Characterization of an Atom Interferometer Gravimeter with Classical Sensors for the Use in Geodesy and Geophysics

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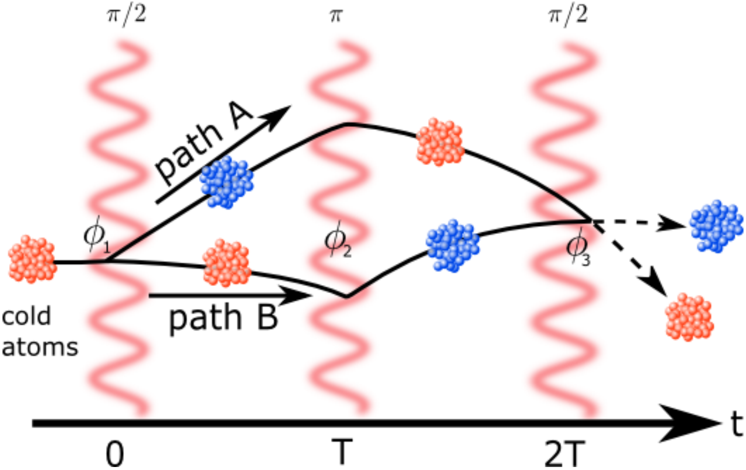
Motivation

- Absolut Gravimetry is dominated by laser interferometers with falling corner cubes
- In recent years a number of Atom Interferometer (AI) gravimeters have been developed
  - AOSense & μQuans: commercial quantum gravimeter
  - LNE Syrte: Cold Atom Gravimeter
  - IQ LUH: in development (QUANTUS modification)
- HU Berlin: Gravimetric Atom Interferometer (GAIN)
  - Characterization by comparison with SCG and AG

Agenda

- **Motivation**
- **Atom interferometry**
- **Geodetic Observatory Wettzell 2013: GAIN + GWR SCG**
- **Onsala Space Observatory 2015: GAIN + GWR SCG + FG5X**
- **Summary and Conclusion**

Atom interferometry



simplified observation eq.

$$P_{|F=2\rangle} = \frac{1}{2}\left[1 - \cos(\Delta\Phi)\right]$$

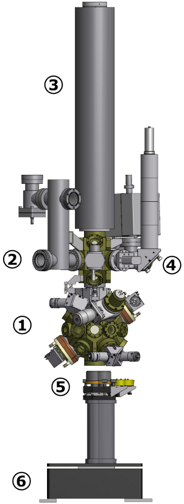
$$\Delta\Phi = k_{eff}\, g T^2$$

Atom interferometry

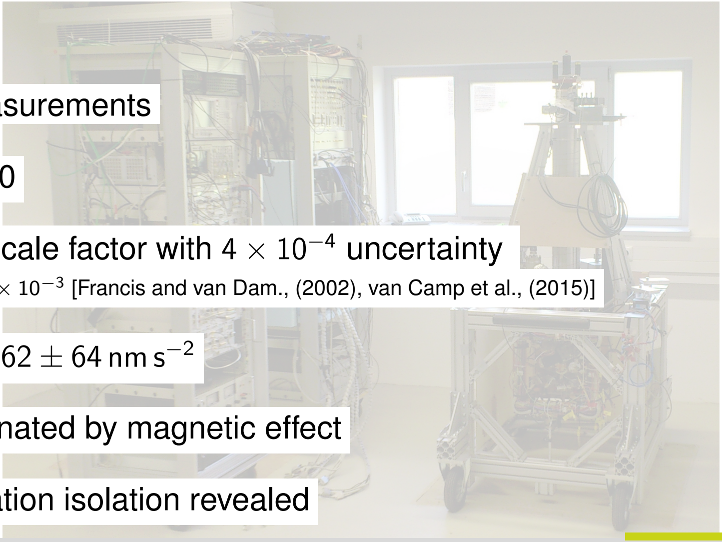
g-experimental sequence

1. Magneto-Optical-Trap → preparation of atoms
2. State selection
3. Light – atom interaction
4. Detection of state populations
5. Tip/tilt mirror → vertical alignment and Coriolis
6. Vibration isolation

cycle rate of *g*-measurement: 1.5 s



Geodetic Observatory Wettzell 2013: GAIN + GWR SCG



November 2013

Two weeks of measurements

In parallel to SG-30

Determination of scale factor with 4 × 10^{-4} uncertainty

Calibration with FG5: 1 × 10^{-3} [Francis and van Dam., (2002), van Camp et al., (2015)]

