GRACE-FO Laser Ranging Instrument: German contribution

J. Sanjuan on behalf of the LRI team

Deutsches Zentrum für Luft- und Raumfahrt (DLR)

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GRACE (Gravity Recovery And Climate Experiment)

- Joint US/German mission (launched March 2002)
- Maps the Earth's gravity field variations (glacials, deformation, hydrology, etc.)
- 2 SC separated by 220 km in a near polar orbit (500 km)
- Two-way microwave-ranging link
- End of mission: expected 2015-2016

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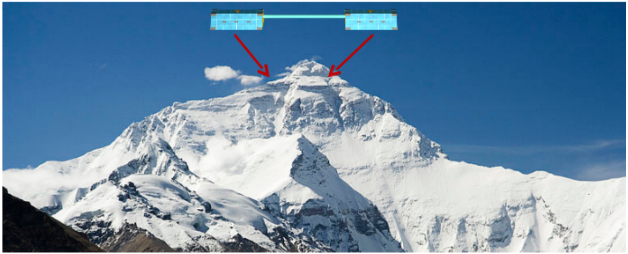

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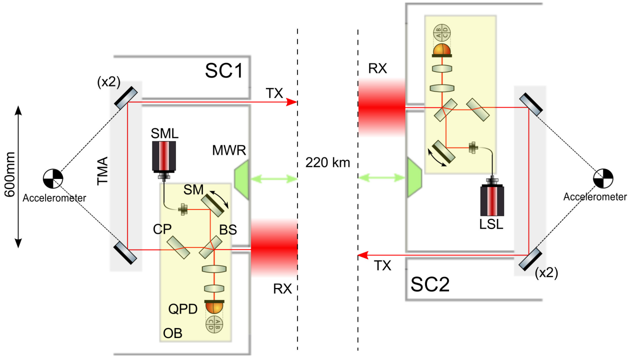
GRACE-Follow On

- To minimize data gap between GRACE and next generation gravity field missions: near rebuild of GRACE
- Launch: August 2017
- **Add-on: Laser Ranging Instrument (LRI) as a technology demonstrator**
    - First inter-satellite laser interferometer

Race-track configuration



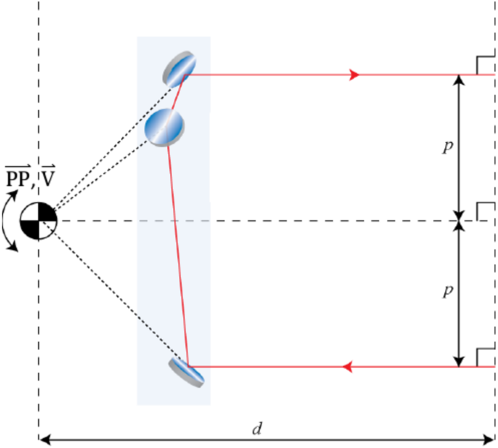
- Heterodyne interferometry: 4 MHz-16 MHz
- “Slave” SC offset phase locked (active transponder)

LRI subsystems and team roles

- Germany (AEI/GFZ/STI/DLR/Astrium)
  - Triple mirror assembly (TMA)
  - Optical bench assembly (OBA)
- US (JPL/Ball Aerospace/Tesat GmbH)
  - Frequency stabilization system
  - Phasemeter and payload processing electronics
  - Laser source
- Australia (ANU/EOS/CSIRO)
  - Triple mirror prototyping
  - Acquisition experiments

TMA: large-lateral offset retroreflector

- 3 orthogonal mirrors
- $2p$=600 mm
- Routes the beam around cold gas tank and MWR
- Places the vertex at the accelerometer
- Rotation (SC jitter) around virtual vertex maintains:
  - Round-trip pathlength
  - Anti-parallel beams

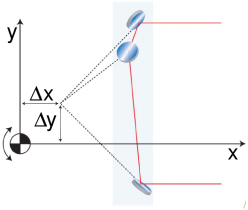


TMA

- Requirements

$$\begin{aligned}\delta x(f) &\lesssim 50 \times \mathrm{NSF}(f)\,\mathrm{nm\,Hz}^{-1/2}\\ k_{\mathrm{roll}} &\lesssim 10\,\mu\mathrm{m\,rad}^{-1}\\ k_{\mathrm{pitch,yaw}} &\lesssim 100\,\mu\mathrm{mrad}^{-1}\end{aligned}$$

- TMA vertex/accelerometer must be within $\sim$100 μm

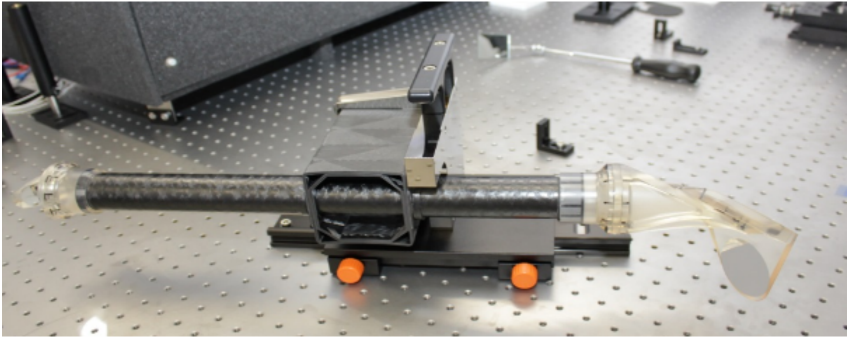


	Δx	Δy	Δz
θ_x	0	0	0
θ_y	$\Delta x\theta_y$	0	$-\Delta z$
θ_z	$\Delta x\theta_z$	Δy	0

