Benefit of Quantum Technology for Future Earth Observation from Space – Gradiometry Case

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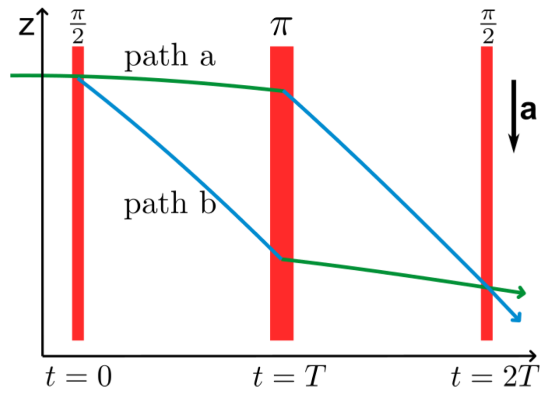
Quantum Satellite Gravimetry

✓ **Satellite gravimetry mission**

- Map the Earth's gravity field and its temporal changes with high precision
- On-board accelerometers (today electrostatic with some limitations)
  - ❖ determine the non-gravitational accelerations acting on the satellite and
  - ❖ are used for gradiometry measuring the gravitational gradients

✓ **Cold Atom Interferometry (CAI)**

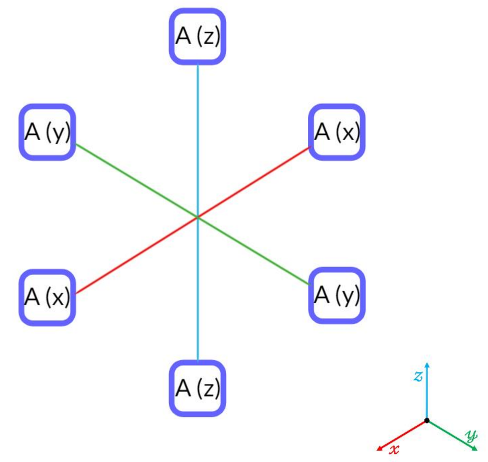
- An alternative technique proposed for future gravimetry missions
- Provides long-term stability and precise measurements of accelerations or gradients
- Enables improved mapping of the Earth's gravity field and its changes



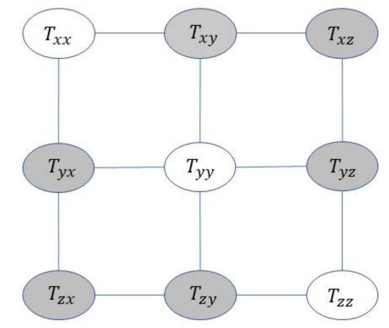
3D Gradiometer

✓ **Accelerometers**

- **ElectroStatic Accelerometer (ES)**
  - ❖ **Alvarez (Alvarez et al 2022)**
  - ❖ **ONERA (Dalin et al 2020)**



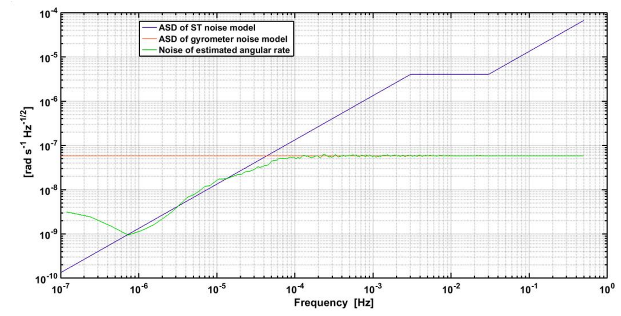
- **Cold Atom Interferometry (CAI)**
  - ❖ **CAI with noise level 10^{-11} $(m/s^2/Hz^{1/2})$ (CAI 11)**
  - ❖ **CAI with noise level 10^{-12} $(m/s^2/Hz^{1/2})$ (CAI 12)**
- **Hybrid Accelerometer**
  - ❖ **Alvarez + CAI 11**
  - ❖ **Alvarez + CAI 12**
  - ❖ **ONERA + CAI 11**
  - ❖ **ONERA + CAI 12**



Measurable components by mentioned gradiometer

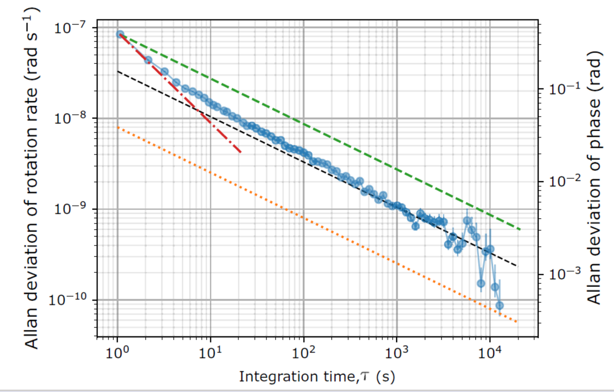
Satellite orientation

✓ ElectroStatic Gyro and Star tracker (Douch et al 2018) as the "realistic Gyro"



