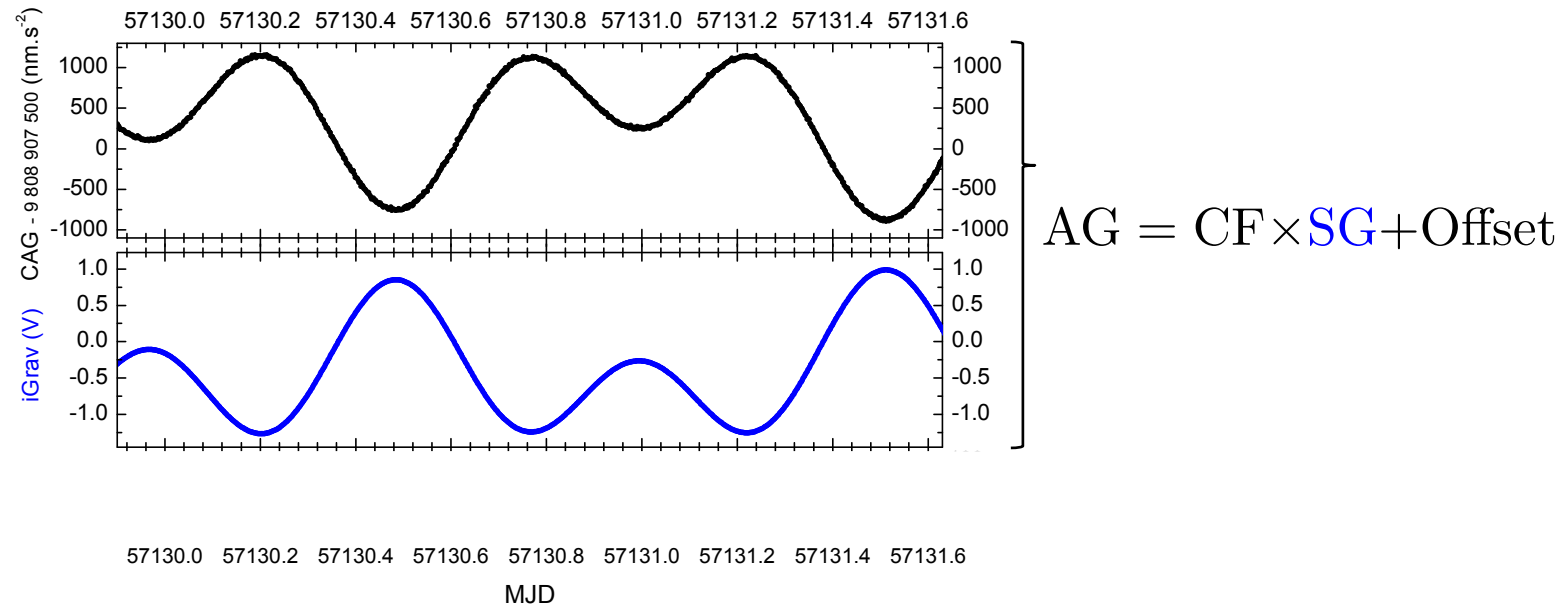
*P. Gillot et al.,
Metrologia 51 (2014)*

What about
long term ?

?

Need of good models of gravity variations to correct for.
Or a second sensor with same or better performances.

1.7 d common view measurement CAG vs iGrav

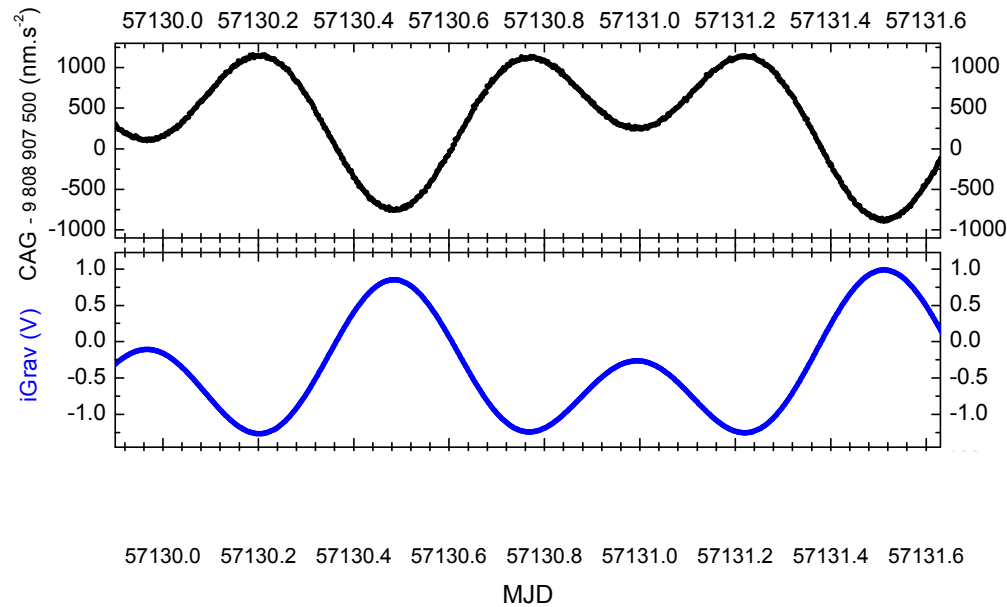


No drift in the fit.

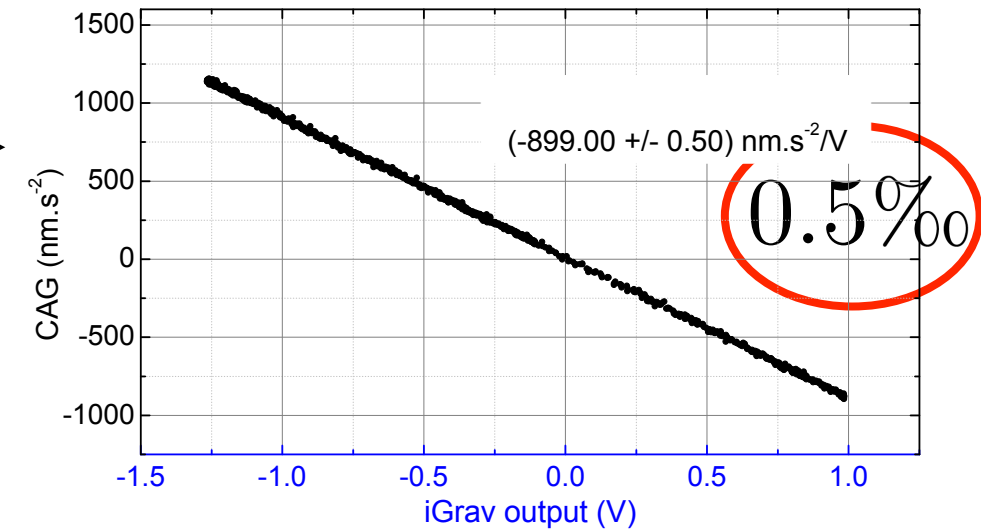
SG is dedrifted based on long term measurement

Take into account a drift possibility in the fit would modify our CAG data and improve the long term sensitivity (which is what we investigate).