Difference to g_{ref}: $62 \pm 64\,\mathrm{nm\,s^{-2}}$

Error budget dominated by magnetic effect

Hysteresis of vibration isolation revealed

Onsala Space Observatory 2015: GAIN + GWR SCG + FG5X

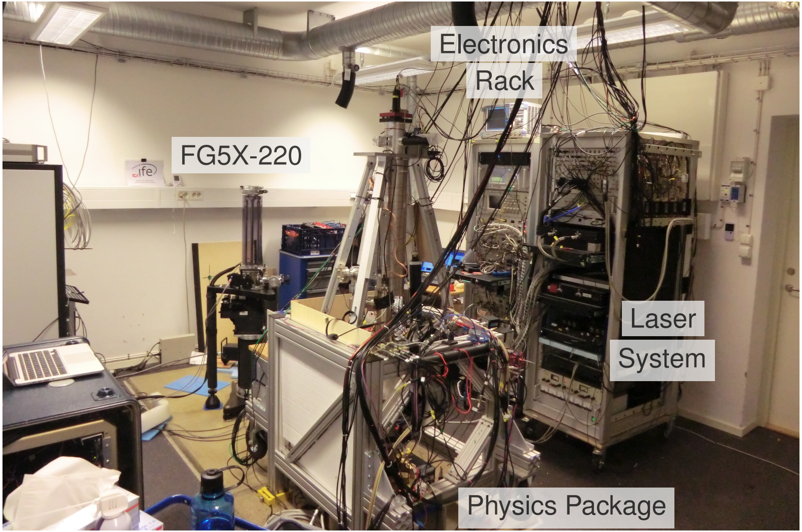
Four week campaign in February

- OSG-054 and GAIN: precision
  → almost 4 weeks of recordings
- FG5X-220 and GAIN: absolute accuracy
  → switch of positions after 4 days

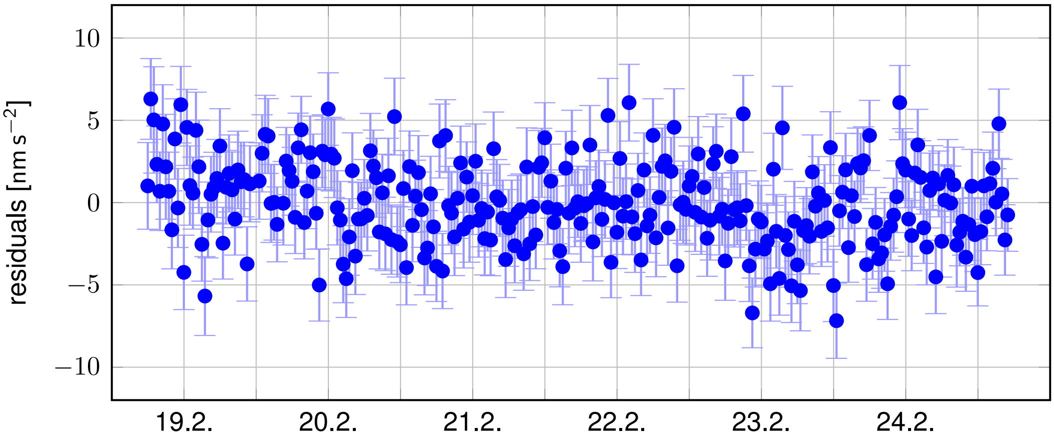
Improvements of GAIN after Wettzell

- Magnetic shielding of MOT
  → quicker setup of instrument
  → removal of systematic effect
- Readjustment of vibration isolation
- Post-correction for residual vertical mirror movement [Le Gouët et al., (2008)]