- Roll jitter (θ_x) also couples for a non-ideal TMA: coalignment $\lesssim$40 μrad
- Thermal effects

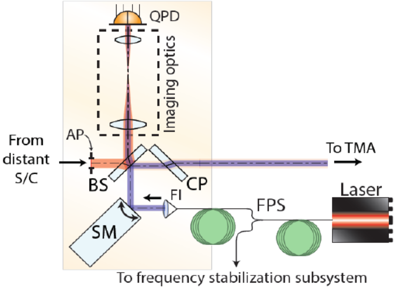
QM TMA

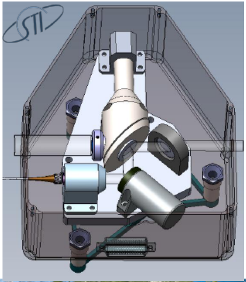
- TMA design by STI
- DM and QM tested for performance and environment



Optical bench assembly (OBA)

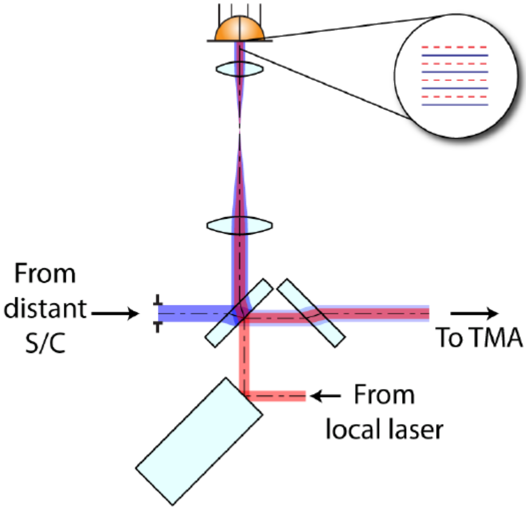
- Measures the phase difference between the LO and the far SC beam
- Measures the relative angle between the LO and the far SC beam (DWS)
- Steers the local beam to align it with the far SC beam
  - SC pointing not sufficient to keep lock
  - Control loop zeros DWS to keep beams aligned





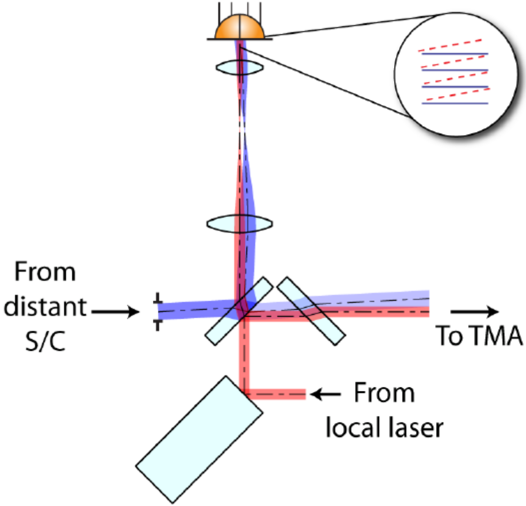
Pointing control

- Ideal position



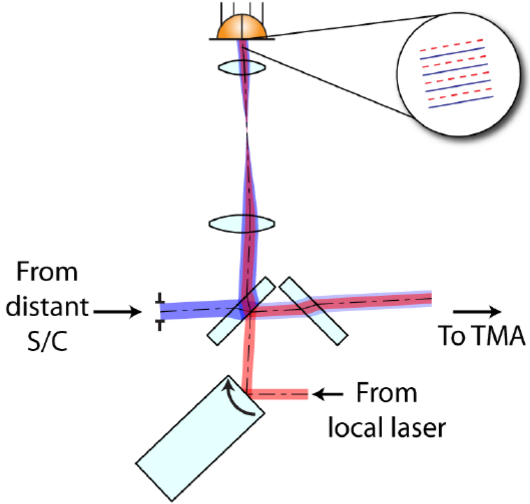
Pointing control

- SC rotates



Pointing control

- DWS-steering mirror correction



OBA components

- Quadrant photoreceiver
  - Type: InGaAs
  - Bandwidth: 4 MHz-16 MHz
  - Noise: 5 pA $Hz^{-1/2}$
  - Size: 1 mm diameter
- Fast steering mirror
  - Voice coil motors and position measurement (Kaman)
  - Dynamic range: $\pm$8.1 mrad
  - $\pm$3 mrad at 150 Hz ($\simeq$2 rad s^{-1})
- Fiber injector assembly
  - Quartz block-aspheric lens
  - Beam radius: 2.5 mm
  - Collimated beam planarity $\leq \lambda/15$
- Imaging optics
- Compensation plate

