GRACE-I: A joint US-German mission for continued mass transport monitoring and enabling global biodiversity monitoring

ESA Living Planet Symposium 2022
24.05.2022

Frank Flechtner[1,3] (frank.flechtner@gfz-potsdam.de),
Christoph Dahle[1], Markus Hauk[2] , Josefine Wilms[1], Michael Murböck[3]
Michael Nyenhuis[4], Peter Schaadt[4]

1: Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Germany
2: Max-Planck-Institute for Gravitational Physics, Hannover, Germany
3: TU Berlin, Institute for Geodesy and Geoinformation Science, Germany
4: German Space Agency at DLR, Department Earth Observation, Germany

GFZ Helmholtz Centre POTSDAM · TU berlin · DLR · HELMHOLTZ

GRACE-I Background

- GRACE-FO has **2 single point of failures** (GFO-2 IPU, GFO-1 ACC) **which could end the mission any time.**
- The NASA Earth Science Decadal Survey Report highlights **mass transport monitoring** as **one of five top priorities in EO for the next decade**.
- To realize such as Mass Change Mission (MCM) **NASA is seeking for international partnership**.
- **US and D have very high interest to continue the very successful technological and scientific** GRACE/ GRACE-FO **partnership**
- Germany proposes a **joint US-D GRACE-I (MC) mission** = GRACE concept plus an (optional) ICARUS payload (International Cooperation for Animal Research Using Space) which would combine 2 NASA Designated Observables (Mass Change and Surface Biology and Geology).
- Major objective: **quickly realized single-pair GRACE-FO successor based on LRI SST with launch in 2027 into a polar orbit to guarantee data continuity.**
- In parallel ESA is currently preparing a **NGGM/MAGIC** mission in the Mission of Opportunity element of FutureEO. MAGIC also considers **hybrid Bender pair configurations** to be launched in a staggered approach. GRACE-I could be the polar pair P1.

GRACE-I Phase 0 Study (Mar-Dec 2021)

Mission Analysis (Funded by DLR, Lead by DLR)

- Two technologically enhanced satellites based on GRACE-FO @ 490 or 420 km altitude
- **Essential:** Redundant LRI instead of MWI for SST, improved acceleration measurement (3 GRACE-FO-type ACC)
- **Optional:** Improvements in the propulsion concept and additional payloads (ICARUS, QGG, MARVEL)
- **Study Goal:** Investigation of the technical feasibility of options (incl. 3 TIMs with JPL)

	Option 1 (Grace-FO heritage)	Option 2 (add linear cold gas)	Option 3 Add ICARUS instrument	Option 4 Add MARVEL reflector	Option 5 Add QGG tech-demo
Instruments	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver no additional payloads	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver no additional payloads	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver ICARUS	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver ICARUS MARVEL	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver ICARUS QGG

11:40 am
Review of MARVEL pre-Phase-A
Jean-Michel Lemoine | CNES - Centre national d'études spatiales | France

- **Major outcome documents:**
  - Mission concept (focusing on instruments and requirements for the platform)
  - Preliminary Customer Technical Requirement Specification (user & basic system requirements)

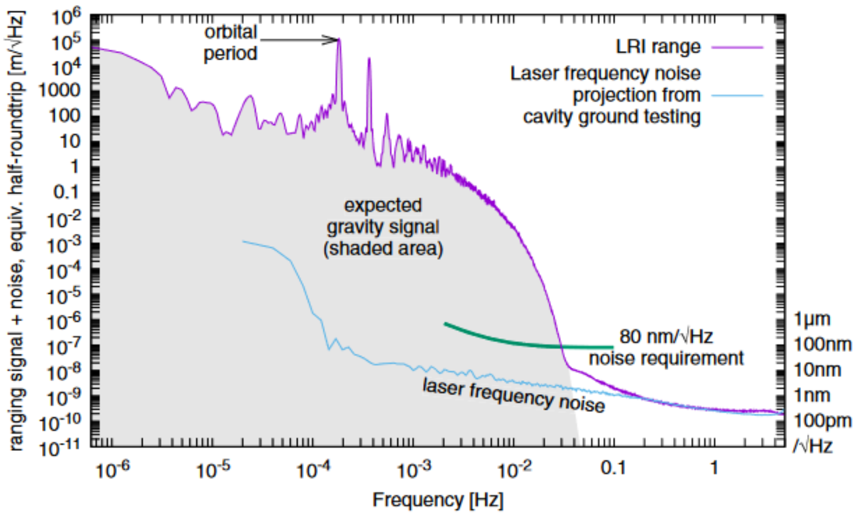
GRACE-I Phase A Study (Apr-Sep 2022)

