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Höchstauflösende Optische Metrologie

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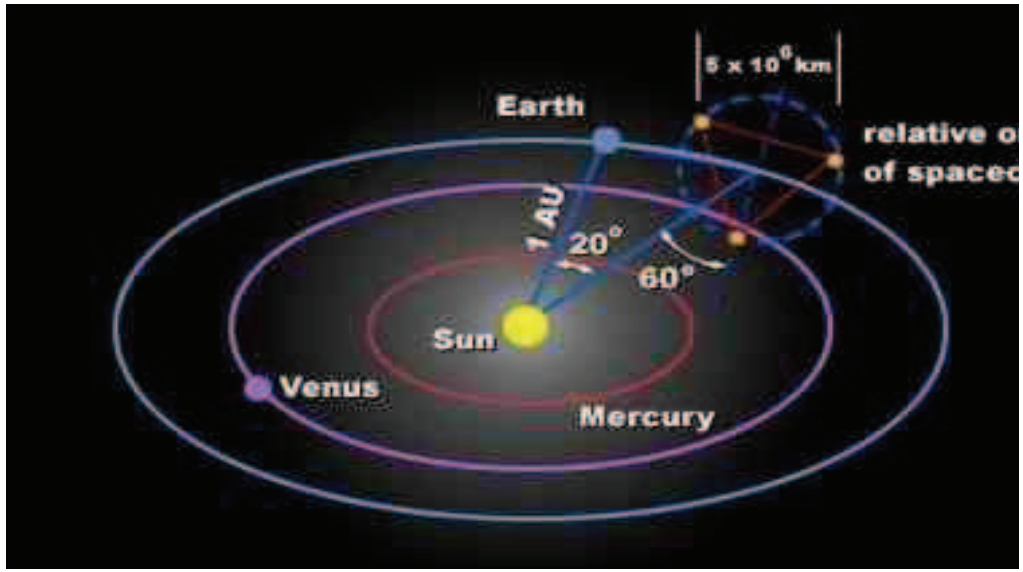
Outline

- Motivation: LISA, GRACE-FO…
- Measurement Principle and Dilatometry
- Optical Setup
  - Heterodyne Interferometer
  - Cavity-stabilized laser
  - Iodine-stabilized laser
- Mechanical Setup
- Measurements
  - Zerodur
  - Clearceram
- Summary
- Outlook

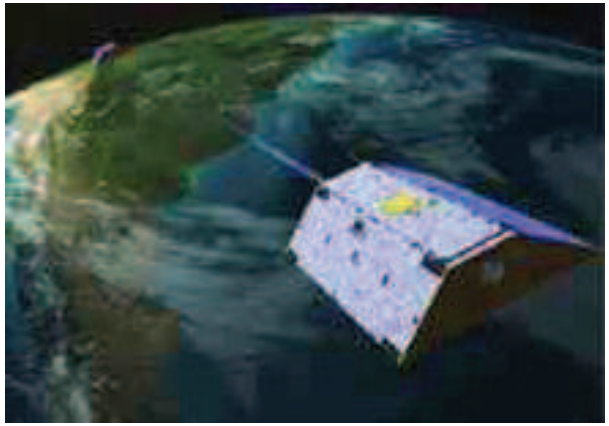
Motivation LISA

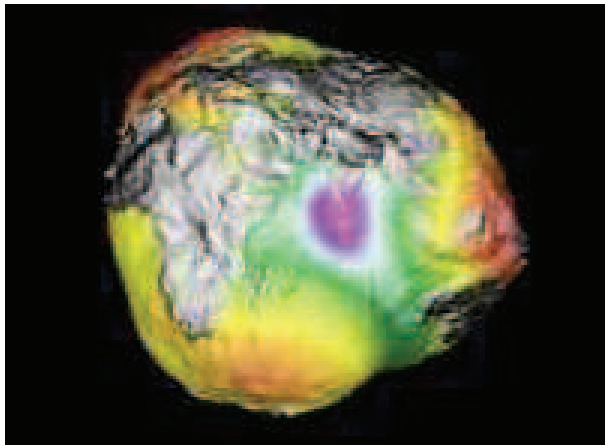
- Laser Interferometer Space Antenna
- Weltraum-gebundener Gravitationswellendetektor im Frequenzbereich zwischen 30 µHz und 1 Hz
- Start vorgesehen für 2020
- 3 Satelliten bilden ein Interferometer mit einer Armlänge von etwa 5 mio km
- Endspiegel des Interferometers sind durch frei-fliegende Testmassen realisiert