1.7 d common view measurement CAG vs iGrav



$$AG = CF \times SG + \text{Offset}$$

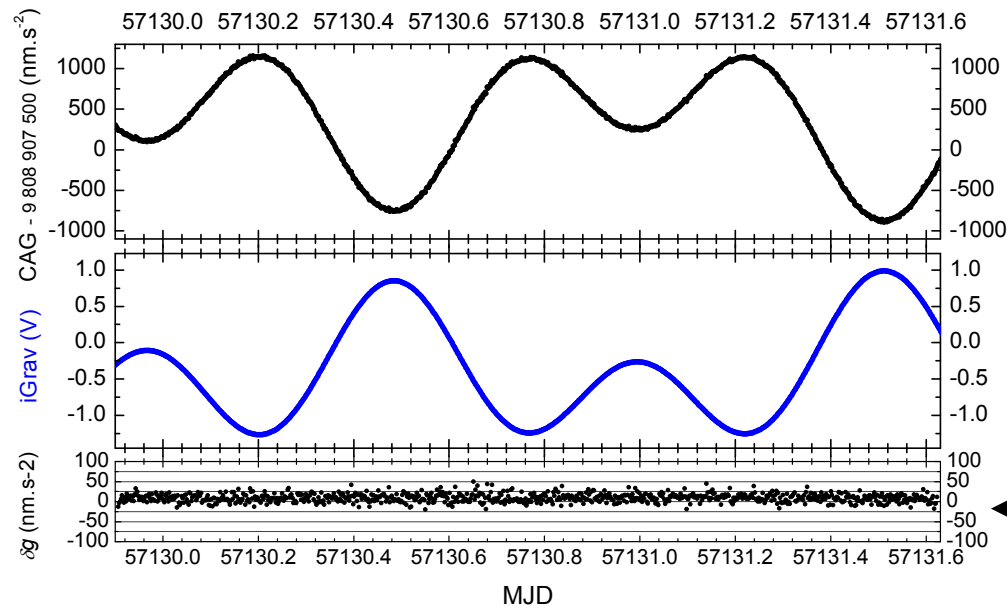


No drift in the fit.

SG is dedrifted based on long term measurement

Take into account a drift possibility in the fit would modify our CAG data and improve the long term sensitivity (which is what we investigate).

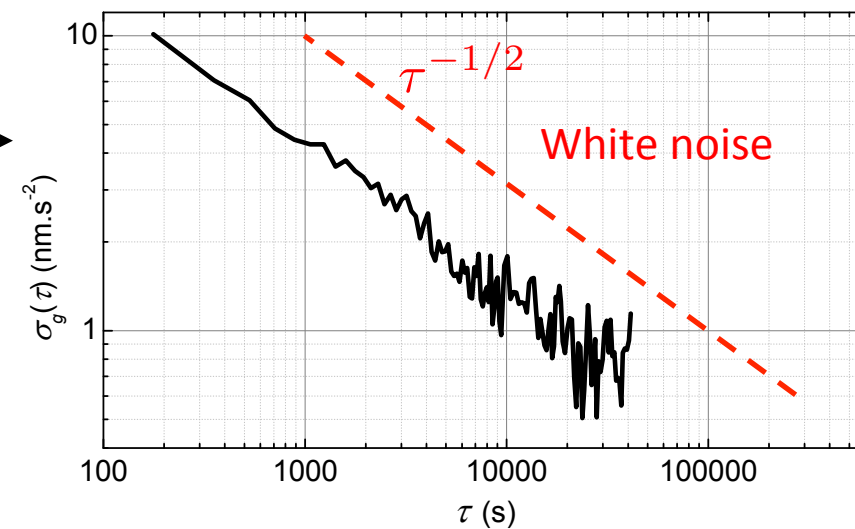
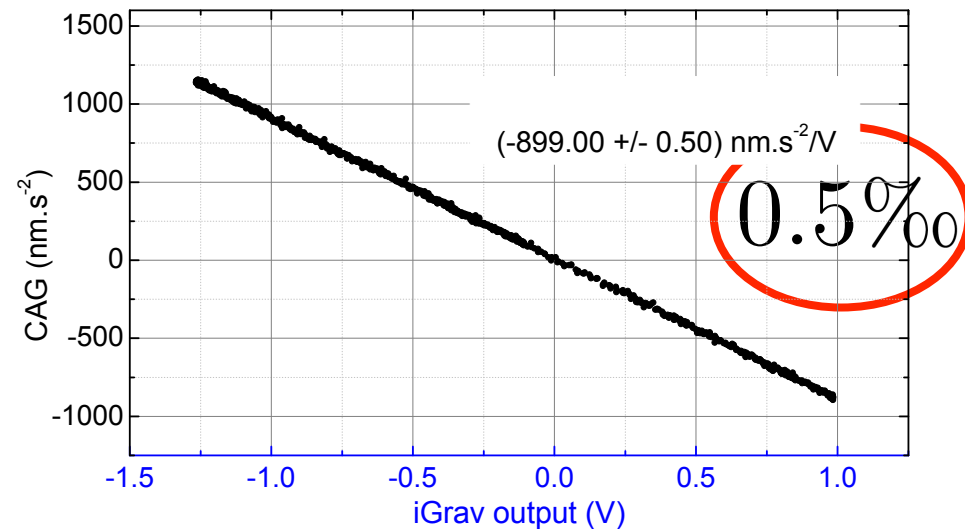
1.7 d common view measurement CAG vs iGrav



$$AG = CF \times SG + \text{Offset}$$

residual

Allan Std Dev analyse



No drift in the fit.

