ACES Payload system test

Scientific relevant results

DEFENCE AND SPACE

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20.10. 2022

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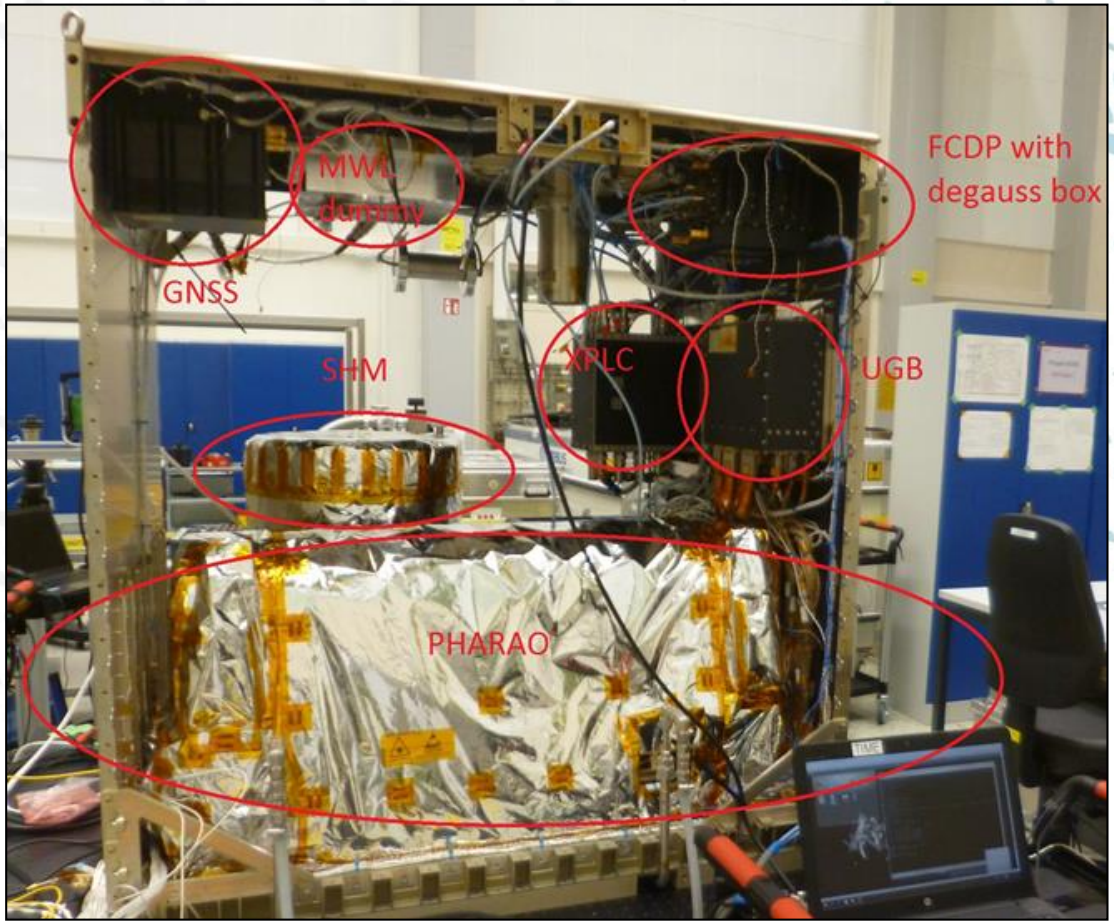
Agenda

- SHM PHARAO FCDP standalone
- Stand alone environmental
- STSL/AMPM
- STSL magnetic environment
- LTSL
- Orbital simulation
- Lessons learned



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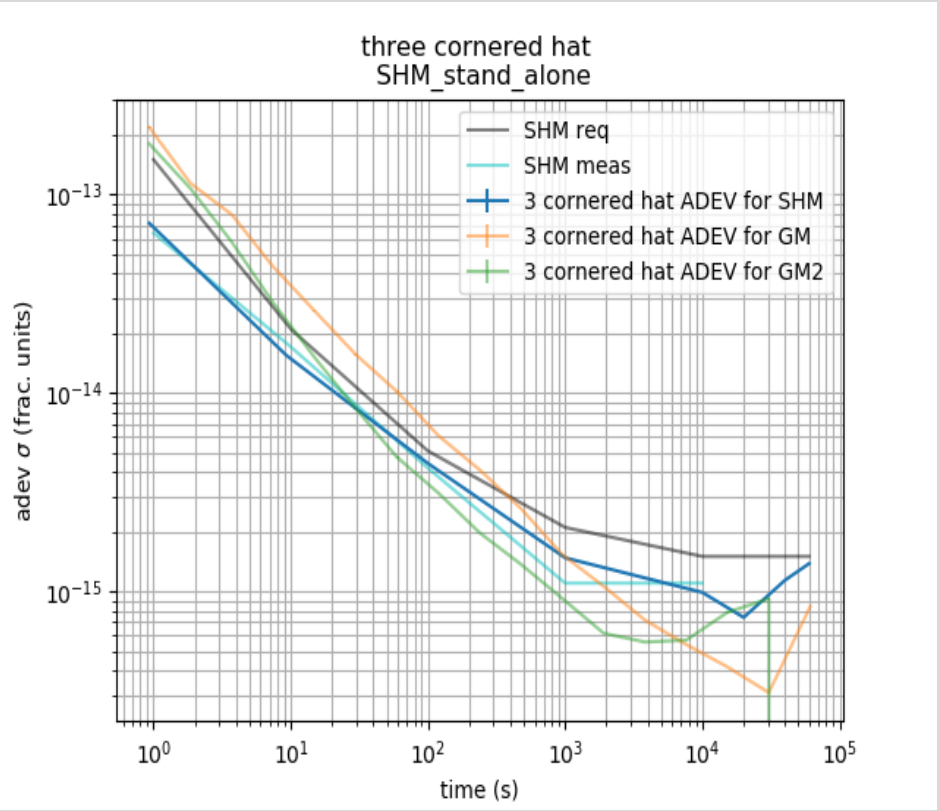
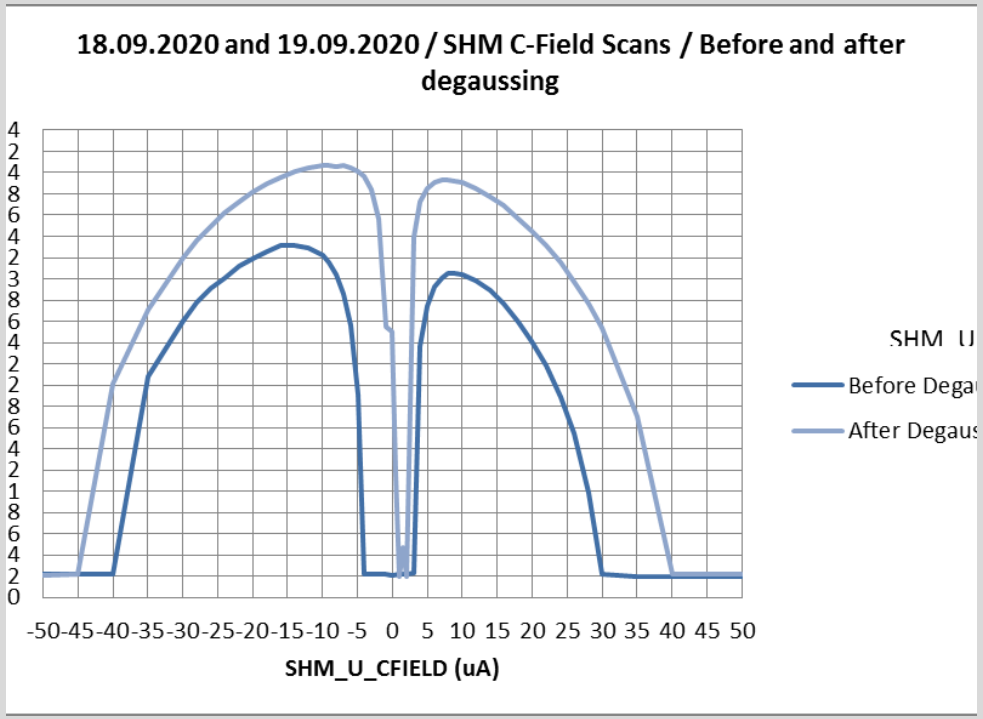
Stand alone measurements:

Calibration of active Hydrogen Maser (SHM), Cs clock (PHARAO) FCDP.
Not included is the Microwave link (MWL)
see Achim Helm





Stand alone instruments

SHM

Three cornered hat measurement
SHM well within requirement
Degaussing works nicely.

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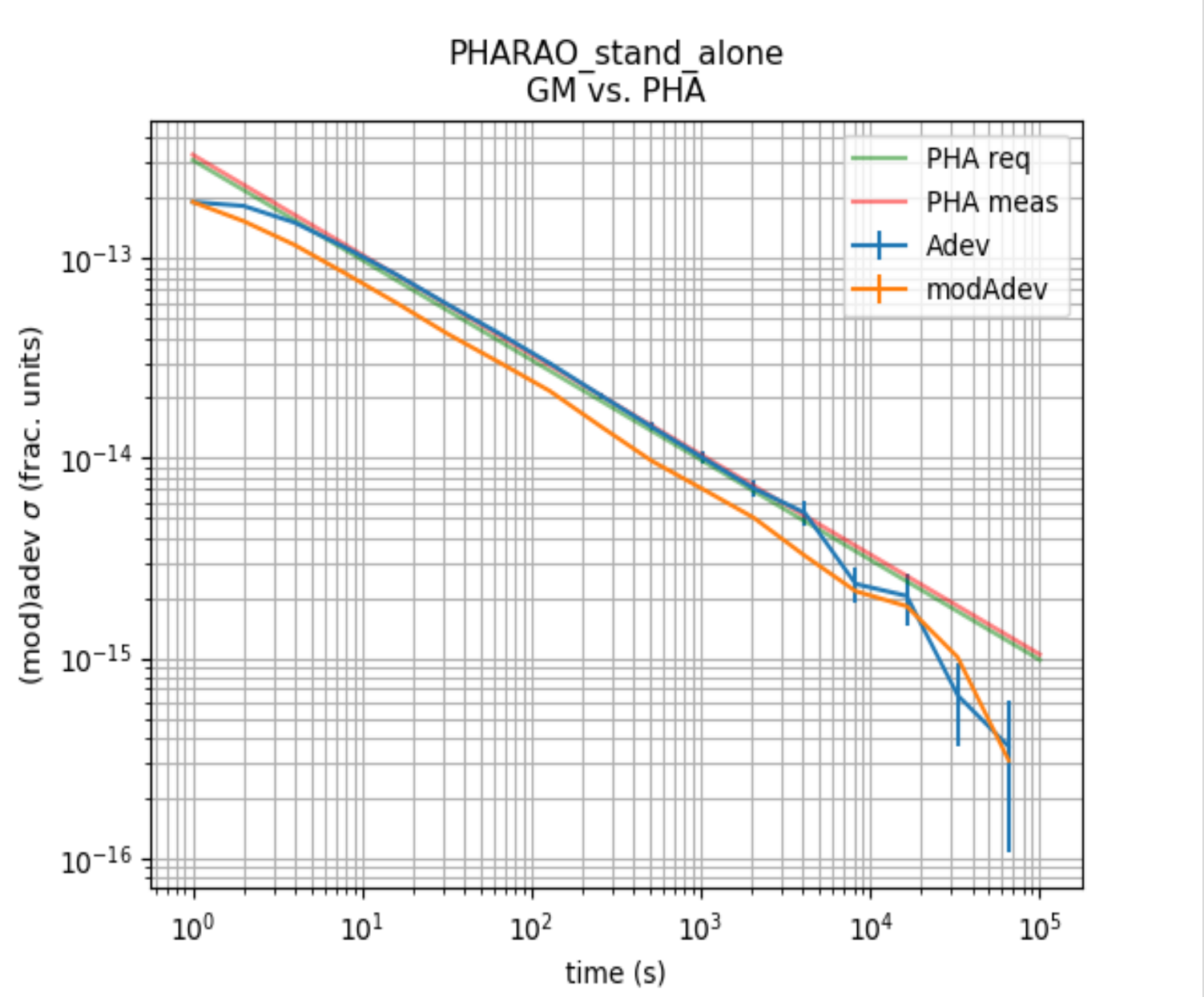

PHARAO stability

As expected. Measurement against external maser

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[Airbus Amber]

Stand alone environment

Subtitle

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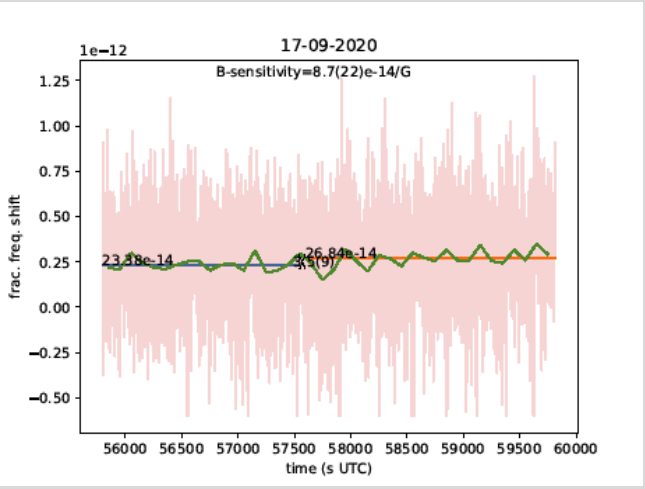
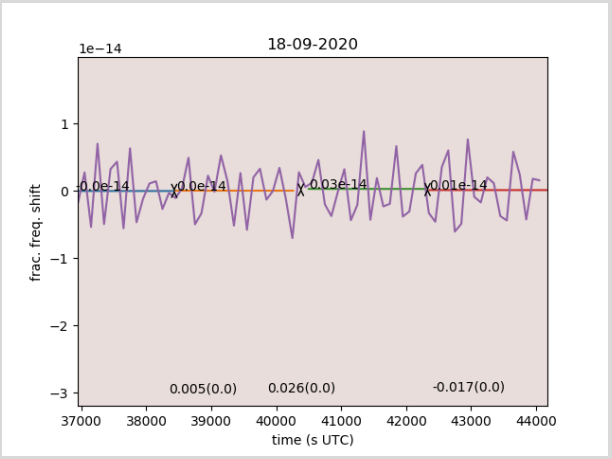
Stand alone environment

