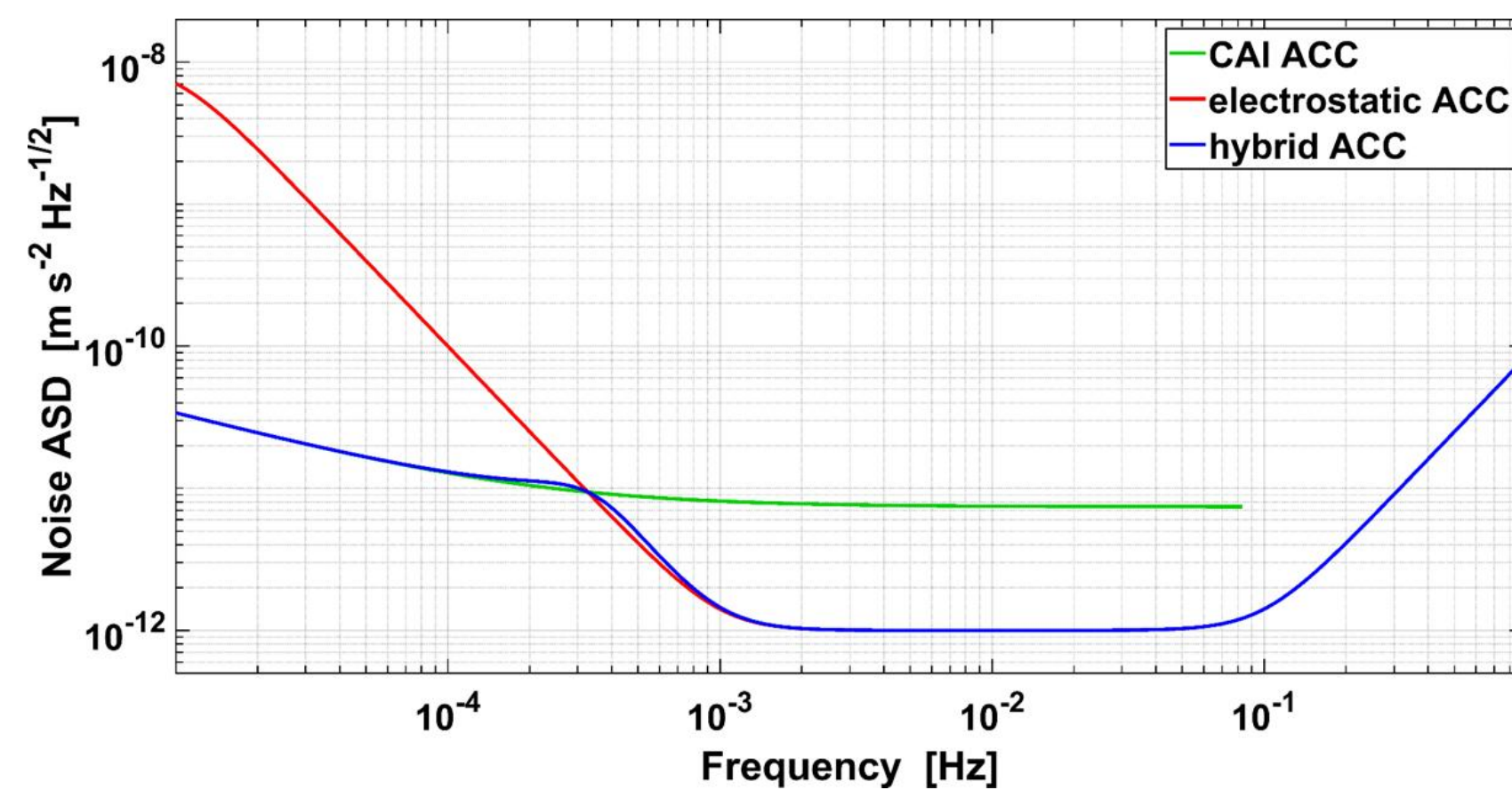


1. Accelerometers for Satellite Gravity Missions

- Low-low Satellite-to-Satellite Tracking (ll-SST): accelerometer in the center of mass to measure the non-gravitational accelerations
- Satellite Gravity Gradiometry: measure differential accelerations along a short baseline to obtain gravity gradients
- Characteristics of electrostatic and Cold Atom Interferometry (CAI) accelerometers [1, 2]:



- Electrostatic accelerometer (EA)
 - Drift in low frequencies
 - Continuous output
- CAI accelerometer
 - Long-term stability
 - Lower sampling rate