Motivation GRACE-FO

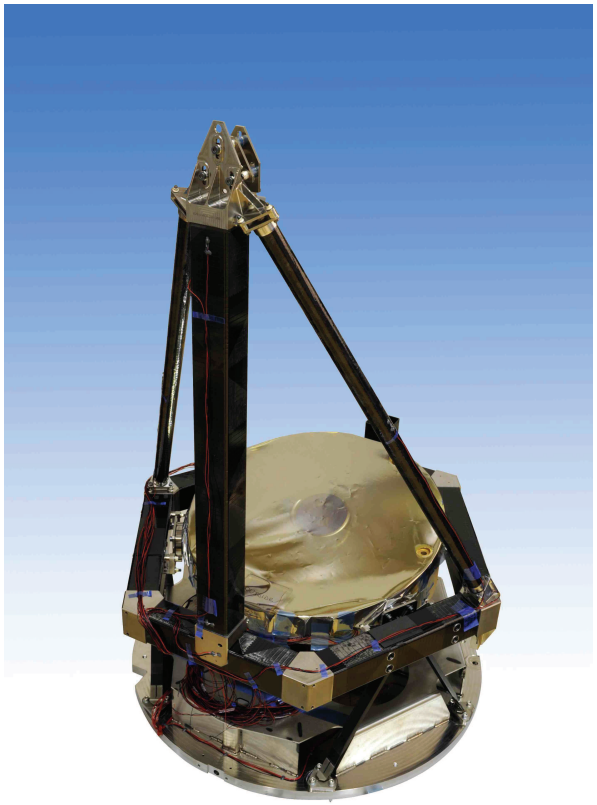
- Gravity Recovery and Climate Experiment - Follow-on
- Extremely high precision gravity measurements
- Construction of gravity field models
- GRACE consists of two satellites (A, B) serving one mission
- 200km distance between the Satellites
- Sub-nm measurement accuracy

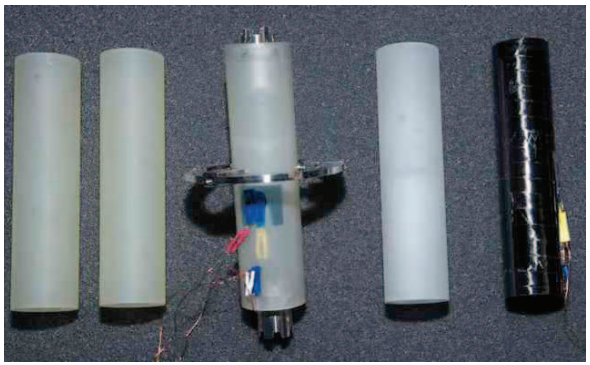




Motivation

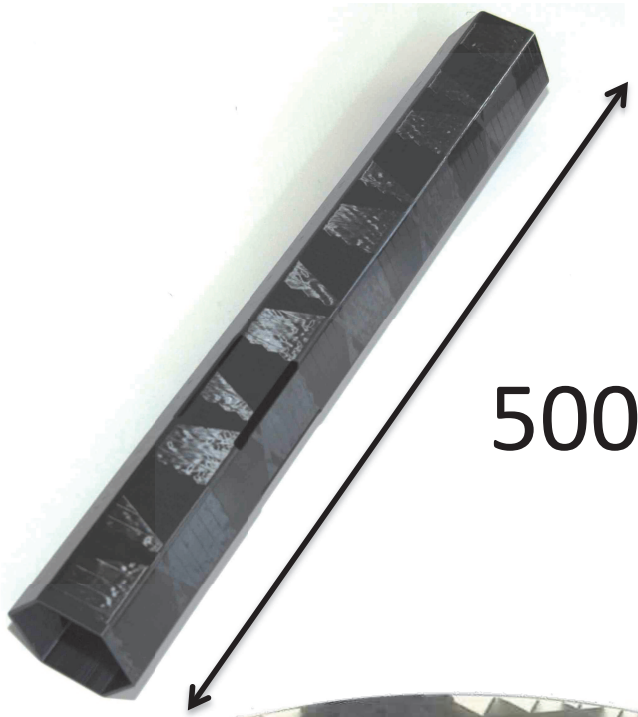
- Highly temperature stable structural materials are needed for space missions such as
  - NGO/LISA,
  - GRACE-FO,
  - …
- Up to pm path length stability
- Materials:
  - Zerodur
  - ULE
  - Clearceram
  - CFRP

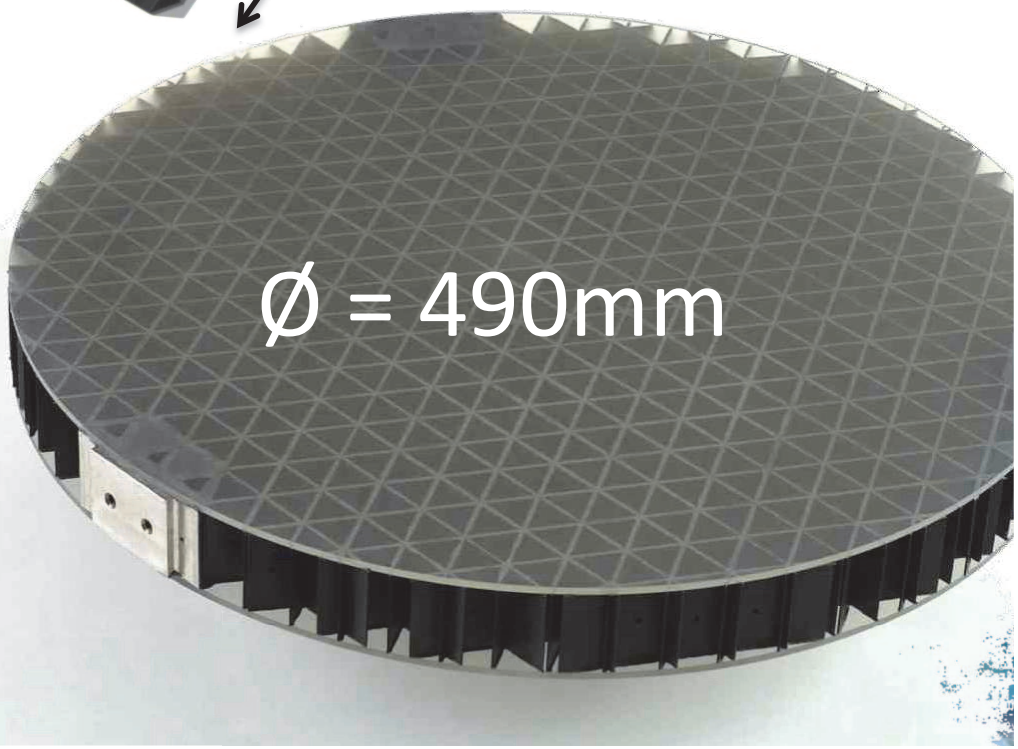




Motivation

- Lightweight and stable structures
- Highly stable CFRP triple mirror assembly for GRACE-FO laser ranging (nm dimensional stability)
- Zerodur-CFRP-sandwich breadboard for e.g. LISA (sub-nm dimensional stability)