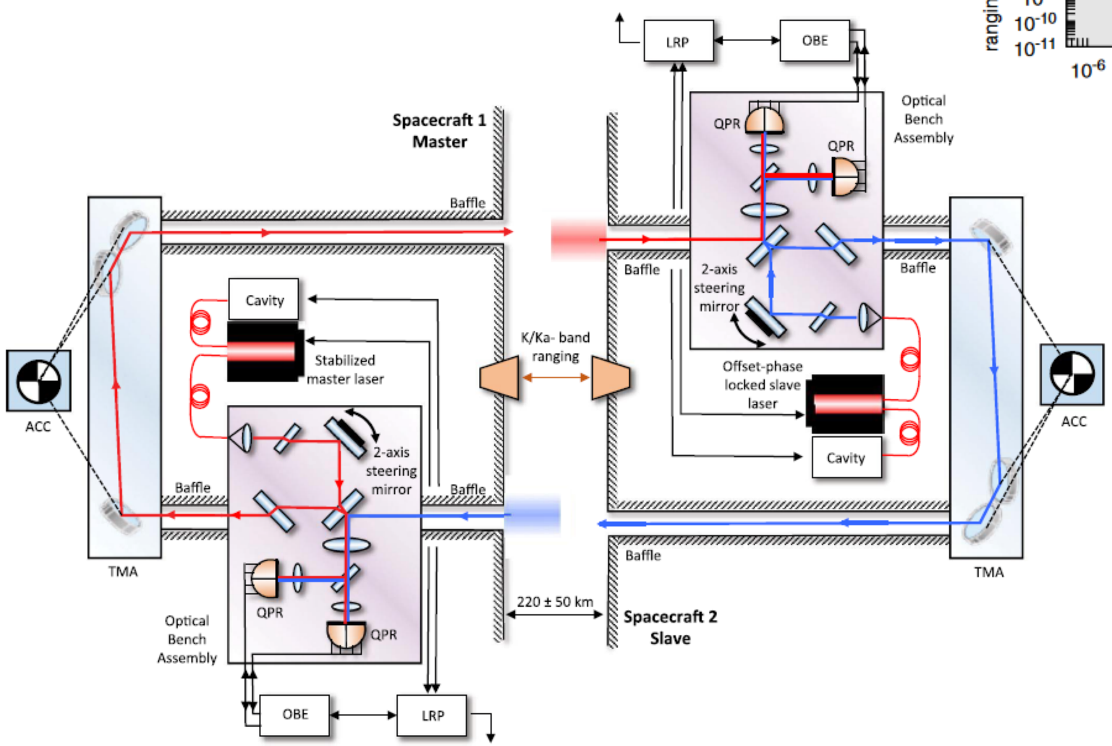
Detailed Mission Analysis (Funded by BMBF, Lead by GFZ, supported by DLR)

- **Objectives:**
  - Concretization of Phase 0 mission options and payload configurations (e.g., Electric Propulsion, ICARUS, QGG demo and accelerometers).
  - Perform weighting of system-level options
  - Derive a detailed design of required technical improvements wrt GRACE-FO
  - Derive a detailed schedule and cost estimation
- **Expected Outcome of Phase-A:**
  - Revised Customer Technical Requirement Specification (CTRS) and
  - **A technically and scientifically feasible GRACE-I / MC mission scenario mutually agreed on between DLR/GFZ and NASA/JPL to be jointly realized within phase B/C/D**
- **NASA/JPL and ESA have to agree on possible ESA contributions on GRACE-I**
  - Analyse accommodation of a Tech Demo microSTAR on P1 GRACE-I
    - Identify synergies, commonalities, schedule and other programmatic elements between P1 and P2
    - ESA participated in 1st TIM to discuss technical and programmatic collaboration
  - Finalize Constellation Requirements Document
- **Exemplarily details on mission elements shown next…**

Laser Ranging Interferometer (GRACE-FO)

- LRI is flown as technology demonstrator
- Excellent ranging performance, especially at the higher end of the measurement band
- Successful signal acquisition without a dedicated sensor