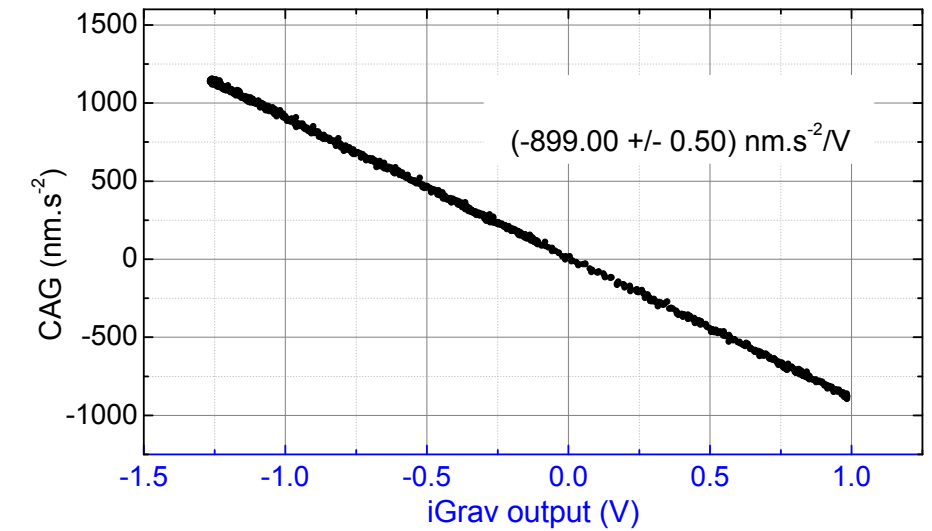
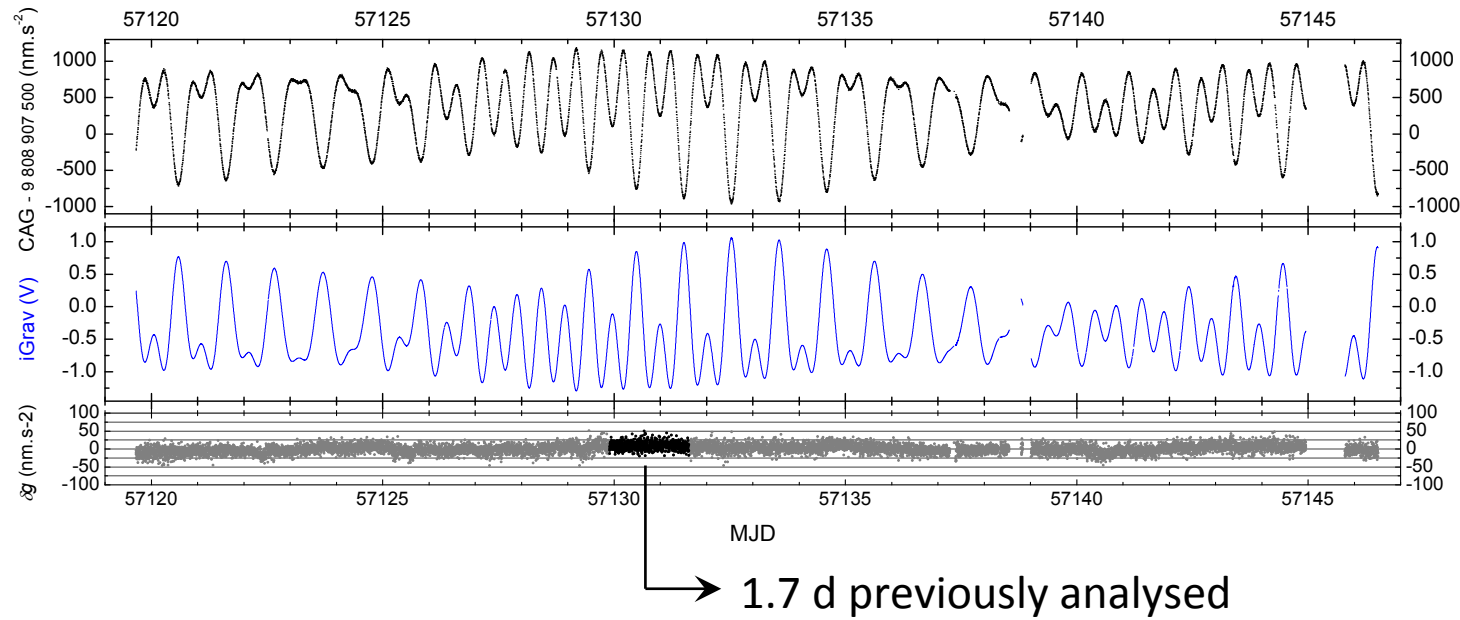
SG is dedrifted based on long term measurement

Take into account a drift possibility in the fit would modify our CAG data and improve the long term sensitivity (which is what we investigate).

0.5 – 0.6 nm.s⁻² in 20 – 30 000 s, moreover CF at 0.5‰ in less than 2d.