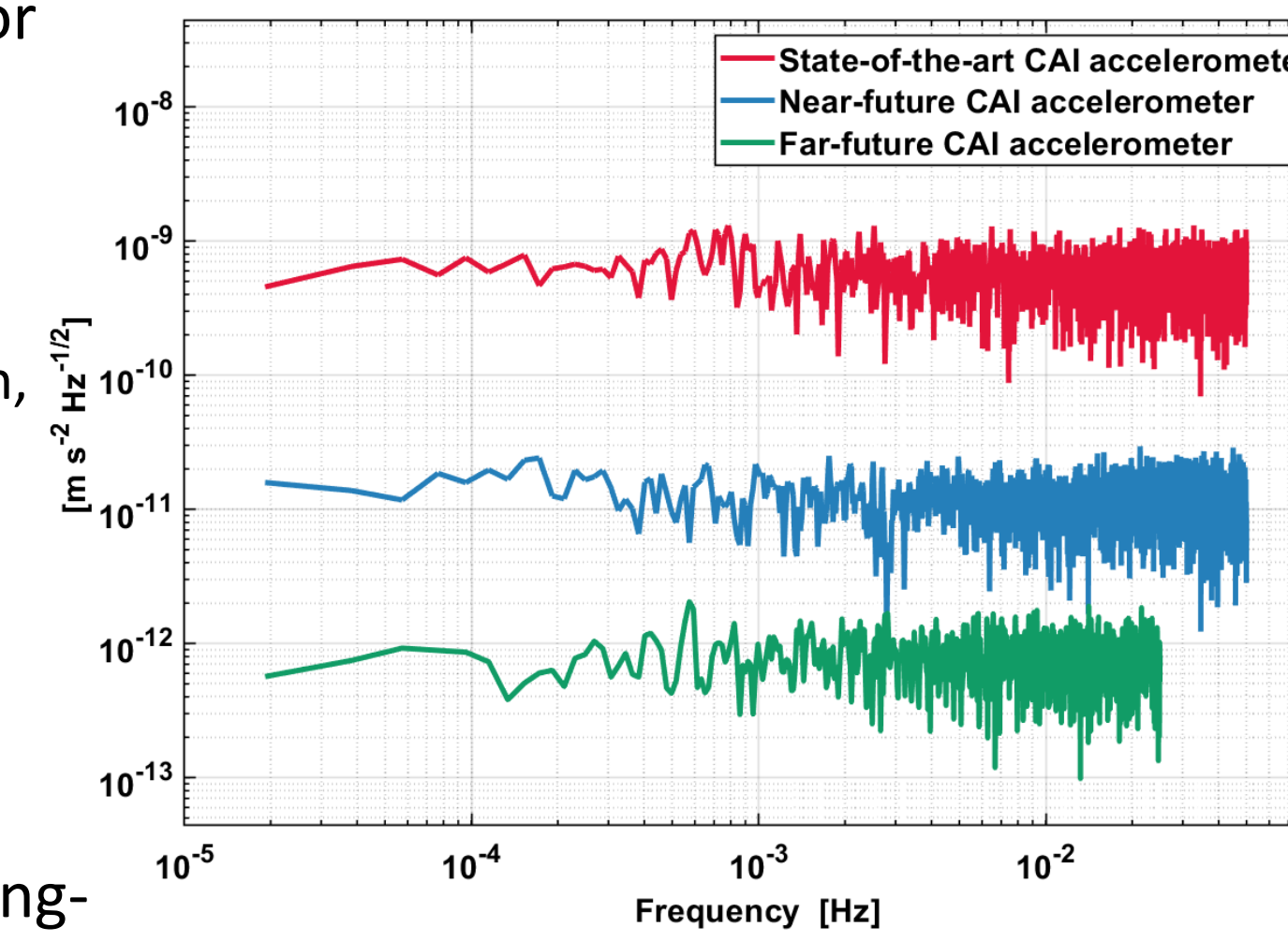
2. Cold Atom Interferometry Accelerometer Performance

- Phase shift using an active Raman mirror rotating against the rotation rate of the satellite