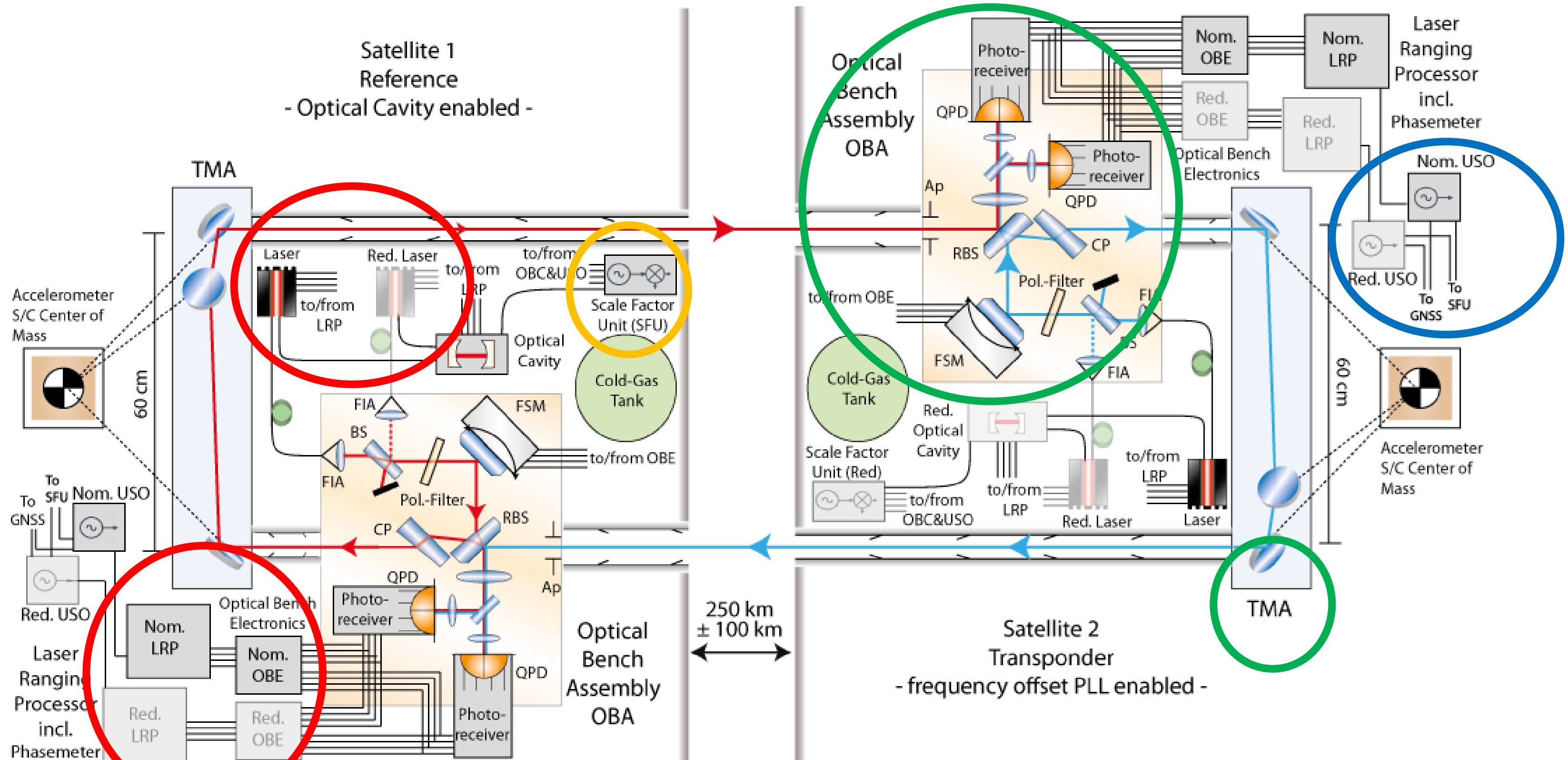




 HELMHOLTZ

Laser Ranging Interferometer (GRACE-I Architecture)

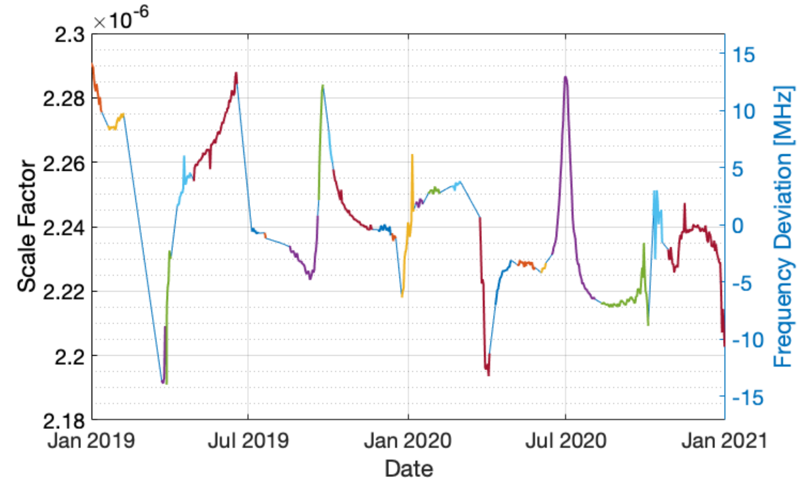
- Same responsibilities US (electronics, Laser) / D (optics)
- Added more redundancy (e.g. LRP, OB Electronics, Laser heads)
- Still non-redundant optical paths (TMA & OBA)
- (Redundant) USO added
- Scale Factor Unit added (no MWI available)
- Lessons learnt from GFO (e.g. reduce Laser sensitivity to thruster shocks (valve open/close))