Magnetic PHARAO

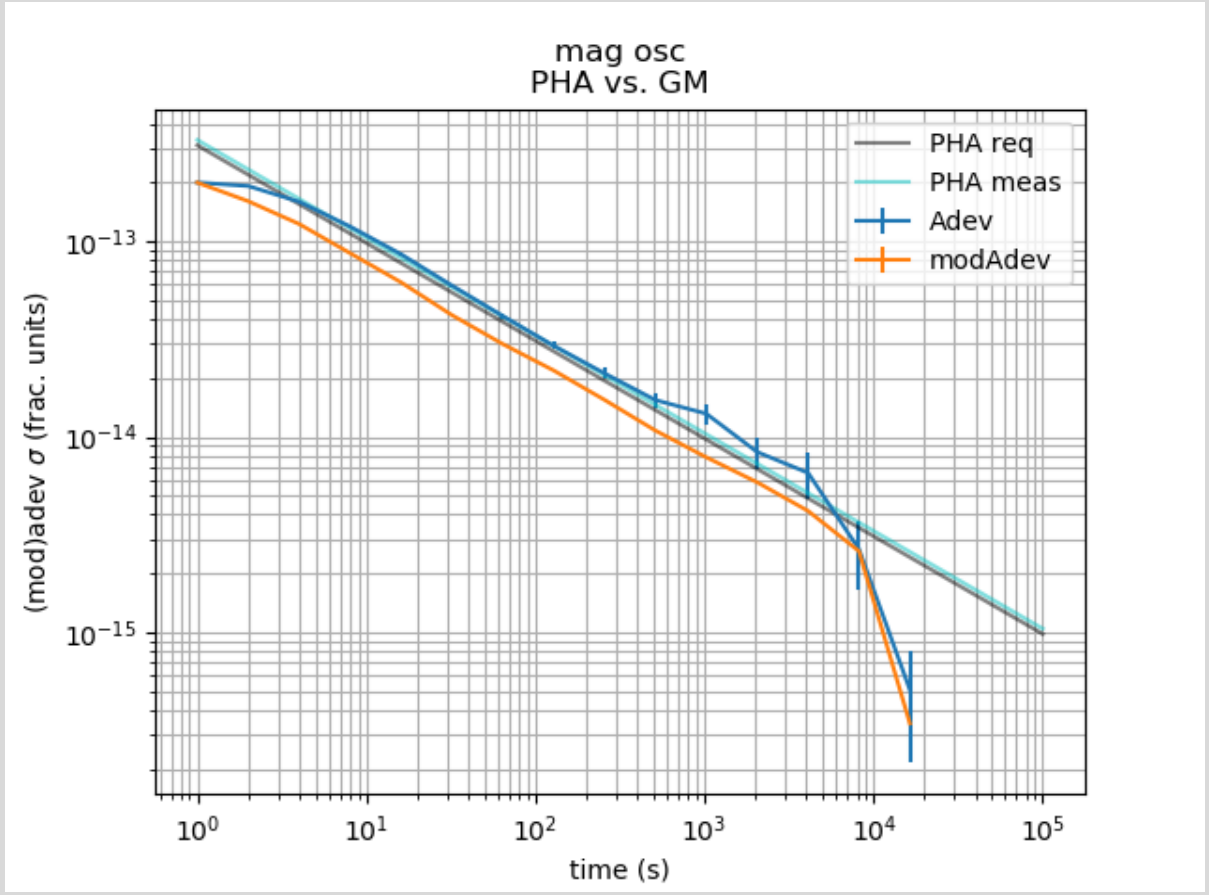
- PHARAO is barely susceptible (respecting it noise level)
- In orbit it may be directly visible



PHARAO axial
B sensitivity 8.7(2.2)e-14/G



PHARAO radial
B sensitivity
(SHM measurement)



Magnetic orbital: 5000s

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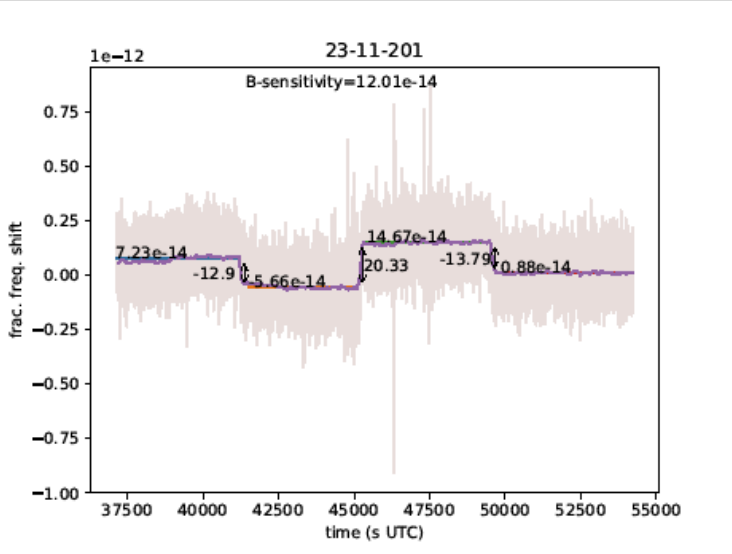
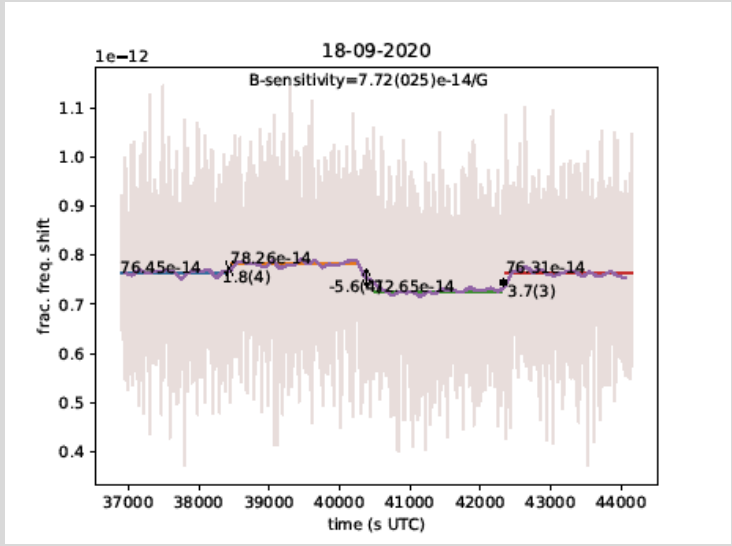
Stand alone environment

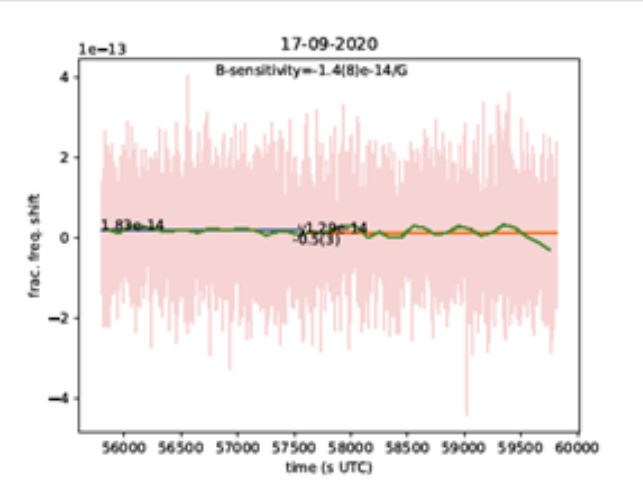
Magnetic SHM



Stand alone reference: 1.2e-13/G at earth field pm 1 Gauss



ACES 7.73(25)e-14/G with 0 pm 0.35 Gauss



Radial B susceptibility 1.4(8)e-14

- SHM after degaussing in zero field is less susceptible (shielding of vac chamber already included)
- SHM is clearly susceptible

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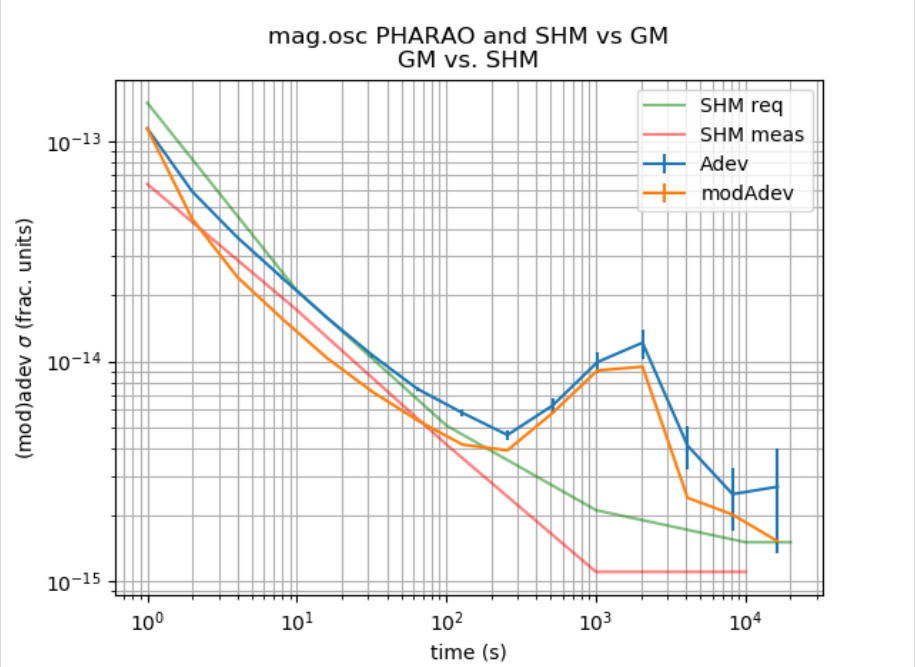
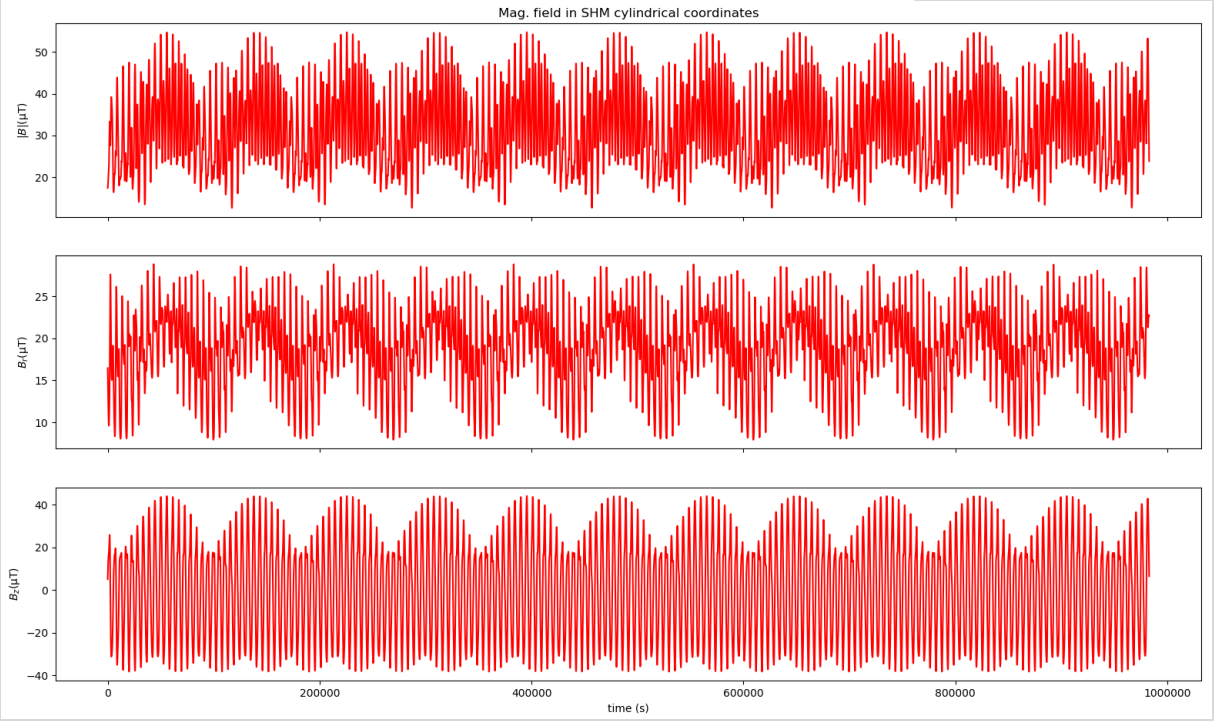
Stand alone environment





Total field

Radial to SHM

Axial to SHM

Magnetic SHM

- Magnetic oscillation clearly seen in ADEV
- Magnetic field known in 3d and time

