

Teilprojekt 2.1: Miniatur Lasersensor

Claus Braxmaier^{1,3}

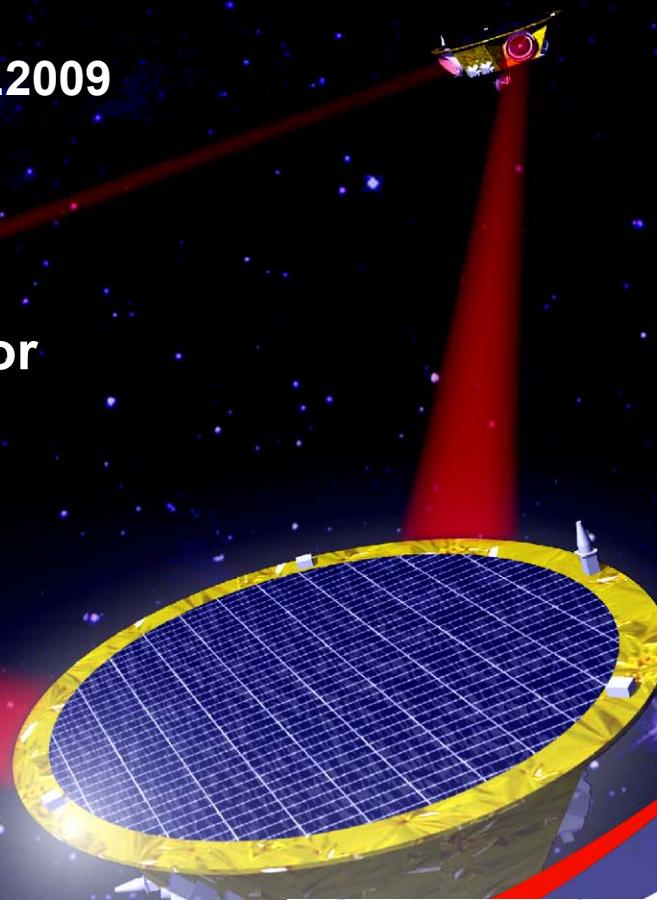
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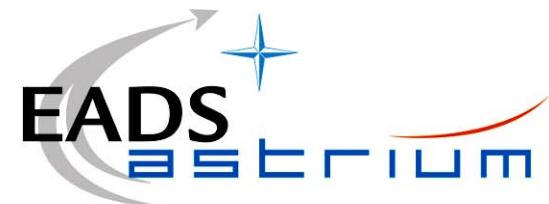


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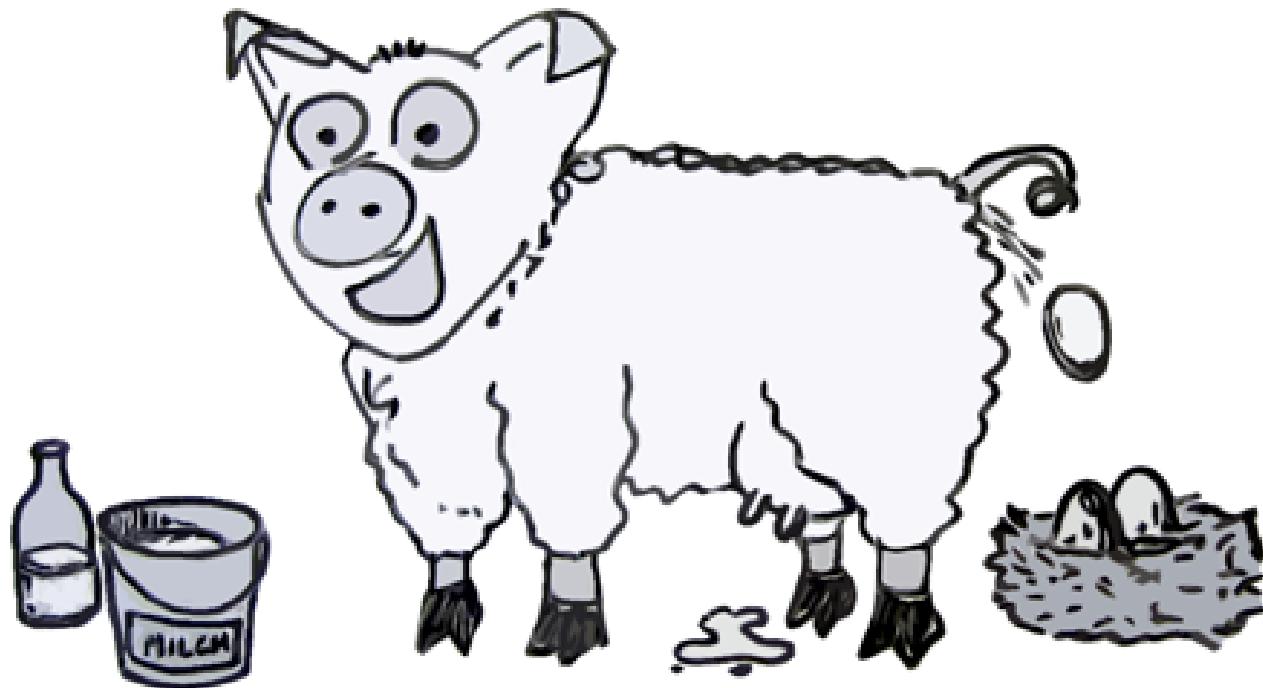


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UNIVERSITY OF APPLIED SCIENCES

- Motivation
 - LISA: Interferometrie
 - Aktoren zur Verifikation und Strahlstellung
 - Anwendungen
- Interferometrie
 - Aufbau- & Verbindungstechnologie
 - Neuer Aufbau
- Aktoren – Design Status
- Anwendungen
 - Profilometrie...erste Schritte
 - Dilatometrie...erste Schritte

Motivation...

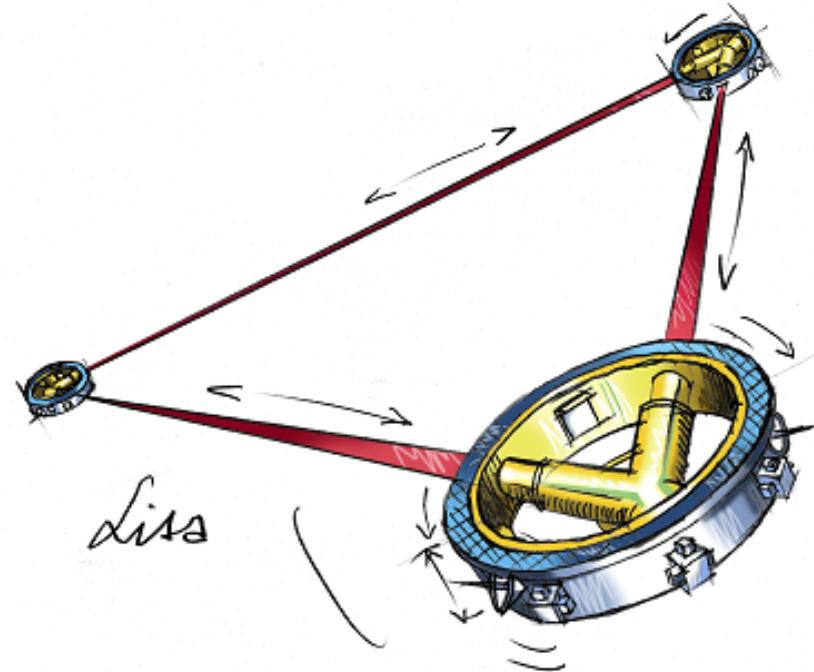
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WE



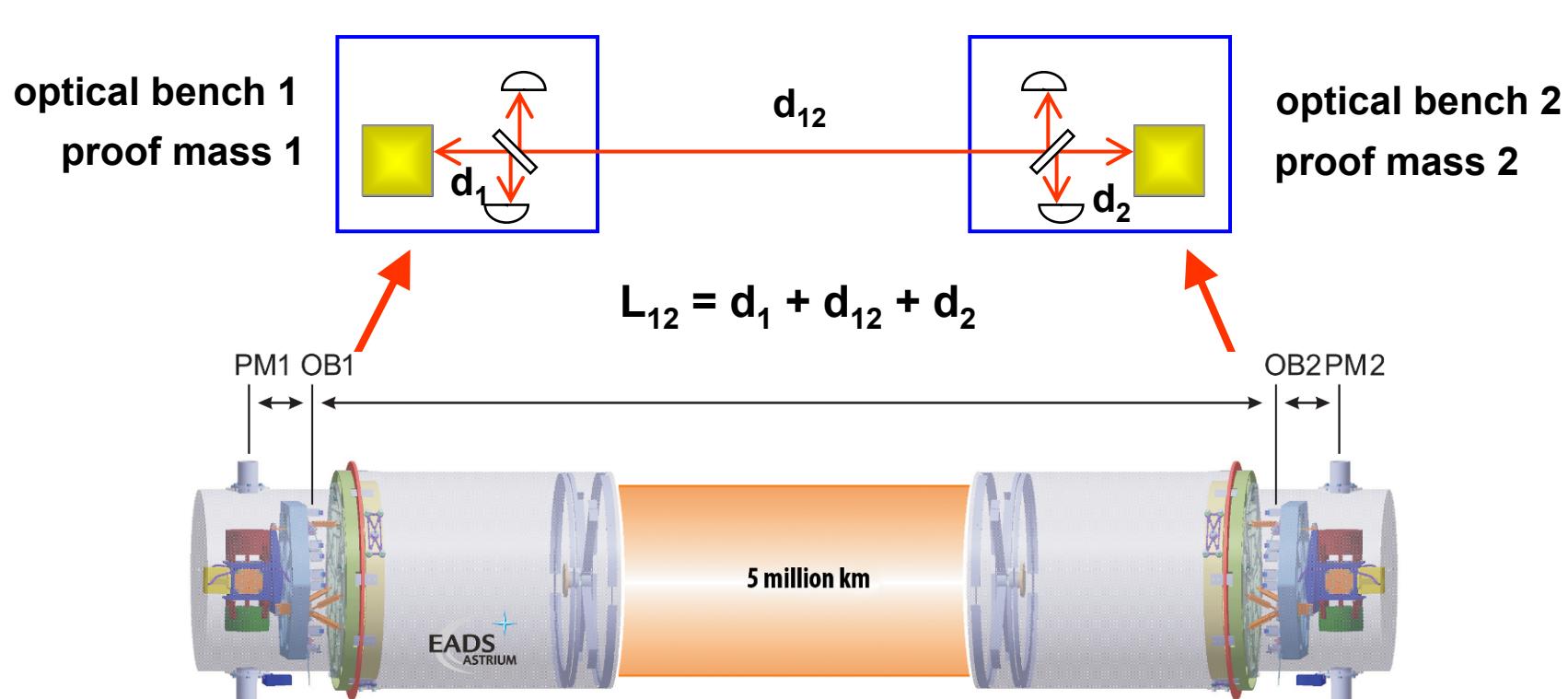
All the space you need

Laser Interferometer Space Antenna

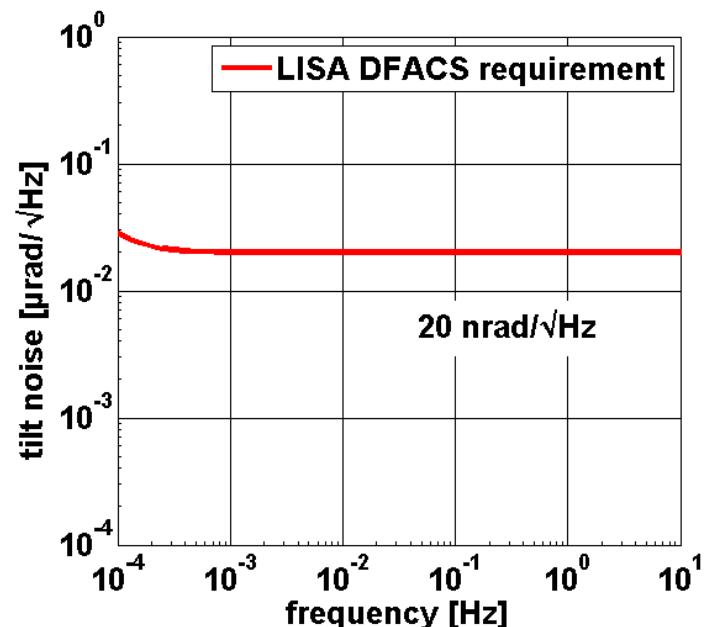
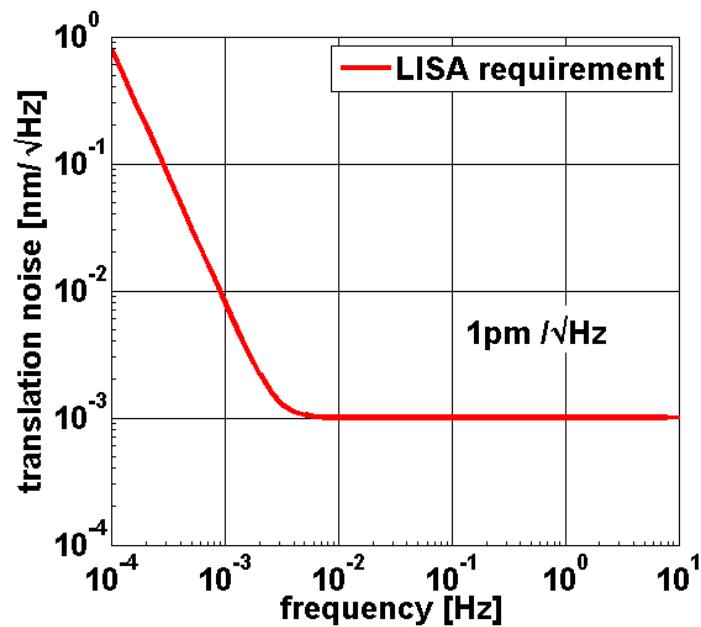
- cooperative ESA / NASA mission
- launch foreseen around 2018
- spaceborne gravitational wave detector
frequency range $30\mu\text{Hz}$ to 1Hz
- three spacecraft forming a interferometer with an armlength of ~ 5 million km
- end mirrors of the interferometer are represented by free floating prisms
- individual earth-trailing solar orbits of the three spacecrafts



