Evaluation of Optical Accelerometry for Next Generation Gravimetry Missions

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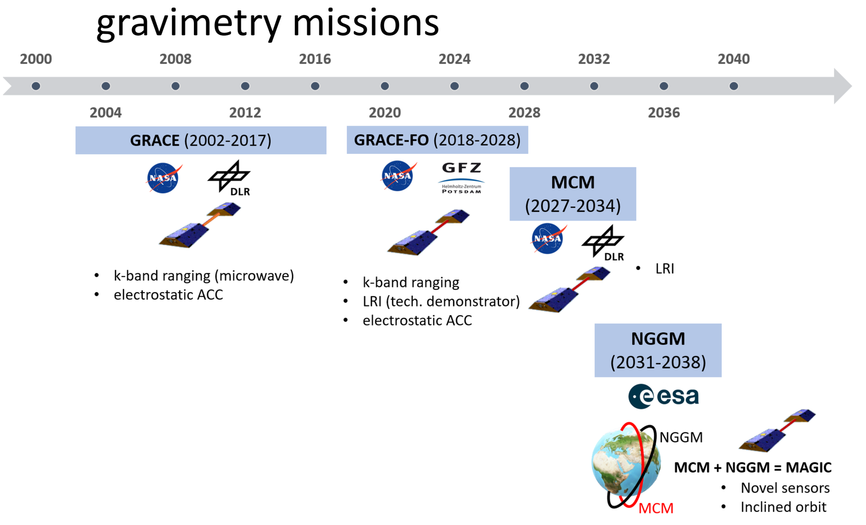
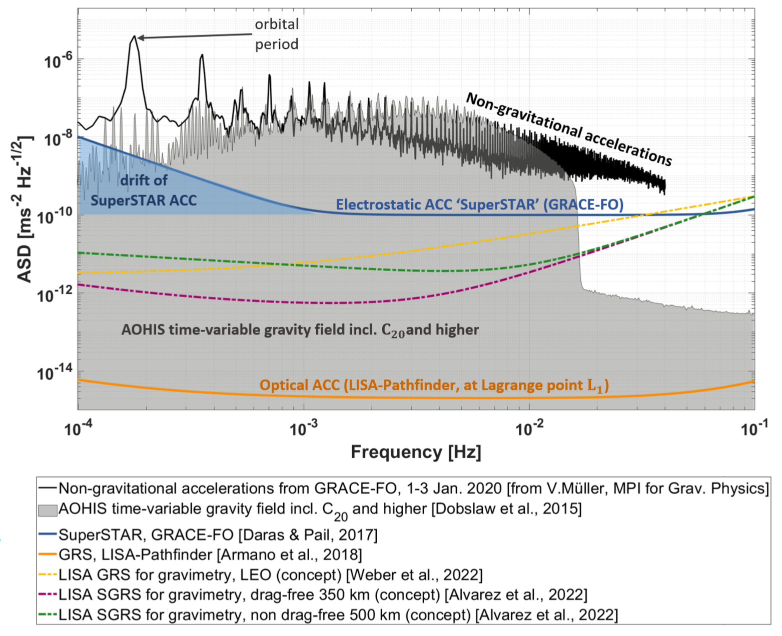
1. Current state of gravimetry missions

- Ongoing climate change underlines the urgent need to continue >20 years gravimetry measurements with enhanced concepts and sensors
- Low-frequency noise of electrostatic accelerometers (EA) - one of the limiting factors in gravity field recovery (GFR)
- EA are partly responsible for a systematic effect in gravity field solutions (North-South 'striping')
- LISA-Pathfinder (LPF) optical accelerometry demonstrated promising results for gravimetry missions