$$\Delta\Phi = 2 k_{\text{eff}} T^2 (a_x + x_0 \Omega_y^2)$$

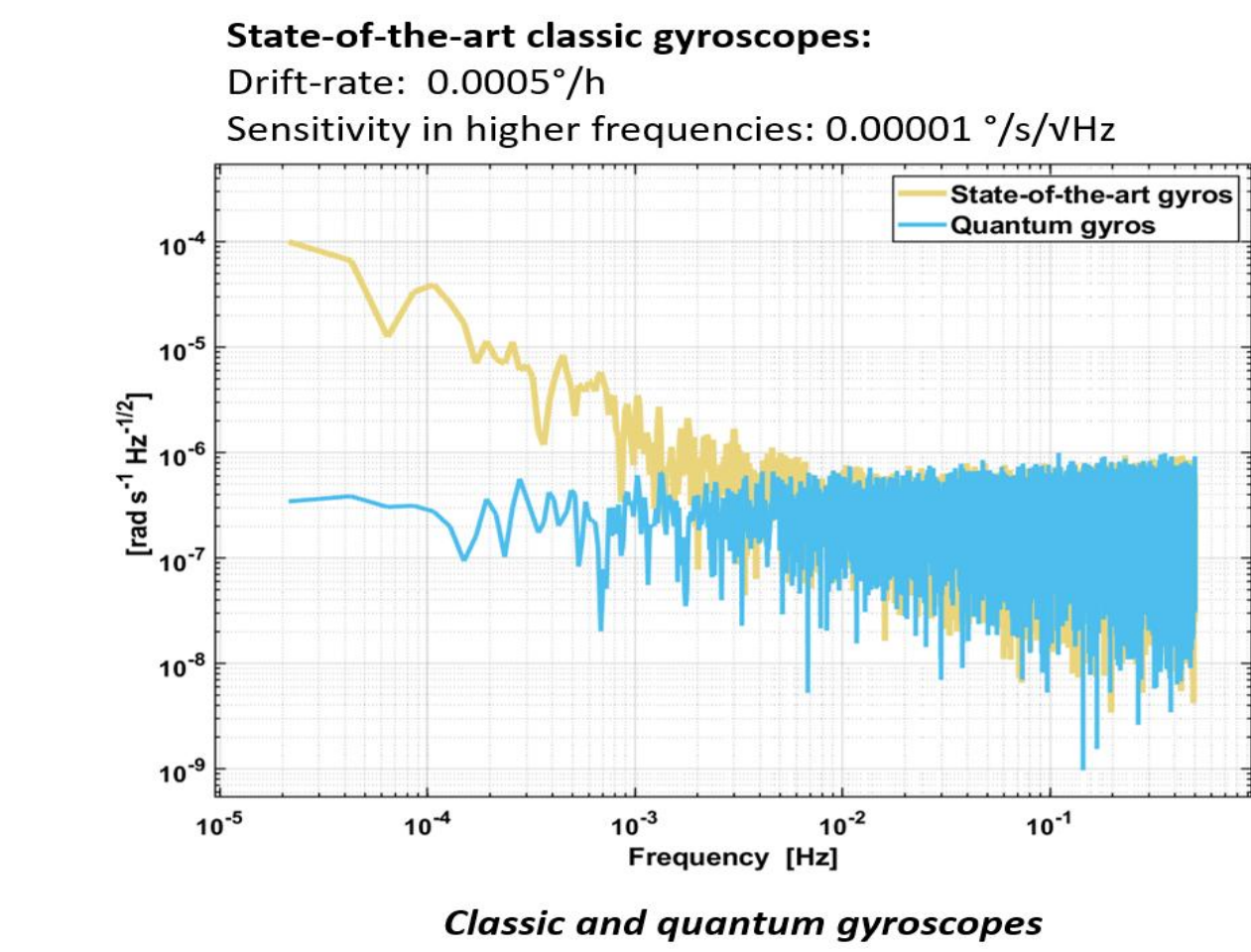
with a_x : acceleration in along-track direction, T : time interval of pulse separation, k_{eff} : norm of effective wave vector, x_0 : initial distance of atoms to the center of mass, Ω_y : satellite angular velocity around the cross-track axis

- CAI accelerometer measures in along-track direction, but is placed on cross-track axis



	State-of-the-art	Near-future	Far-future
Interferometer duration	5 to 10 s	10 s	10 to 20 s
Number of atoms	5×10^5	1×10^6	1×10^7
Atomic temperature	100×10^{-12} K	1×10^{-12} K	0.5×10^{-12} K

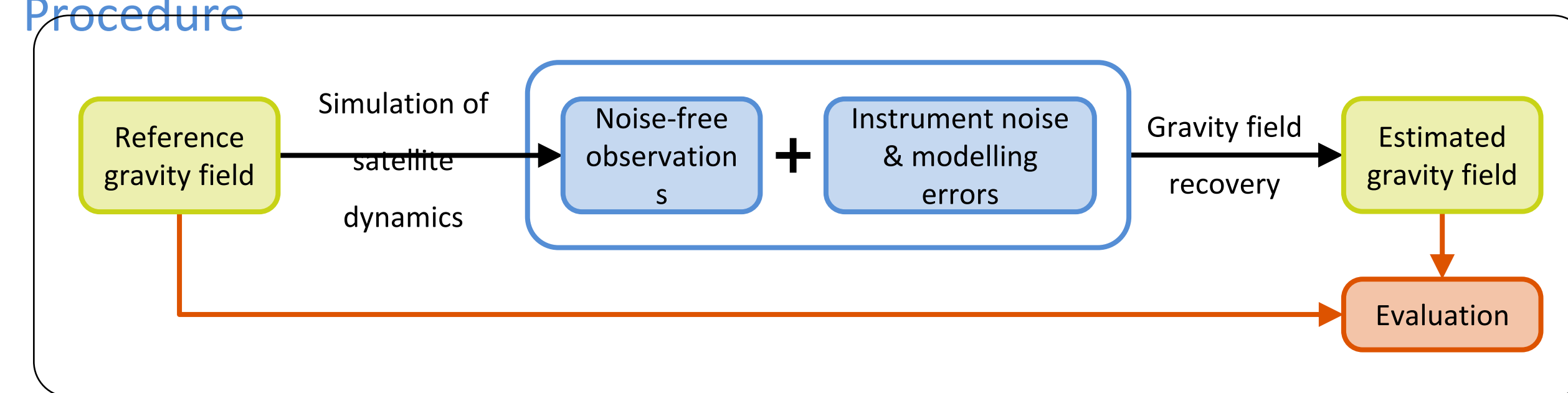
3. Benefit of Quantum Gyroscopes



- Measurement of the rotation rate is a critical factor for the required rotation compensation and also in gradiometry scenarios.
- Quantum gyroscopes enable drift-free measurements of angular rates.
- The performance of onboard quantum accelerometers can be significantly improved by enabling bias-free rotation compensation.