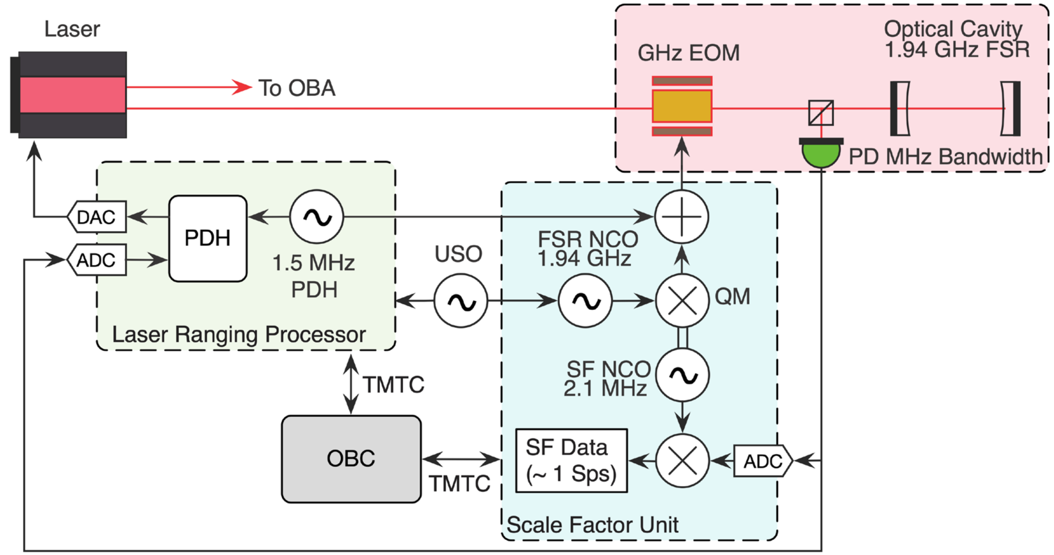
New: LRI Scale Factor Unit

- Scale factor definition:
  - A correction applied to ground-measurement of laser wavelength when converting from optical phase [Cycles] to displacement [m]
  - Gravity simulations show the scale needs to be known to 1e-8 level
- Scale factor correction in GRACE-FO:
  - The scale is inferred by comparing MWI and LRI range measurements
  - Peak-to-peak deviation is ~1e-7 (see plot)
- Scale Factor Unit (SFU) for MC-LRI relates laser frequency to Ultra Stable Oscillator (USO), providing a measurement of long-term laser frequency stability:
  - Separate unit to the Laser Ranging Processor (LRP), will be used to phase modulate laser at the cavity Frequency System Reference (FSR, see diagram)
  - Lab experiments (see paper) show performance ~3e-9 level over a month

GFO Scale Correction from MWI-to-LRI Comparison



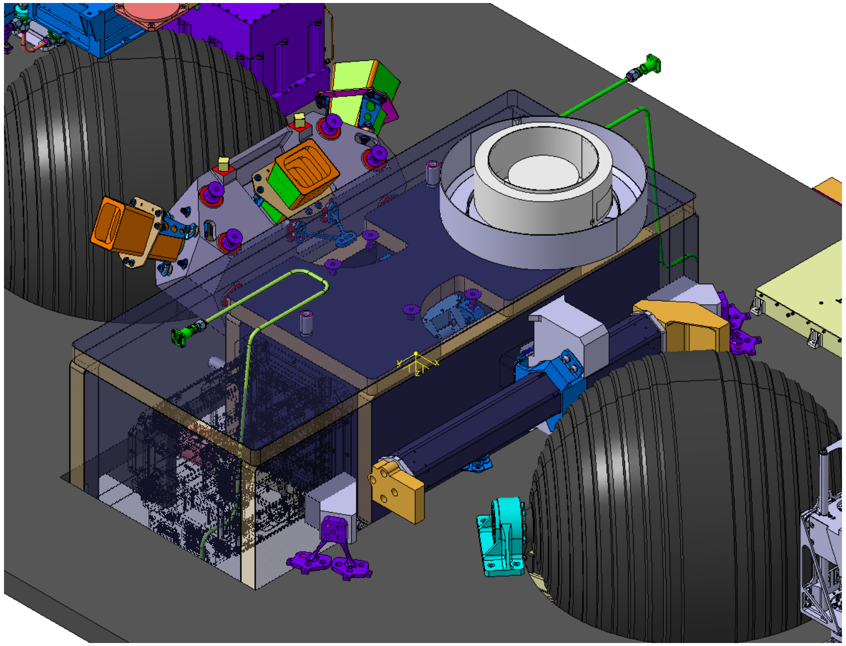
Scale Factor Unit (SFU) Concept



Paper: Emily Rose Rees, et al., Opt. Express **29**, 26014-26027 (2021)