- combined interferometers: PM1-OB1, OB1-OB2, OB2-PM2
- accuracy $12\text{pm} / \sqrt{\text{Hz}} (\approx 1/10 \varnothing_{\text{ATOM}})$



- measurement noise requirements

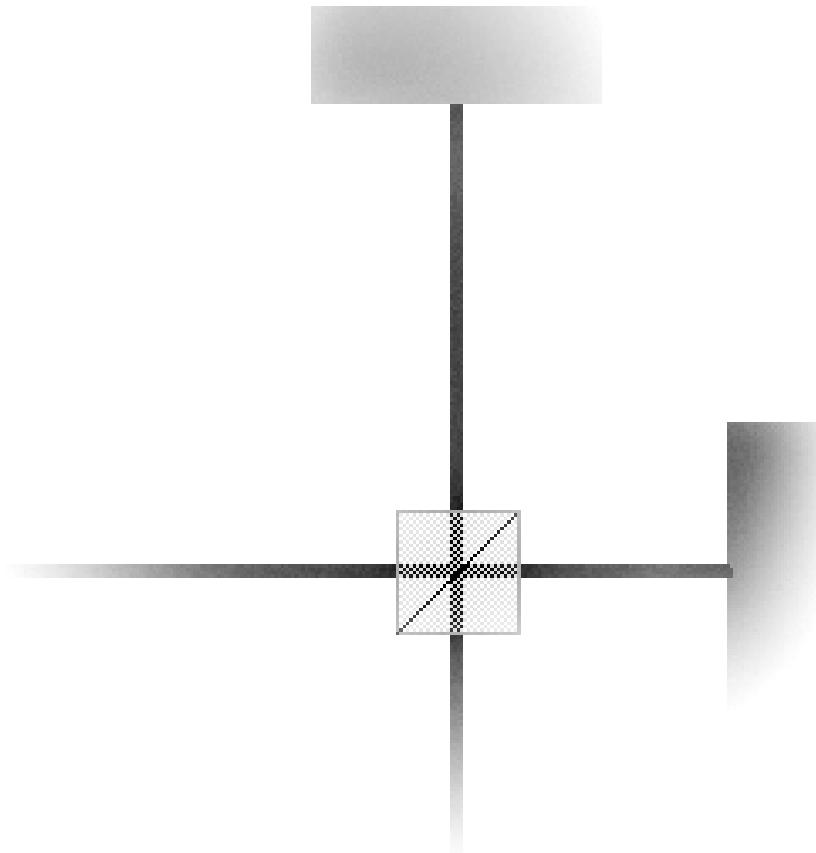


Was ist dazu nötig?



- Hochauflösende Interferometrie für Winkel und Translation
 - Intertialer Sensor
 - Messinstrument für die Lageregelung
- Hochgenaue Aktorik für mindestens 1 Winkel
 - Strahlkontrolle (pm und nrad)
 - Performance Verifikation des Interferometers
- Weitere Anwendungen
 - Dilatometer
 - Profilometer

Interferometrie...



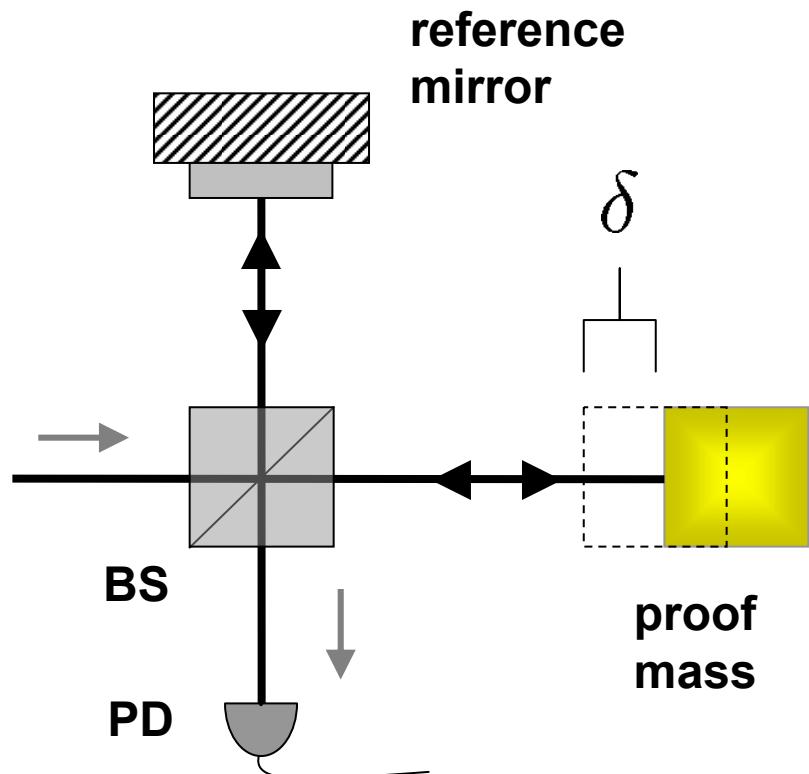
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Interferometer Concept

Michelson Interferometer

- DC-Signal hard to handle
- AC-Signal preferred
- → heterodyne measurement

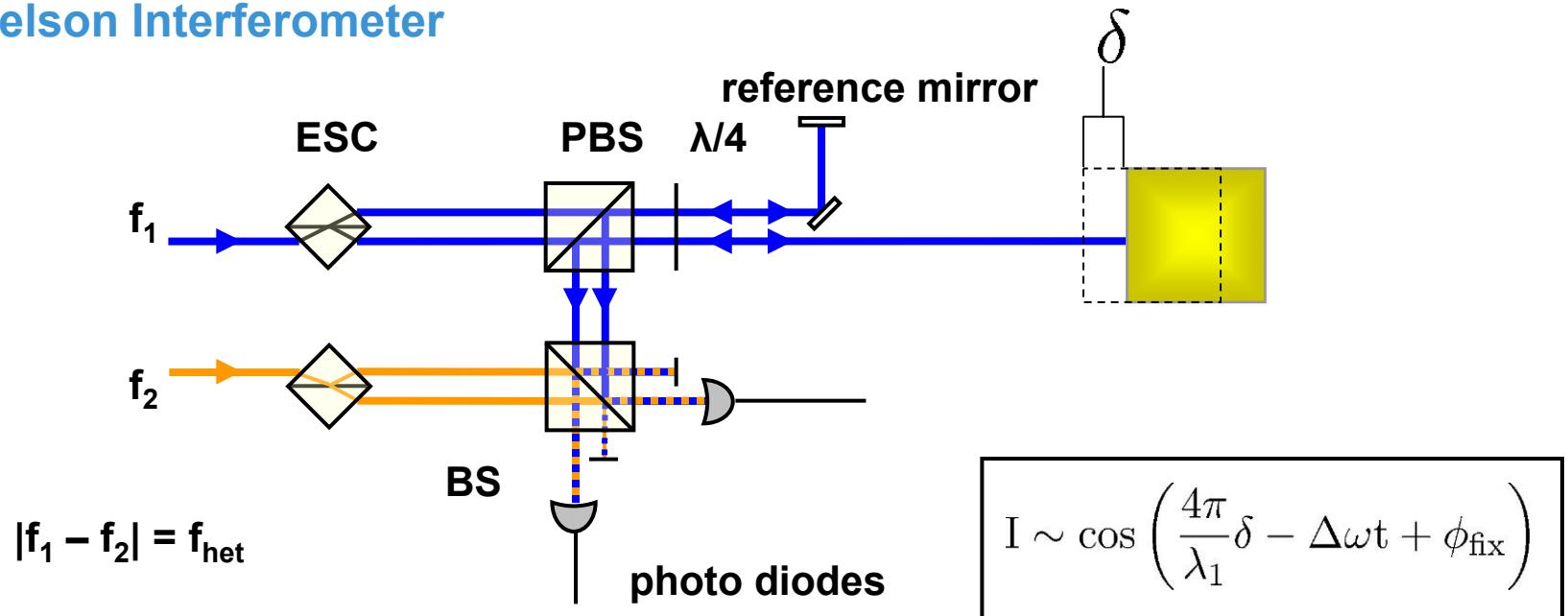
$$I \sim \cos\left(\frac{4\pi}{\lambda}\delta\right)$$



Interferometer Concept

heterodyne Michelson Interferometer

Highly Symmetric Heterodyne Michelson Interferometer

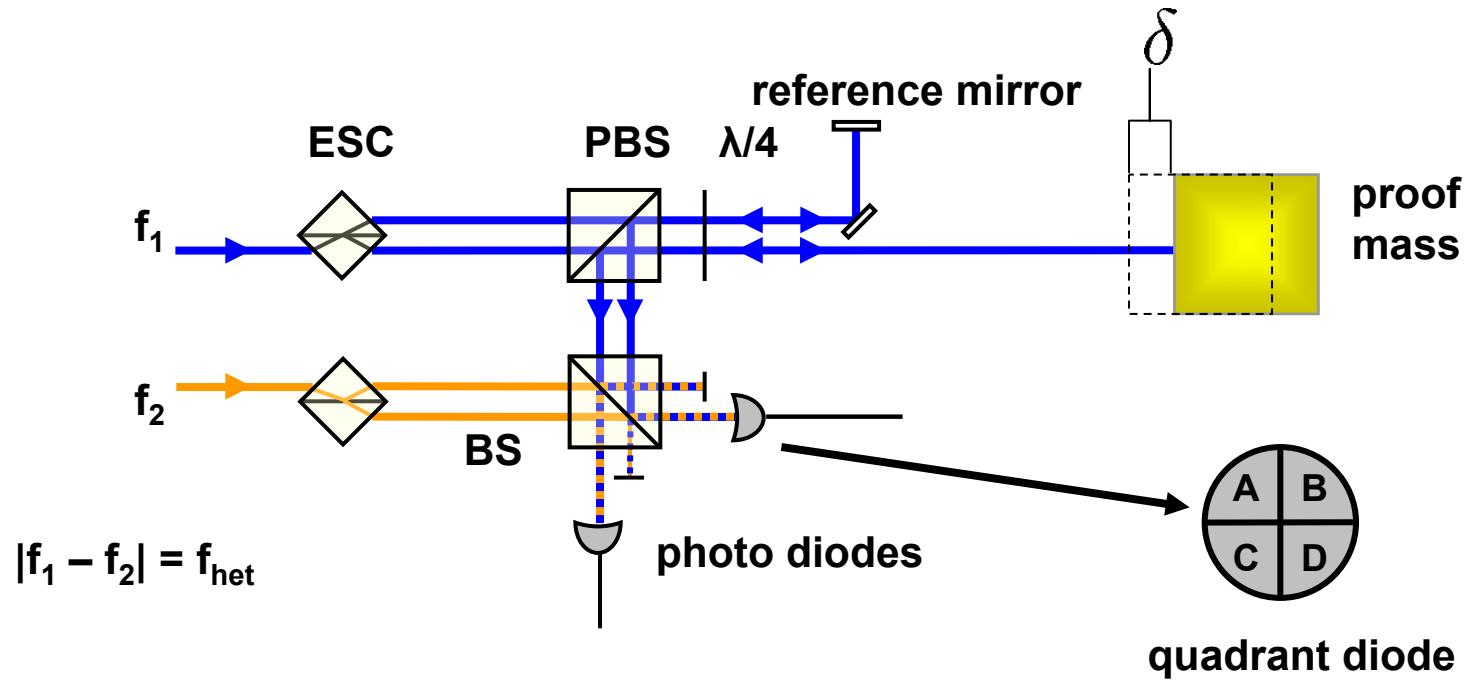


cf. C.-M. Wu, S.-T. Lin, and J. Fu; Optical and Quantum Electronics 34: 1267 (2002)