Onsala Space Observatory 2015: GAIN + GWR SCG + FG5X

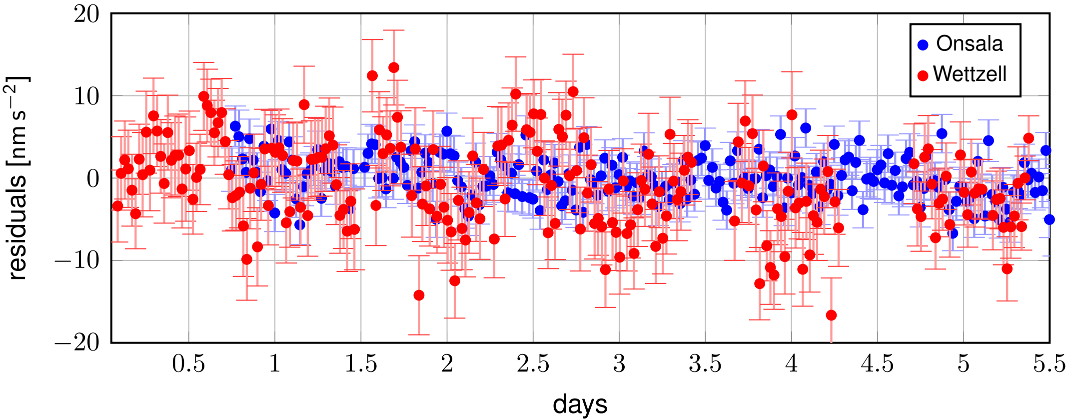


Onsala Space Observatory 2015: GAIN + GWR SCG + FG5X



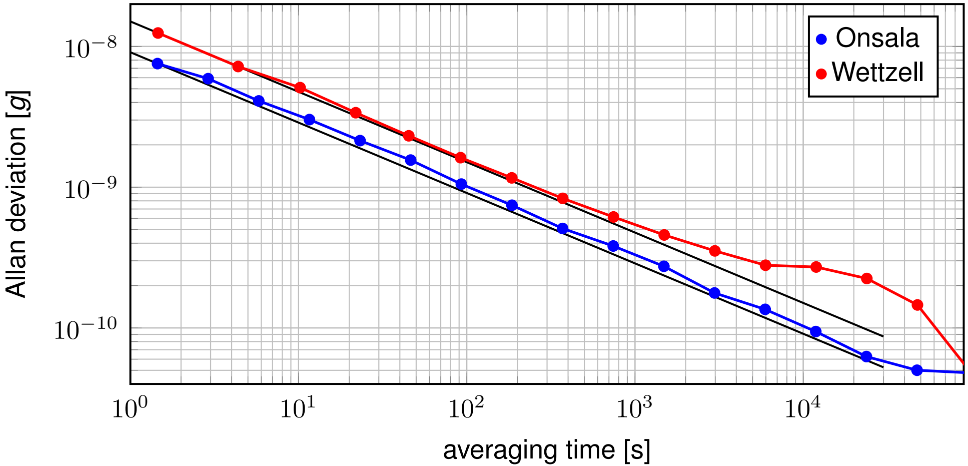
Difference of GAIN and OSG-054 from 30 minute averages.

OSO 2015 vs. Wettzell 2013



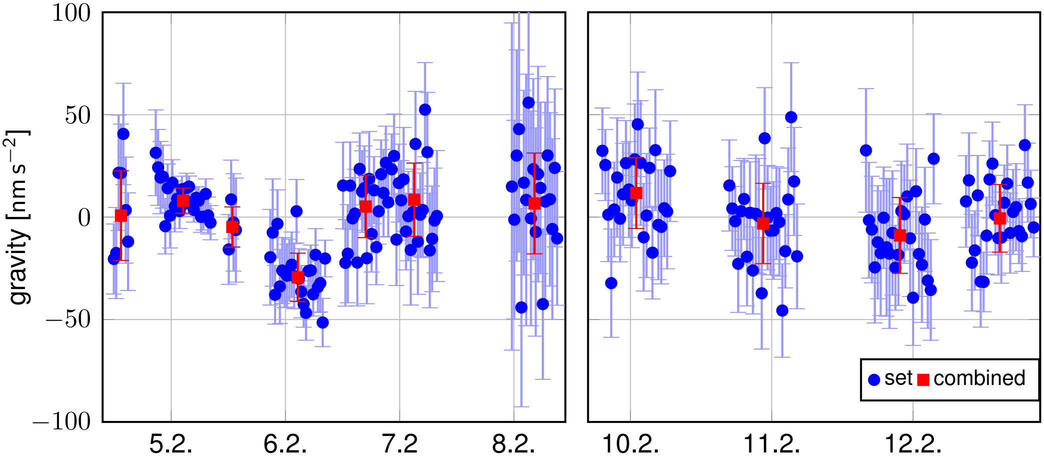
Difference GAIN – SCG (RMS: 3 nm s^{-2}/6 nm s^{-2}).