Estimation of one component of the angular velocity

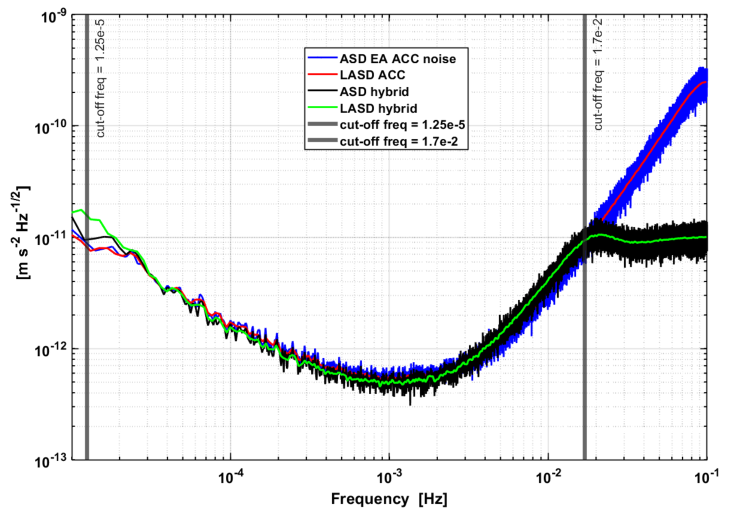
✓ CAI Gyro (Savio et al 2018) as the "future Gyro"



Stability analysis of a CAI Gyro

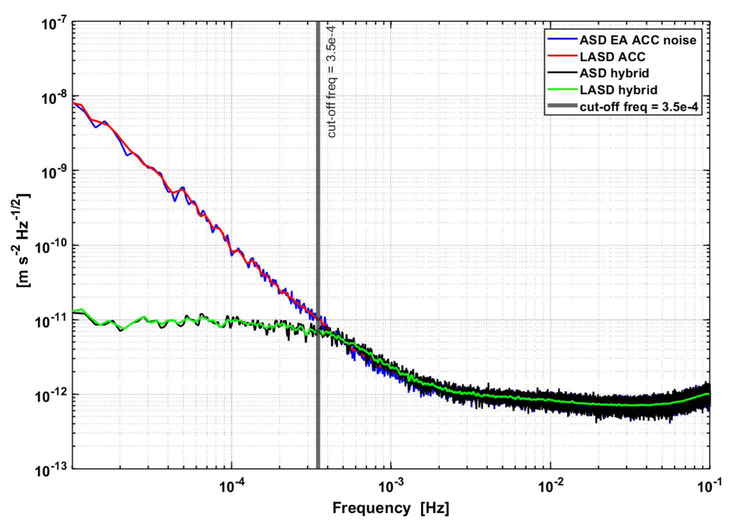
Realistic Hybrid ACCs

a) Alvarez + CAI 11



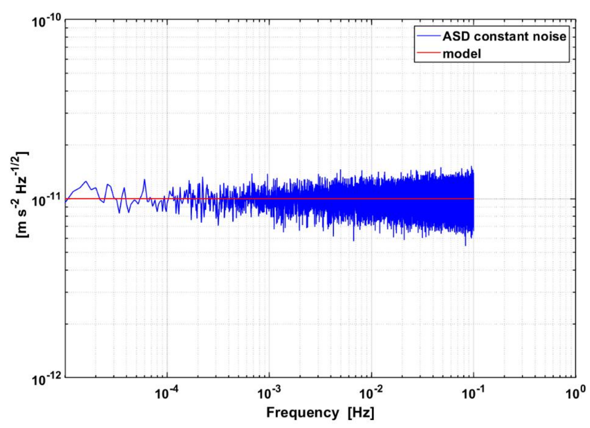
ASD of Alvarez ACC and hybrid with CAI 11