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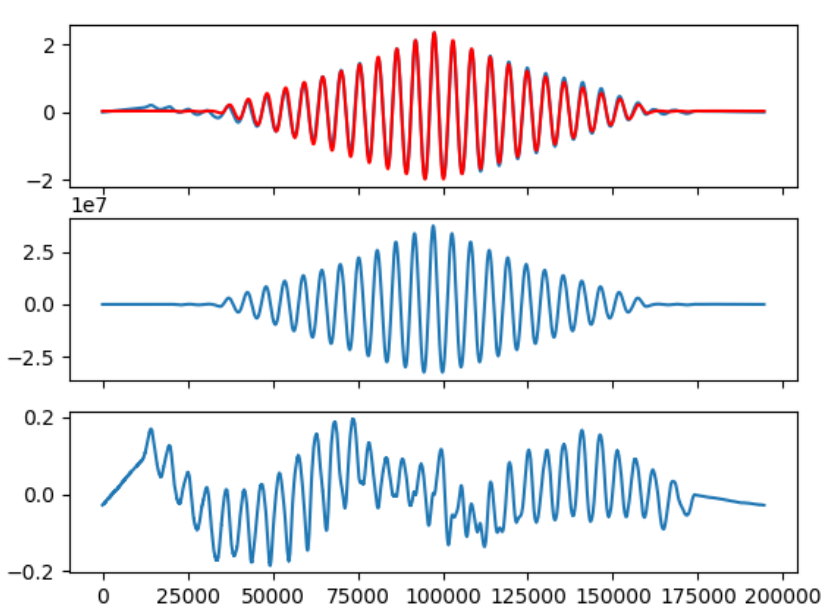
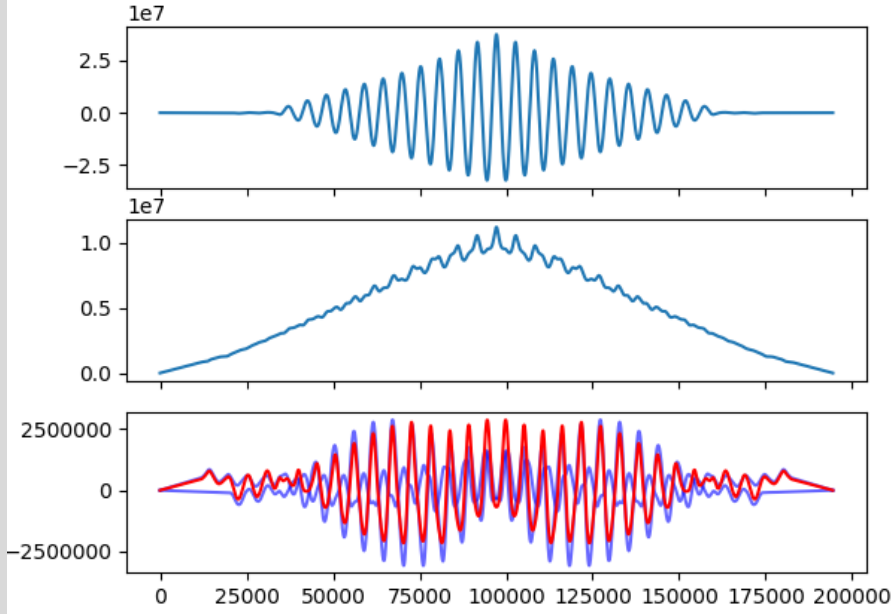


From top to down:

- Data with fit: 5.7640(15)e-14/G
- Auto correlation
- residual

Same result as direct fit
Residual not strong enough to fit radial effect



From top to down:

- Axial auto correlation
- Radial auto correlation
- Cross correlation axial and radial: in red Bz*Br+Br*Bz

Stand alone environment

Magnetic SHM

Correction cross correlation

Same result, somewhat more precise. Radial effect visible

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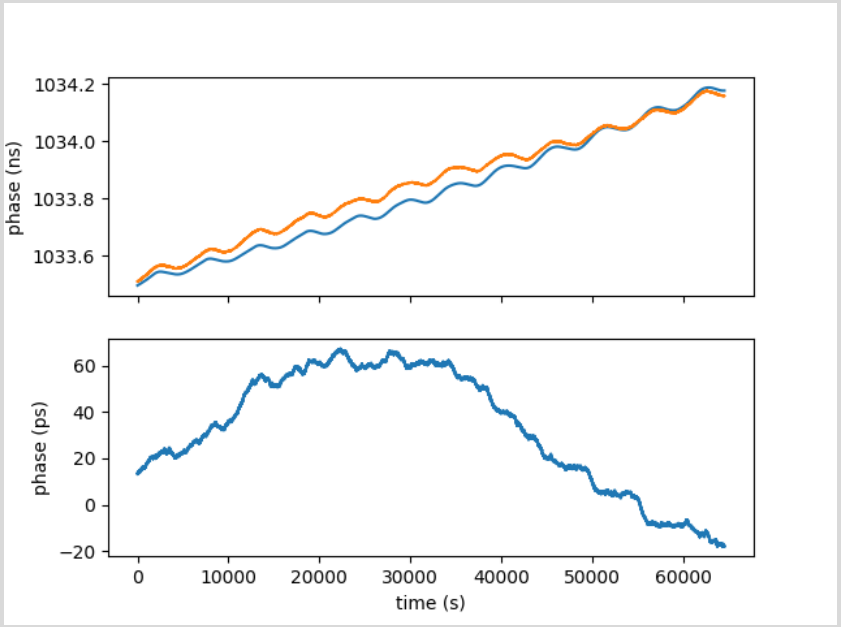
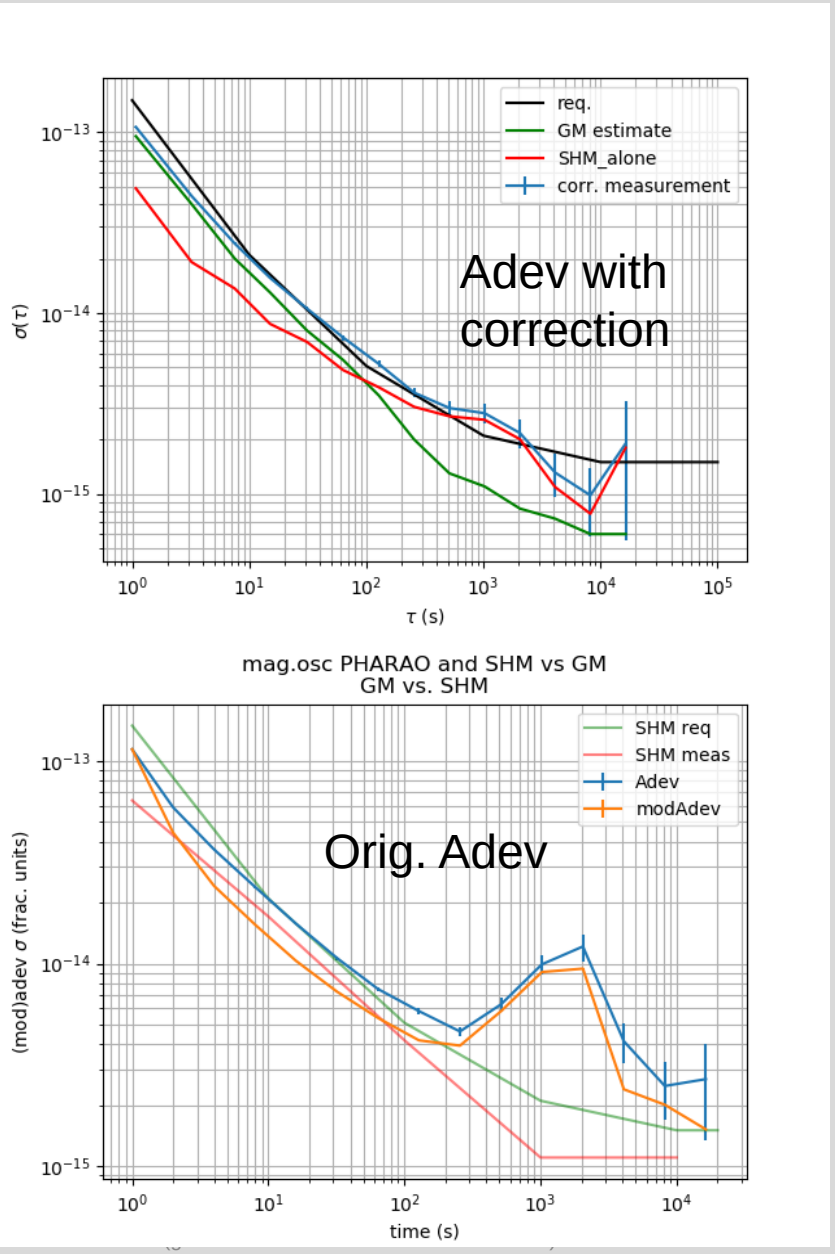


Integrate and apply frequency correction to raw PCO data:
Top: data (blue) and correction (orange)
Bottom: Phase track after removing drift and correction



Stand alone environment

Magnetic SHM

Correction

- ADEV is nearly in requirement
- 5 fold suppression of the magnetic susceptibility
- B vector components must be known
- Not sensitive to angle of orbital simulator (pm 10° did not change final result)

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Stand alone environment

Temperature requirements

Improvements necessary
Difficult to implement

Heater installed to compensate environmental conditions are used to induce expected residual effects on the instruments

Limited by heater power

Instrument	Low temp required (°C)	Low temp reached (°C)	Amplitude required (pp°C)	Amplitude reached (pp°C)
PHARAO	14.9 (av TP)	(17.5+21)/2=19.2	3	2.5
SHM	21.2	24	1.5	1.5
FCDP	14.9	15	3.5	3.5

Limited by cooling power of shroud

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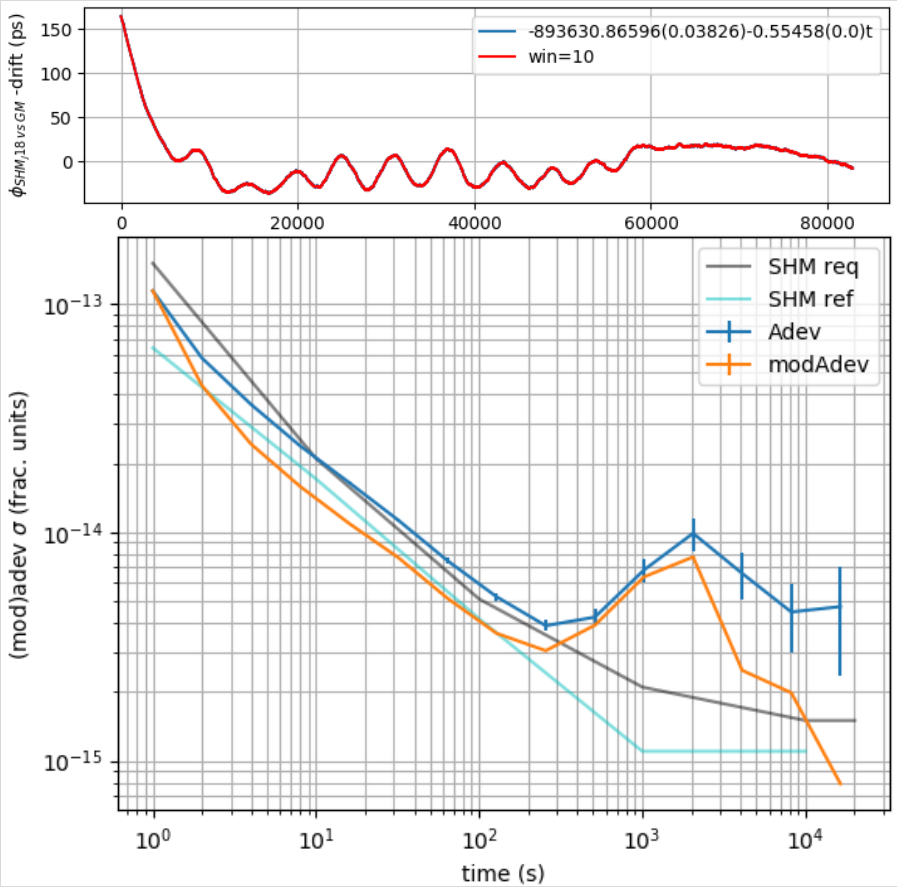
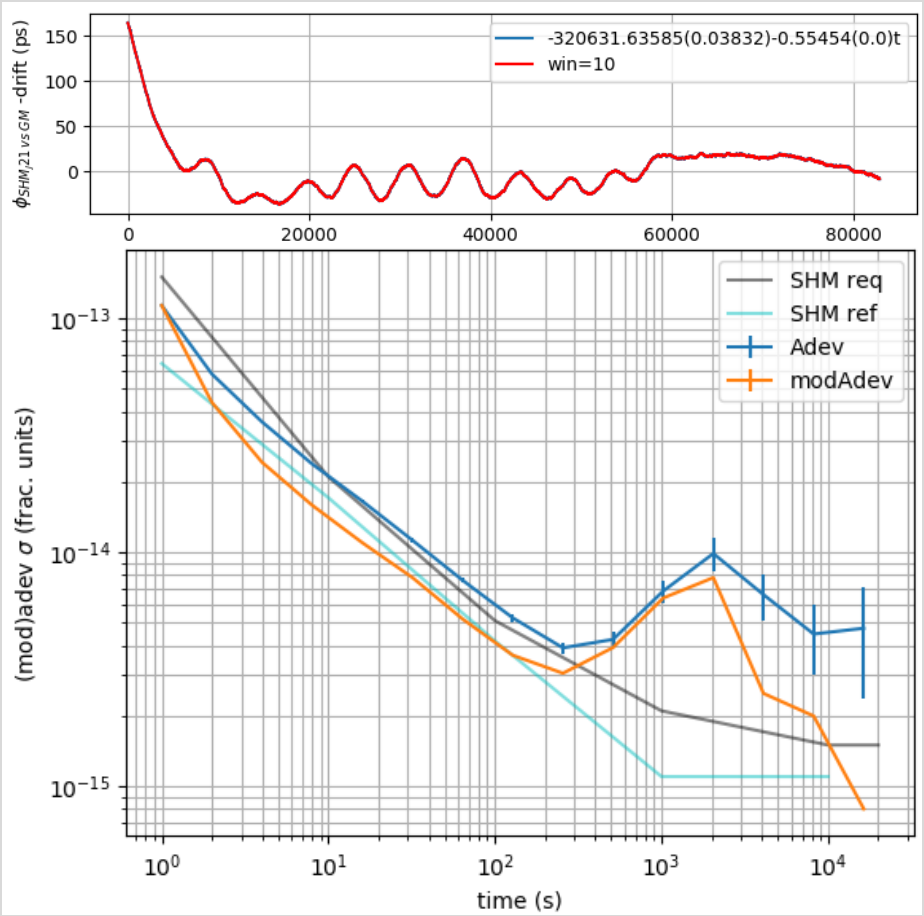
Stand alone temperature