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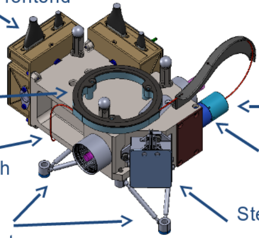
OBA components

Photoreceiver Frontend



Fiber coil

Titanium Bench

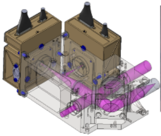
Iso-static mounts

Optical fiber

Fiber Injector

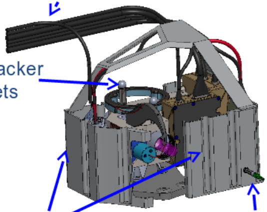
Steering Mirror

Photoreceiver Frontend



Harness Support

Laser Tracker Targets

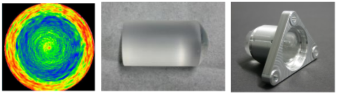


Thermal shields

Fiber connector

Beamsplitter

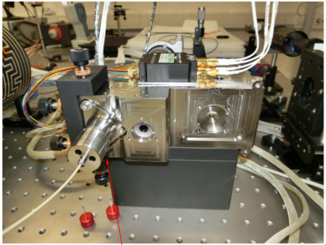
Fiber Injector Assembly

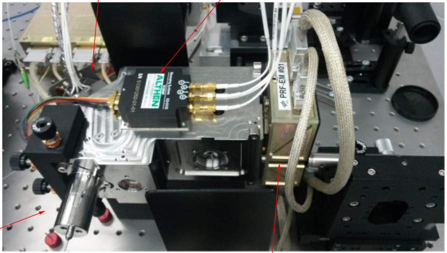


OBA

Fast steering mirror

Position sensor system



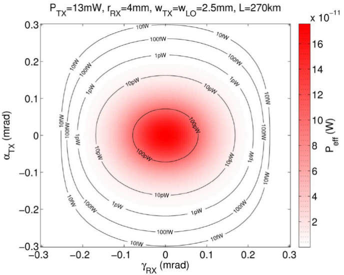


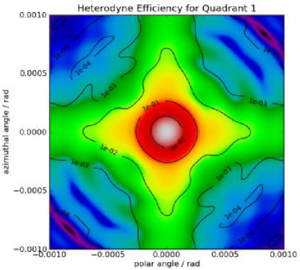
Fiber injector assembly

Photoreceiver front–end

Acquisition strategy

- 5 DoF (2 angles on each SC plus laser frequency)
- No real time communication between SC
- Needed:
  - Small beam divergence angle ($\pm 200\,\mu$rad)
  - Small frequency range (12 MHz)
- Starting point:
  - Large initial pointing uncertainty (± 3 mrad)
  - Large initial frequency offset uncertainty (400 MHz)





Acquisition procedure

- Scan over the complete uncertainty space: 9 hours
- Send data to ground
- Search for the maximum detector output
- Estimate the line of sight and frequency
  - Only once the unknown pointing biases needs to be determined, which are caused by integration tolerances, launch vibrations, g-release, etc.
- Update information to SC
- Re-acquisition algorithm (reduced parameter space): $<$1 minute
- Enable DWS

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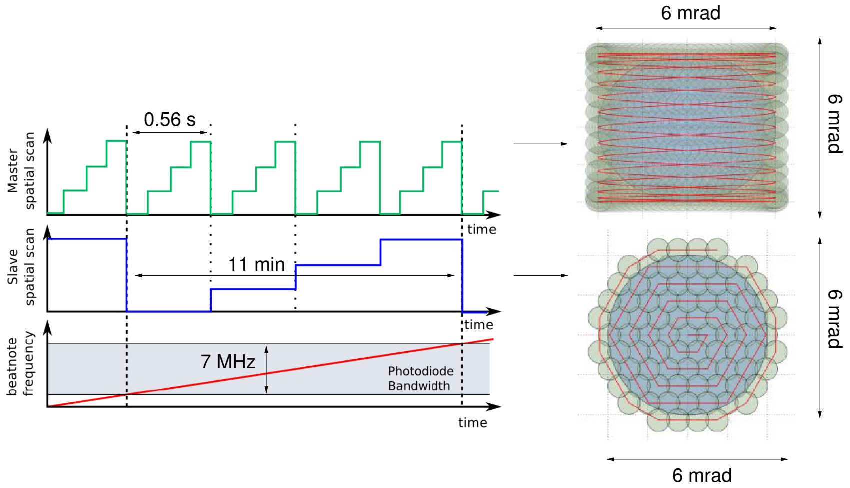
Acquisition procedure



Summary

- GRACE-FO will be the first inter-satellite laser interferometer
- Expected to generate better data than MWR
- Expected to provide valuable information for LISA
- German subsystems at CDR level:
  - TMA: CDR passed on March 2014 (FMs will be ready by the end of 2014)
  - OBA: CDR currently taking place (May 2014)
- Exhaustive analysis, simulations and experiments have validated the acquisition algorithms

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