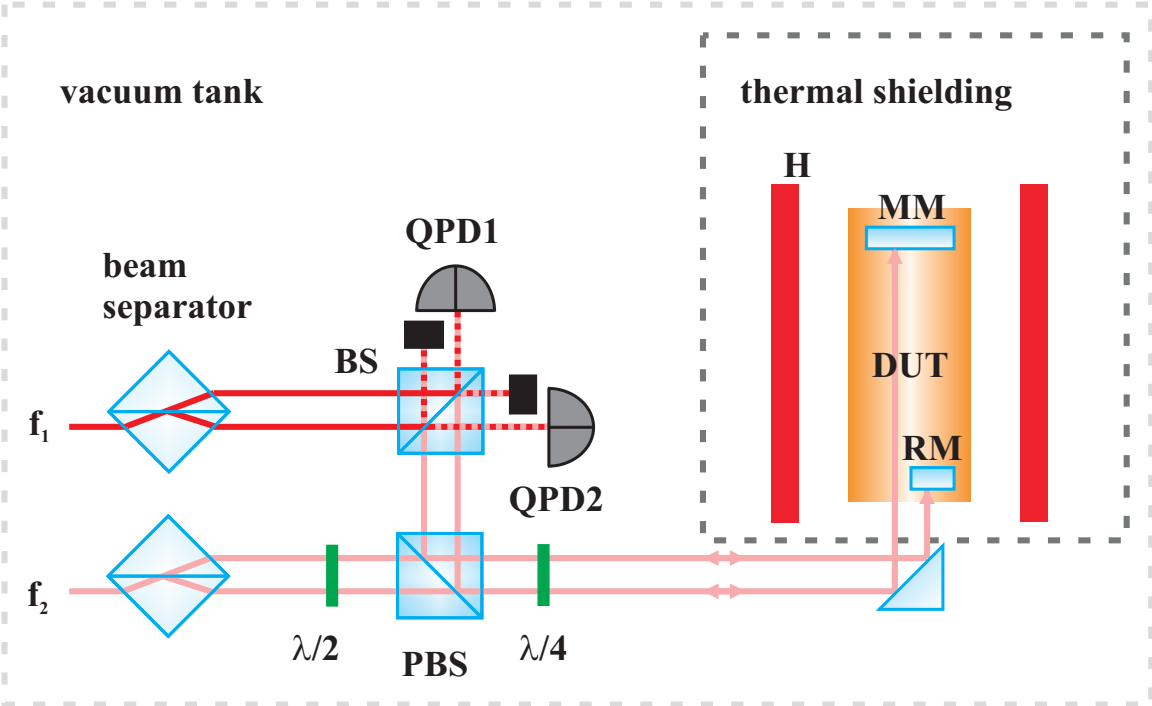




Measurement Principle

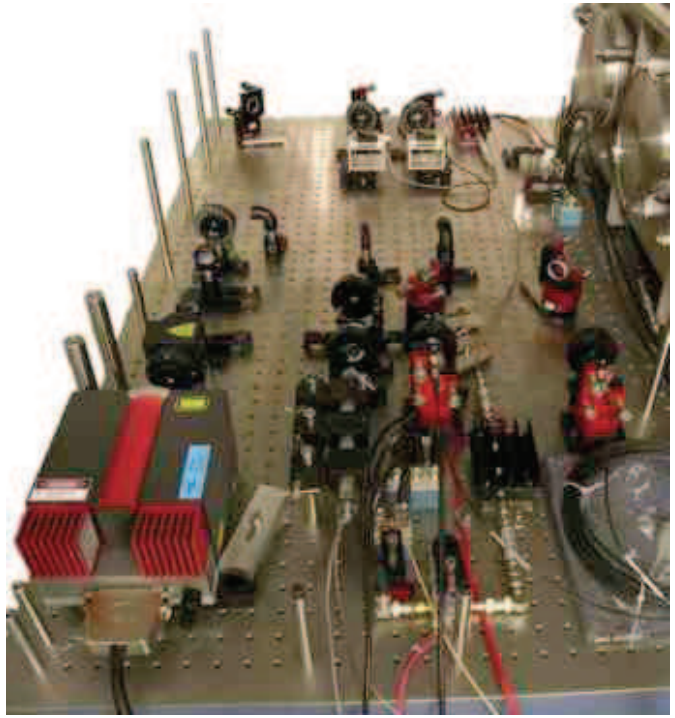
- The device under test (DUT) is a cylindrical tube
- Reference mirror (RM) and measurement mirror (MM) clamped in the DUT
- Pt100 sensors are glued to the sample