Thermal SHM



SHM through FCDP MWL output



SHM direct

- Large thermal bump as expected
- FCDP has little impact on ADEV

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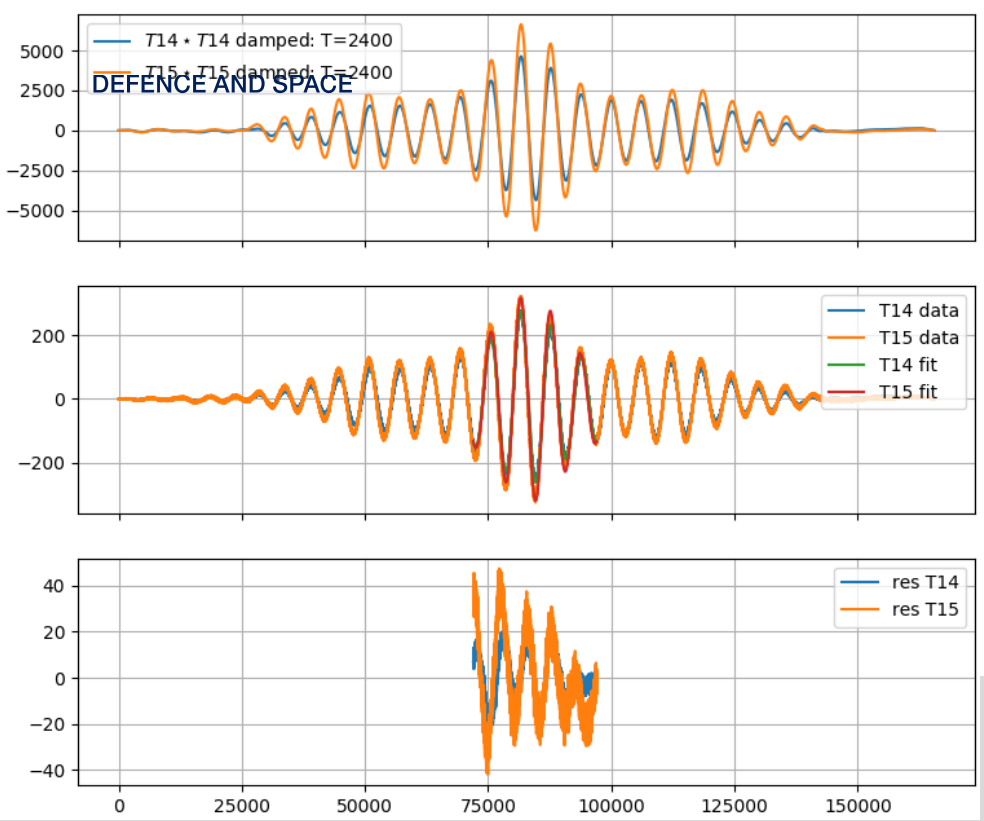

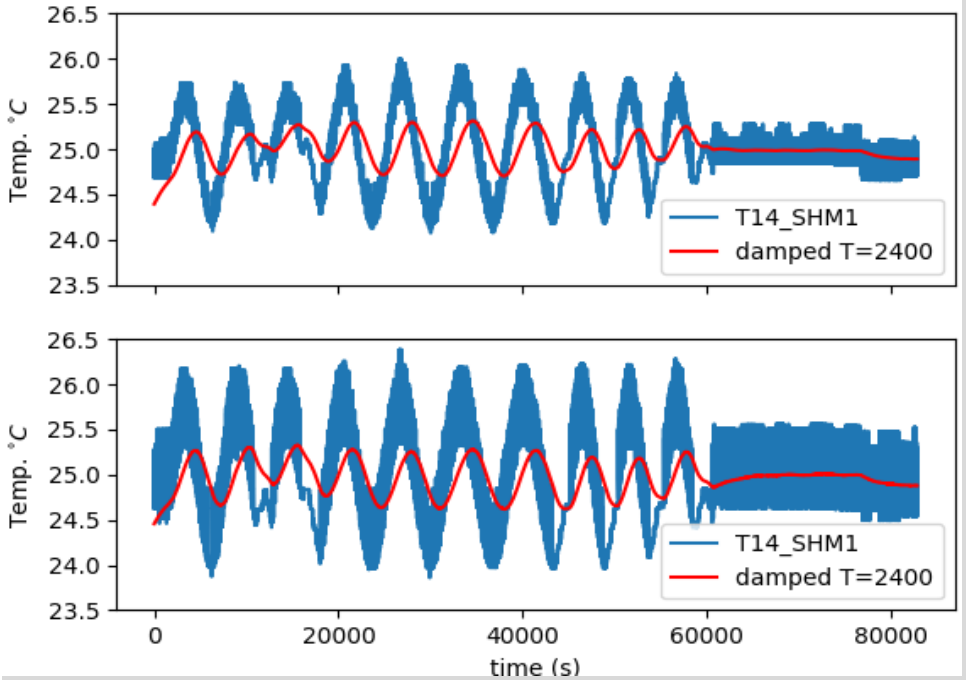

Stand alone temperature

Thermal SHM

Cross correlation

with damping

Cross correlation with damped temperature and frequency data

Damped temperature oscillations using convolution with:

Simple RC damping: $\frac{\mathrm{X}}{T} e^{-\frac{t}{T}}$

Data	Amplitude (Hz/K s)	Damping T (s)	Offset (µHz/K s)	χ_T (µHz/K)
T14_SHM1@J21	2.481(1)e-05	2.431(3)e+03	-2.64(6)e+00	6.031(7)
T15_SHM2@J21	1.994(2)e-05	2.799(3)e+03	-2.9(1)e+00	5.581(8)
T14_SHM1@J18	2.471(1)e-05	2.45000000(8)e+03	-2.58(7)e+00	6.054(2)
T15_SHM2@J18	1.984(2)e-05	2.822(4)e+03	-2.8(1)e+00	5.60(1)

- Small residuals – good model
- Results roughly in agreement
- Fit error to small (residuals)

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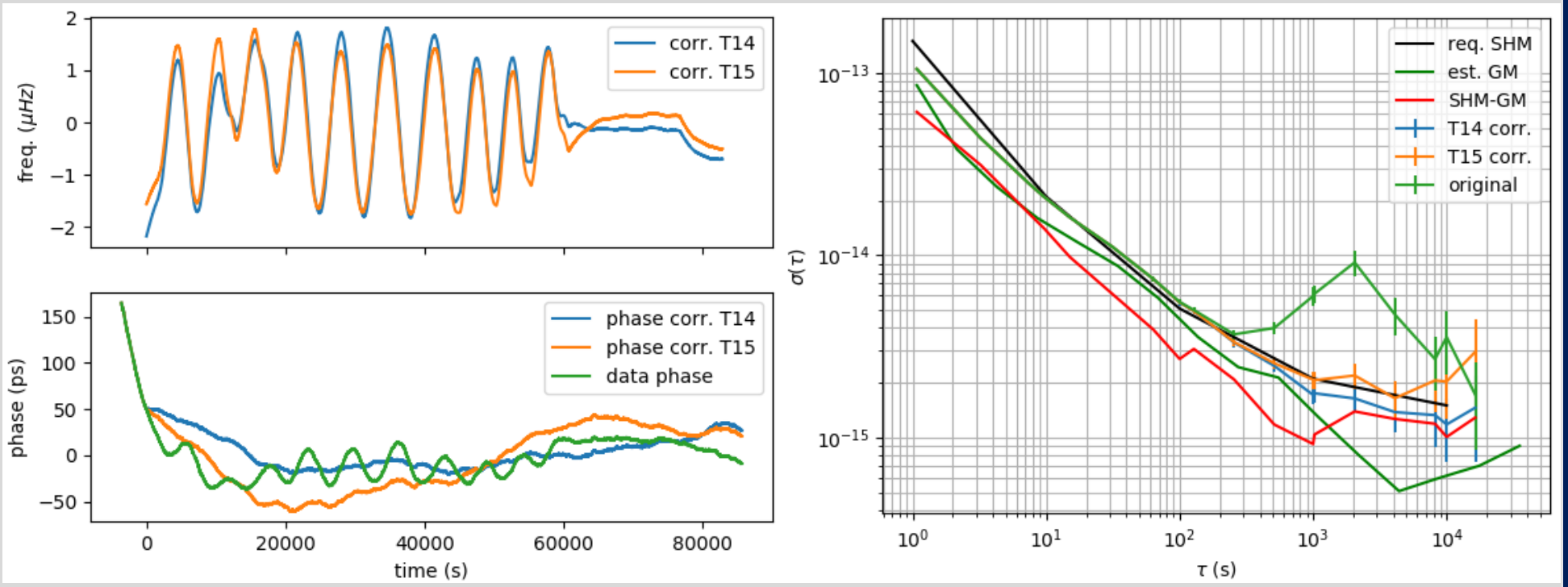

Stand alone temperature

Thermal SHM

Checking results on data

χ_T (μHz/K)	Damping T (s)
6.031(7)	2.431(3)e+03

- SHM can be corrected to be within requirement
- Influence of temperature sufficiently understood for calibration
- T14 gives a better estimate

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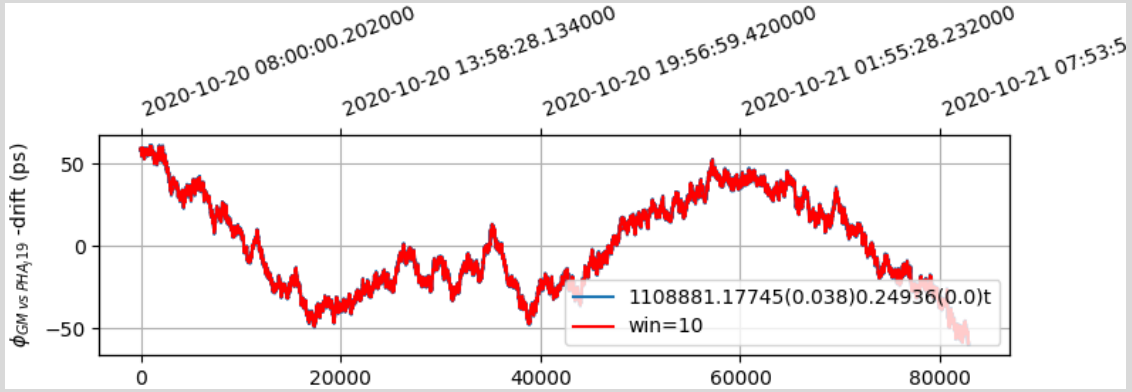
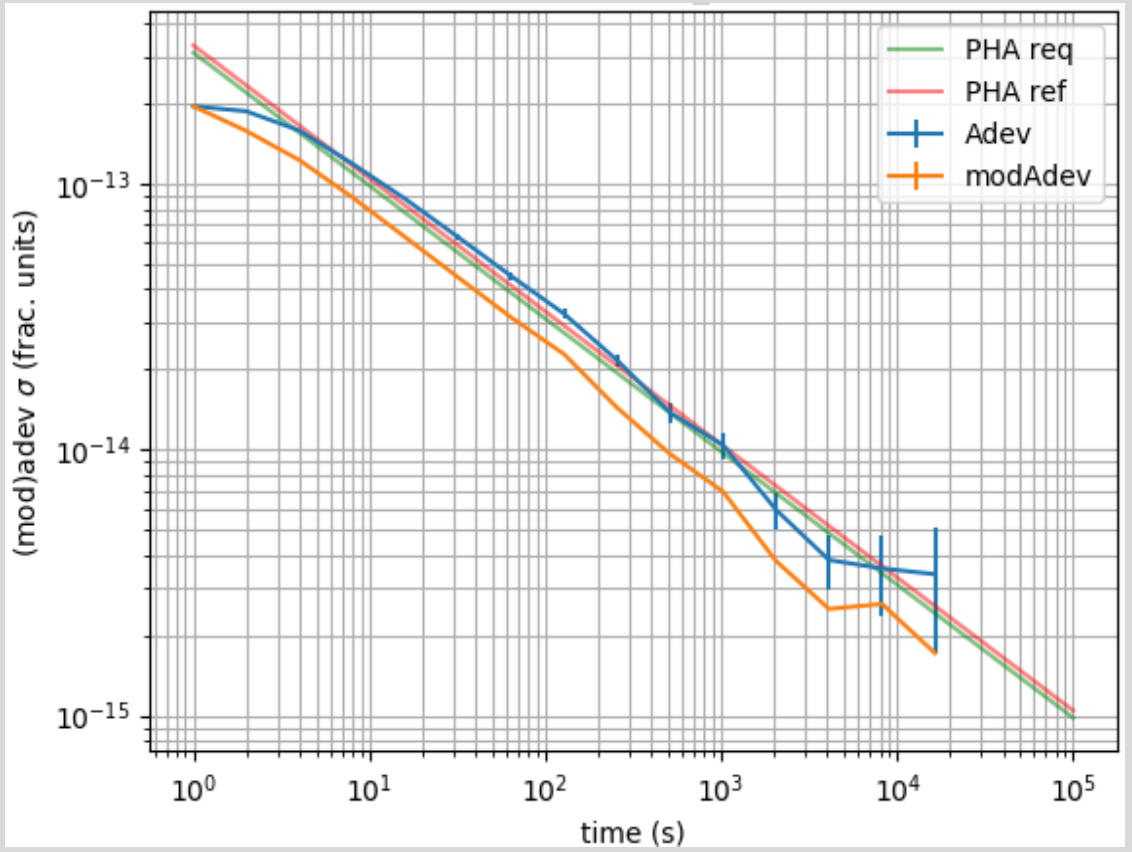
Stand alone temperature