OSO 2015 vs. Wettzell 2013



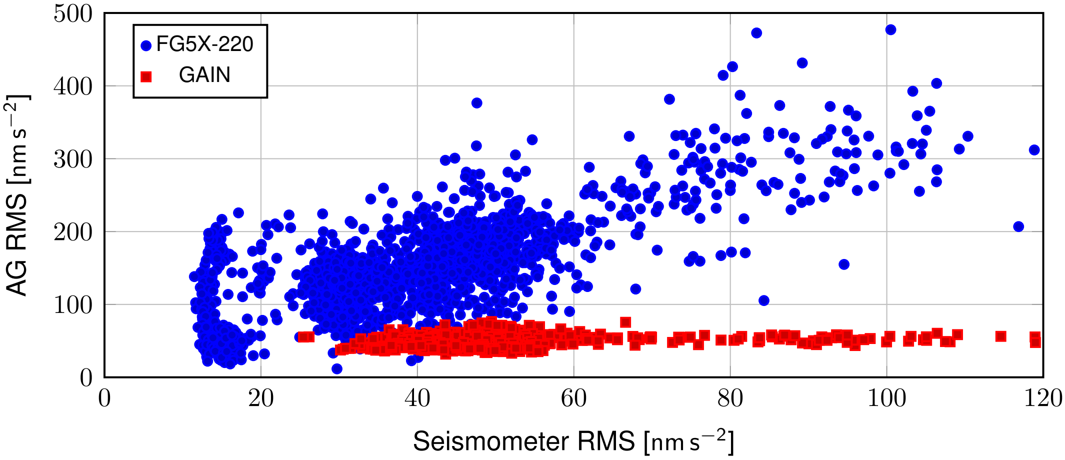
Allan deviation of GAIN – SCG.

OSO 2015: FG5X-220



Pillar AC ($\sigma = 5\,\mathrm{nm\,s^{-2}}$) and AA ($\sigma = 9\,\mathrm{nm\,s^{-2}}$) with the $\bar{g}$ of each pillar subtracted.

OSO 2015: FG5X-220 and GAIN



RMS of Seismometer vs. AG (FG5X-220 from 4.2.-12.2. and GAIN from 7.2.-12.2.).

Summary and Conclusion

Results GAIN

- Continuous operation with minor down time
- Improvement of sensitivity to $< 1 \times 10^{-10}\, g$
- Difference to FG5X-220 mean g-result $32 \pm 39\,\mathrm{nm\,s^{-2}}$
- Error budget dominated by wavefront aberration [Schkolnik et al. (2015)]
- Confirmation of SCG scale factor with uncertainty 2.6×10^{-4}

Summary and Conclusion

Results FG5X-220

- Measurements under unfavorable conditions due to microseismic activity
- Results fit to land-uplift determined with previous FG5 Measurements [Timmen et al. (2015)]
- Currently no indication for orientation dependent instrumental effect → improvement over FG5-220 [Gitlein, (2009)]

Summary and Conclusion

Next Steps

- Comparison with SCG essential for characterization of AI sensitivity and identification of instrumental effects
- Reduction of systematic effect
- Participation in international comparison of absolute gravimeters

Thank you for your attention

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DFG Deutsche
Forschungsgemeinschaft