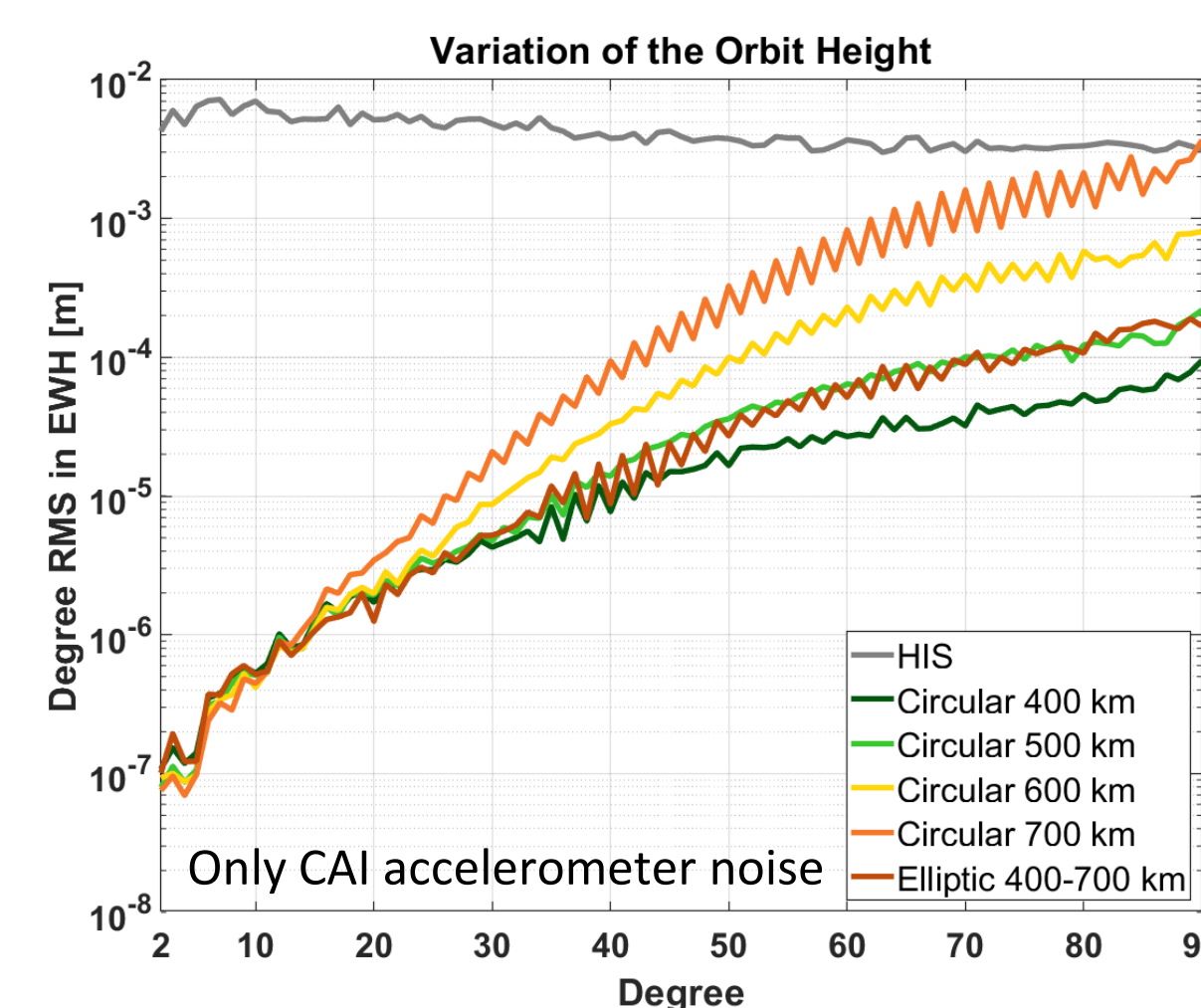
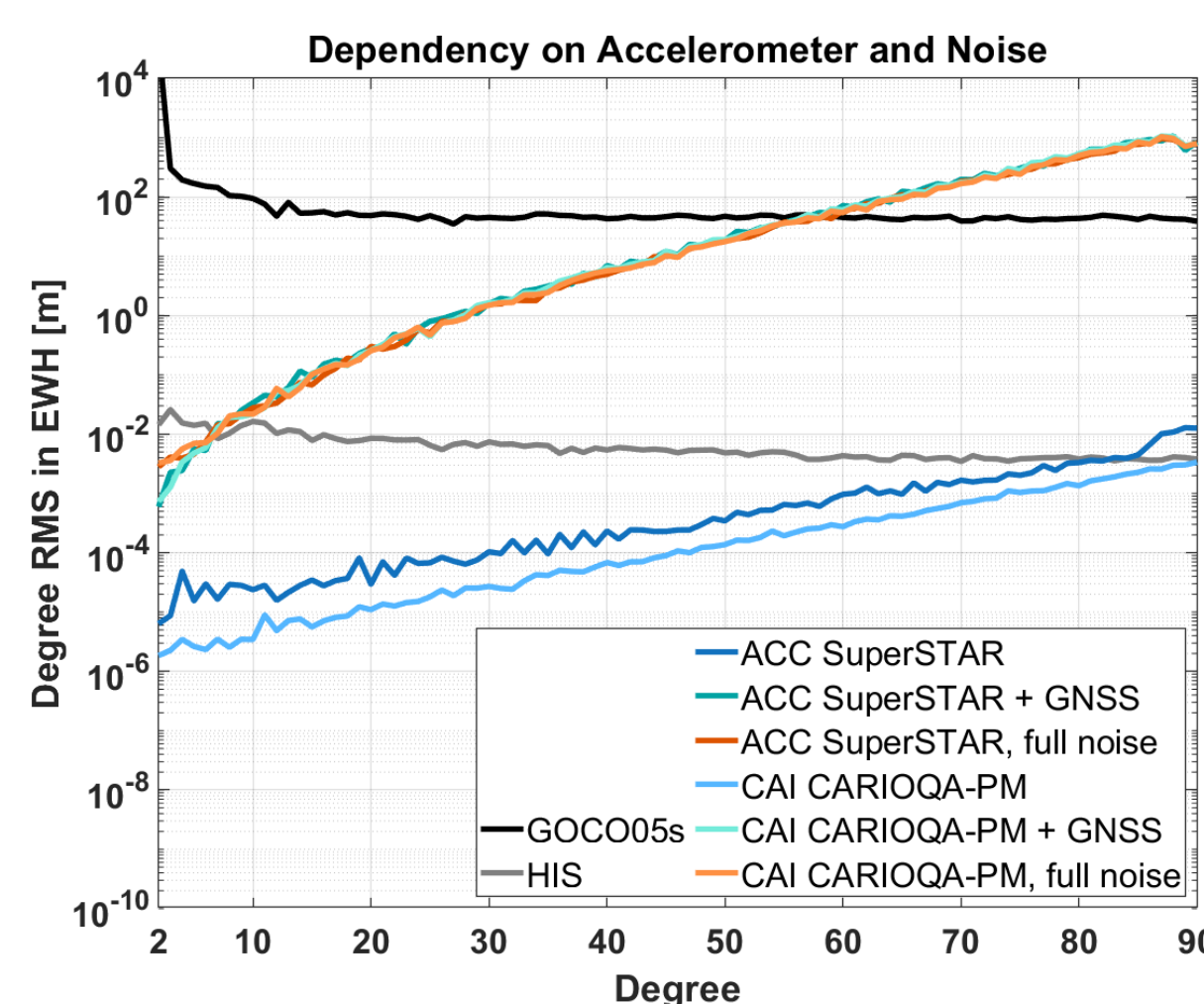
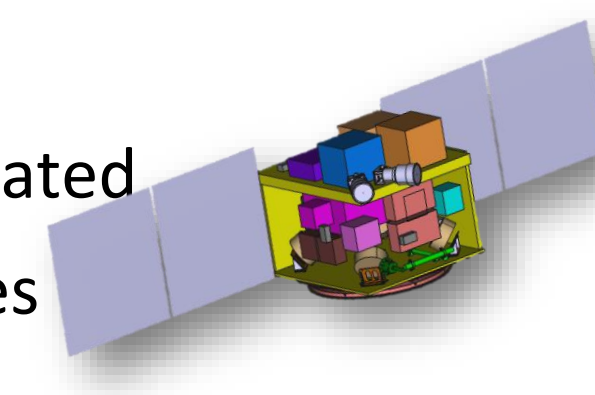
4. Closed-loop Simulation