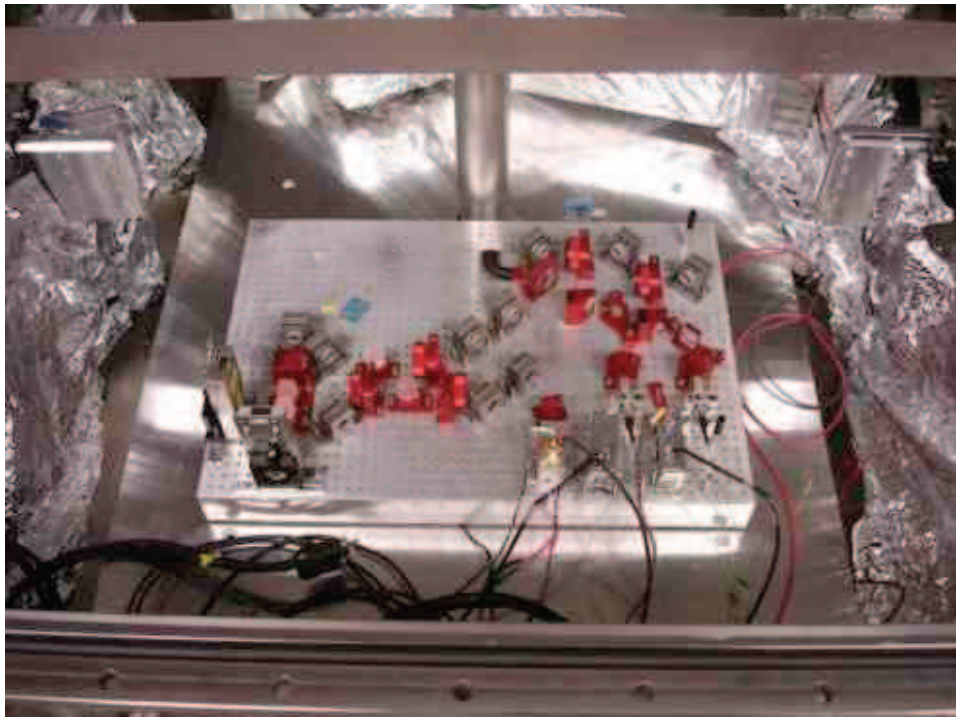
$$\mathrm{CTE}_{\mathrm{linear}} = \Delta L * \frac{1}{\Delta T} * \frac{1}{L}$$



Optical Setup – Heterodyne Interferometer

- Differential wavefront sensing (DWS) enables tip- and tilt-measurement simultaneous to translation measurement
- Demonstrated sensitivity
  - pm at translation measurement
  - nrad at tip- and tilt measurement