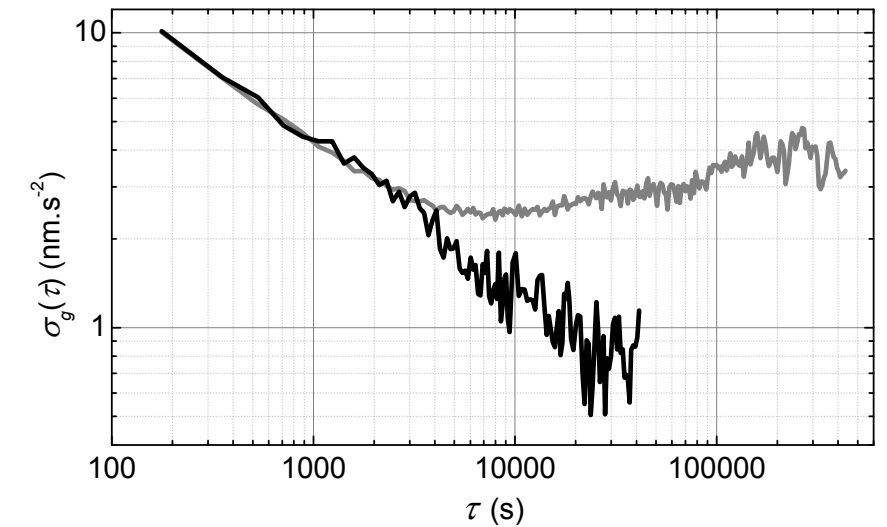
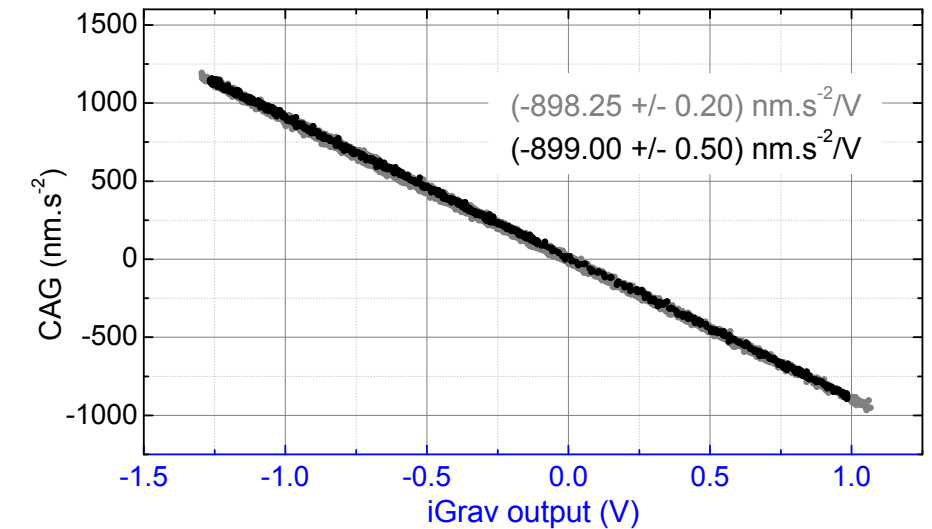
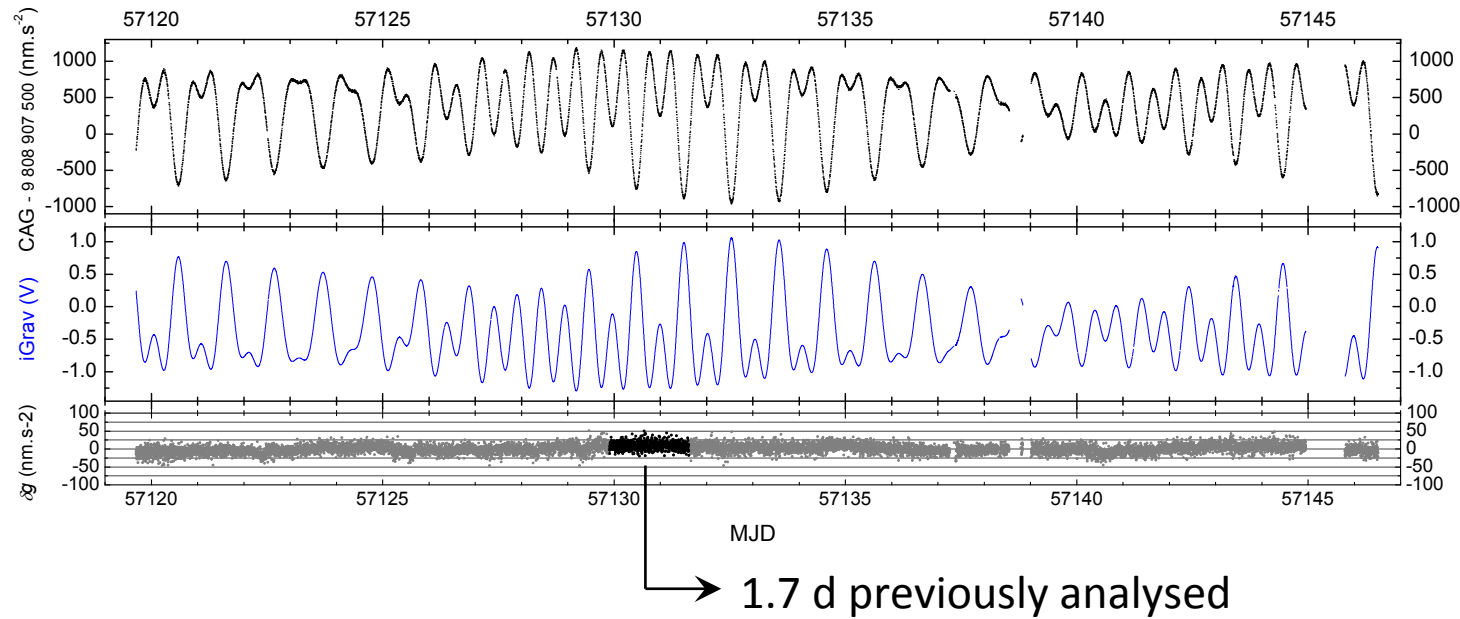
Study finished.

Not ~~1.7 d~~ but 27 d common view measurement CAG vs iGrav



No drift in the fit. $AG = CF \times SG + \text{Offset}$
Repeat the treatment for the long measurement

Not ~~1.7 d~~ but 27 d common view measurement CAG vs iGrav



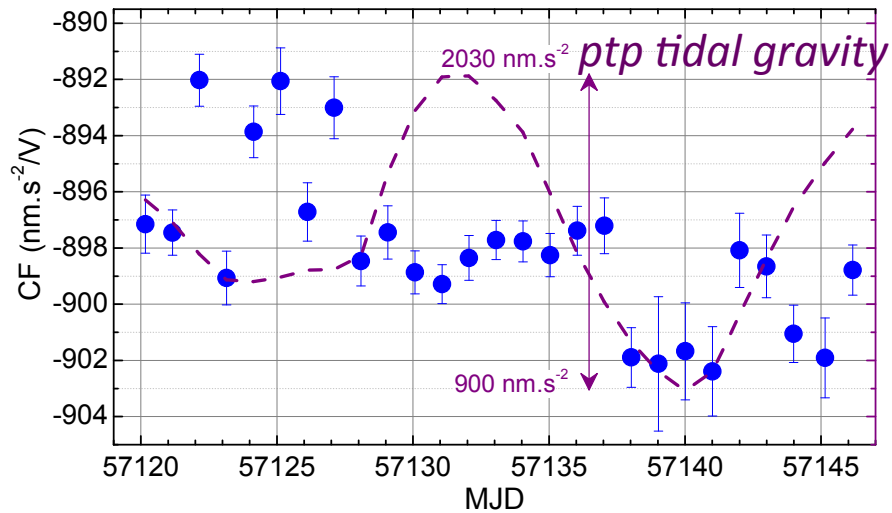
No drift in the fit. $AG = CF \times SG + \text{Offset}$
 Repeat the treatment for the long measurement

CF ? Agreement.
 Level ? 0.2 ‰ ?

Long term stability ?