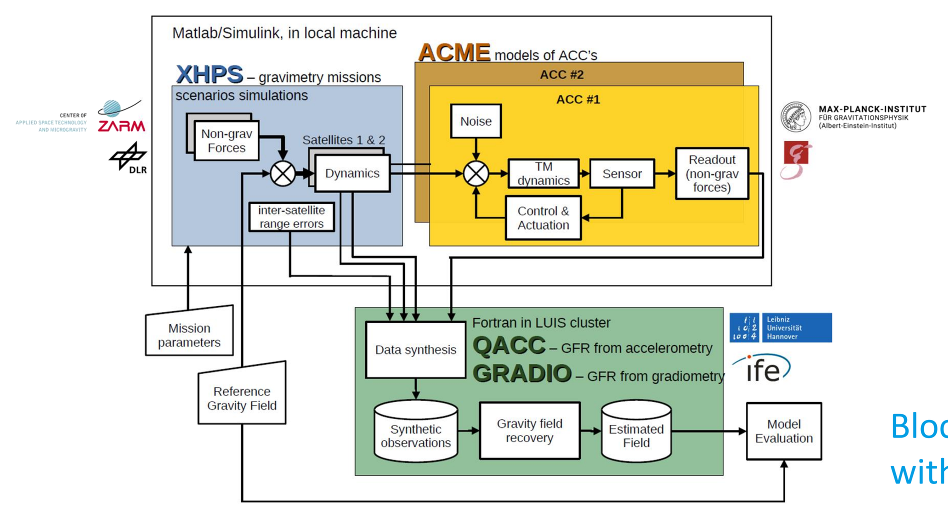




Left: Timeline of the gravimetry missions;
Right: Comparison of the ACCs ASD sensitivities for current instruments and advanced concepts w.r.t. time-variable gravity signal.

2. Methods

- Mission scenarios were run in eXtended Hybrid simulation Platform for Space systems (**XHPS**) in Matlab/Simulink, including simulation of space environment
- Accelerometer Modeling Extended (**ACME**) is a framework developed in Matlab/Simulink to model past, current and proposed accelerometers (ACCs)
- Gravity field recovery (GFR) was carried out using **QACC** and **GRADIO** software tools



Block diagram of simulation procedure within the used software parts.

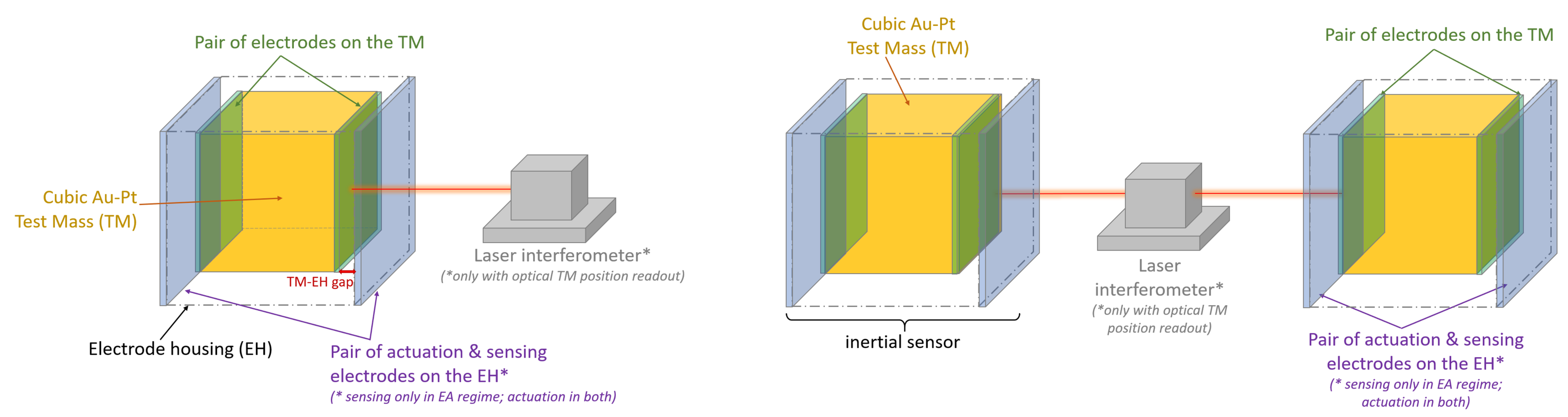
3. Accelerometer & gradiometer modeling

ACME:

- Simulates the dynamics of ACCs using parametric models
- Includes noise models of sensors (capacitive, optical) and actuators (electrostatic)

EA and optical ACC principles:

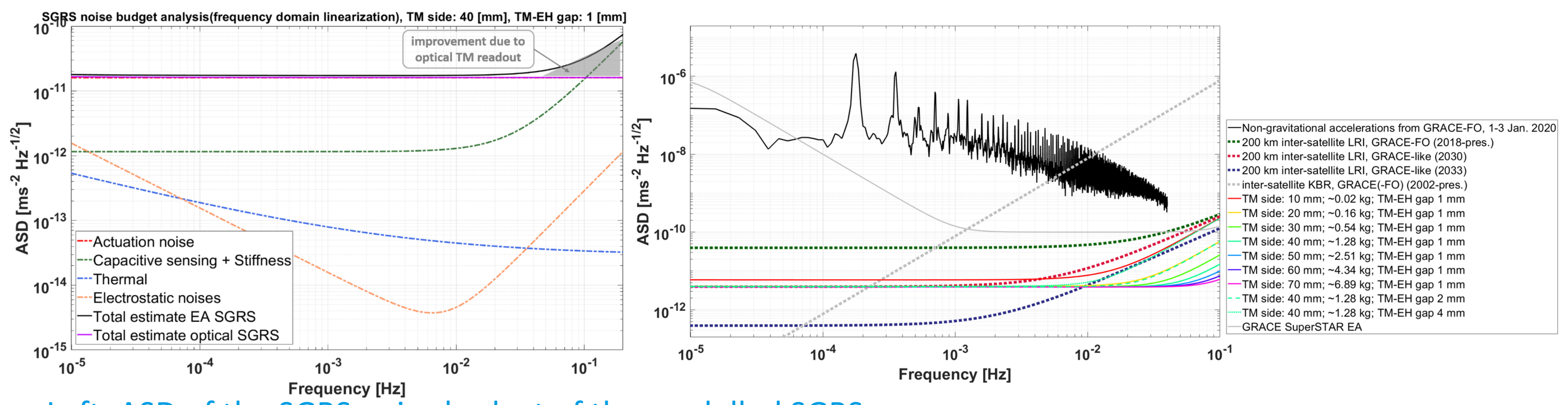
- EAs measure the change in capacitance to determine TM displacement
- Optical ACCs assumed to have a better performance by using a laser-based measurement to exclude the capacitive sensor noise



Left: Illustration of 1 degree of freedom (DOF) accelerometer model;
Right: Scheme of the 1 DOF optical gradiometer.

4. Accelerometer noise budget & parametrization

- Noise budget of the SGRS [Alvarez et al., 2022], modeled in ACME includes: actuation, capacitive sensing, stiffness, thermal bias and electrostatic noises