Thermal PHARAO





- PHARAO is not affected by temperature variations for stand alone

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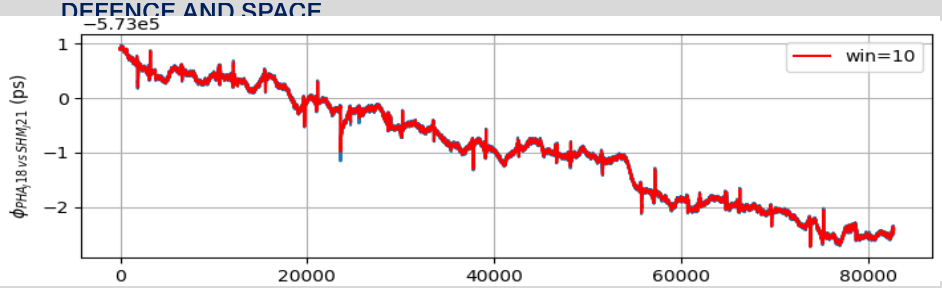
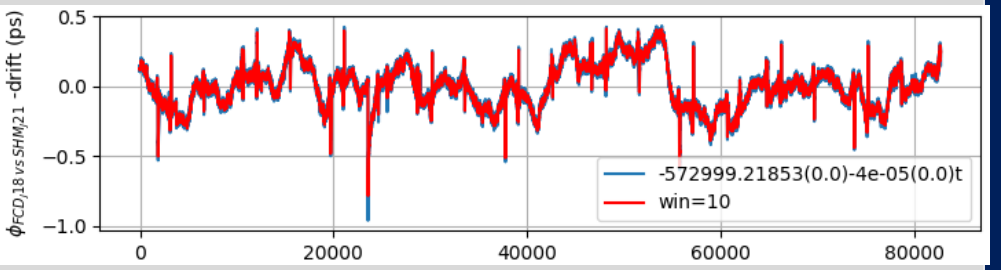


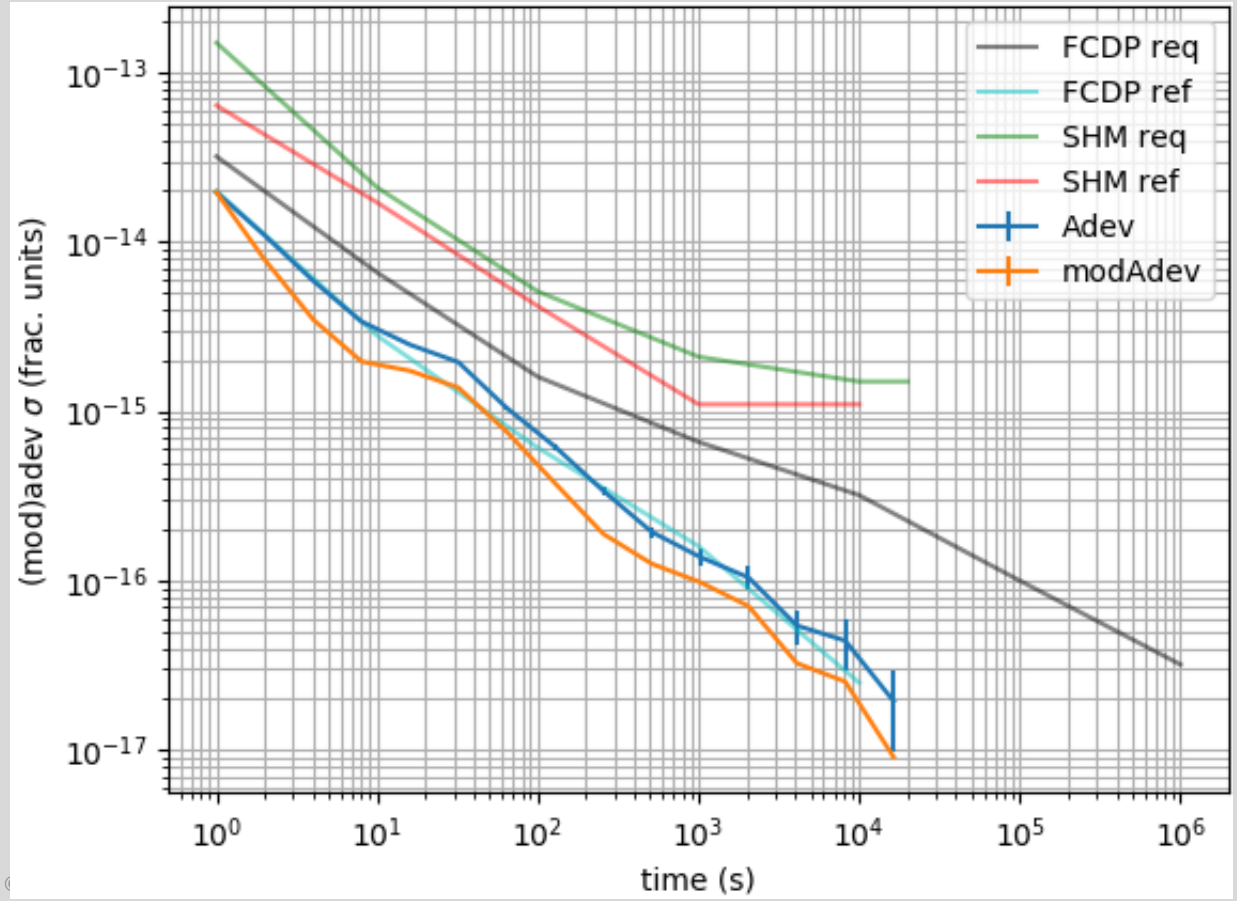


Stand alone temperature

Thermal FCDP

- ADEV is not impacted

SHM MWL vs SHM, FCDP by pass



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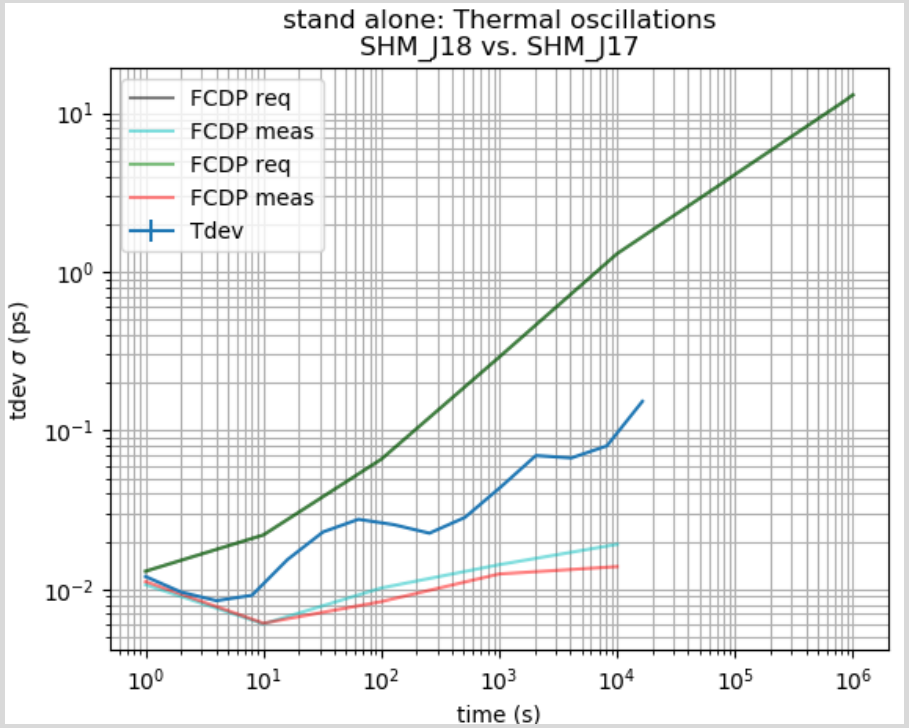
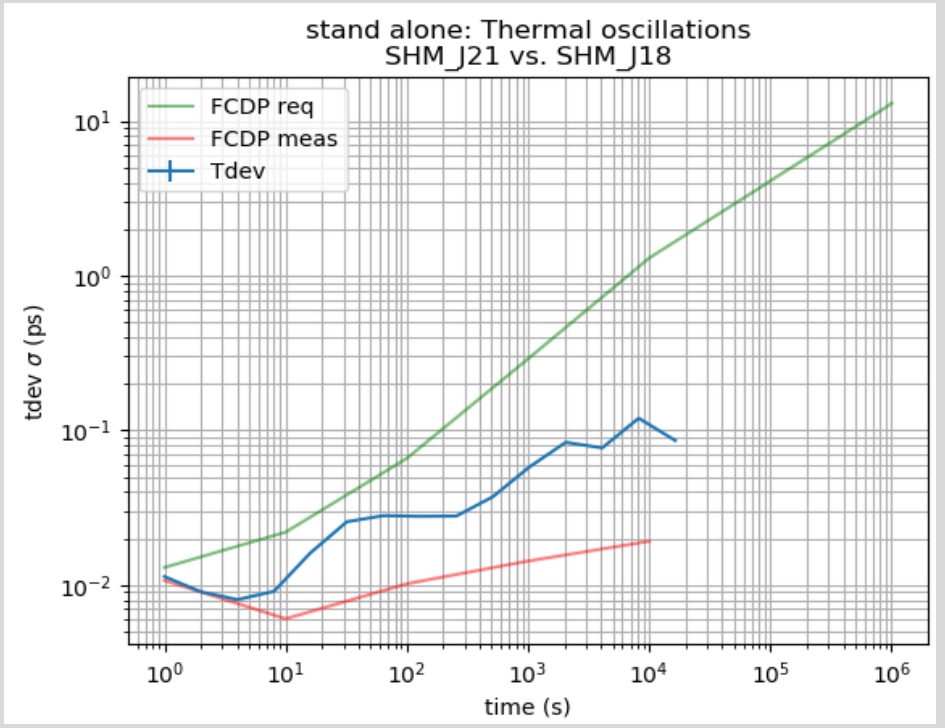


MWL vs Test ouput



MWL vs FCDP bypass

Stand alone temperature

Thermal FCDP

TDEV in requirement

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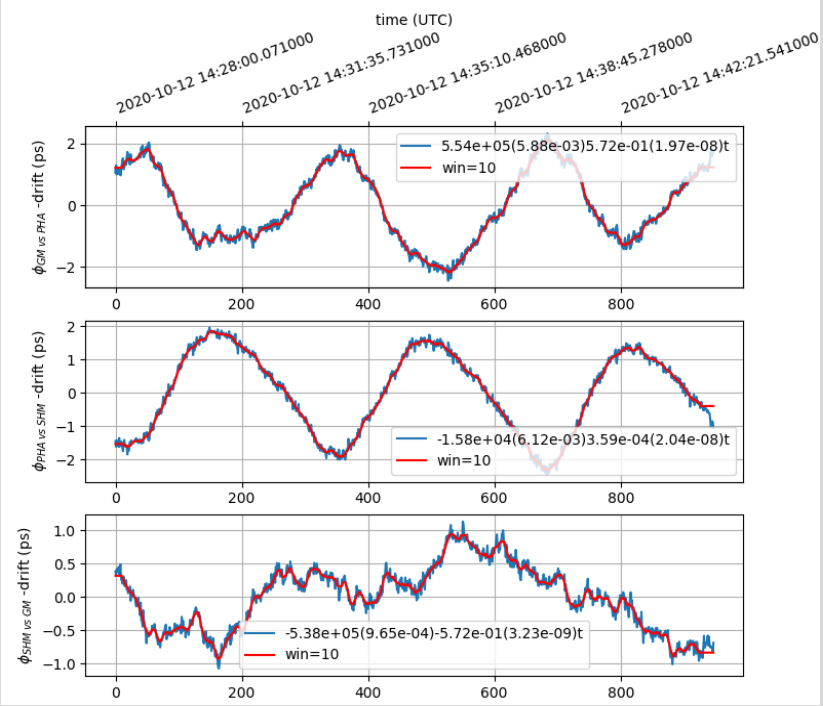
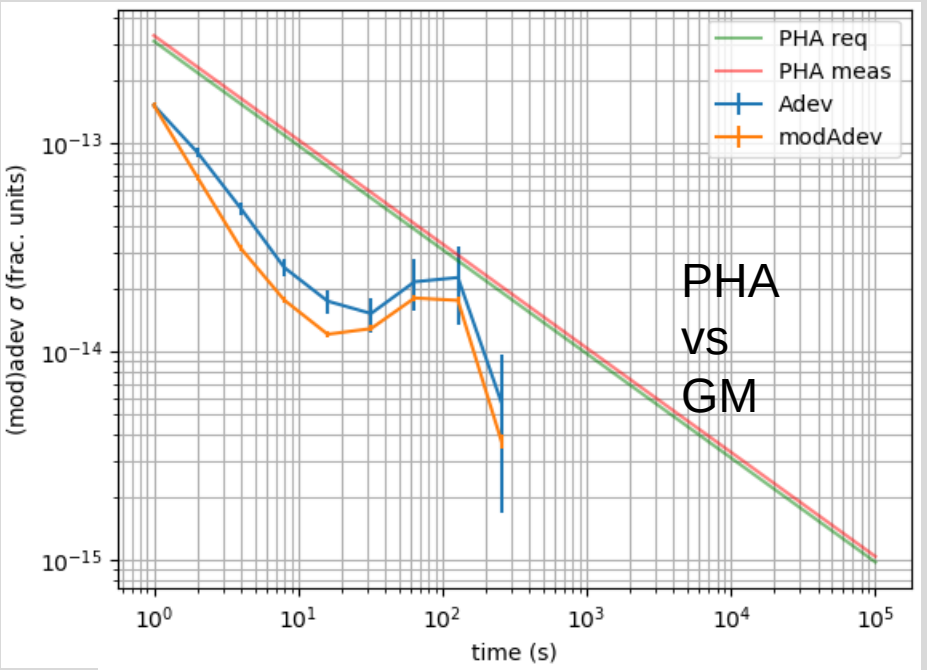
Short Term Servo Loop