Not White noise, so 0.20/898.25 not possible

Segmentation analysis: 27d / 27 = 1d long analysis

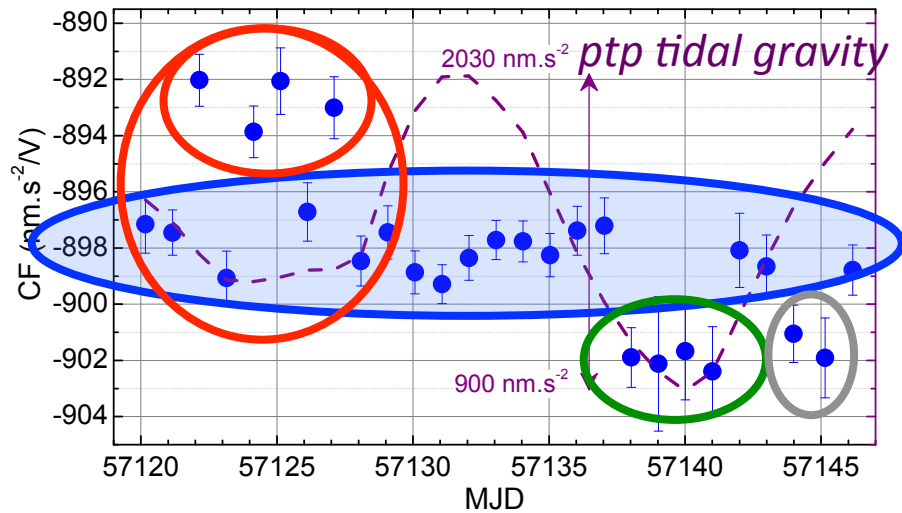


Error bars: error of the individual linear fits (err),
err mean value = $1.05 \text{ nm.s}^{-2}/\text{V} < \text{sd}_{\text{CF}} = 2.77 \text{ nm.s}^{-2}/\text{V}$ (close to factor 3!)

CFs ptp CF = $10 \text{ nm.s}^{-2}/\text{V}$!

Error of fits underestimate the uncertainty in CF determination

Segmentation analysis: 27d / 27 = 1d long analysis



Error bars: error of the individual linear fits (err),
err mean value = $1.05 \text{ nm.s}^{-2}/\text{V} < \text{sd}_{\text{CF}} = 2.77 \text{ nm.s}^{-2}/\text{V}$ (close to factor 3!)

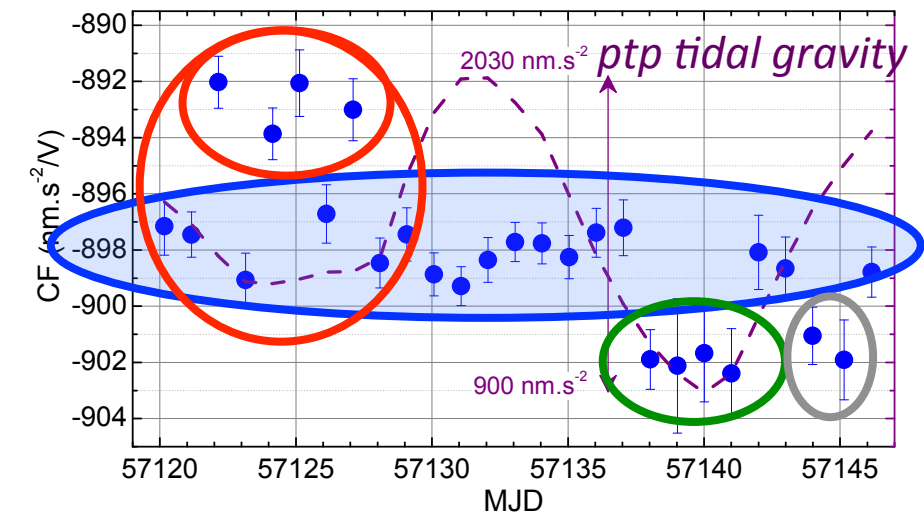
CFs ptp CF = $10 \text{ nm.s}^{-2}/\text{V}$!

Error of fits underestimate the uncertainty in CF determination

Problem of signal amplitude ?

Mean result. Small *g* amplitude but $|CF| > |Cf_{\text{mean}}|$. Same *g* amplitude but different CFs. High *g* amplitude but different CFs.

Segmentation analysis: 27d / 27 = 1d long analysis



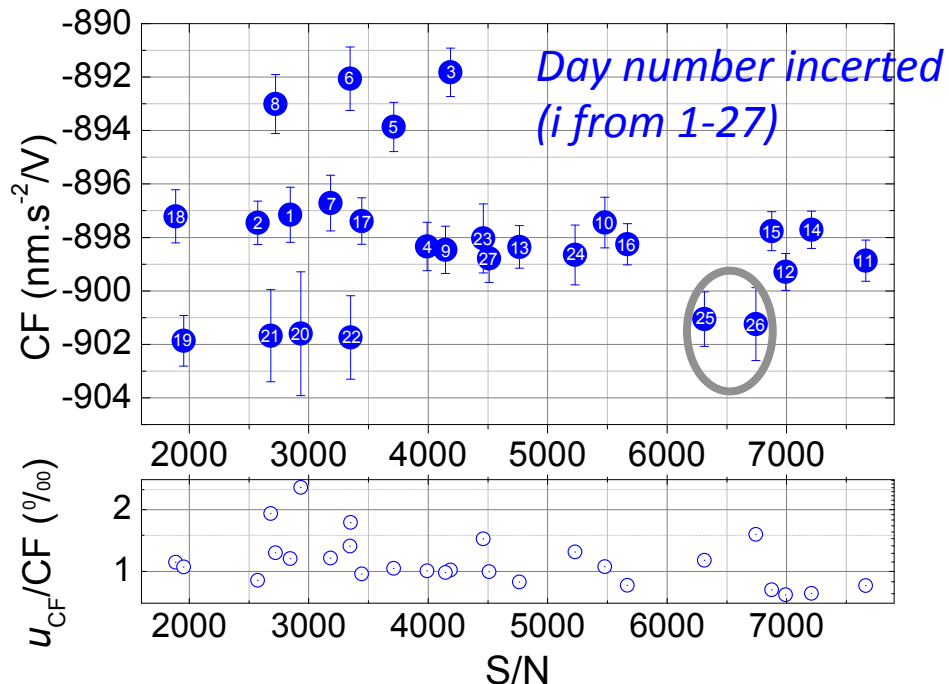
Error bars: error of the individual linear fits (err),
err mean value = $1.05 \text{ nm.s}^{-2}/\text{V} < \text{sd}_{\text{CF}} = 2.77 \text{ nm.s}^{-2}/\text{V}$ (close to factor 3!)

CFs ptp CF = $10 \text{ nm.s}^{-2}/\text{V}$!

Error of fits underestimate the uncertainty in CF determination

Problem of signal amplitude ?

Mean result. Small g amplitude but $|CF| > |CF_{\text{mean}}|$. Same g amplitude but different CFs. High g amplitude but different CFs.