Interferometer Concept

heterodyne Michelson Interferometer

Highly Symmetric Heterodyne Michelson Interferometer

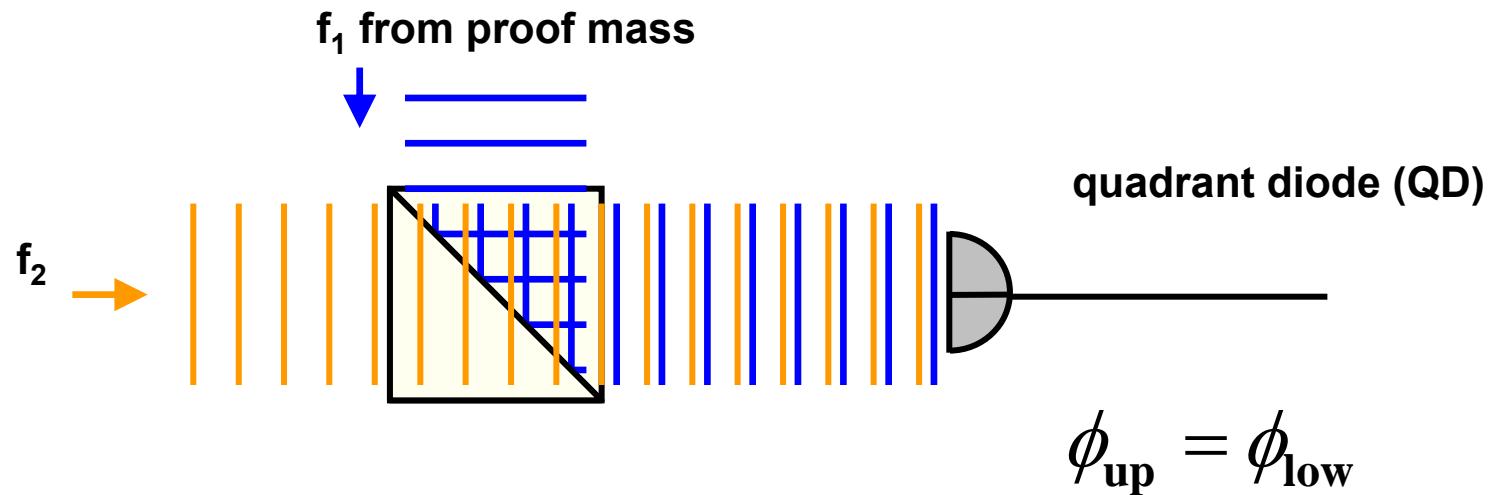


cf. C.-M. Wu, S.-T. Lin, and J. Fu; Optical and Quantum Electronics 34: 1267 (2002)

Interferometer Concept

tilt measurement

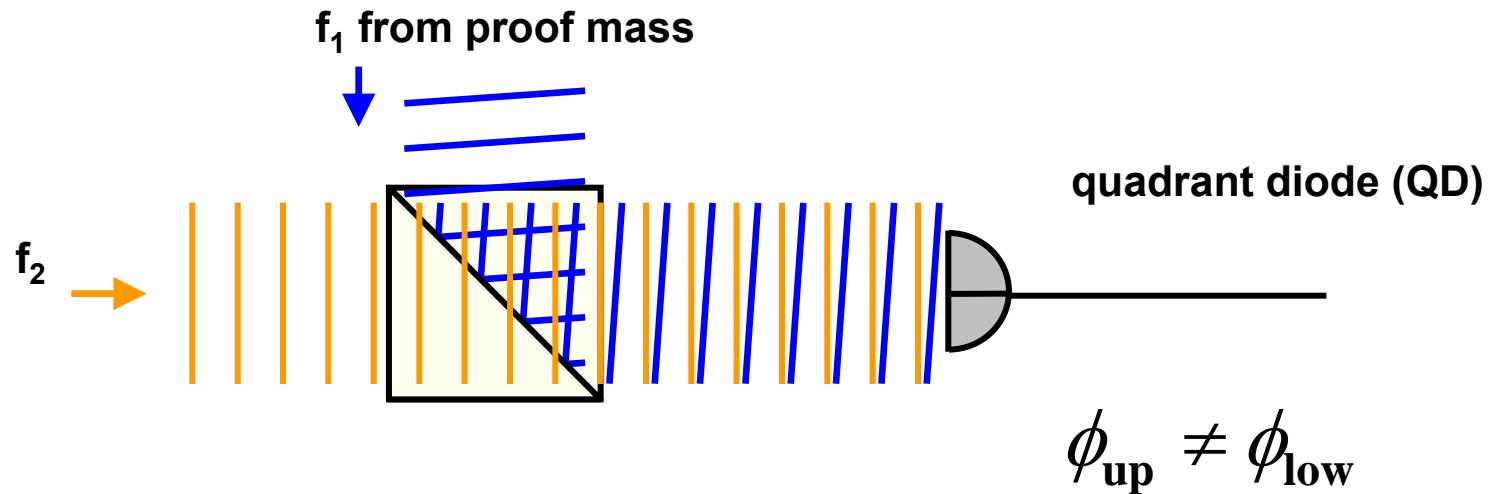
Differential Wavefront Sensing (DWS)



Interferometer Concept

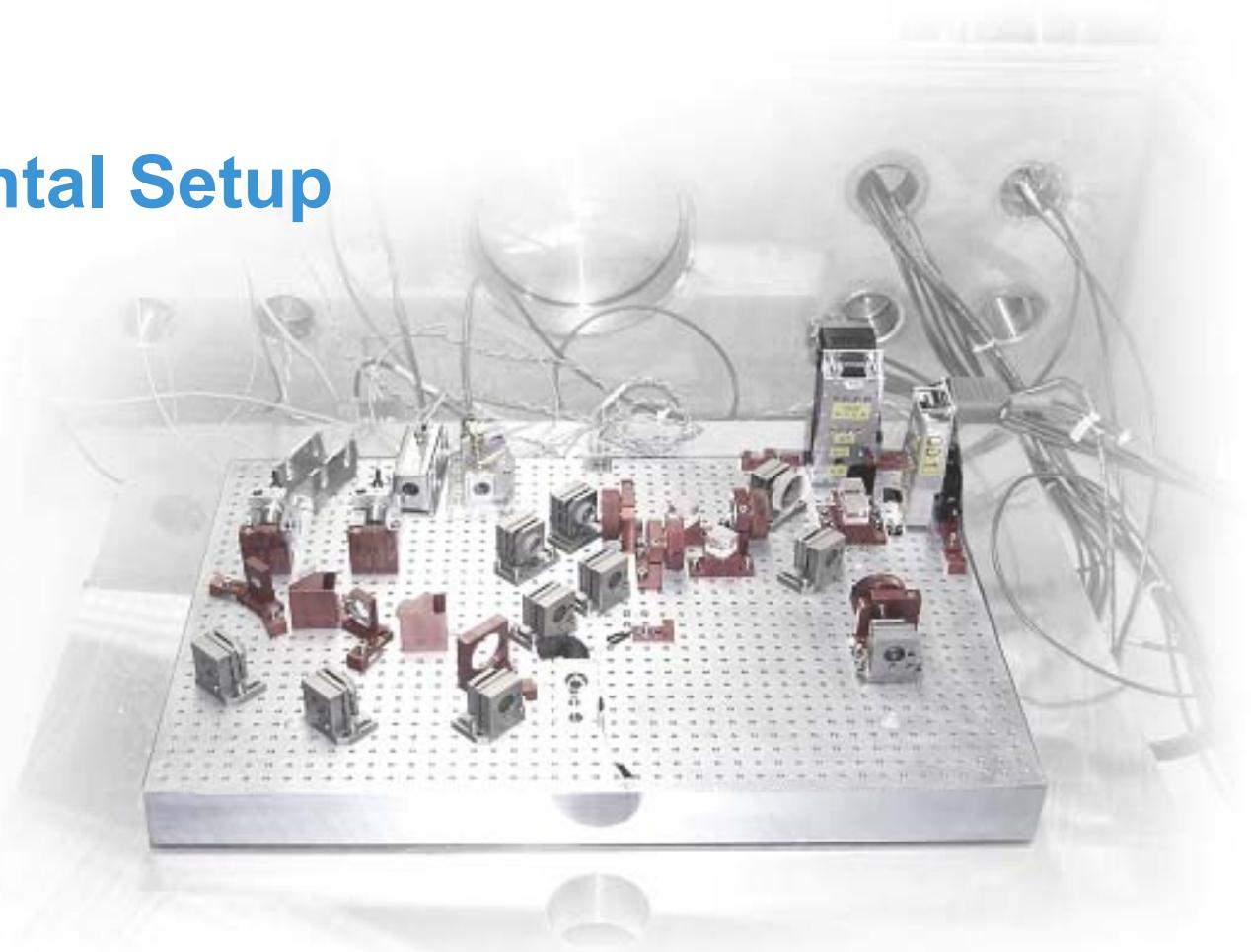
tilt measurement

Differential Wavefront Sensing (DWS)