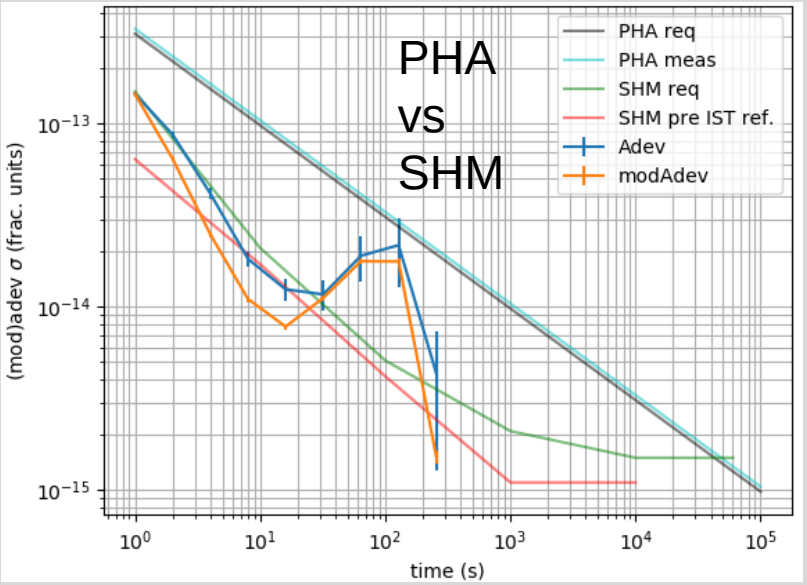
STSL

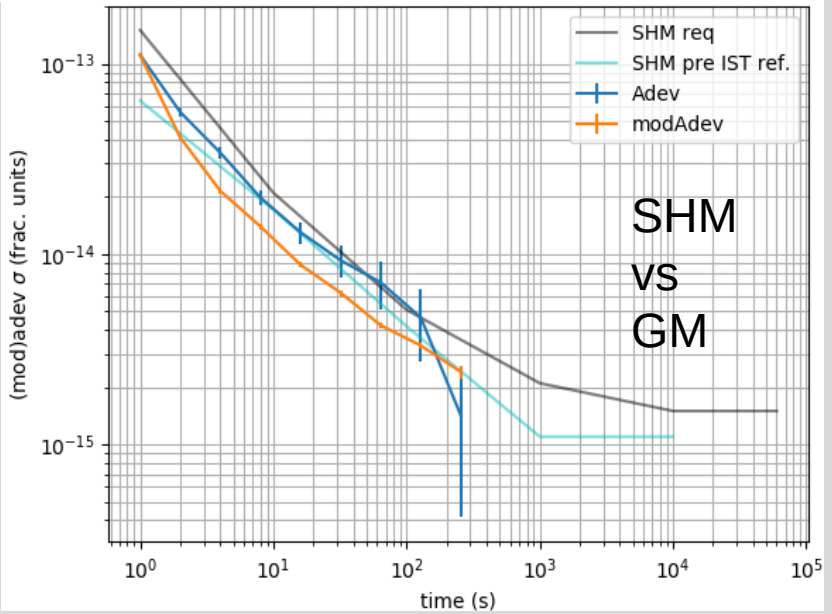
First Data AMPM

- STSL works in principle
- AMPM is a clear problem









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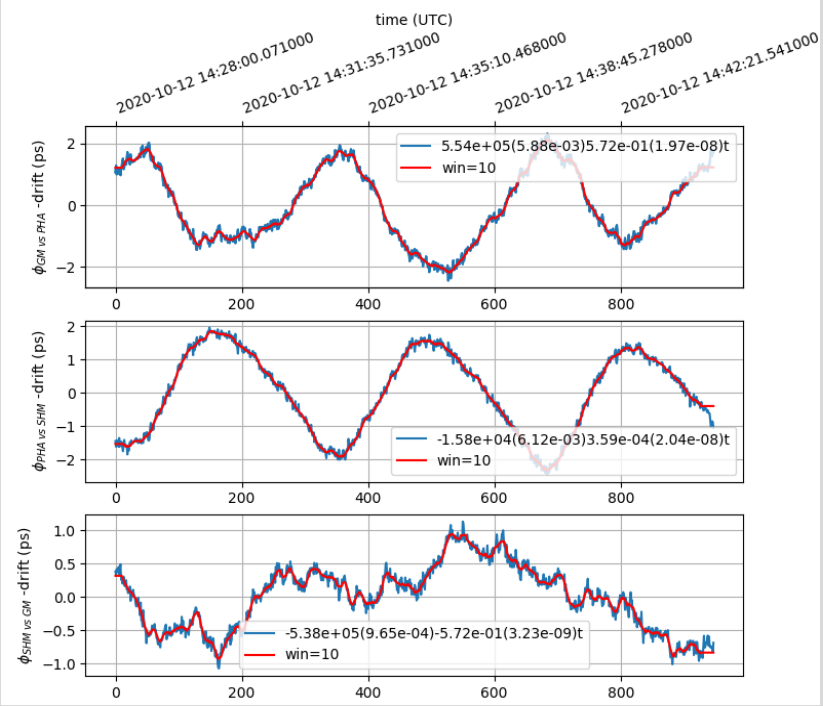
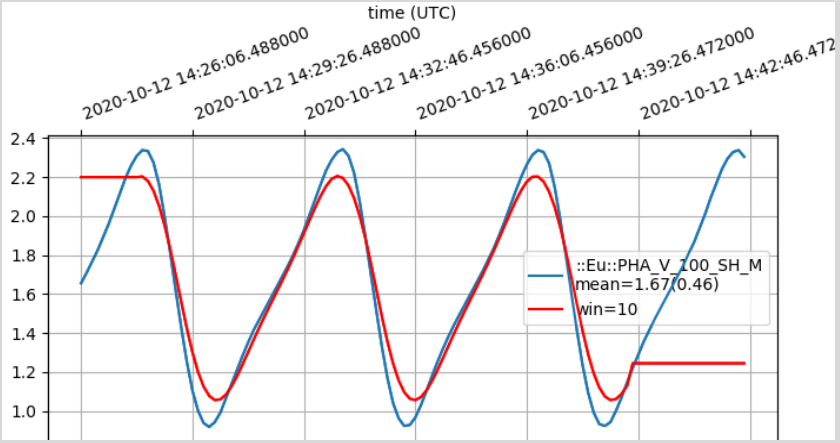
STSL

STSL correction

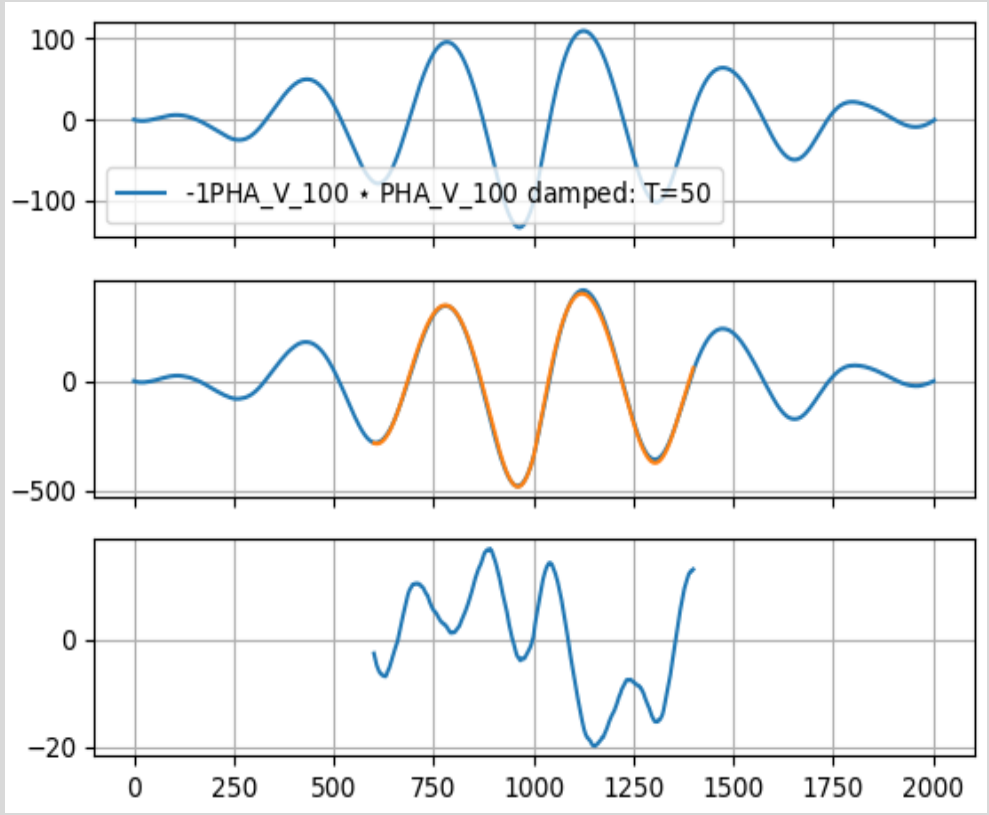
- Cross correlation shows good match
- Residual is no more than 4% of signal
- Residual appears to oscillate at a higher frequency





Cross correlation with damped effect of the voltage:

$$\frac{X}{T} e^{-\frac{t}{T}}$$



Rapid oscillations due to temperature sensitivity of PLL and oscillating temperature controller (HW)

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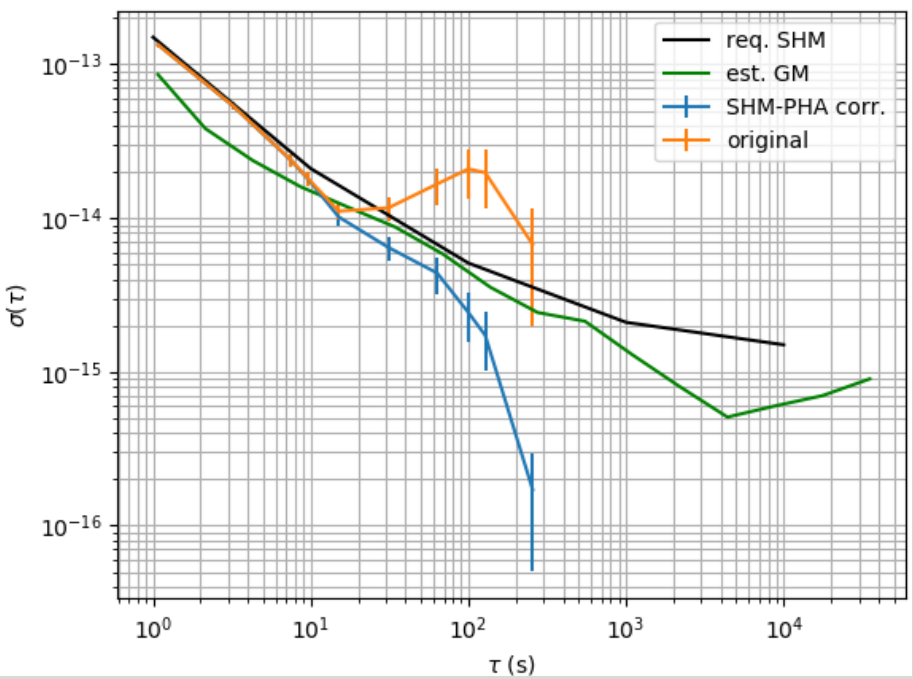