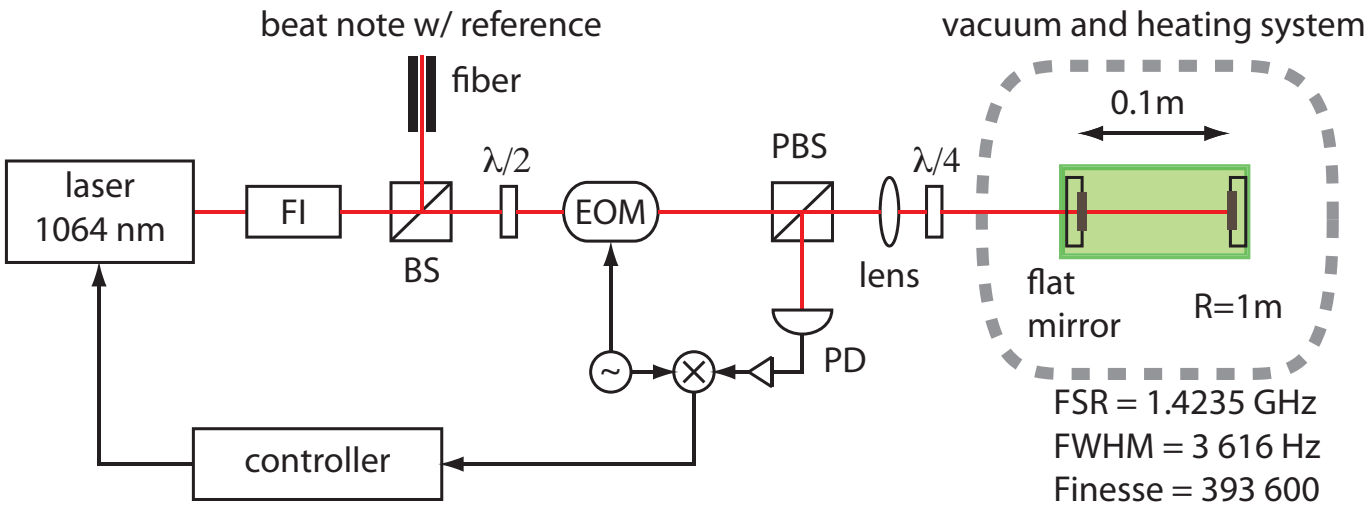




Optical Setup – Reference Cavity

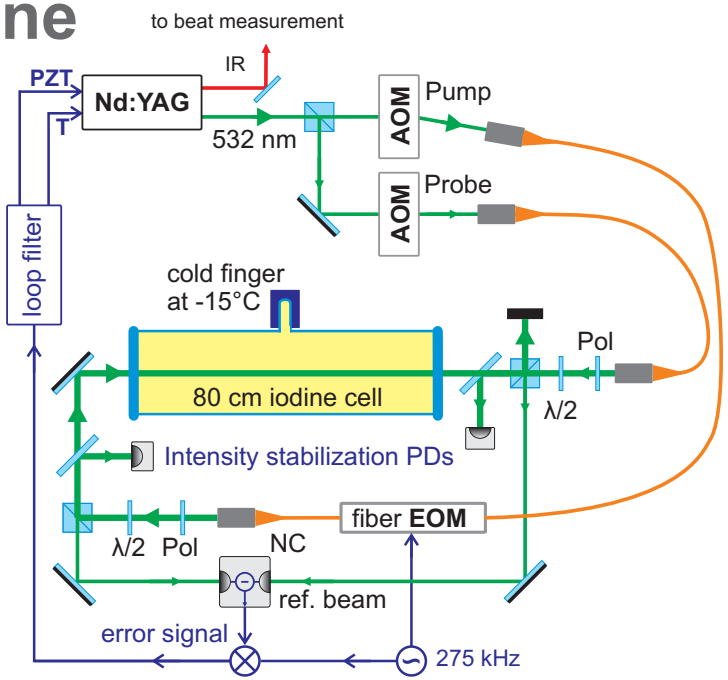
- Cavity-stabilized laser as reference (PDH)
- The unequal armelengths of the Interferometer causes the most dominant noise source
- Frequency noise of the dilatometer laser is measured in the beat-signal and subtracted in post-processing
- The frequency noise can be converted to a translation noise:

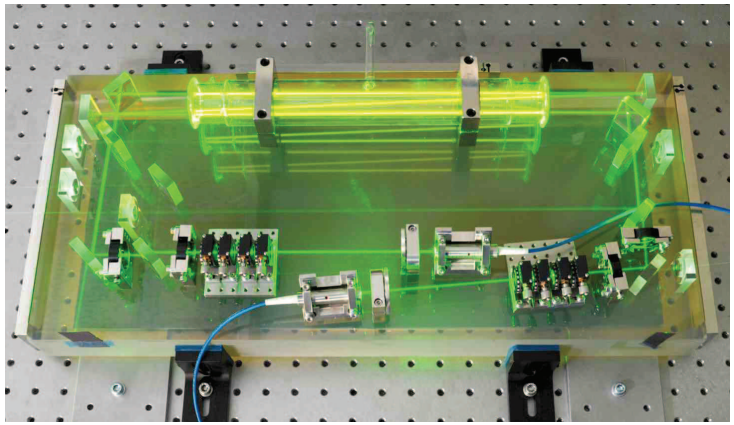
$$\Delta L = \frac{\lambda}{c} * z * \Delta f \qquad \text{-> 0.355 nm/MHz}$$



Optical Setup – Reference Iodine

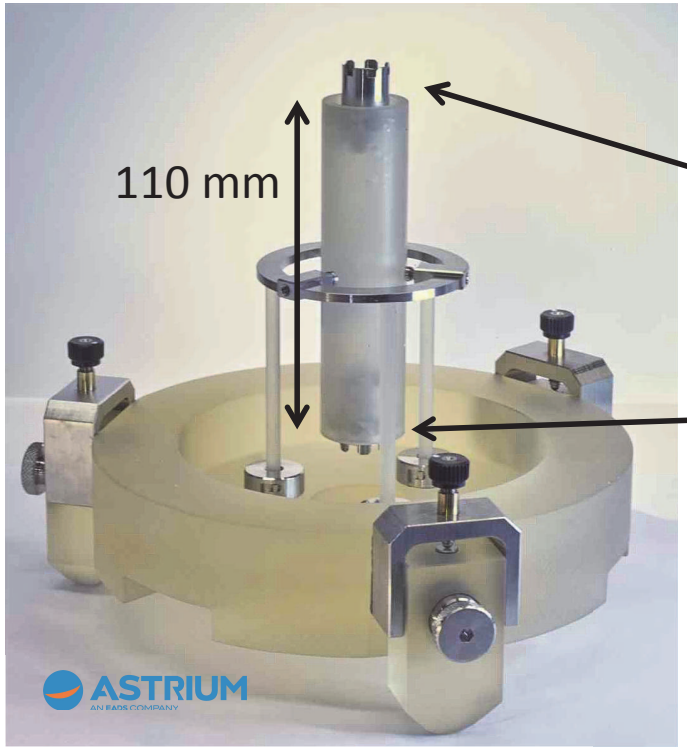
- NPRO-type Nd:YAG laser @ 1064nm
  → intrinsically high intensity and frequency stability
  → frequency-doubled to 532nm
- hyperfine transition in molecular iodine taken as reference (a10 component of R(56)32-0 near 532nm)
  → strong absorption
  → small natural linewidth (380kHz)
- frequency stability of 10^{-15} @ h
- 1s in 30 Mio a
- AI technologie for Space developed