b) ONERA + CAI 11



ASD of ONERA ACC and hybrid with CAI 11

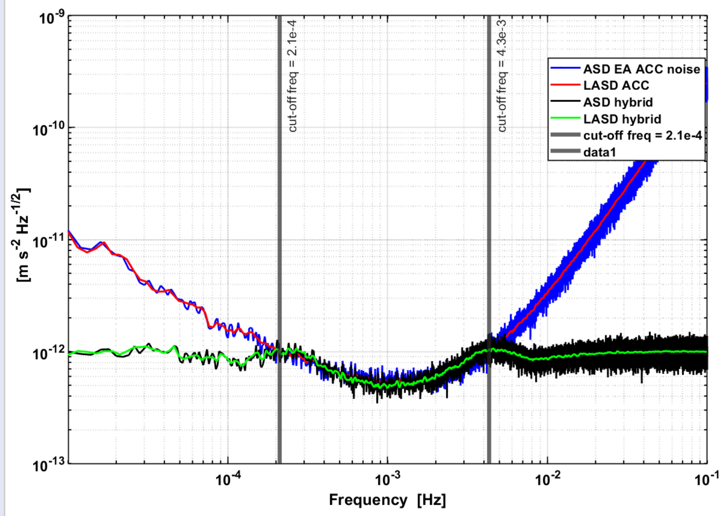
c) CAI 11 only



ASD of CAI 11 only

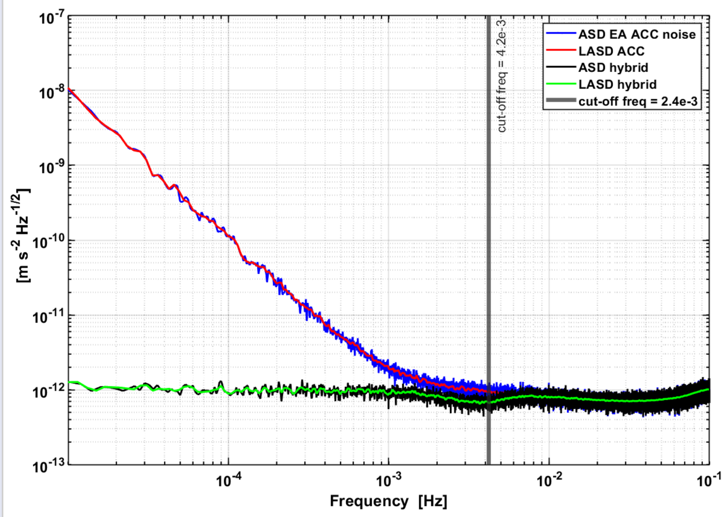
Future Hybrid ACCs

a) Alvarez + CAI 12



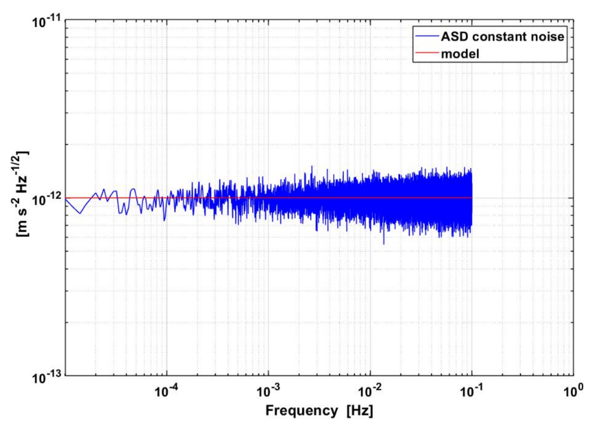
ASD of Alvarez ACC and hybrid with CAI 12