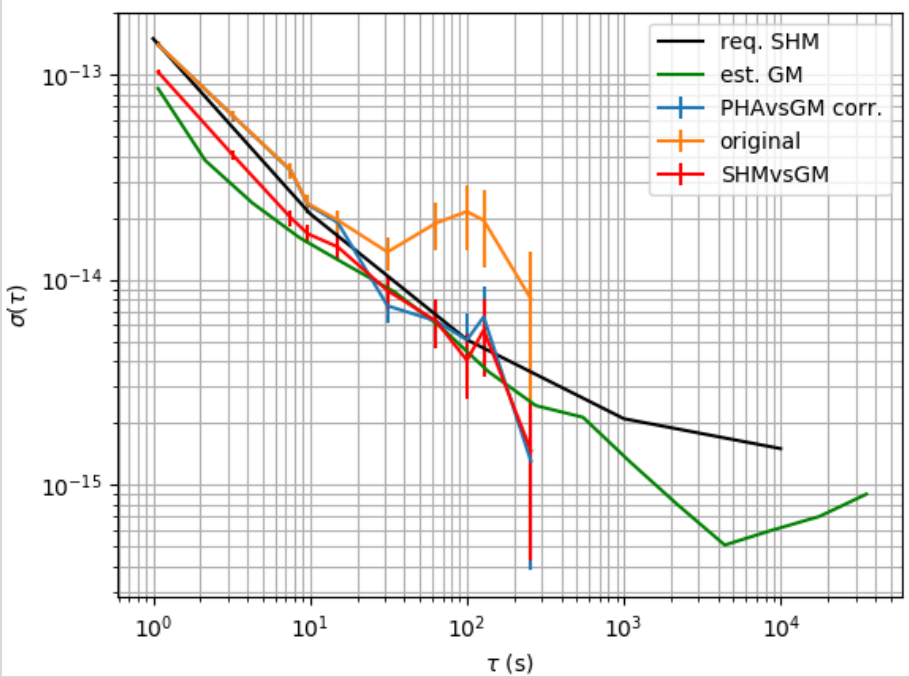

STSL

Correction with average parameter:

Calibration

- Calibration is sufficient

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[Airbus Amber]

Magnetic orbital simulation with Short Term Servo Loop

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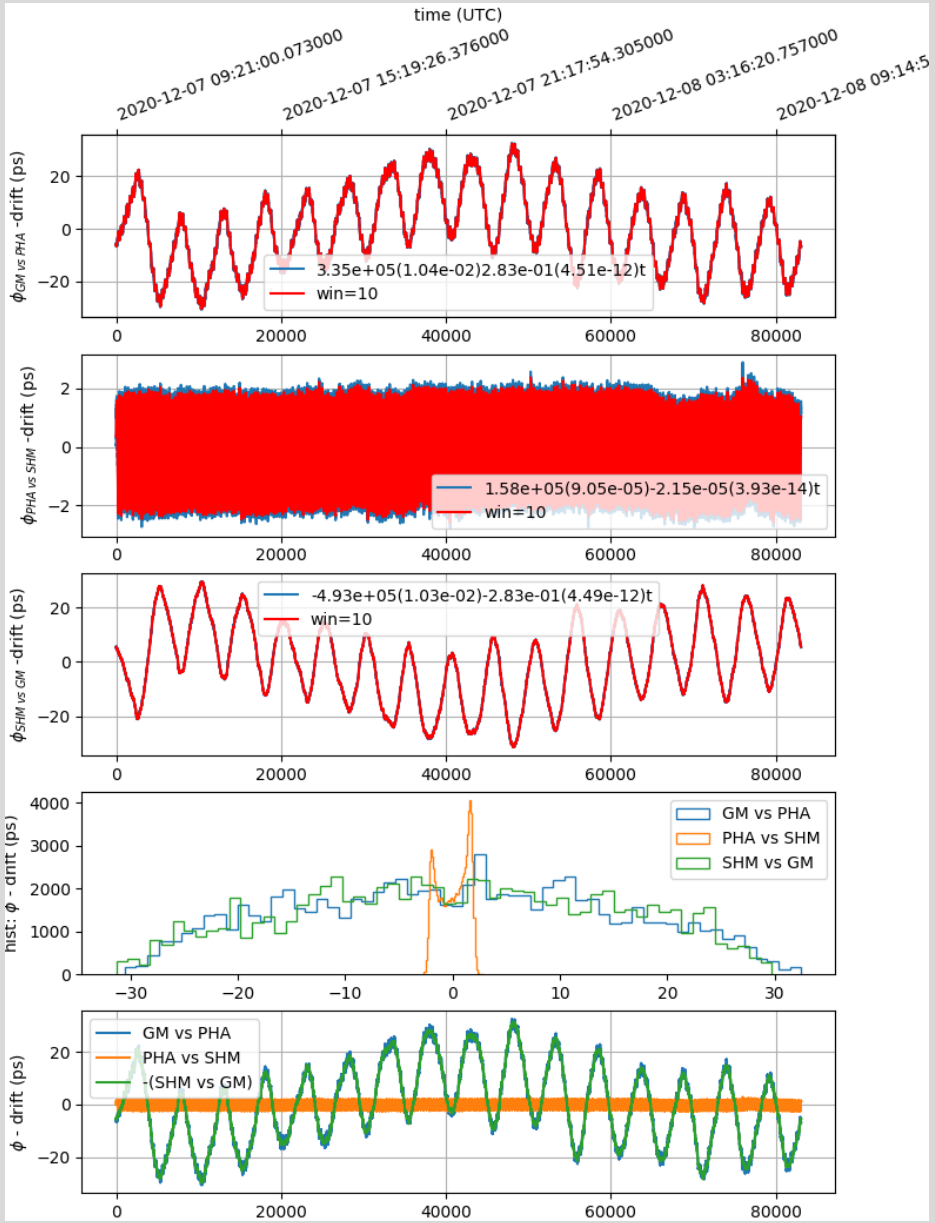

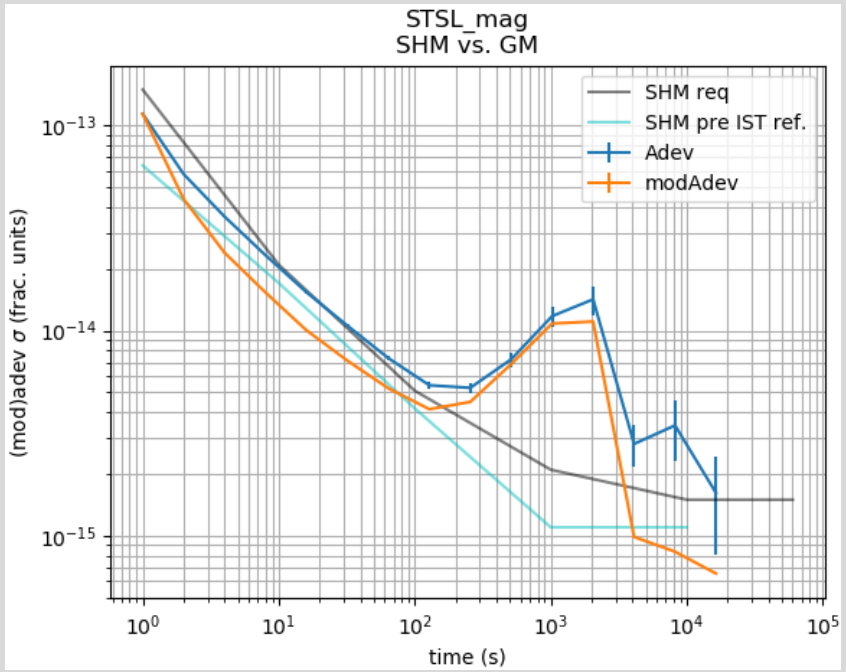

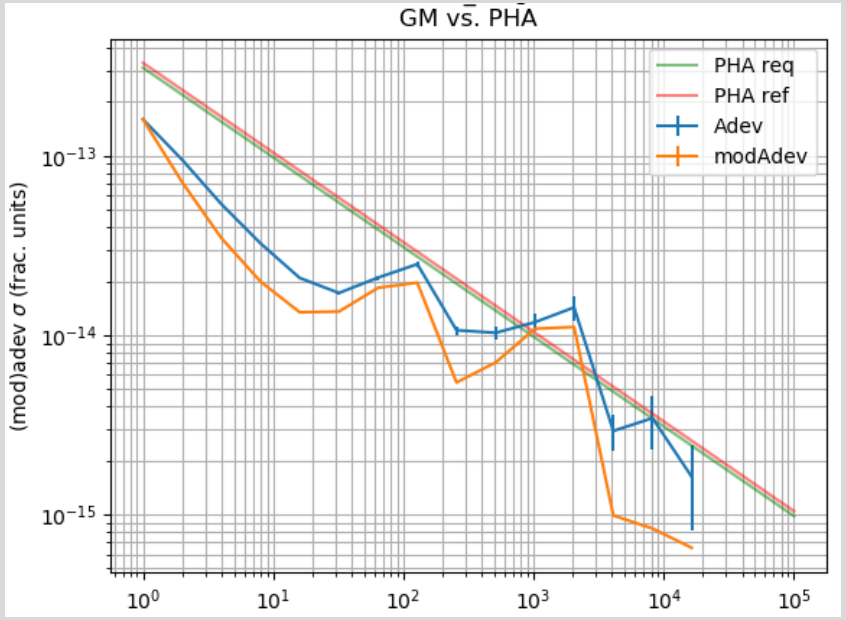

[Airbus Amber]

STSL magnetic orbit

Data

- Large magnetic bump from SHM
- AMPM conversion ontop of PHARO
- No influence on AMPM conversion

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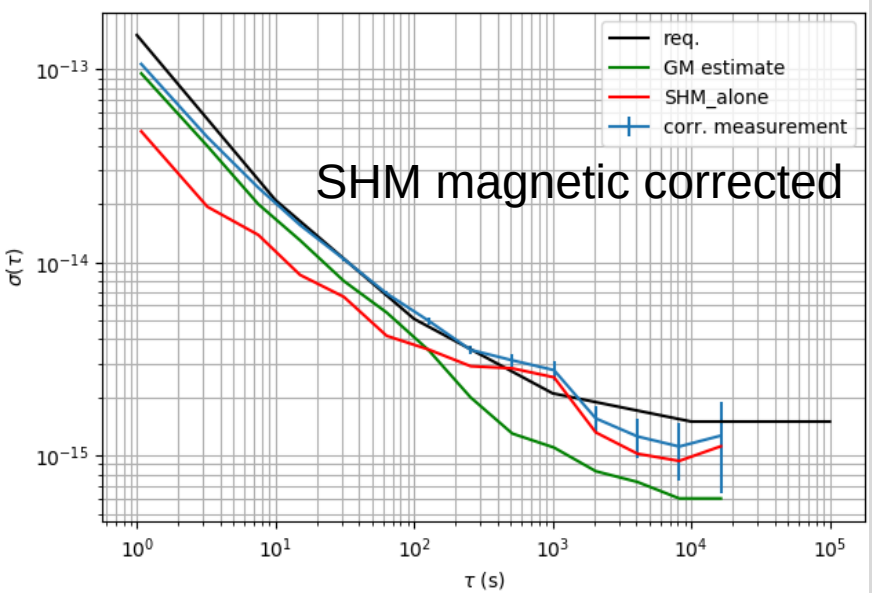
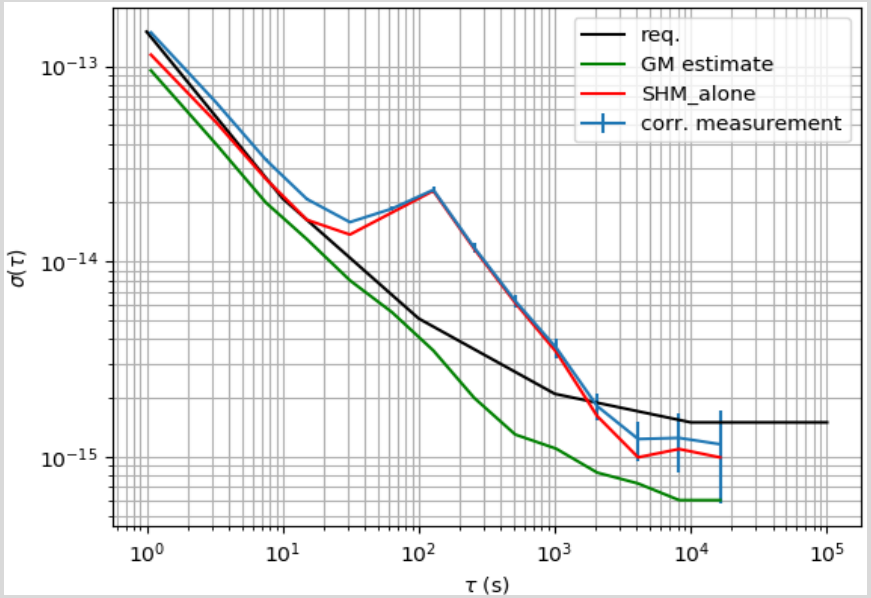
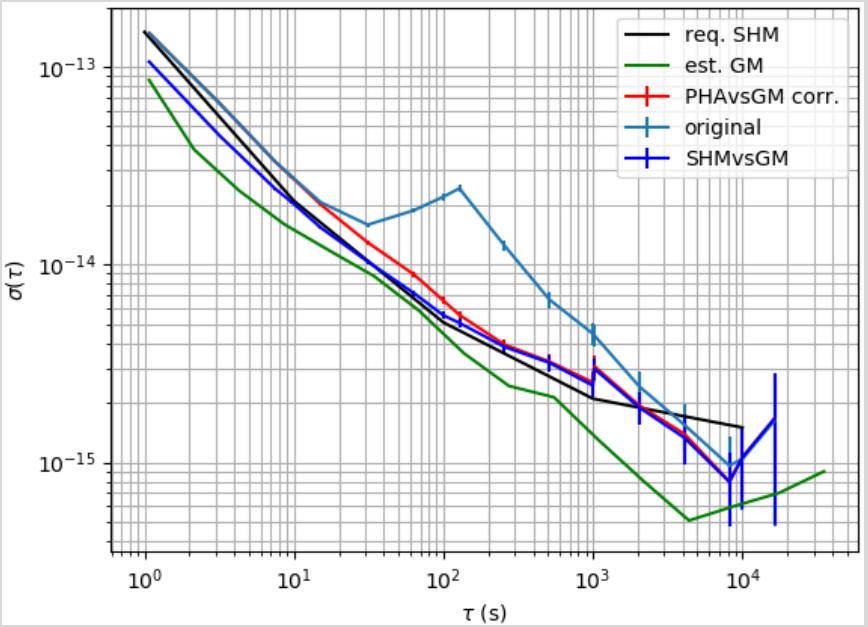
STSL magnetic orbit