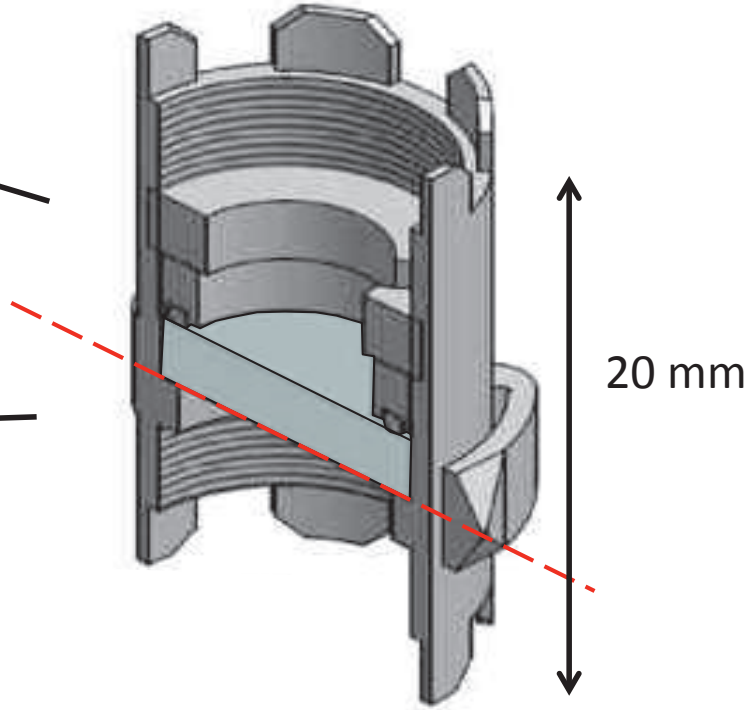




Mechanical Setup I

- DUT support made out of Zerodur minimizes the tilt of the sample tube
- Mirror mounts made out of Invar36 with thermally neutral plane at the reflective surface

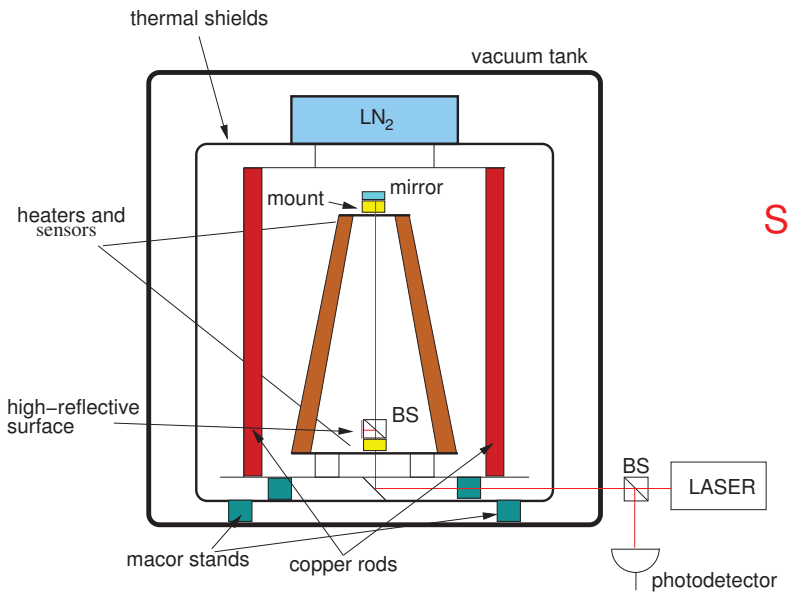


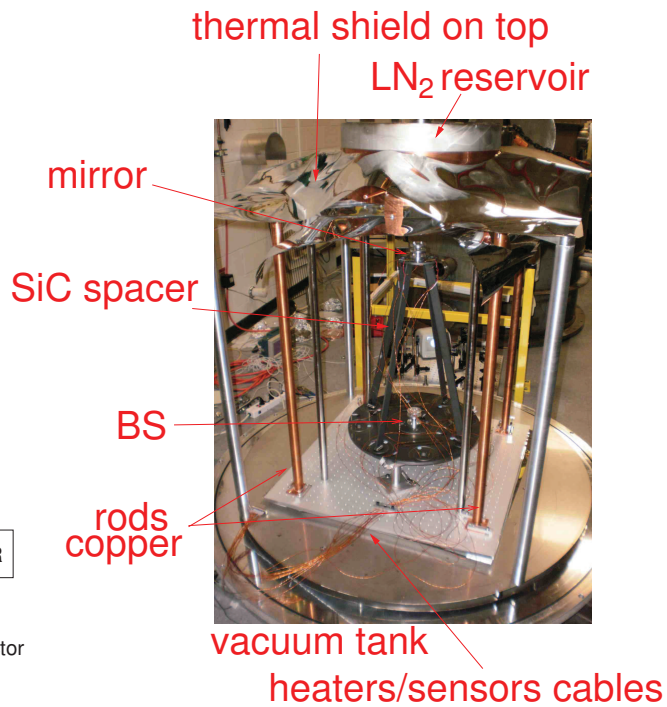


Mechanical Setup II

Tests bei Betriebstemperatur von −70°C :