b) ONERA + CAI 12



ASD of ONERA ACC and hybrid with CAI 12

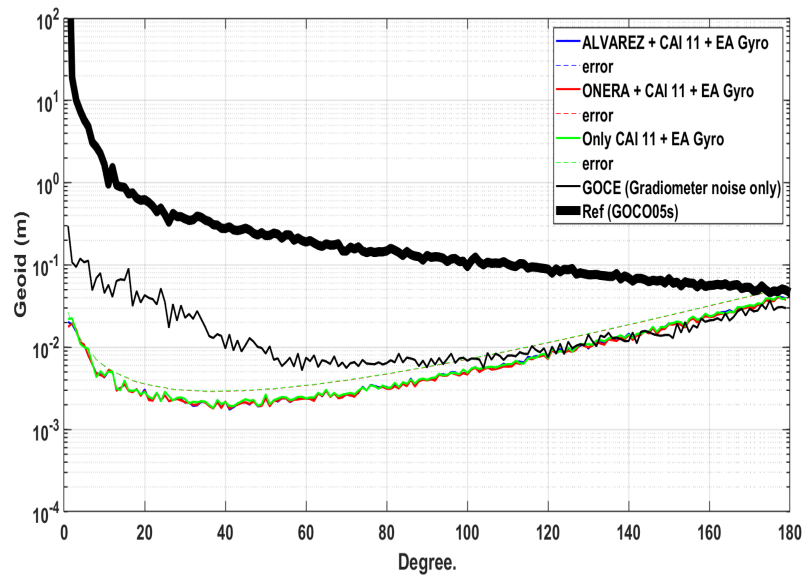
c) CAI 12 only



ASD of CAI 12 only

First Category: Realistic Hybrid ACCs and Realistic Gyro

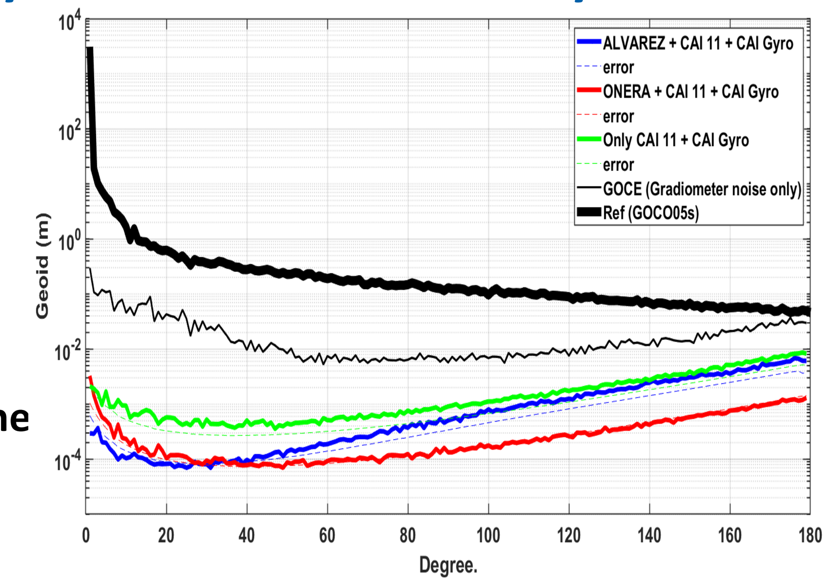
a) Alvarez + CAI 11 + ES Gyro
b) ONERA + CAI 11 + ES Gyro
c) CAI 11 only + ES Gyro



The results of the first category show the dominant impact of ES Gyro

Second Category: Realistic Hybrid ACCs and Future Gyro

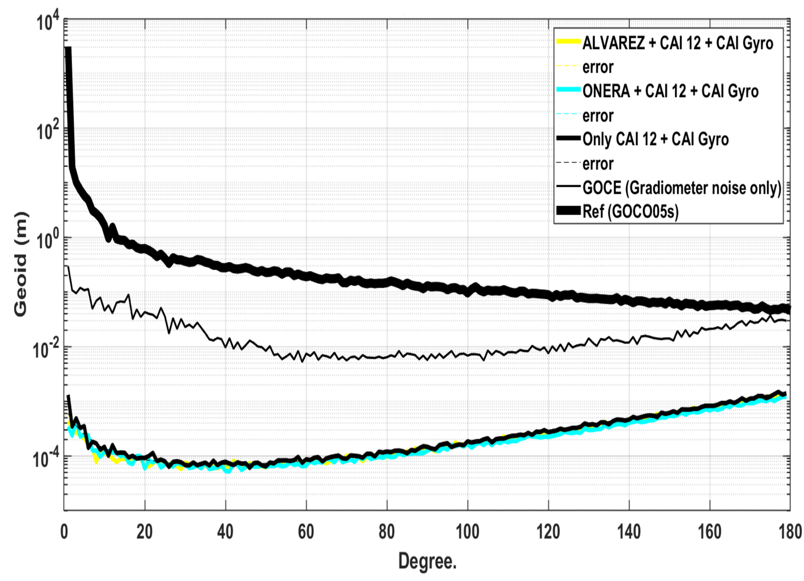
a) Alvarez + CAI 11 + CAI Gyro
b) ONERA + CAI 11 + CAI Gyro
c) CAI 11 only + CAI Gyro



The results of the second category show the improved performance of hybrid ACCs

Third Category: Future Hybrid ACCs and Future Gyro

a) Alvarez + CAI 12 + CAI Gyro
b) ONERA + CAI 12 + CAI Gyro
c) CAI 12 only + CAI Gyro



The results of the third category show the dominant impact of CAI

Major findings

➢ **From First Category**

1) Large (negative) contribution of ES Gyro in recovery results

➢ **From Second Category**

1) Best performance when using ONERA + CAI 11 + CAI Gyro, especially at high degrees and orders
2) Good performance when using Alvarez + CAI 11 + CAI Gyro, because better error ASD of Alvarez than CAI 11 in low frequency part
3) Better performance of hybrid ACCs with respect to CAI only

➢ **From Third Category**

1) Dominant effect of CAI on gravity field recovery
2) Low impact of ES ACCs (Alvarez and ONERA) in hybrid ACCs with respect to CAI 12

➢ **General Aspects**

1) New sensors enable better gradiometer solutions than GOCE
2) Large impact of the Gyro, which is needed because no non-diagonal components are observed for providing angular velocities (as in GOCE)
3) Significant benefit of CAI for d/o higher than 50

Acknowledgements

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References

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