- difference in phase between the quadrants gives tilt measurement

Experimental Setup

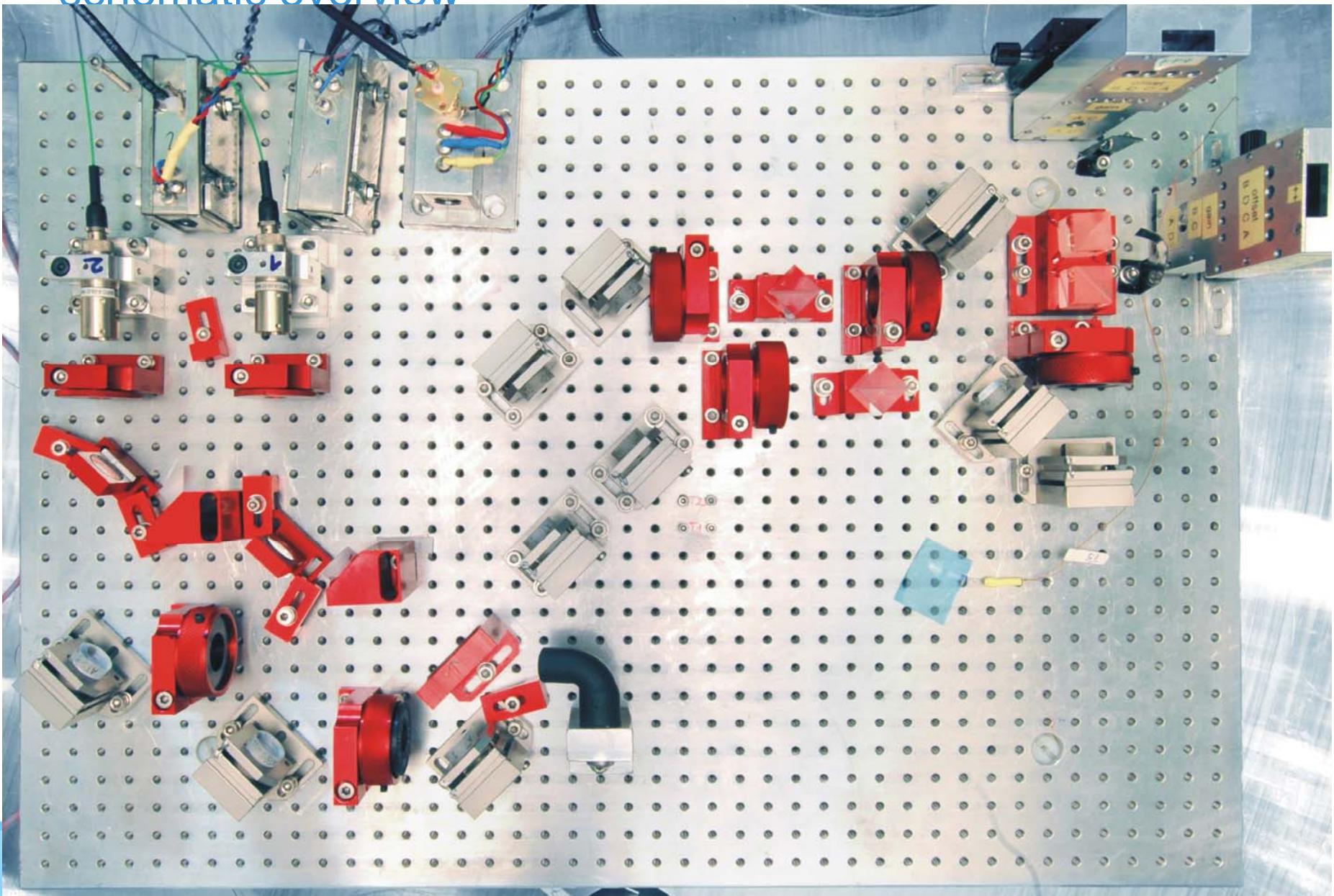


All the space you need

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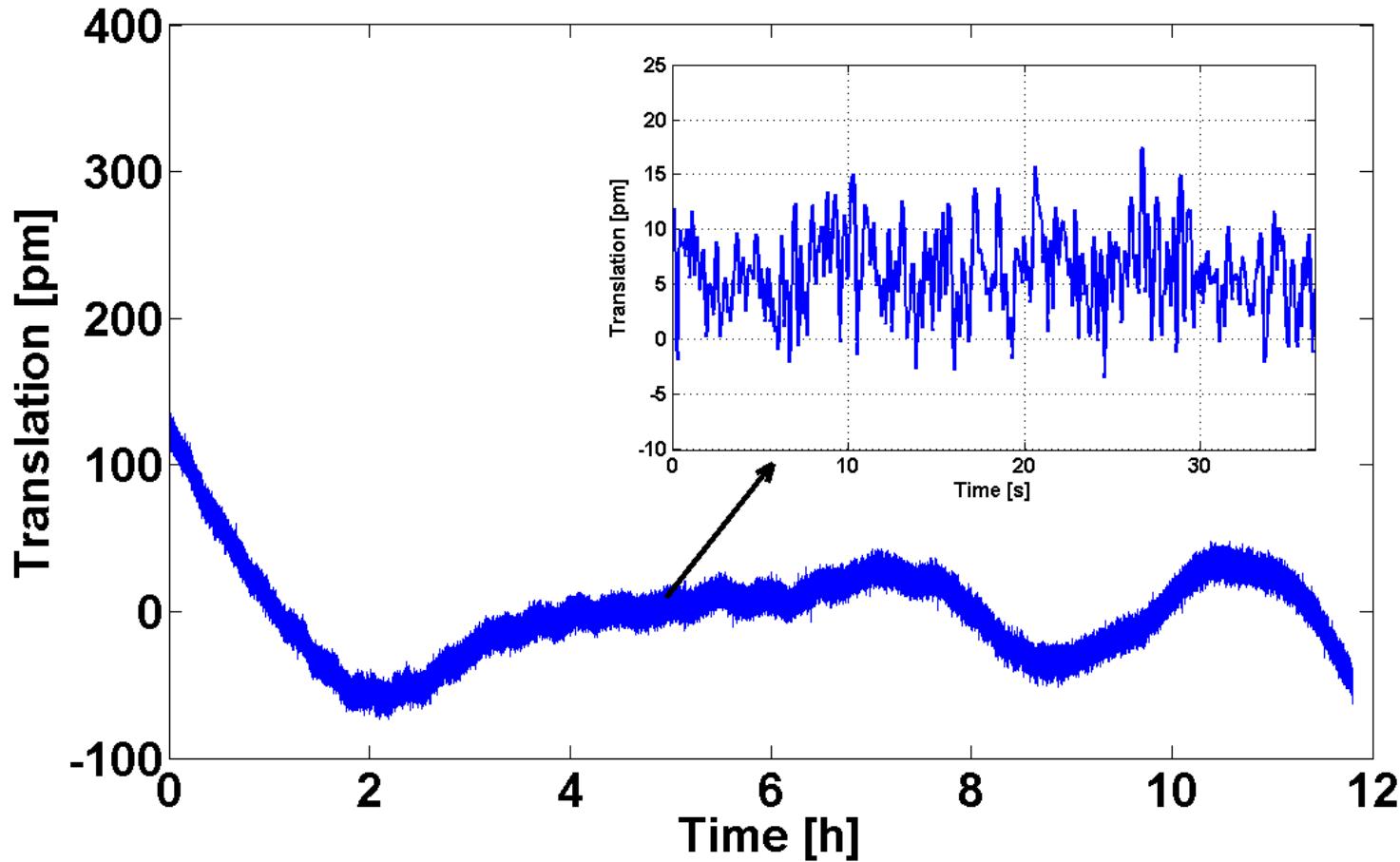
Experimental Setup

schematic overview



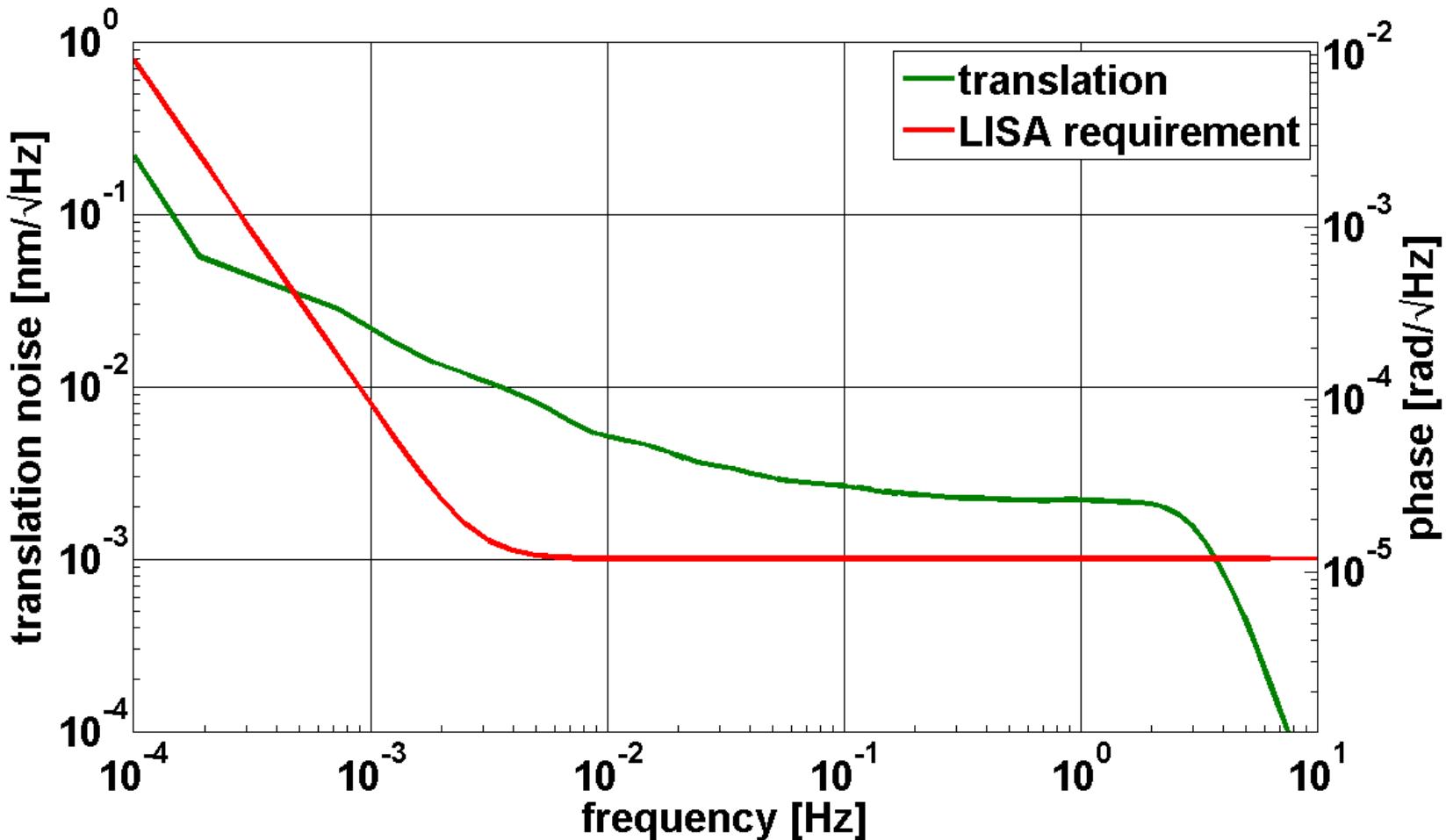
Experimental Setup results

Translation – Time Series



Experimental Setup results

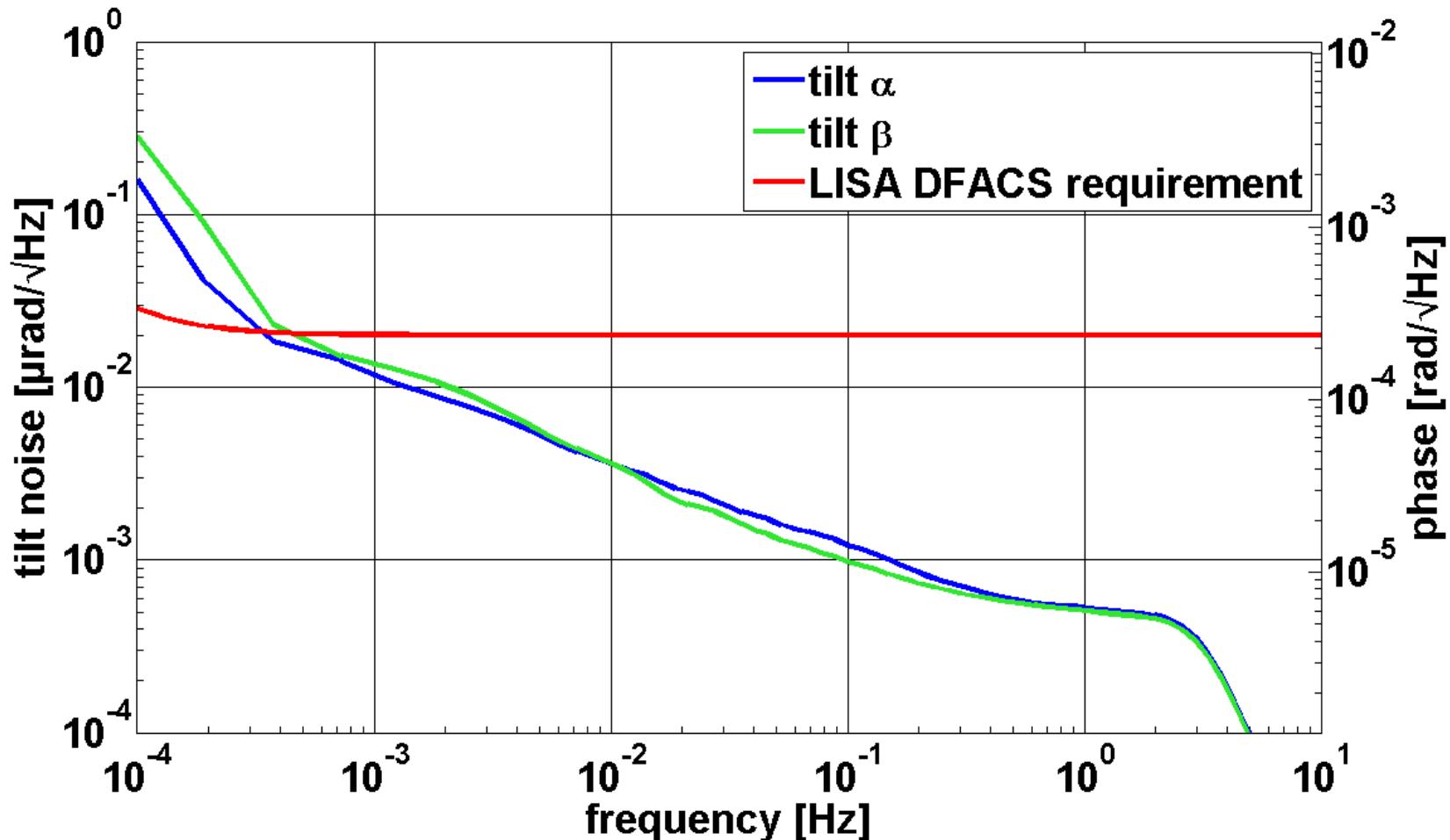
Translation - Power Spectrum Density



Experimental Setup

results

Tilt - Power Spectrum Density

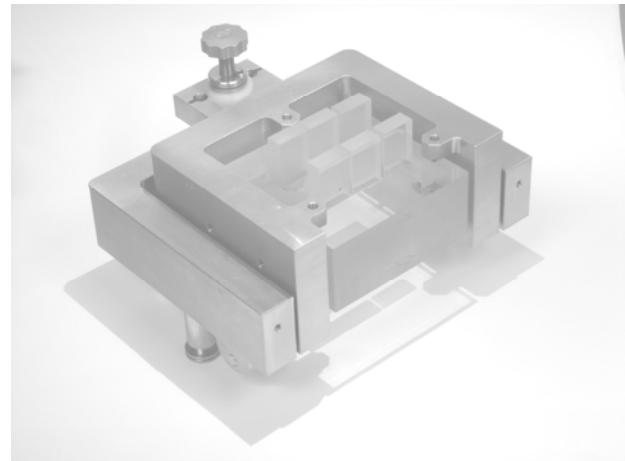


Wo geht es hin?