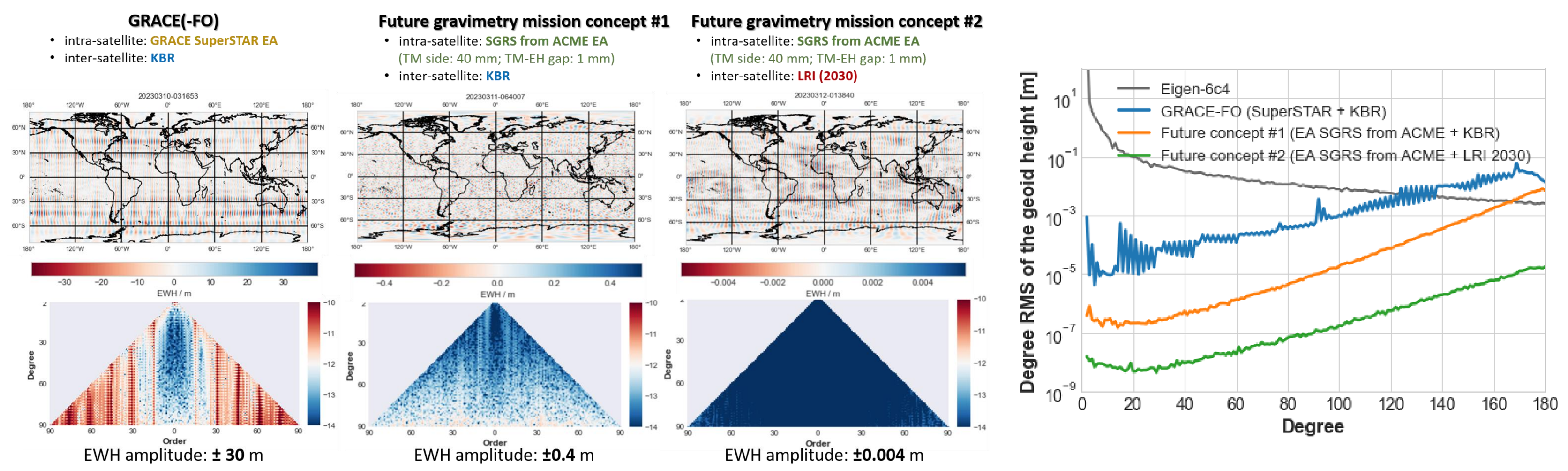


Left: ASD of the SGRS noise budget of the modelled SGRS;
Right: Comparison of the parametrized EAs SGRS ASD sensitivities, non-gravitational accelerations and inter-satellite LRI & KBR errors.

5. Gravity field recovery – simulations

GRACE-FO vs. future gravimetry mission concepts

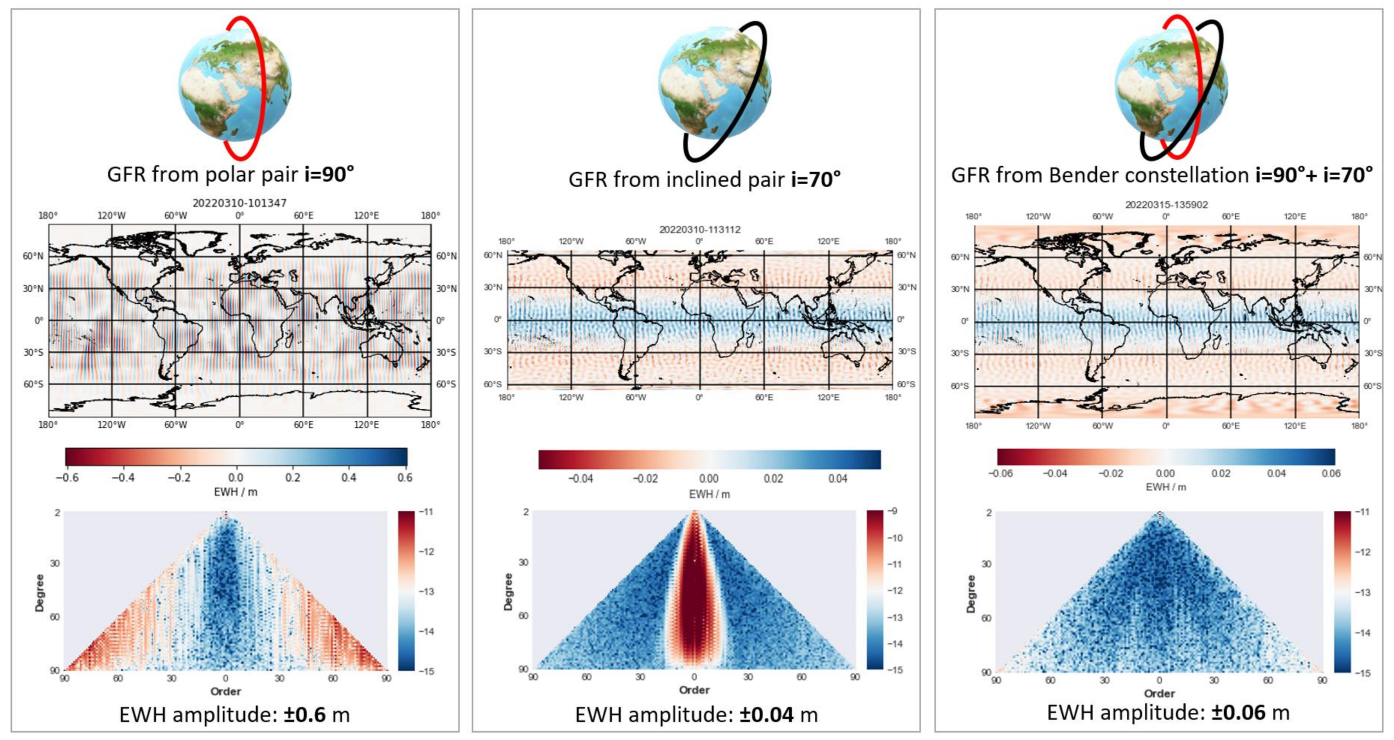
- 1 month mission duration; background models neglected
- h=450 km, non drag-free, i=89°, d=190 km
- By utilizing novel instruments, i.e. enhanced SGRS or LRI it is possible to avoid filtering or post-processing of the gravity field models from GRACE-like polar pair missions