GRACE-FO type Accelerometers

- Trade from Phase 0: Accommodation of three GRACE-FO-type accelerometers in cross track direction with three individual ICUs
  - Provides redundancy for observing non-gravitational forces
- Accelerometer / Star Tracker Support Structure (ASTSS) comprised of:
  - Outer CFRP (Carbon Fiber Reinforced Plastic) Sandwich Main Support Structure with three isostatic mounts
  - Inner Accelerometer Support Structure

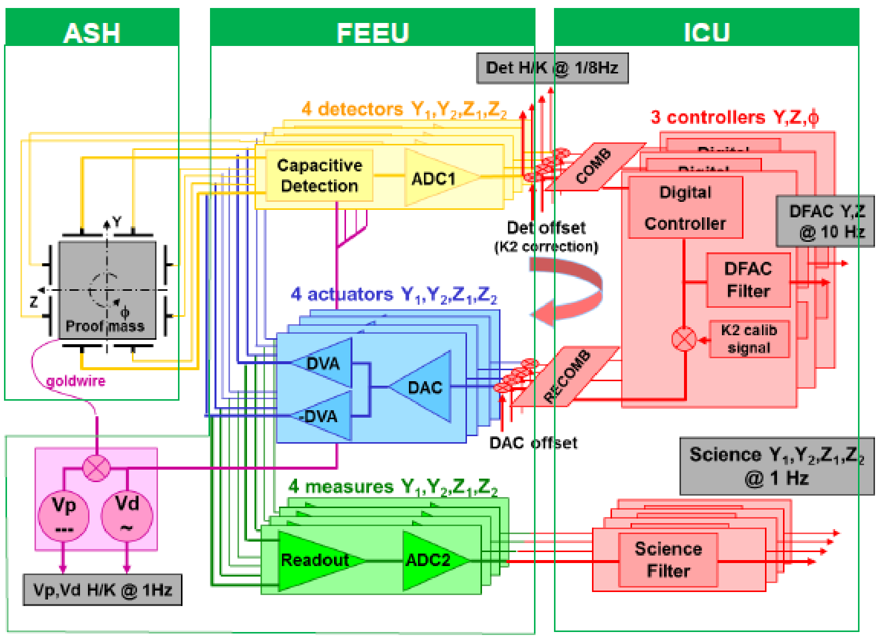


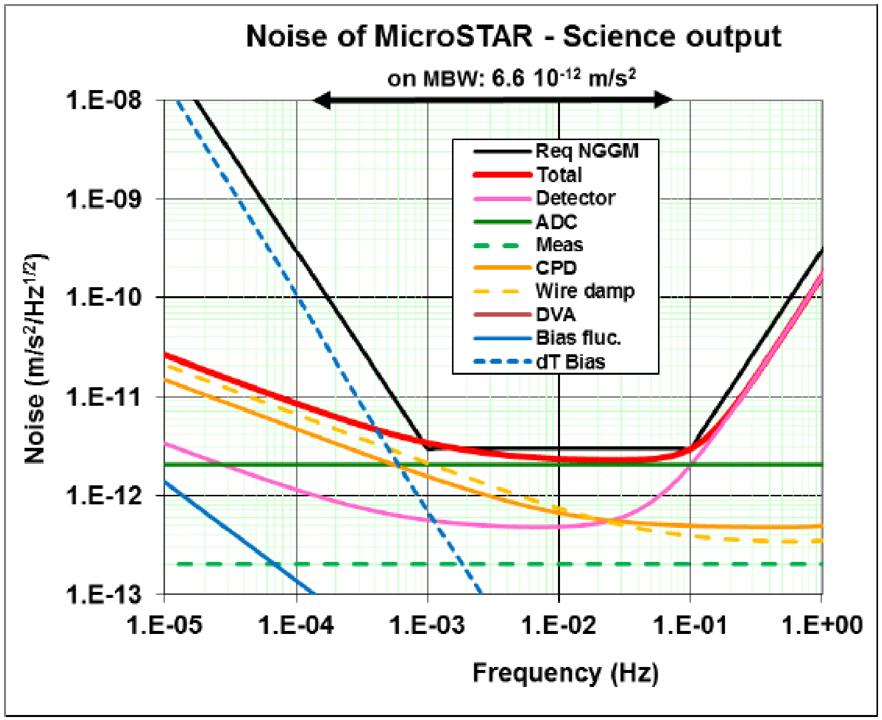
MicroSTAR Accelerometer Tech Demo

Under discussion in Phase-A between JPL, ESA and DLR: Accommodation of a (Tech Demo) MicroSTAR ACC (further development of SuperSTAR, foreseen on P2) on GRACE-I