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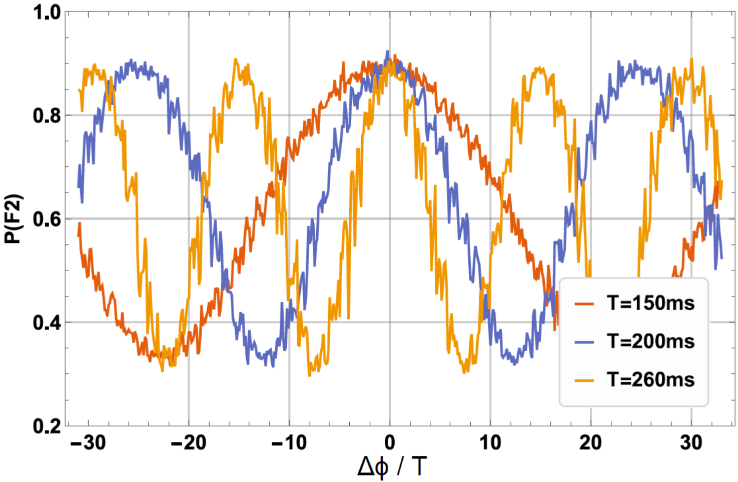
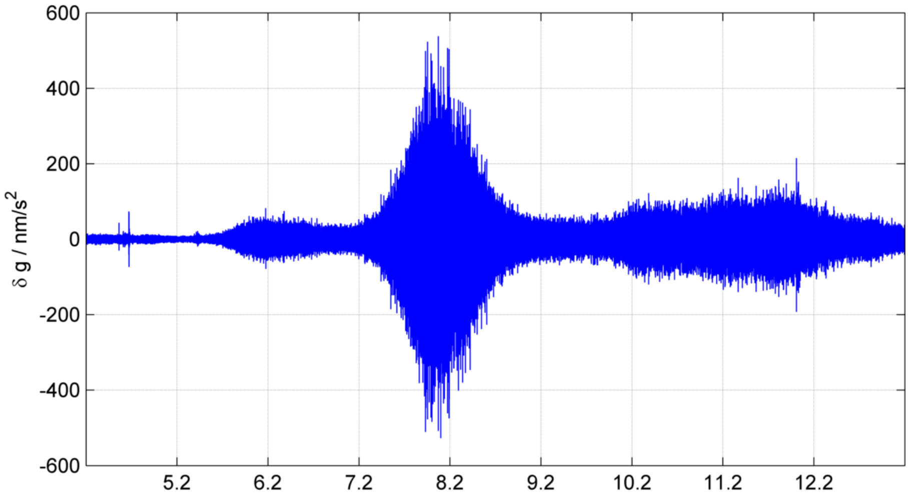
Annex: ambiguity solution



Fringes with different *T* from scanning α: $\Delta\Phi = (k_{eff}g - \alpha) \cdot T^2 + \Delta\phi_L$

Annex: Microseismic activity recorded by OSG-054



Time derivation of 1 Hz SCG data.

Annex: Error budget

GAIN systematic
error Budget for the 2nd campaign.
Values for the 1st campaign
are denoted with an asterisk.
The bias was subtracted
from gravity measurements.

Systematic effect	Bias [$\mathrm{nm\,s^{-2}}$]	Error [$\mathrm{nm\,s^{-2}}$]
Raman Wavefronts	-28	± 22
Coriolis Effect	0	± 15
Magnetic Field Effects	0	± 10
RF Groupdelay	0	± 10
Self Gravitation	19	± 5
Ref-Laser Frequency	$-12 \mid -10*$	± 5
Sync. Vibrations	$0 \mid 92*$	$\pm 5 \mid 50*$
AC Stark Shift (1PLS)	0	± 5
Rb Background Vapor	5	± 3
AC Stark Shift (2PLS)	0	± 2
Vertical Alignment	0 | $1*$	± 1
Total	$-16 \mid 77*$	$\pm 32 \mid 61*$

Annex: Absolute gravity comparisons

First Campaign	**Gravity** $\mathrm{nm\,s^{-2}}$	**Uncertainty** $\mathrm{nm\,s^{-2}}$
GAIN gravity value	9 808 369 285	±61
meas. height correction	400	±10
Reference value	9 808 369 623	±18
Difference GAIN–Ref.	62	±64
Second campaign		
GAIN gravity value	9 817 158 312	±32
meas. height correction	727	±10
Reference value	9 817 159 023	±20
Difference GAIN–Ref.	32	±39

Comparison of absolute gravity values. The vertical gravity gradient was determined previous to GAIN measurements.