Problem of signal amplitude and noise ?

#3-4-5-6-8-9-19-20-21-22: large distribution but half = CF_{mean}

S/N > 4300 almost CF_{mean}

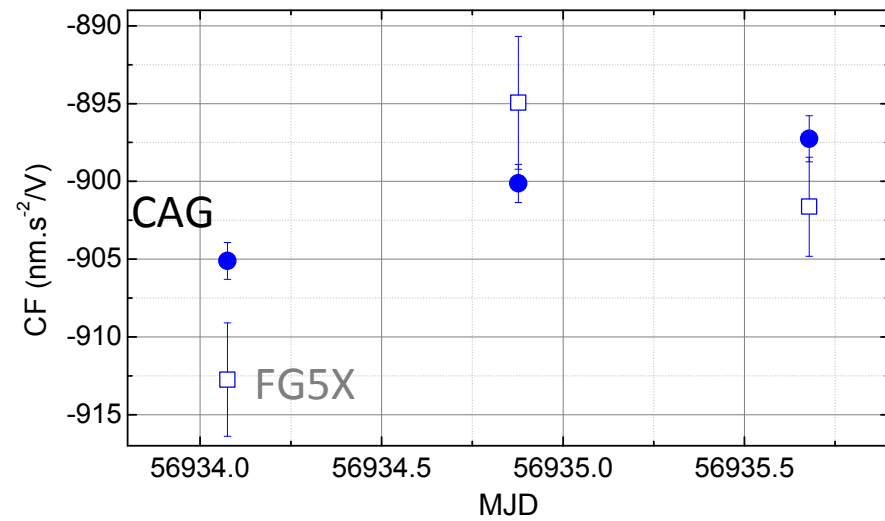
Except #25 and #26 : even if high S/N $CF \neq CF_{\text{mean}}$

Instrumental fluctuations: CAG ? iGrav ?

Comparison with different AGs

Take advantage of a 3 d measurement both with FG5X-220

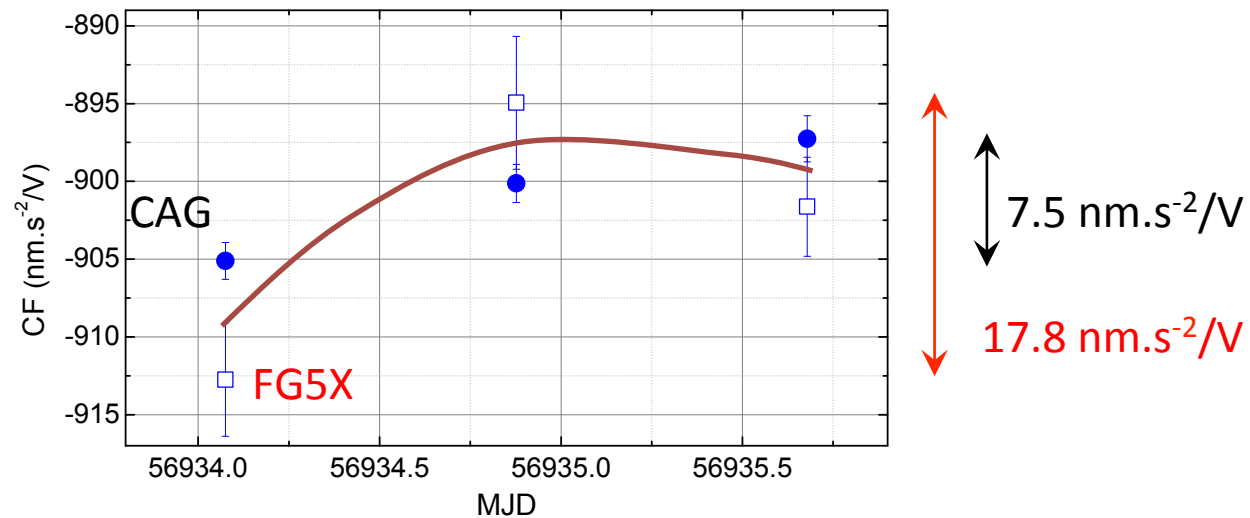
Comparison of one day calibrations $AG = CF \times SG + \text{Offset}$



Comparison with different AGs

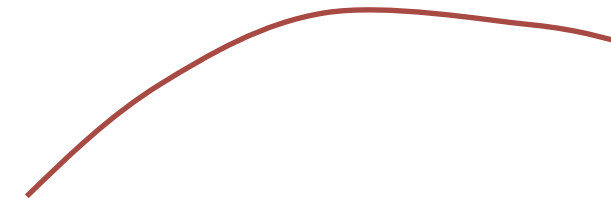
Take advantage of a 3 d measurement both with FG5X-220

Comparison of one day calibrations $AG = CF \times SG + \text{Offset}$



CFs difference ? And evolution ?

Gravity variation seen by AGs and not by SG ?
(or the opposit) leading to CF evolution ?

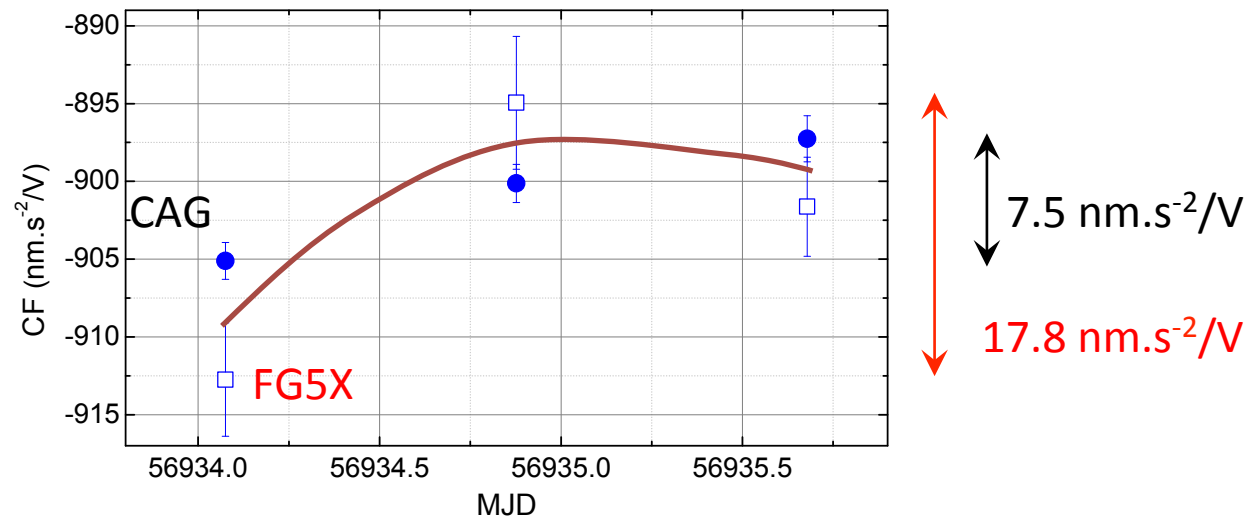


AG instabilities ? SG instabilities ?