- To be considered are e.g. mechanical, thermal, EMC, interface, envelope, AOCS, performance issues and impact that such implementation would have on GRACE-I satellite level
- In the frame of Phase A Airbus will assess the thermal stability that can be achieved on the Airbus proposed accommodation location (based on GRACE-FO flight data)

MicroSTAR electronics schematics

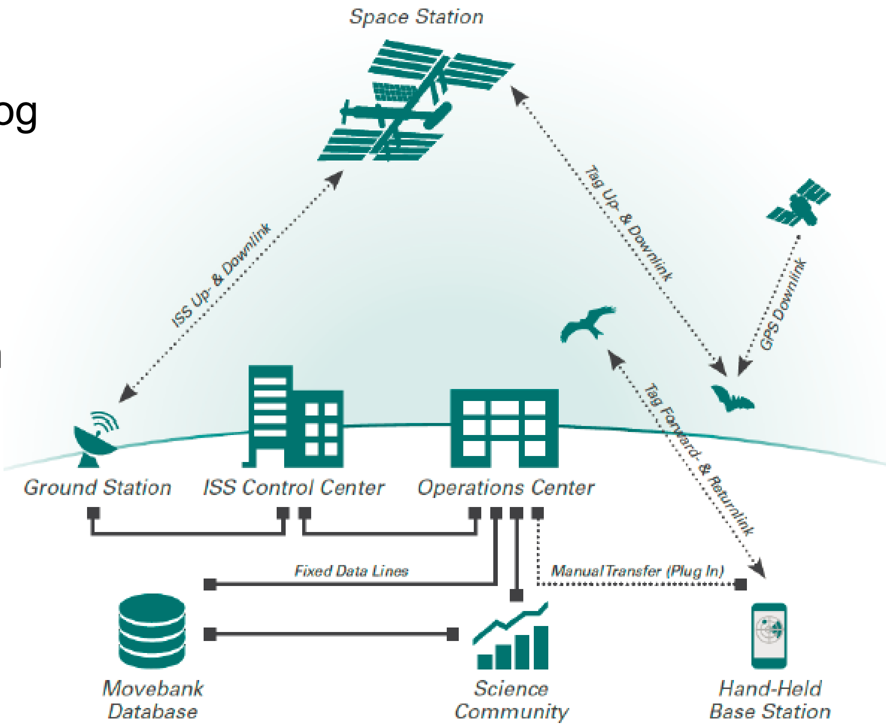


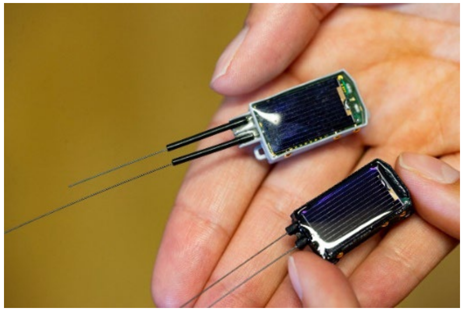


Christophe et al., ONERA accelerometers for future gravity missions, online poster, EGU2020

ICARUS on ISS

- Demonstrator mission for a system to track small animals / objects from space
- Animals / objects are equipped with tags, which log position and other data
- Tags transmit logged data to a space payload installed on Russian segment on ISS
- Data are communicated to ISS Control Center on ground and distributed to users
- Users may also send commands to tags vis ISS

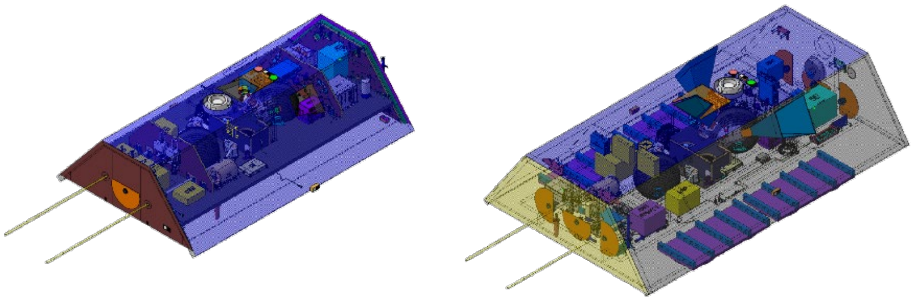




ICARUS on GRACE-I (Phase 0 Option 3)

- **Objective**: First time parallel operational monitoring of the global water cycle and animal tracks leading the way to simultaneous monitoring of linked variables in the Earth System.