Recovered gravity fields (without post-processing and filtering) between simulated GRACE-FO and future gravimetry mission concepts w.r.t. EIGEN-6c4. Left: Global maps in EWH (m) – up to degree 90;
Right: Averaged error degree variance per specific degree in geoid height (m) – up to degree 180.

Satellite formation: Bender constellation

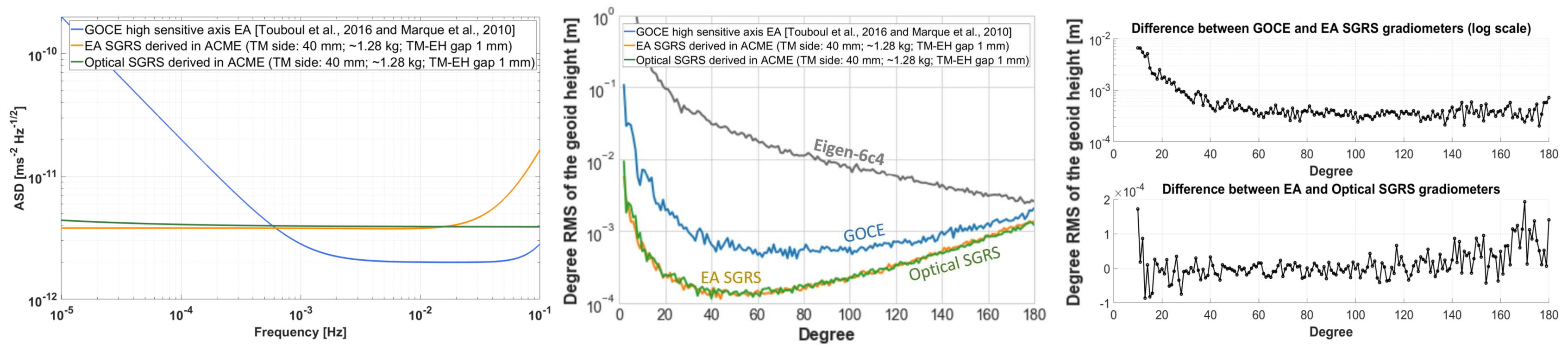
- 1 month mission duration; background models neglected
- h=450-480 km, non drag-free, i=89°, i=70°, d=190-200 km
- Bender constellation will significantly improve the accuracy of the GFR solutions on global scale w.r.t. GRACE-FO current outputs



Recovered gravity fields (raw data, without post-processing and filtering) from Bender constellation.
Left: from polar satellite pair; Middle: from inclined orbit;
Right: combination from 2 satellite pairs w.r.t. EGM2008 in terms of EWH.