Comparison with different AGs

Take advantage of a 3 d measurement both with FG5X-220

Comparison of one day calibrations $AG = CF \times SG + \text{Offset}$



CFs difference ? And evolution ?

Gravity variation seen by AGs and not by SG ?
(or the opposit) leading to CF evolution ?

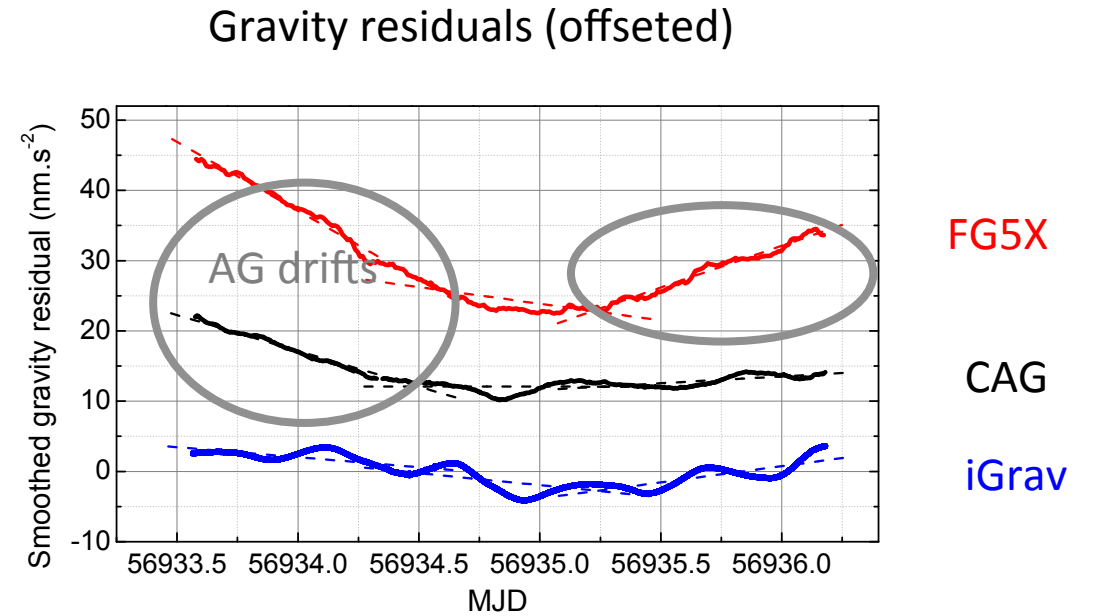
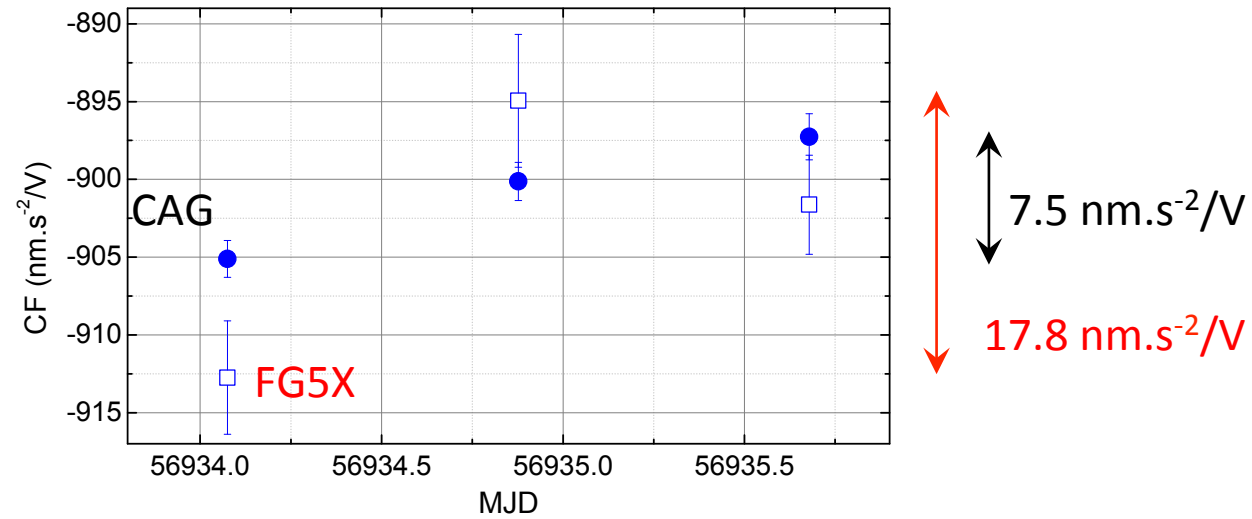
AG instabilities ? (both ?) ~~SG instabilities ?~~

Calculate 3 CFs with tide model : mean = $(-897.3 \pm 0.3) \text{ nm.s}^{-2}/\text{V}$, with 0.8 $\text{nm.s}^{-2}/\text{V}$ agreement