- Miniaturisierung bzw. Kompaktifizierung des Interferometeraufbaus
- Modularisierung des Aufbaus
- Höhere Auflösung
- Dimensional stabile Materialien

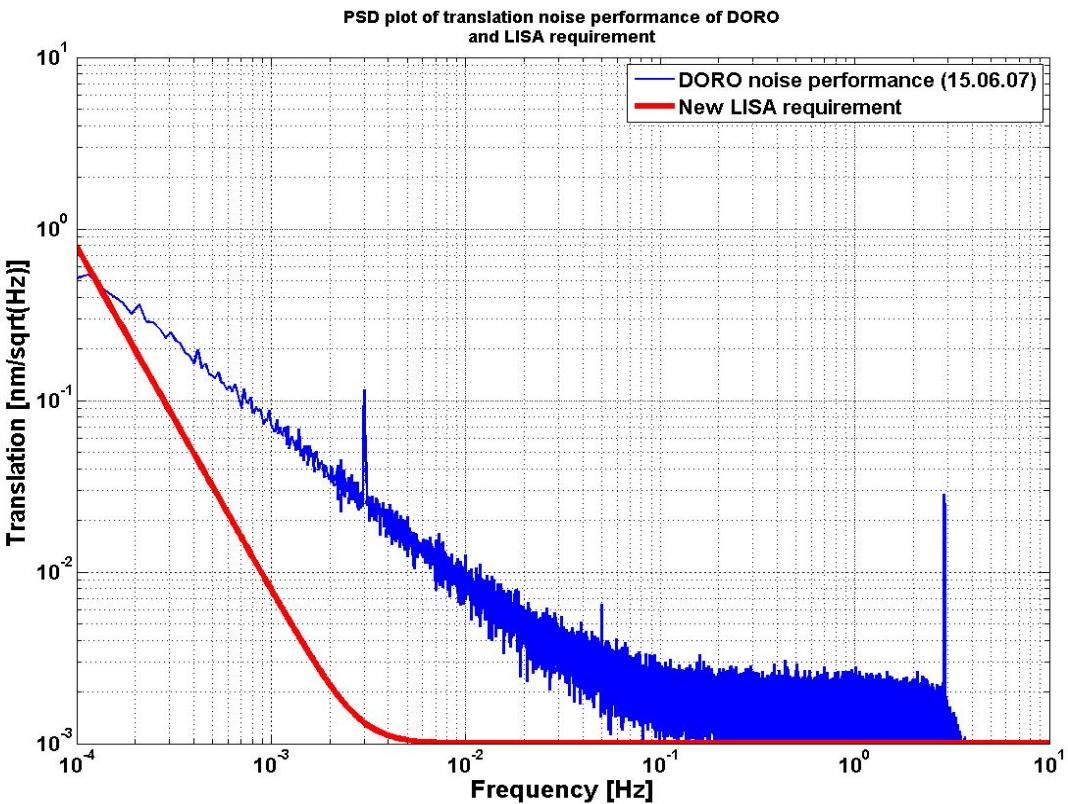
Aufbau- & Verbindungstechnologi e



All the space you need

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Integration Technologies



Höhere Auflösung...
Kompakte Bauweise...



Hydroxide-catalysis bonding

- may occur between flat surfaces if silicate like networks can be created
- takes place in 3 Steps:
 - hydration and etching,
alkine solution (e.g. sodium silicate) is placed on surface
→OH⁻ ions of solution etch silicate surface – Silicon ions are liberated:



released silicate ions lead to reduced number of OH⁻ ions in solution
→decrease of pH. For pH<11 silicate ion disassociates:



- polymerization, and dehydration
Si(OH)₄ molecules combine and polymerize to siloxan chains and water:

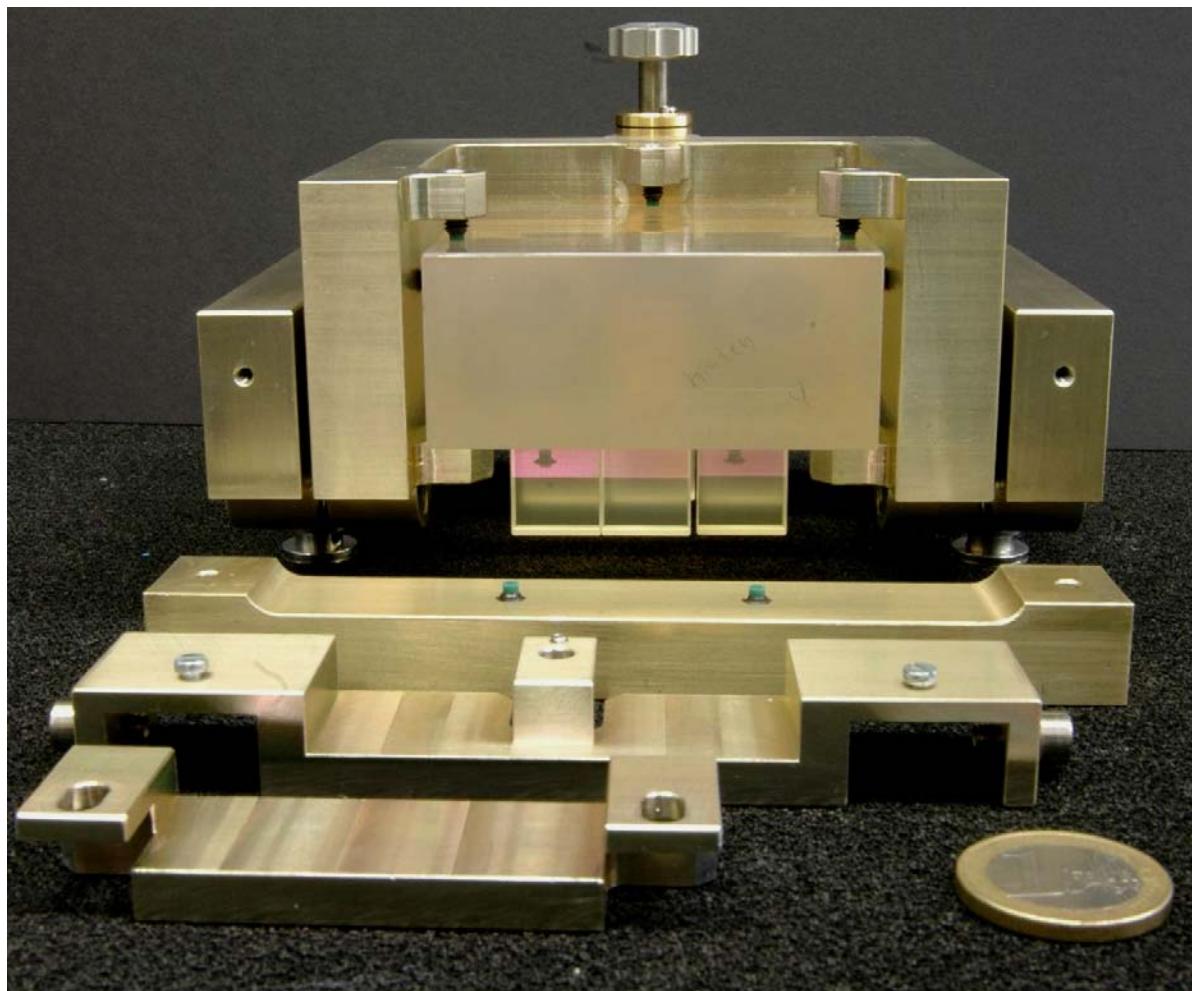


Adhesive bonding

- Two component adhesive Hysol EA 9313 is used
 - features low viscosity
 - bonding layer 1-7 µm
 - provides adhesive strength between -55°C and 49°C
 - provides good long term stability
- Previously used to bond fused silicate to invar
- Adhesive strength due to Van der Waals forces

Test Setup

HT
WK



All the space you need

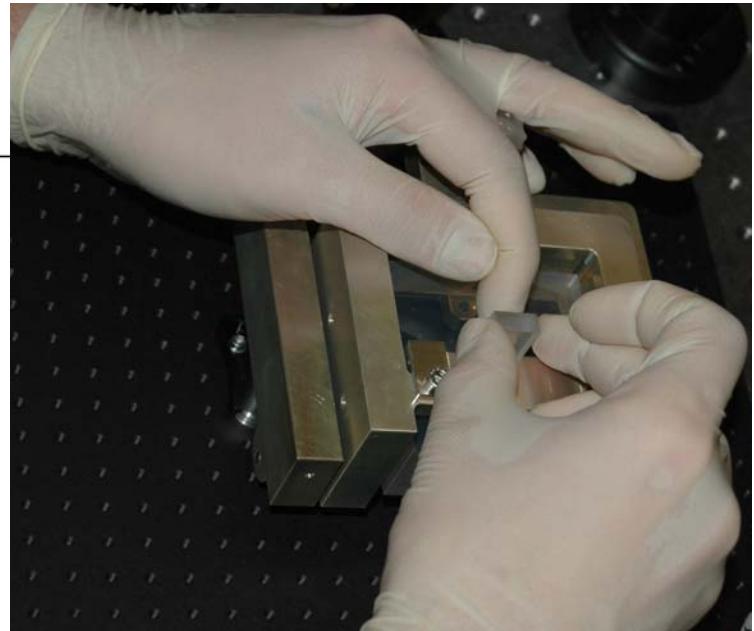
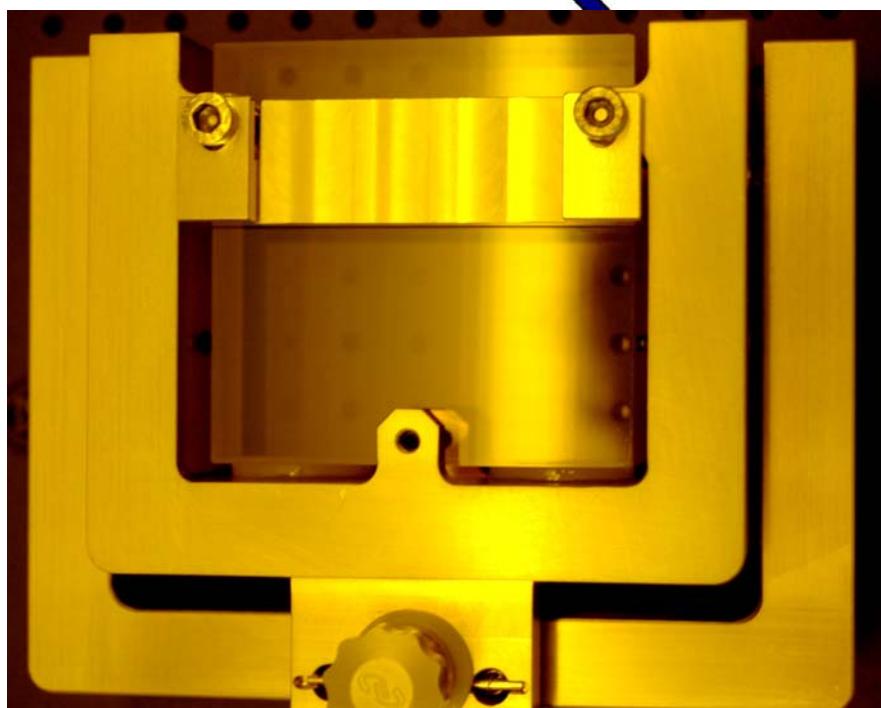
-24-

- Optical alignment setup

- permanent read-out of tilt
- detects angular alignment with accuracy of $\pm 250\mu\text{rad}$