Gradiometer model comparison

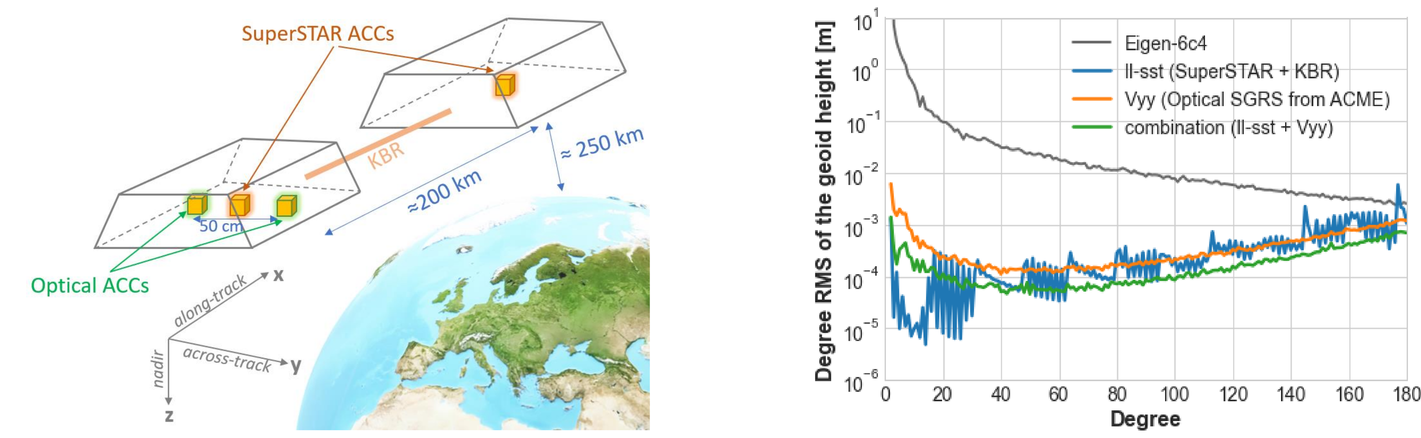
- Modeled gradiometers show significant improvement w.r.t. GOCE high-sensitive gradiometer



Left: ASD of the ACCs that built the gradiometers;
Middle: Averaged degree RMS per specific degree in geoid height (m) from different gradiometer models;
Right: Difference of gradiometer solutions from SH degree 8.

Future gravimetry mission combination concept: ll-sst + cross-track gradiometry

- 1 month mission duration; background models neglected
- h=246 km, drag-free, i=89°, d=193 km
- North-South striping effect reduced
- Benefit from advantages of GRACE (temporal grav. signals) and GOCE (static grav. signals) concepts



Left: Scheme of the combination of the ll-sst and cross-track gradiometry;
Right: Averaged error degree variance per specific degree (m) w.r.t EIGEN-6c4.

6. Results

- Demonstrated the capability of modeling the full circle of gravimetry missions
- Showed that modeled ACCs based on SGRS provide similar performance as the concepts from other research groups
- Modeled ACCs in ACME using a range of parameters
- Applied sensitivity curves derived from SGRS ACME model into accelerometry software QACC and gradiometry software GRADIO for gravity field recovery (GFR)
- Compared GFR solutions from the various parametrized mission scenarios and different gradiometer concepts

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7. References

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