Comparison with different AGs

Take advantage of a 3 d measurement both with FG5X-220

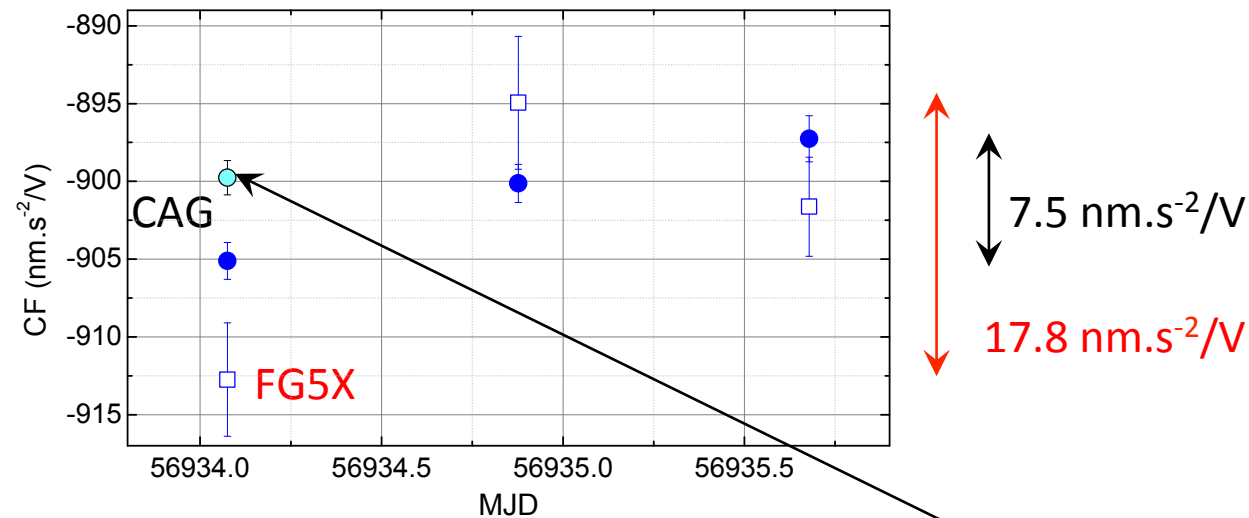
Comparison of one day calibration



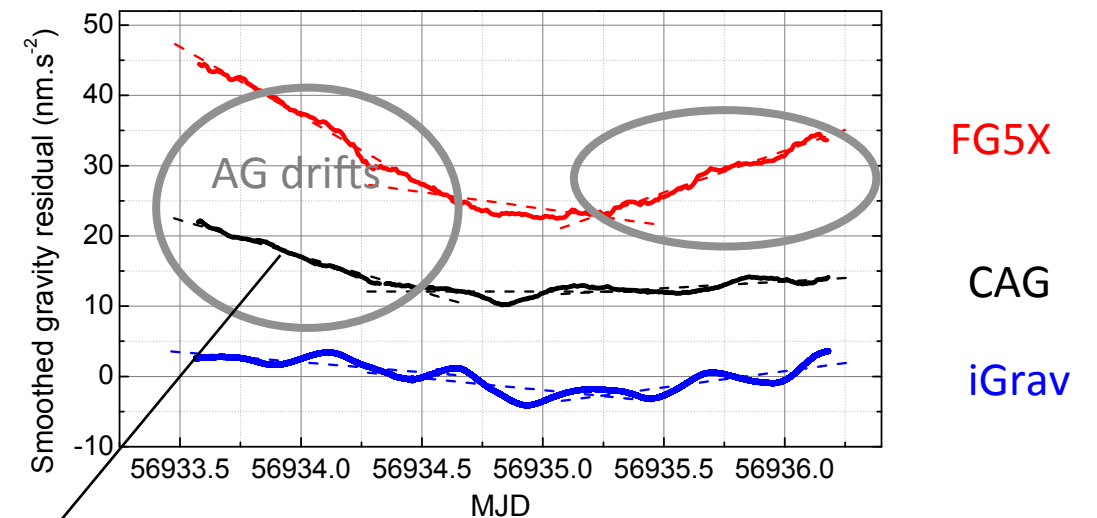
Comparison with different AGs

Take advantage of a 3 d measurement both with FG5X-220

Comparison of one day calibration



Gravity residuals (offseted)



Drift CAG = (-10.19 ± 0.06) nm.s⁻²/d,

Correcting from drift: $|CF(\text{FG5X}) - CF(\text{CAG})| = (1.2 \pm 2.2) \text{ nm.s}^{-2}/\text{V}$

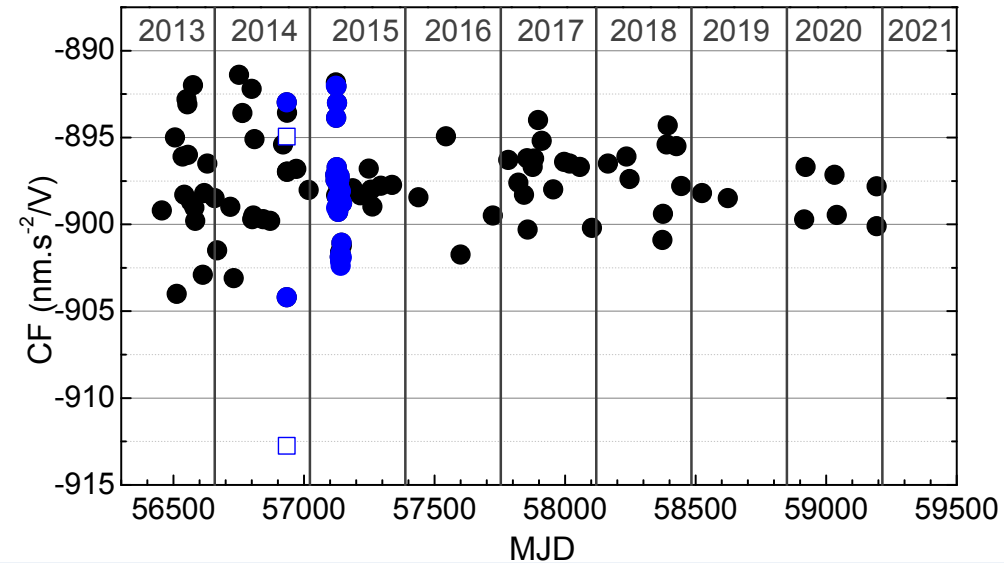
For “deterministic” fluctuation, include polynomial part in AG = CF × SG + Offset ? Better to know the reason, the source, the bias and correct for it.

What are here the bias sources ? CAG TPLS and initial cloud position fluctuation, FG5X ? Unknown, tilts ?

Conclusion

We reproceed the 27-d long measurement and 27 1-d measurement : no change in the 1-d CF dispersion.
(comparison with FG5X was performed in 2014, the 27 d long measurement in 2015 with optical power lock (less TPLS fluctuation !) but fluctuations ! -> initial cloud position !

To be safe: we take all the calibrations since 2013,
CF = mean of the distribution. $(-897.6 \pm 2.7) \text{ nm.s}^{-2}/V$.



CAG Long term sensitivity obtained: $0.5 - 0.6 \text{ nm.s}^{-2}$

CAG allowed CF at 0.5‰ level in 1.7 d and showed possibility for 1‰ level in less than a day (for $1\,500 \text{ nm.s}^{-2} g$ variations)

Improvements: CAG (cloud stabilization, optical power, wavefront, coriolis control), FG5X: tiltmeter ?
Better to avoid drifts part in the SG calibration. A drift, bias, has to be understood and measured to be corrected for.

Article soon in JoG : doi: [10.1007/s00190-021-01516-6](https://doi.org/10.1007/s00190-021-01516-6)