PHARAO magnetic corrected



PHARAO vs Ground Maser corrected for AMPM

Corrections applied

- 5.7720(4)e-14/G correction (within 1% of previous measurement)
- AMPM conversion factor near previous point
- Both corrections successful
- Slight increase in final ADEV

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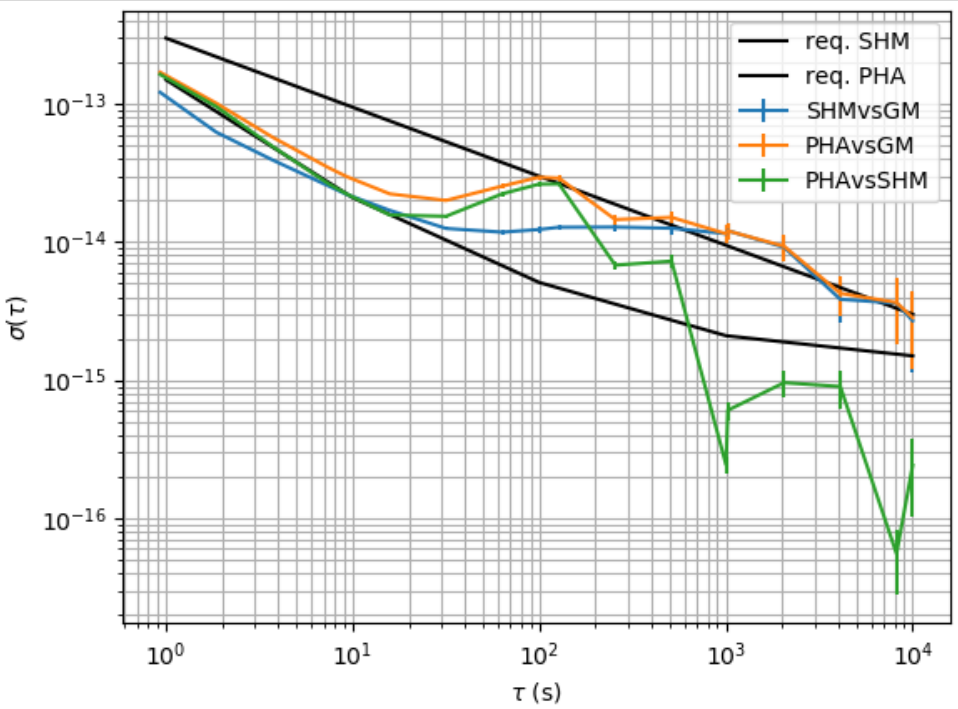
Long Term Servo Loop

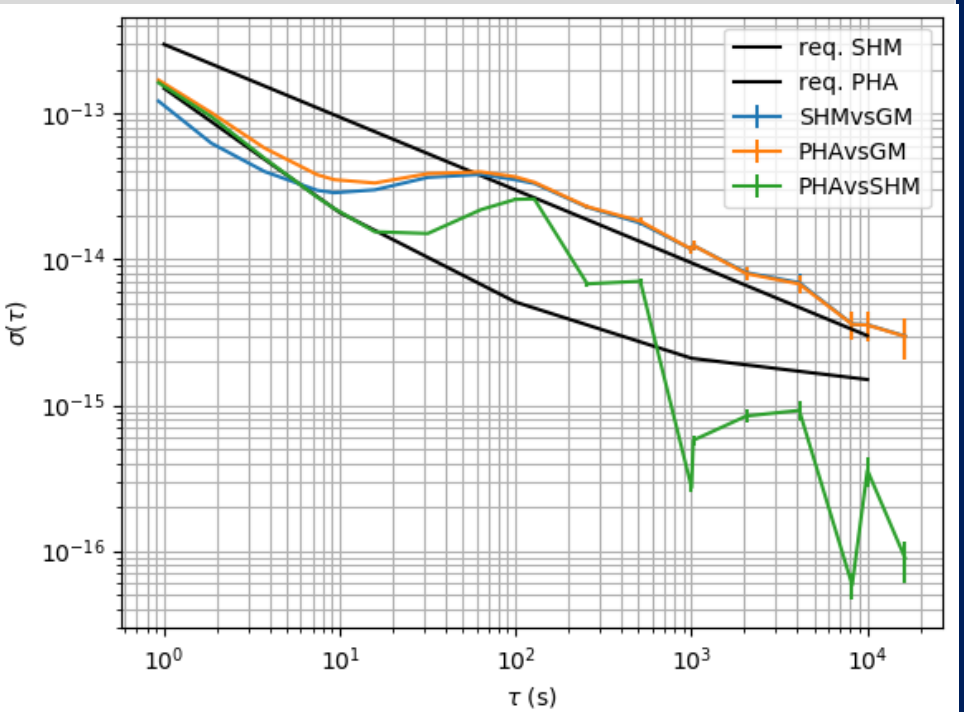
LTSL

25 Sets of LTSL parameters tested
KA should be 0
KB small and negative (-0.0005)
KC small and positive (0.005)

KB=-0.0005 KC=+0.005



KB=-0.0025 KC=+0.01



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Full orbital simulation with STSL and LTSL

Full orbital simulation

Temperature range

8 x 10 oscillations with 2 hours break in between
Discriminating them from magnetic oscillations

Cooler limitation

Instrument	High temp required (°C)	High temp reached (°C)	Amplitude required (pp°C)	Amplitude reached (pp°C)
PHARAO	29.5 (av TP)	(24.85+26.4)/2=25.65	3	2.5
SHM	33.4	30.2	1.5	1.5
FCDP	42.6	22.8	3.5	3.5
Instrument	High temp required (°C)	High temp reached (°C)	Amplitude required (pp°C)	Amplitude reached (pp°C)

Heater/cooler limitation

Safety margin thermo stat

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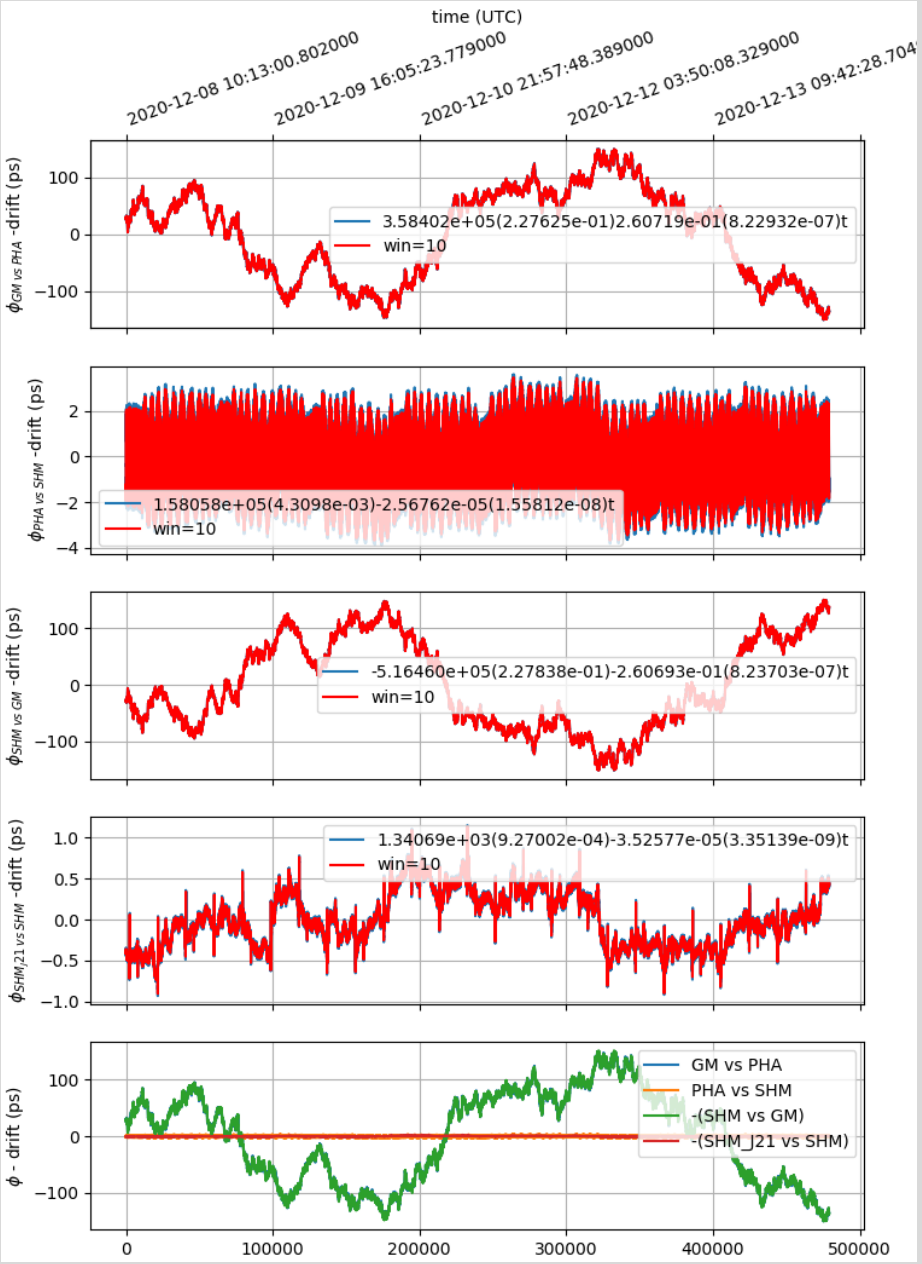
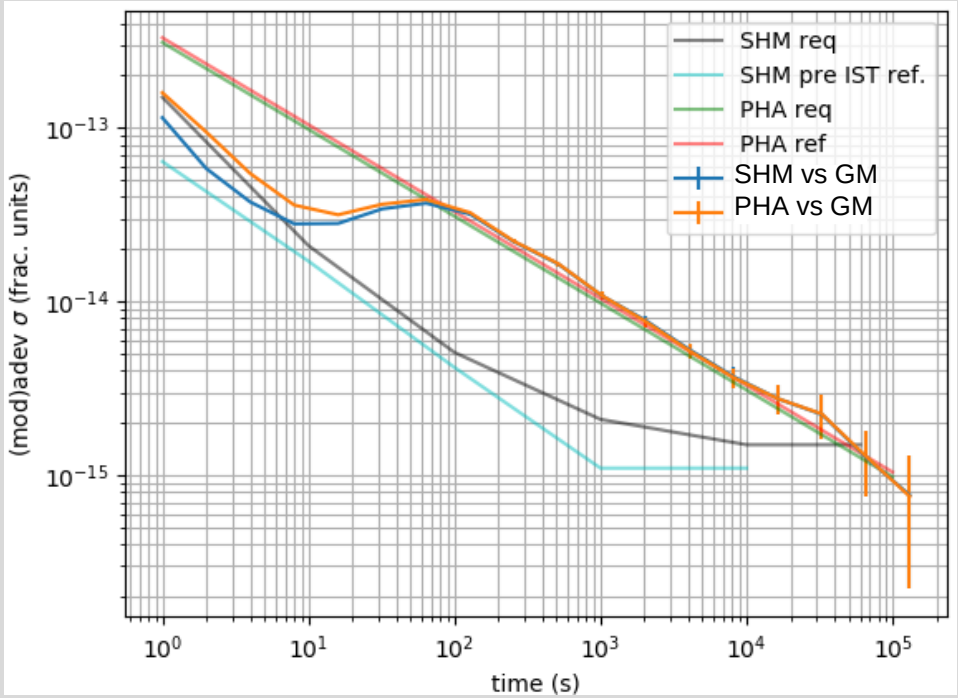
Full orbital oscillation

PCO data





Nearly 6 days measurement
STSL: Kp=40000 Ki=500
LTSL: KA=0 KB=-0.00250 KC=+0.001

- LTSL is covering AMPM
- Influence of orbital conditions not observed in ADEV

AIRBUS

Quick Summary

Lessons learned

Magnetic field:

SHM susceptibility is 5.76(5)e-14/G in axial direction.
PHARAO has no significant magnetic susceptibility (compared to on earth instability)
The orbital magnetic field can be matched to the SHM frequency difference to better than one minute using correlations and fitting.

Thermal variation

SHM susceptibility is 6.03e-13/K damping time 2430 s
PHARAO susceptibility insignificant (compared to on earth instability)
Setup needs to be improved (on the way)

LTSL

Best parameter set is KA=0, KB=KC=0.0005

STSL

Optimal parameter near Kp=40000(-10000+5000) Ki=500(-100+500)
AMPM susceptibility -3.65(11) ps/V damping time 48.2(3.7)s
AMPM susceptibility is temperature dependent (not shown 0.53 ps/K) and can be calibrated in orbit

SHM needed refurbishment due to vacuum problems
Setup needs improvement for temperature range
MWL will be included in next test

Thank you