Simulation Procedure

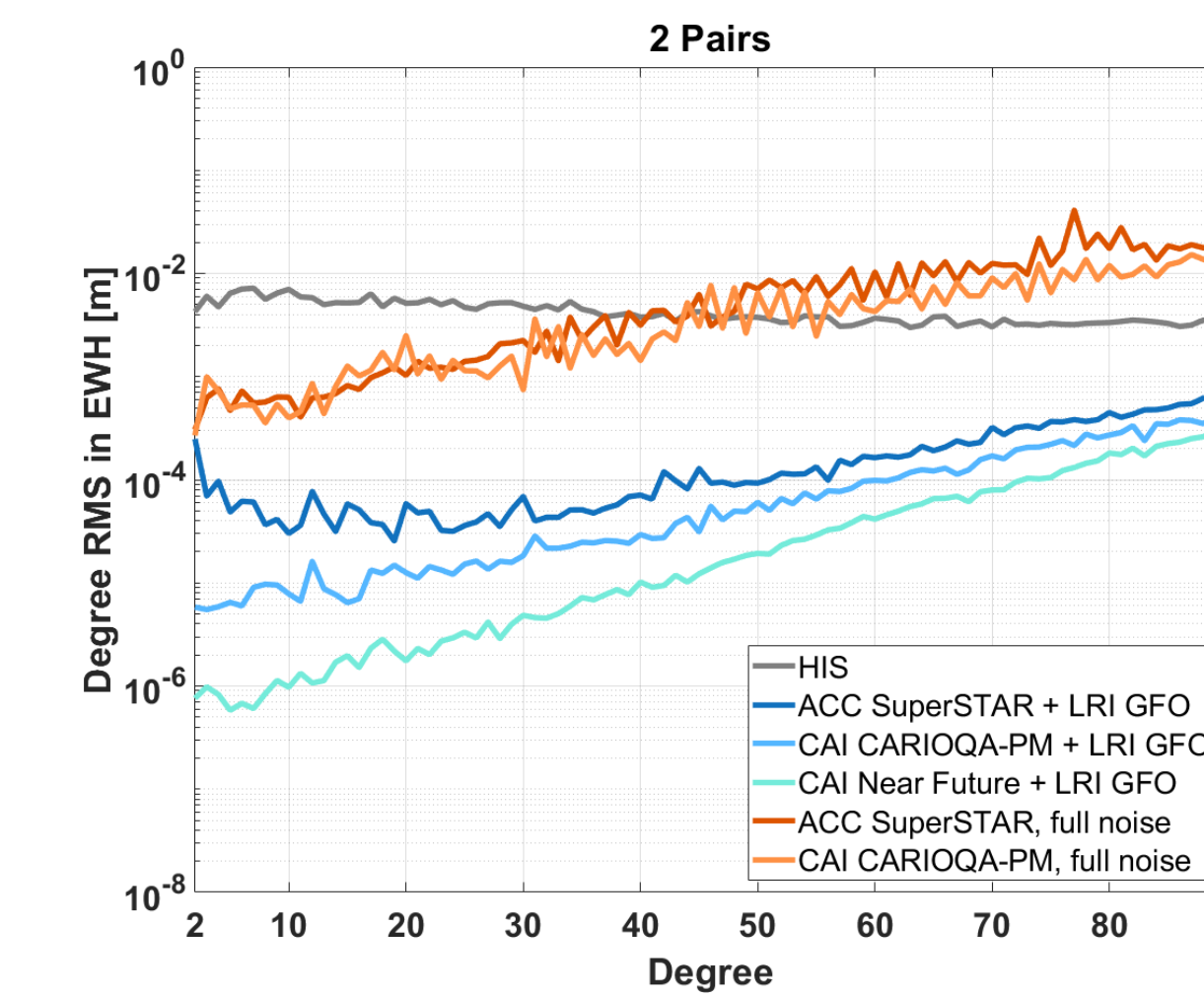
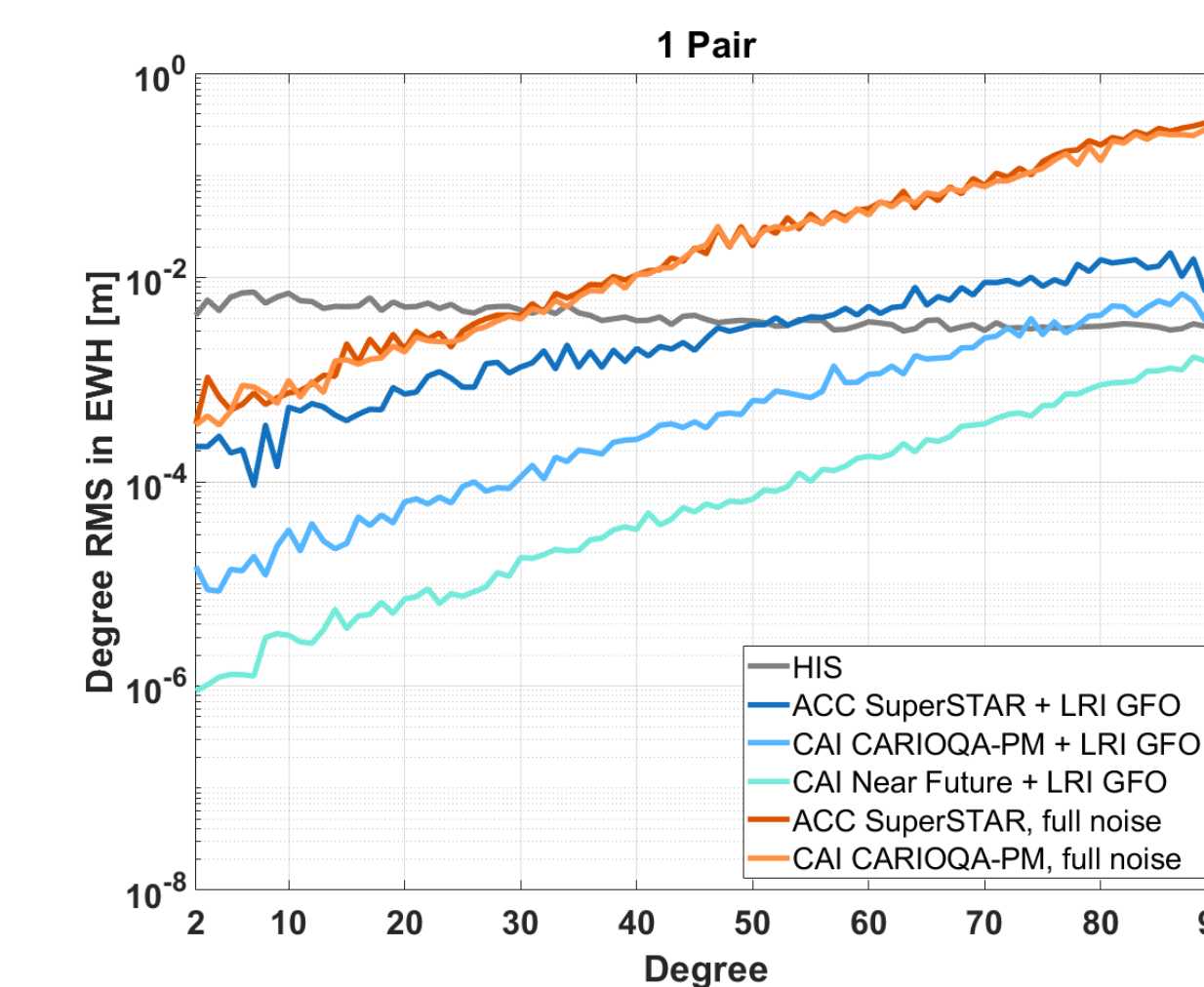