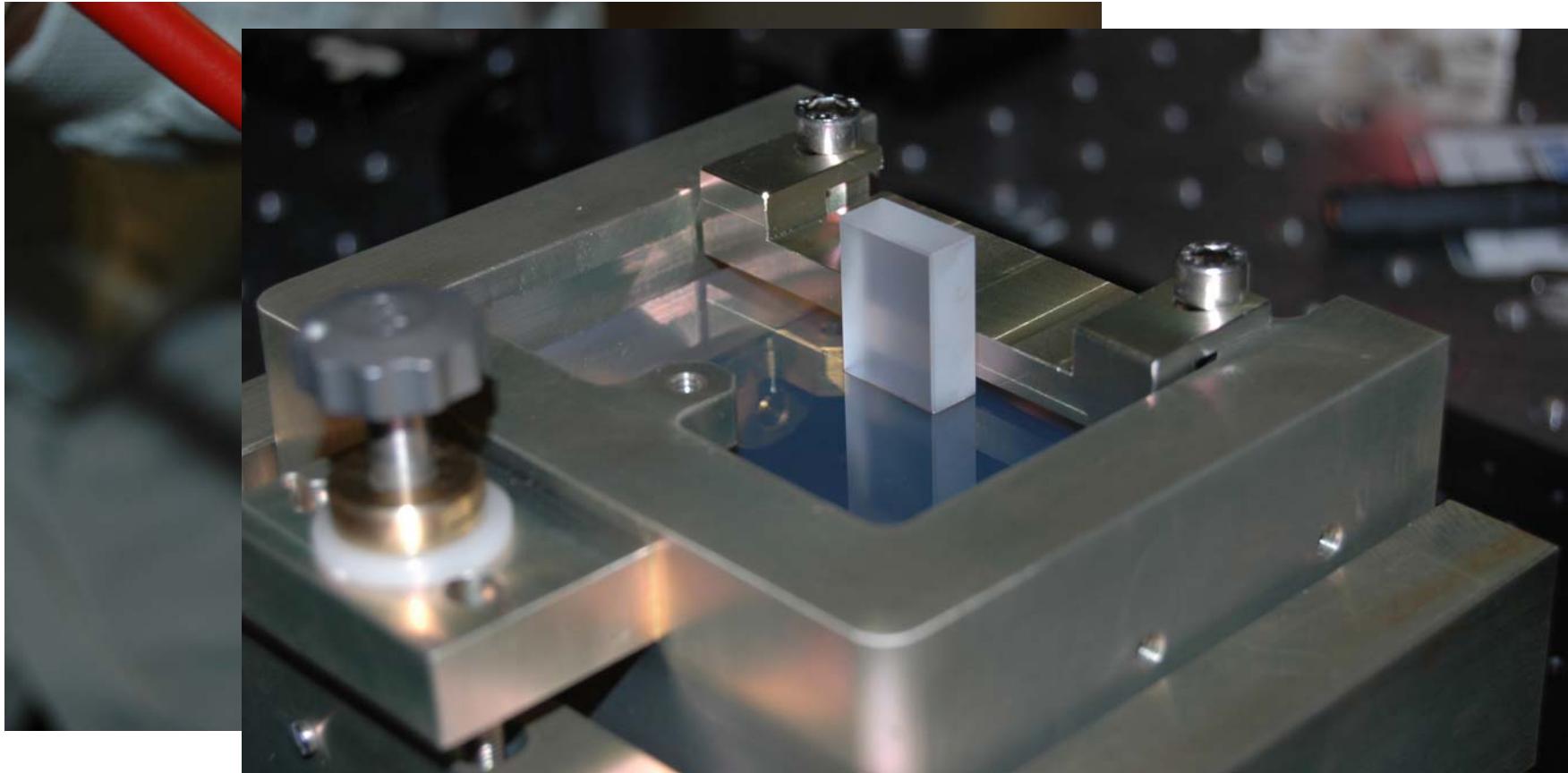
- Alignment templates

- permit fast initial rough alignment
- guidance by lay-on surface



Integration Process hydroxide catalysis bonding

HT
WK



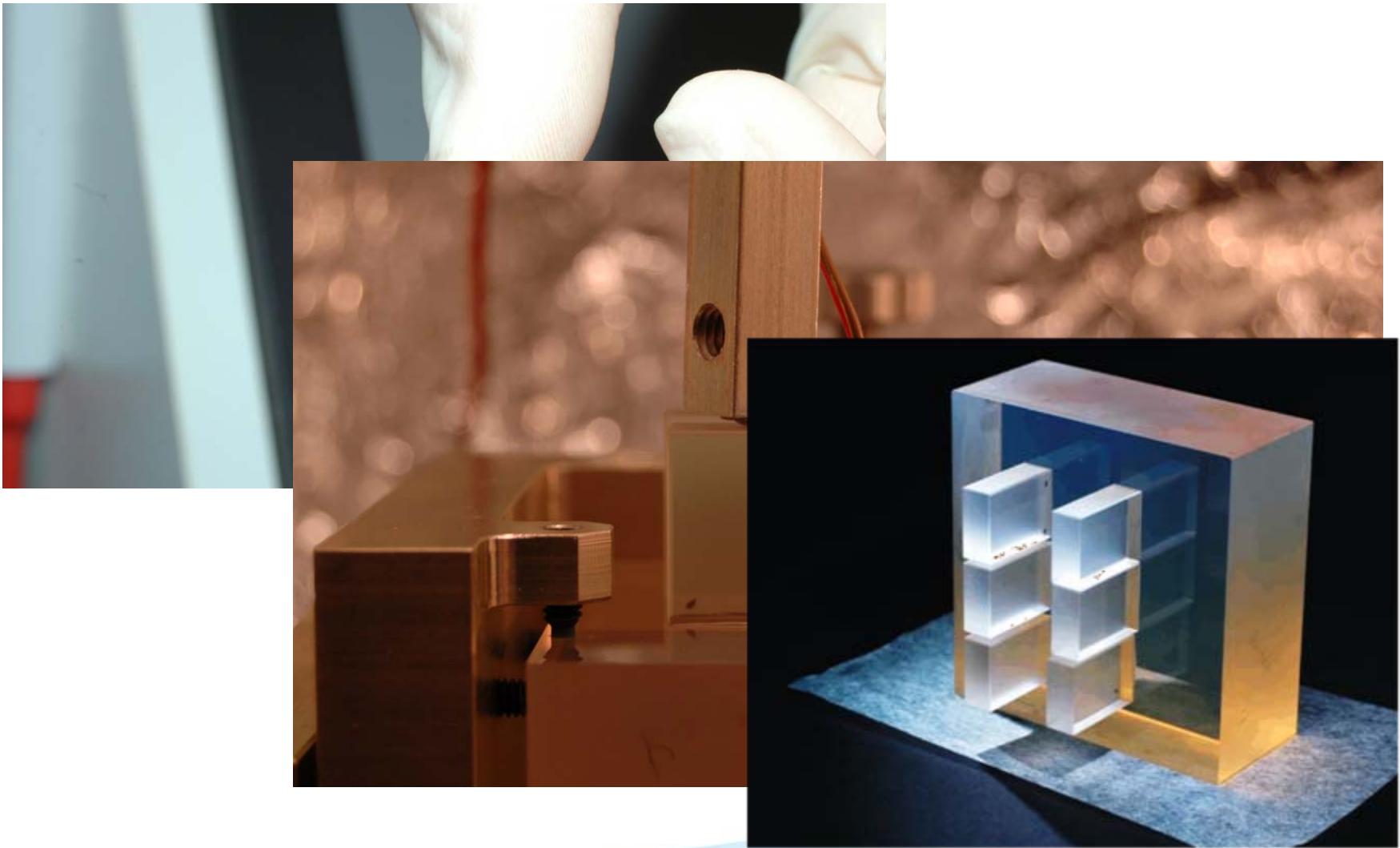
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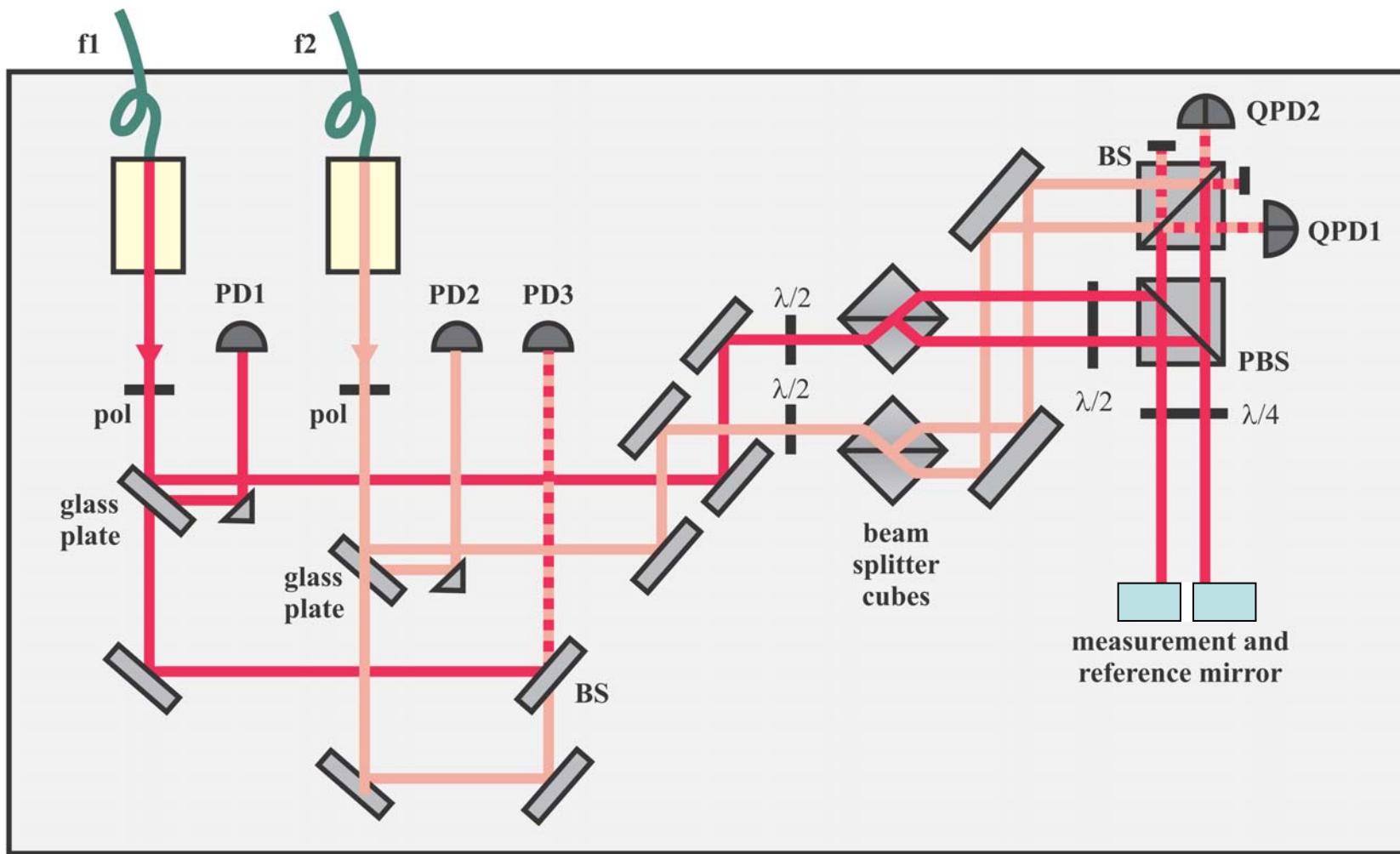
Integration Process adhesive bonding