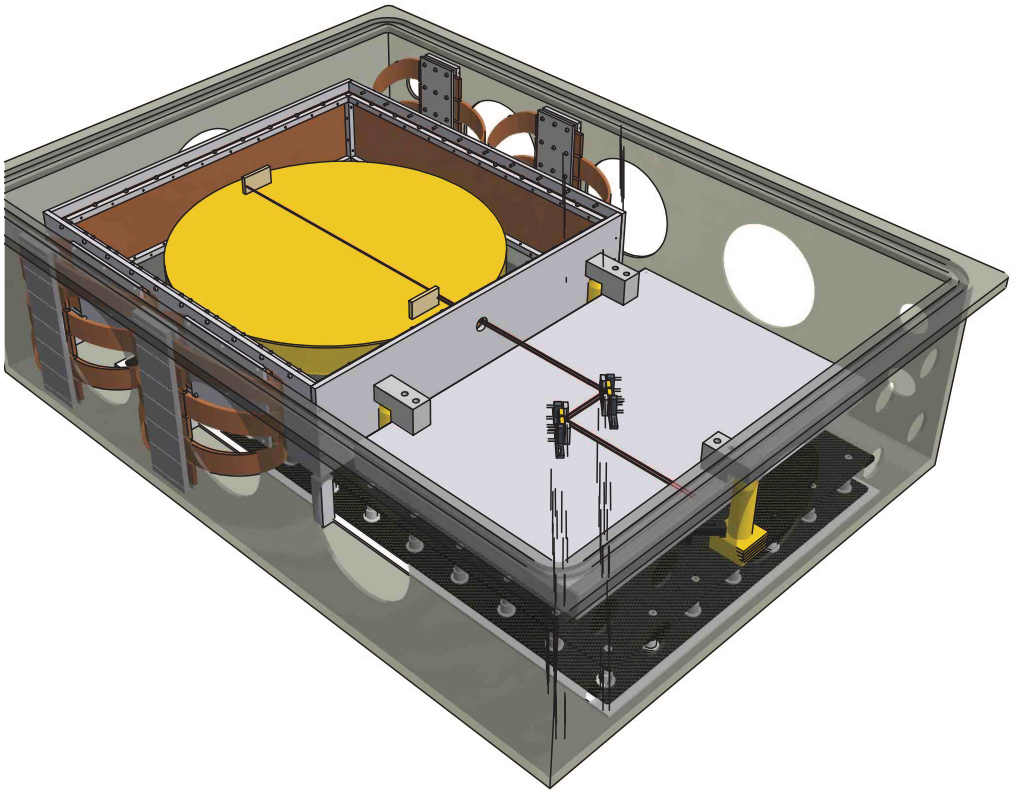
- LN2 Reservoir eingebaut im Vakuum Tank
- Heizelemente und Temperatursensoren für die Regelung der Temperatur im Vakuumtank
- Schwingungsisolierung im Tank zur Verringerung der Vibrationen im Teleskop

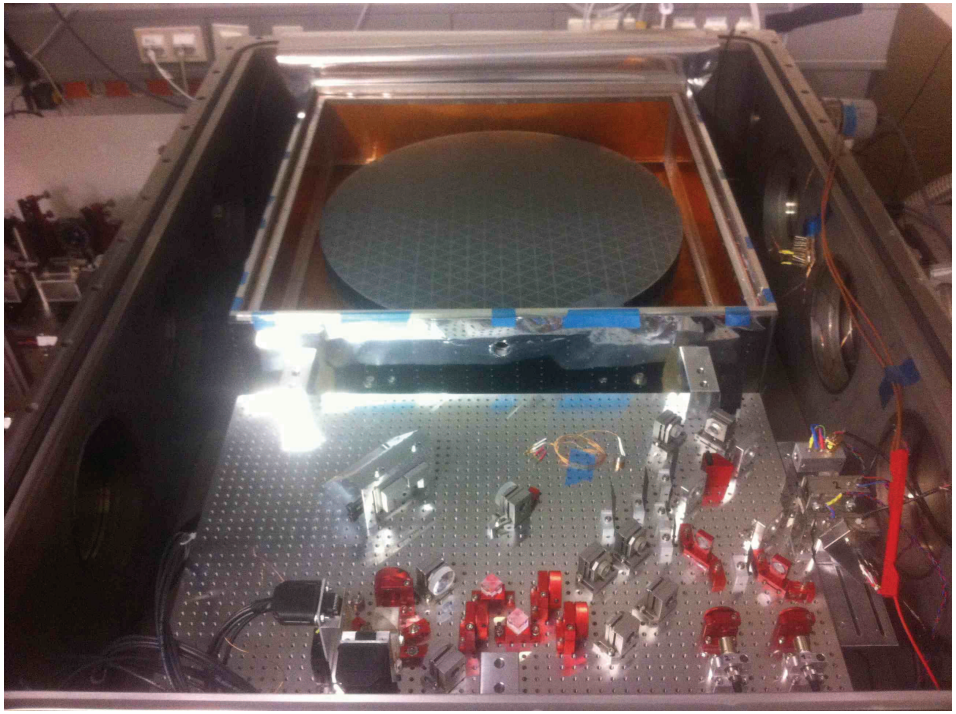




Measurement Setup III

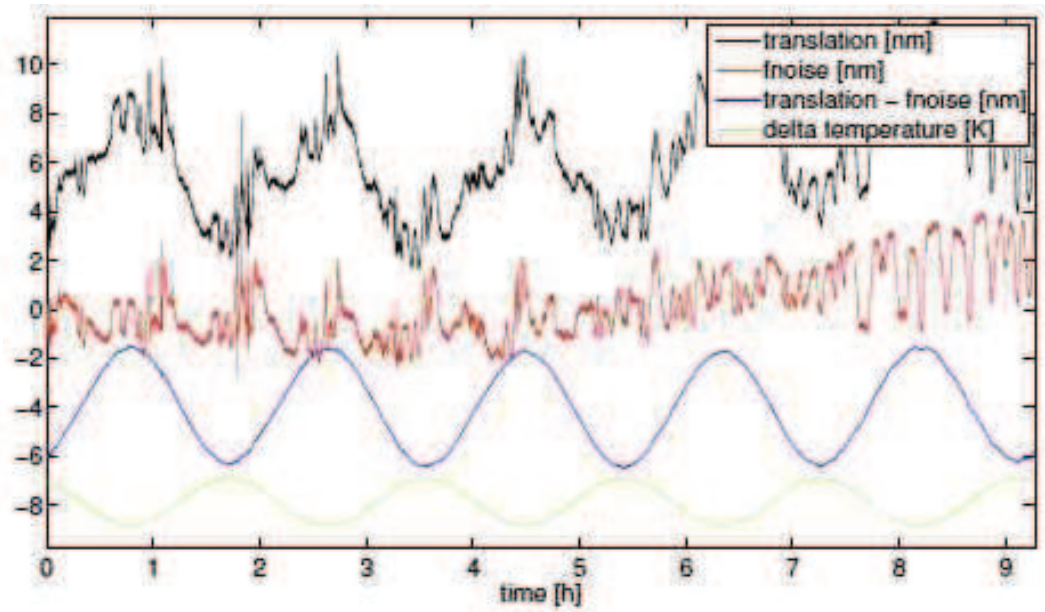
- Measuring the stability of respective structures of GRACE-FO or LISA (NGO)