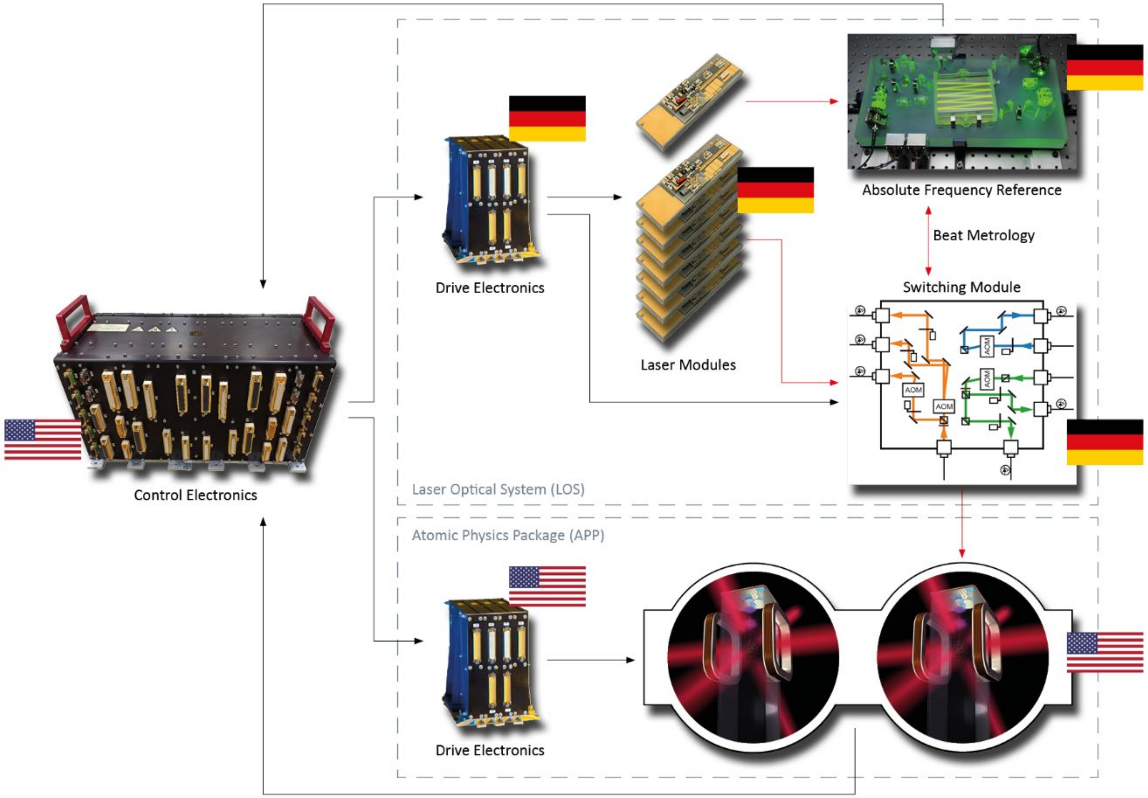
- Implementation will affect satellite size, mass and power consumption
- No disturbance of gravity mission guaranteed:
  - No moving parts
  - ICARUS H/W on both S/C in same operational modus -> minimize thermal imbalance
- Changes wrt ISS needed, e.g.:
  - Various ICU adaptions (housing design, replacement of commercial parts by higher performance level parts)
  - Implementation of redundancy
  - RX & TX antenna design adaptions