HT
WK



All the space you need

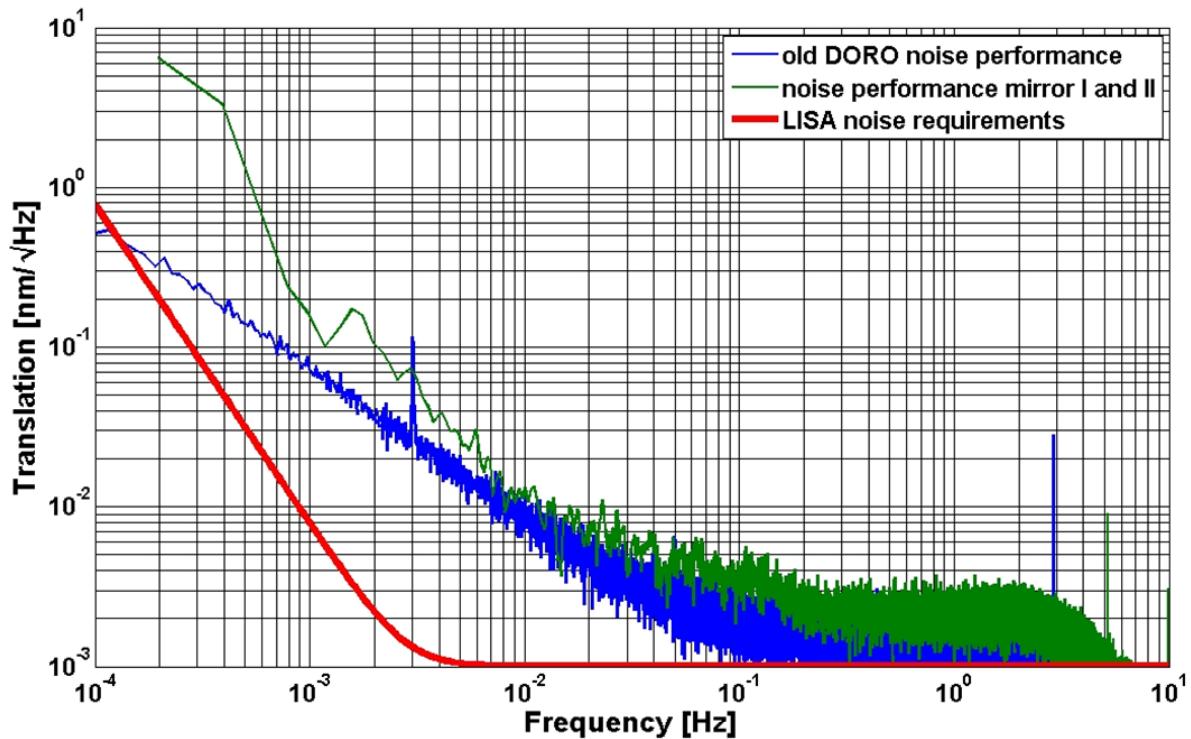
Beam Path DORO

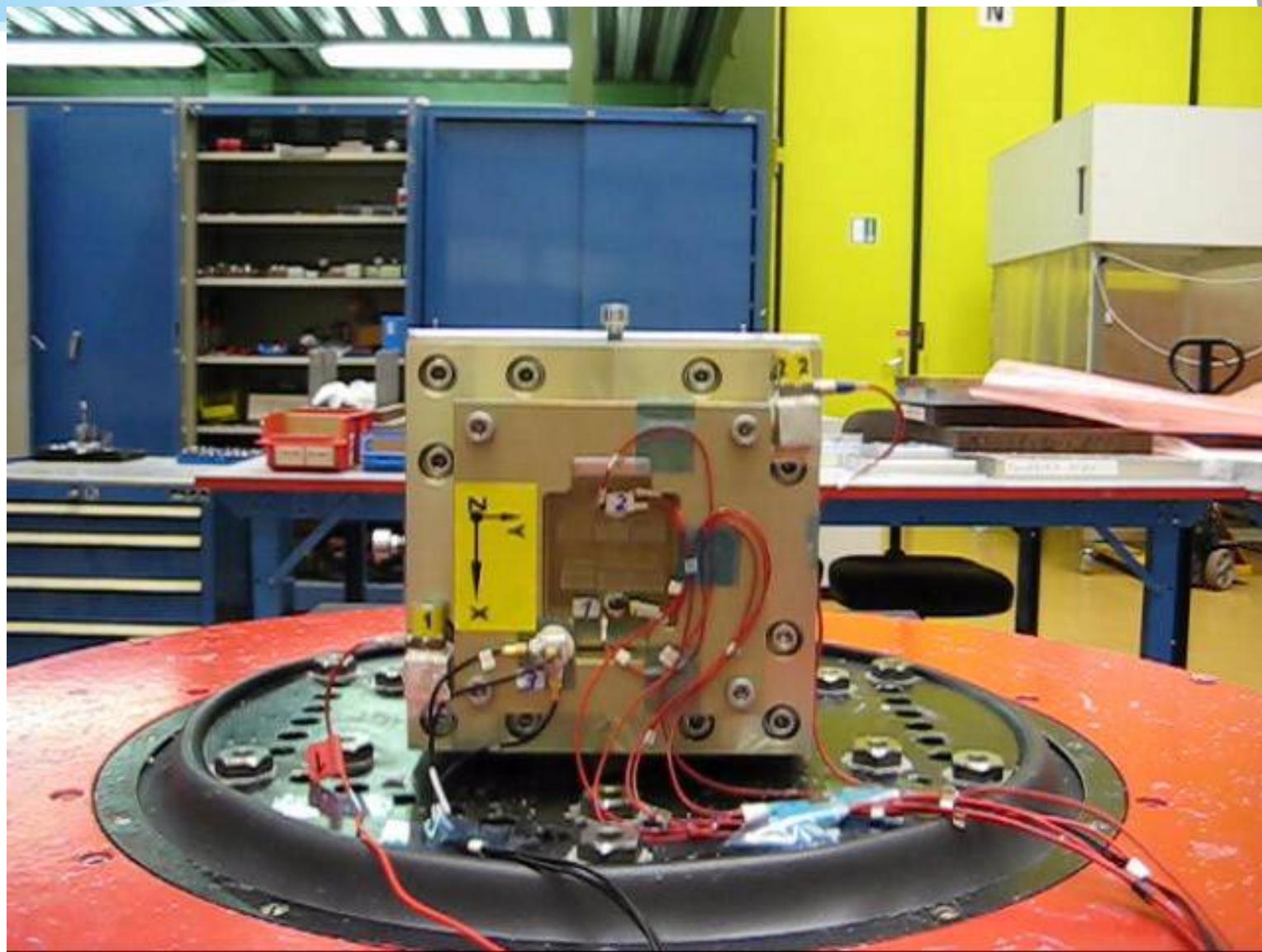


All the space you need

Performance Tests

- PSD plot of translation

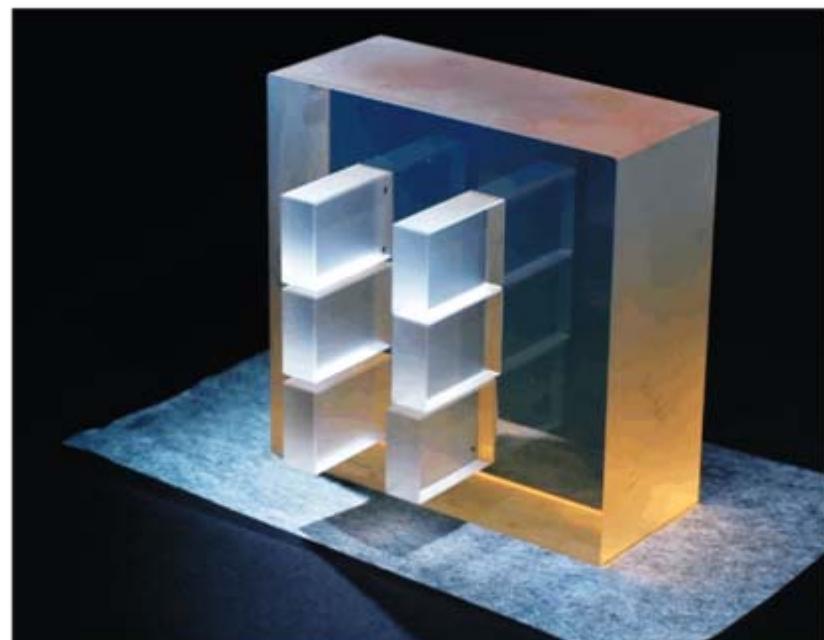




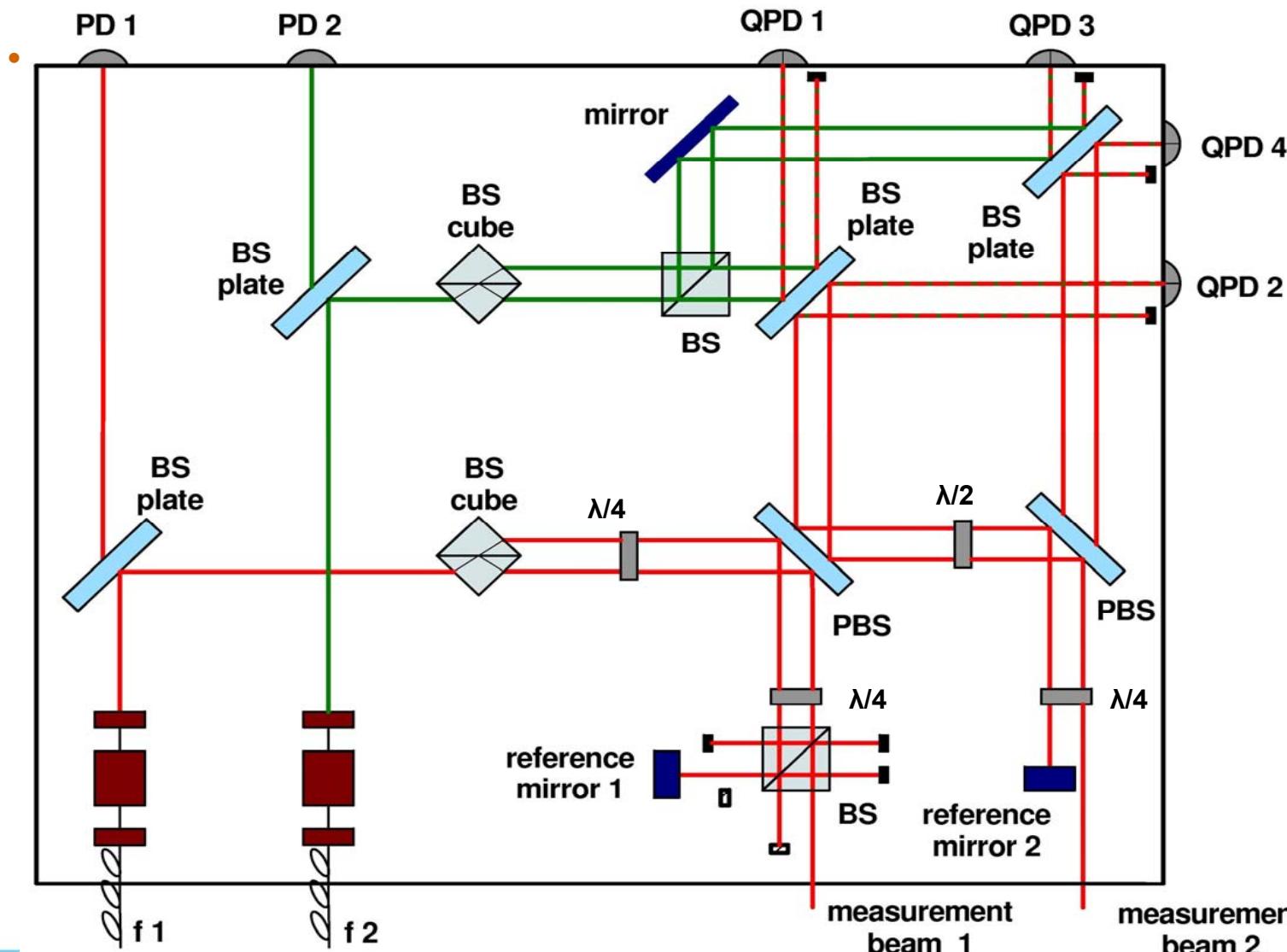
All the space you need

-30-

- **Testboard**
- **hydroxide catalysis bonding vs. adhesive bonding**
 - handling
 - Noise performance
 - Strength
 - Long time stability
 - Thermal stability
- **Both methods applicable**