CARIOQA Pathfinder Mission

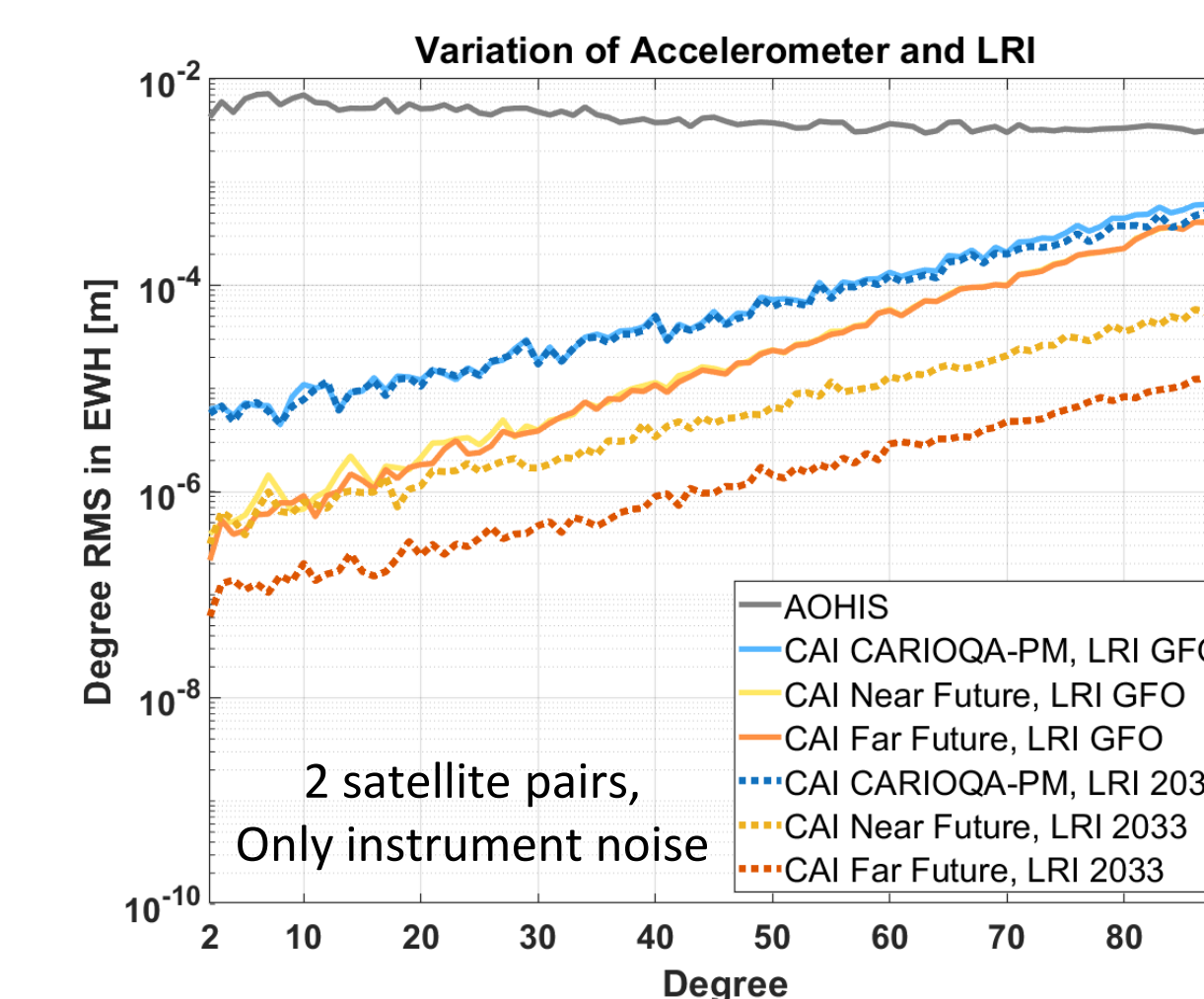
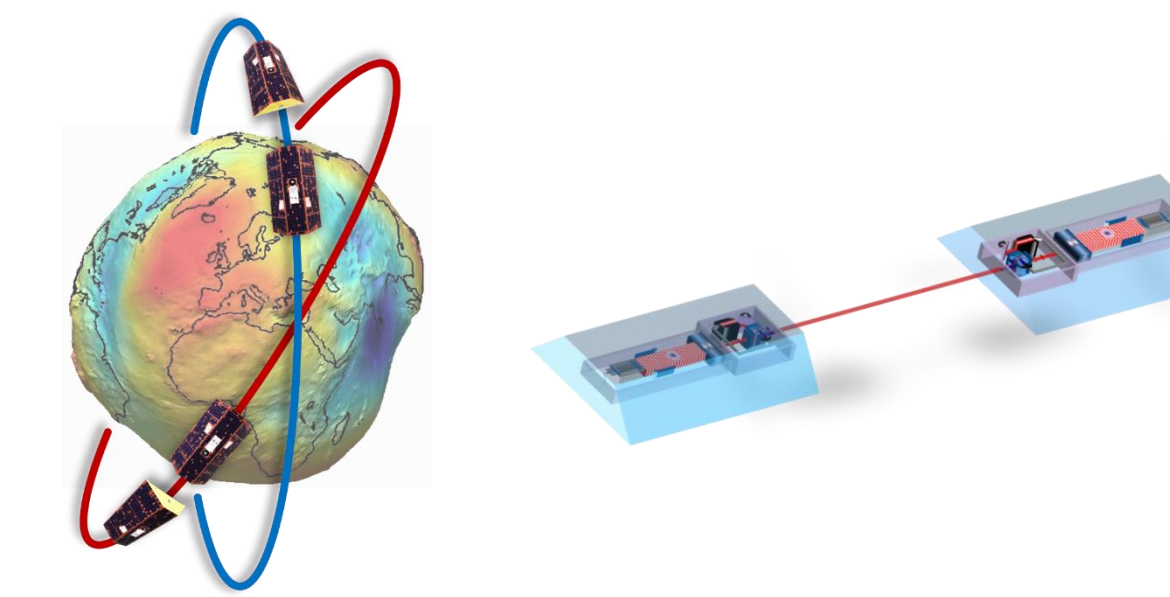
- Single satellite in nadir pointing mode, operating in ll-SST mode via GNSS
- One CAI accelerometer in along-track direction to be demonstrated
- Gravimetry is a secondary objective along thermosphere studies
- Orbit is trade-off between requirements of CAI and gravimetry



Future Quantum Space Gravimetry



- Pair(s) of satellites in constellation, based on the GRACE-FO satellites & MAGIC constellation studies
- Operation in ll-SST mode with LRI
- Further increase in sensitivity of CAI accelerometer expected
- Development of hybrid accelerometers (electrostatic + CAI)
- Improvement of other sensors to state-of-the-art as well – but progress in equal measure required
- Background models are used in the simulation to compensate temporal aliasing but introduce errors



5. Conclusions

- Cold Atom Interferometry performance with state-of-the-art technology is expected to be at the level of $5 \times 10^{-10} \text{ m/s}^2/\sqrt{\text{Hz}}$, in the far-future scenario at the level of $10^{-12} \text{ m/s}^2/\sqrt{\text{Hz}}$ with active rotation compensation method
- Regarding the CARIOQA Pathfinder mission, ll-SST closed-loop simulation results are limited by GNSS but the low degree time-variable gravity field can be determined
- The ll-SST solutions show the dominance of background modeling errors and temporal aliasing but utilisation of CAI accelerometers promises improvement compared to the commonly used electrostatic ones
- Further development of CAI accelerometers has to be accompanied by improvement of all sensors to decrease the limitations by instruments

Acknowledgment



We acknowledge the support by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – EXC-2123 QuantumFrontiers – 390837967, the European Union for the projects CARIOQA-PMP (Project-ID 101081775) and the Federal Ministry for Economic Affairs and Climate Action (BMWK), Project 50NA2310A (SpaceQNav).

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