Measurements: Zerodur Tube

- Measurement of a Zerodur sample
- Converted laser frequency noise used for correction of the translation measurement
- Small temperature variations applied



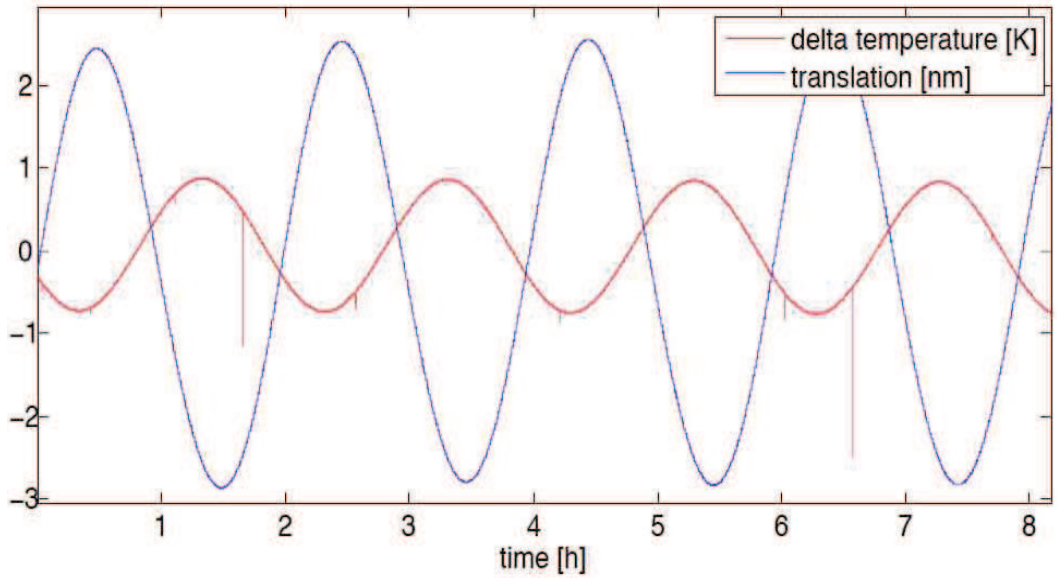
→ T= (30 ± 1.34)°C

→ Measured CTE: $-1.75 \cdot 10^{-8}\ K^{-1}$

→ CTE by SCHOTT: $0 \pm 3 \cdot 10^{-8}\ K^{-1}$

Measurements: Clearceram Tube

- Measurement of a Clearceram sample
- Translation measurement performed with frequency stabilized laser
- Very small temperature variations applied



→ T= (29 ± 0.8)°C

→ Measured CTE: $-3.205 \cdot 10^{-8}\ K^{-1} \pm 0.0039 \cdot 10^{-8}\ K^{-1}$

→ CTE by OHARA: $0 \pm 2 \cdot 10^{-8}\ K^{-1}$

Summary

- Investigated Materials:

Material	Measured CTE [K^{-1}]	Expected CTE [K^{-1}]
CFRP	$(-3.1 \pm 0.1)\cdot 10^{-6}$	$2.5\cdot 10^{-6}$
CFRP (Meteosat 2nd Gen)	$(-0.519 \pm 0.024)\cdot 10^{-6}$	$-0.647\cdot 10^{-6}$
Zero-CTE CFRP	$(-0.335 \pm 0.004)\cdot 10^{-6}$	$\sim 10^{-8}$
C-SiC (BepiColombo)	$-0.05\cdot 10^{-6}$	-
CFRP	$(-0.2 \pm 0.02)\cdot 10^{-6}$	-
Zerodur	$-1.75\cdot 10^{-8}$	$0\pm 3\cdot 10^{-8}$
Clearceram	$(-3.205 \pm 0.039)\cdot 10^{-8}$	$0\pm 2\cdot 10^{-8}$

Outlook

- New optical setup with at least the same sensitivity using multiple beam interferometry (Fabry-Perot) to compare the measurement principles
- Setup of a cryogenic (~150K) measurement facility for CTE tests at the specific operating temperature
- Compare our measurement facility with a calibrated facility
- Characterization of low-CTE materials like Zerodur, Clearceram, ULE, CFRP, C-SiC, C/C-SiC,...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für Höchstfrequenztechnik

Lieber Herbert...

Danke sehr für die wunderbare ZAFH-Zeit...!

In der Hoffnung es gibt neue Zusammenarbeit...

„Die Wissenschaft ist immer auf dem Wege und nie am Ziel...“
Pichler

ZAFH-Photon^{n}

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