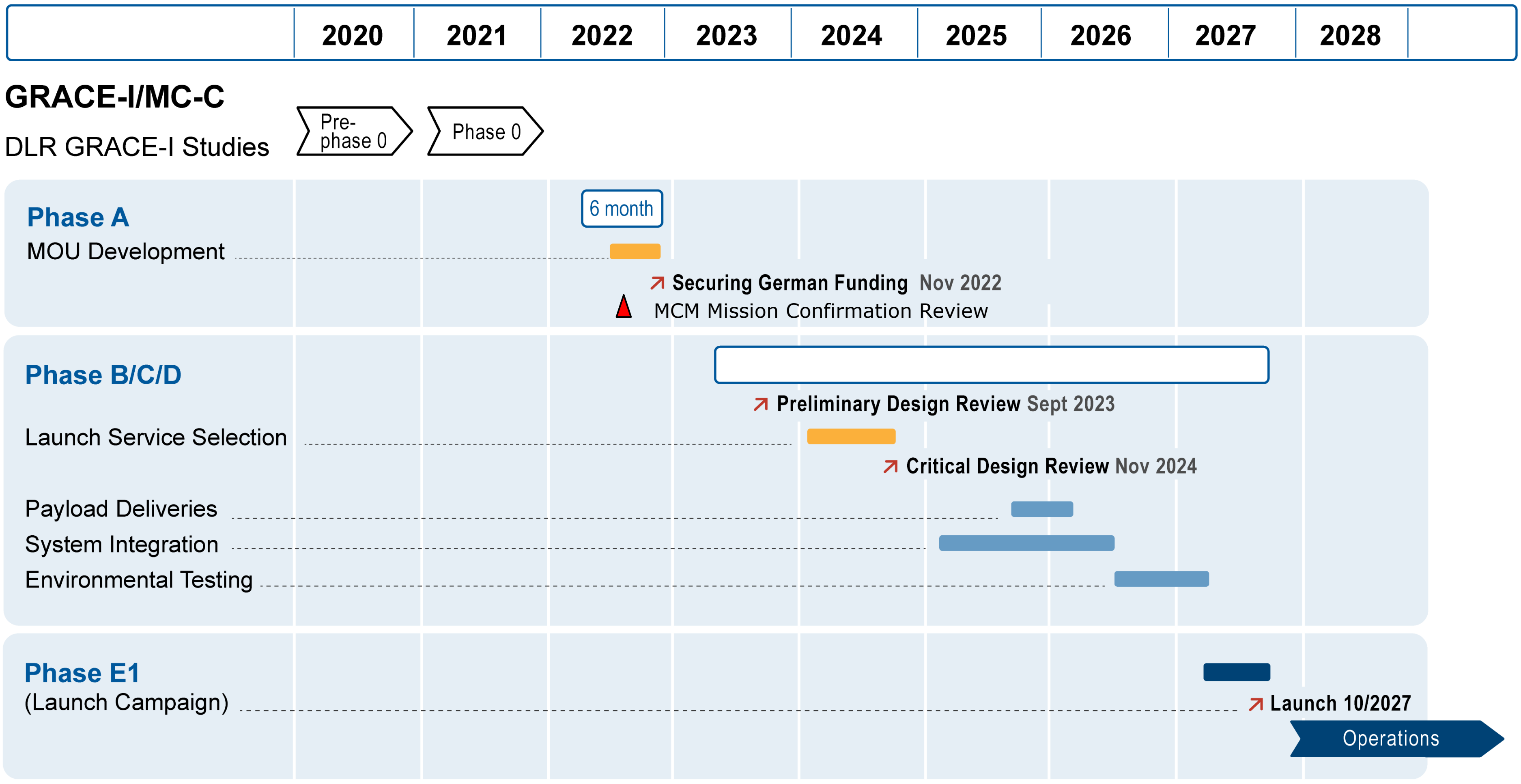
	Option 1 (Grace-FO heritage)	Option 3 Add ICARUS instrument
Instruments	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver no additional payloads	Redundant LRI 3 ACC (SuperSTAR) GNSS Receiver ICARUS
Power	Power Capability 349W	Power Capability 539W
Structure	LxWxH: 3.1 x 1.9 x 0.8 m Mass: ~630kg	LxWxH: 3.7 x 2.4 x 0.9 m Mass: ~830kg

Quantum Gravity Gradiometer (Phase 0 Option 5)

- QGG Tech Demo would be the first Quantum Gravity Gradiometer in space (similar to LRI idea on GFO)
- Responsibilities shared between Germany and US:
  - DE: Laser Optical System
  - US: Atomics Physical Package & Control Electronics
- System level impact of QGG implementation under assessment



GRACE-I Schedule (to be consolidated in Phase A)



Summary

- GRACE-I (MC) mission shall be realized jointly between Germany and JPL/NASA to guarantee mass transport data continuity
- Based on LRI and 3 GRACE-FO-type ACC as well as improved propulsion system
- German contributions similar to GRACE-FO: optical components LRI, launcher, mission operations, SDS contribution; satellites shall be build again by Airbus (subcontract from JPL)
- Launch in fall 2027, lifetime 5 years, consumables for 7 years (till 2034)
- GRACE-I could be P1 of a staggered P1/P2 Bender constellation
- Optional ICARUS payload would realize first time operational biodiversity monitoring in parallel to variations in the global water cycle
- Implementation of a Tech Demo MicroSTAR ACC (provided by ESA) will be further analysed in Phase A
- Implementation of a Tech Demo QGG under assessment
- German funding shall be secured till November 2022

Projects on which this publication is based were carried out on behalf of the Federal Ministry of Economic Affairs and Energy (FKZ: 50EE2004; 50EE2019) and Federal Ministry of Education and Research (FKZ: 03G0920A)