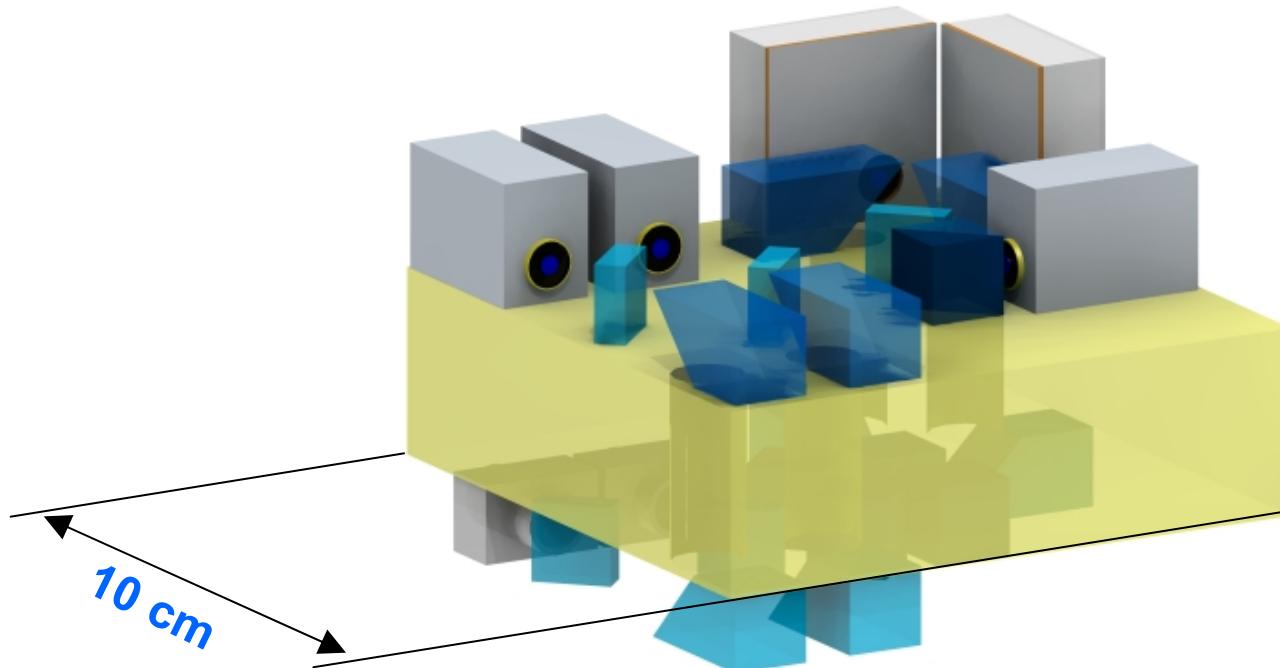


Design of High Precision Interferometer



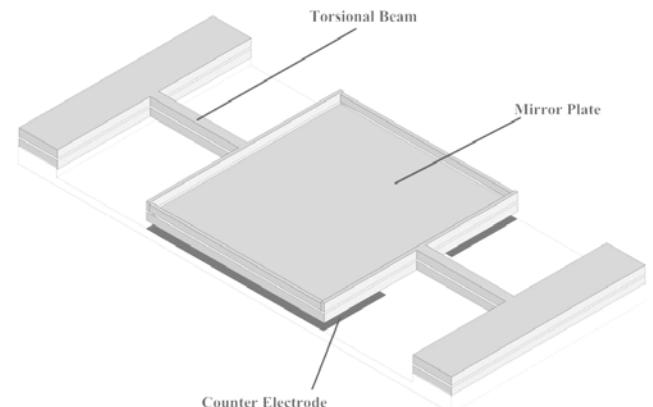
Nächste Schritte...

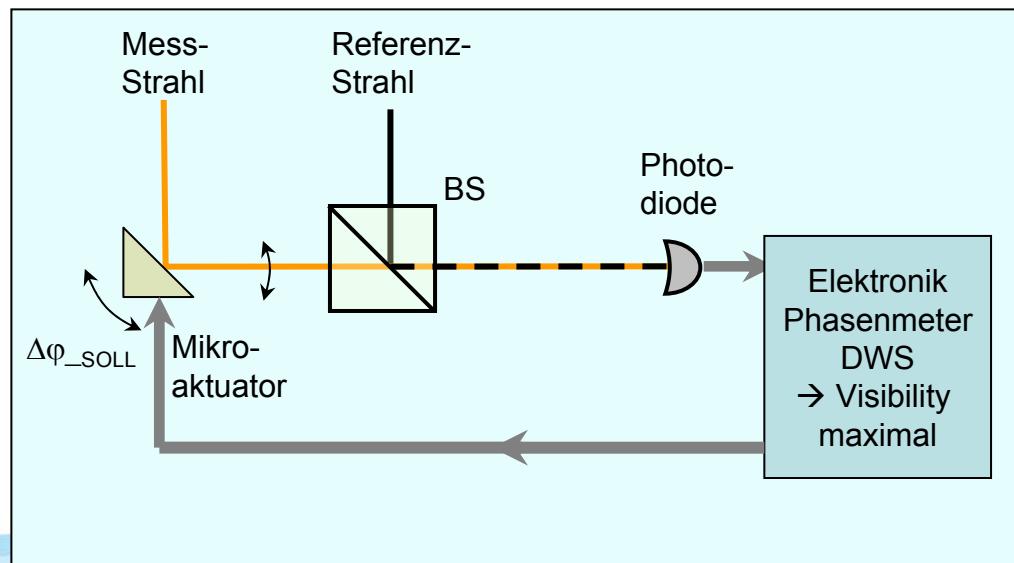
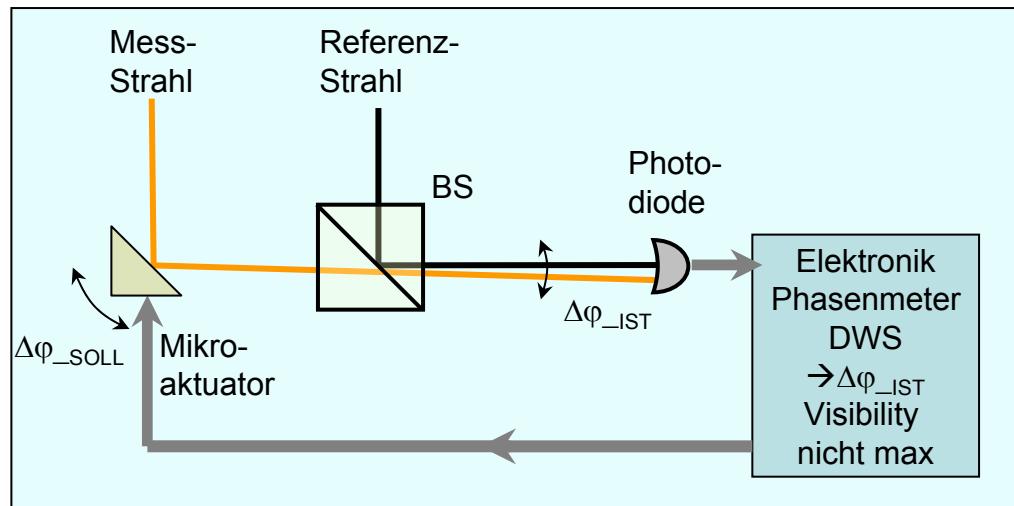
- quasi-monolithischer Aufbau auf fused-silica auf Zerodur
- Performance Tests



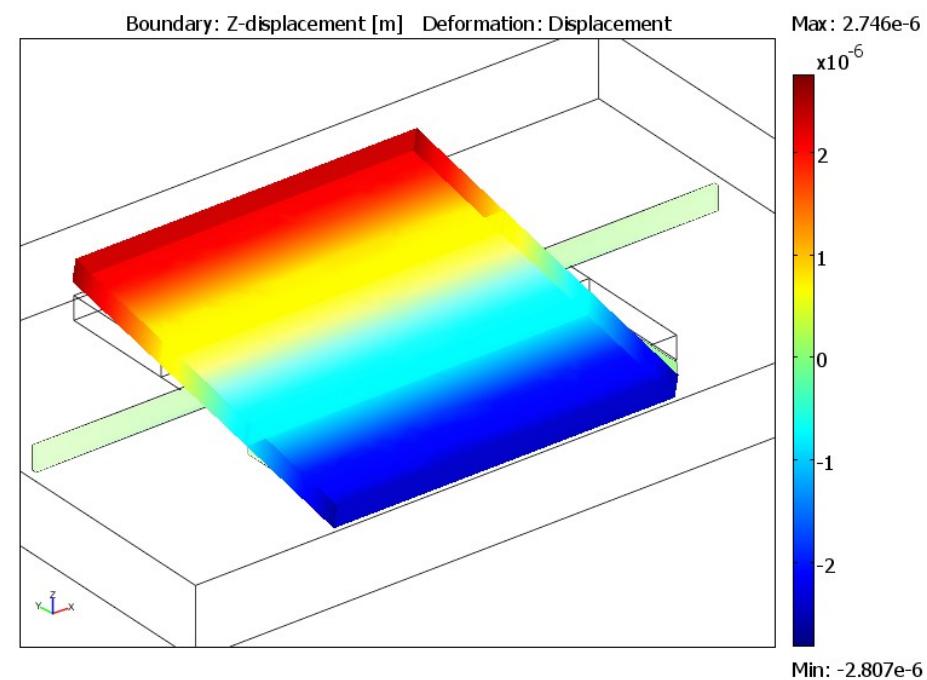
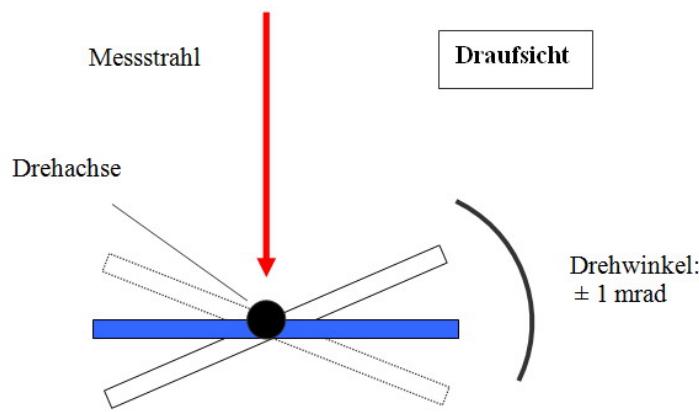
Aktorik...

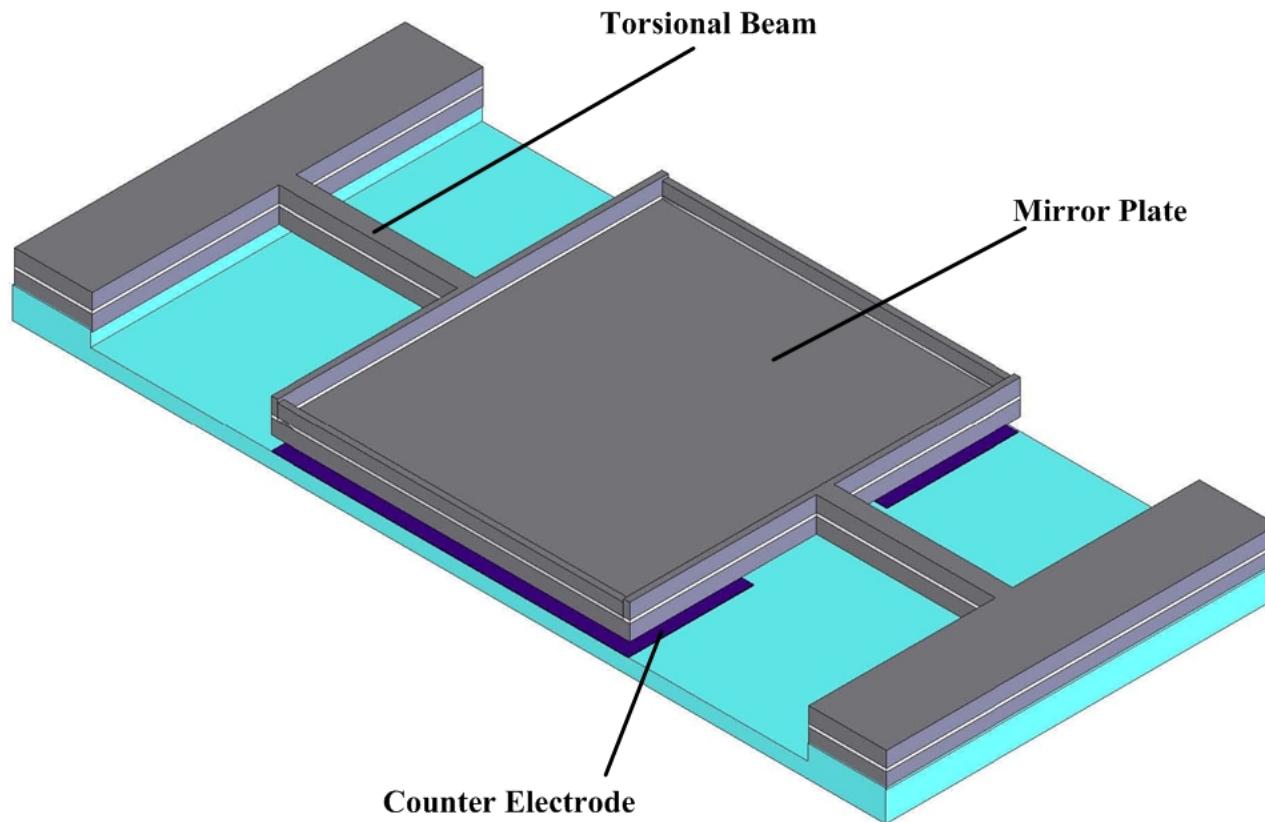
...präzise
Strahlkontrolle...





Design des Aktors...





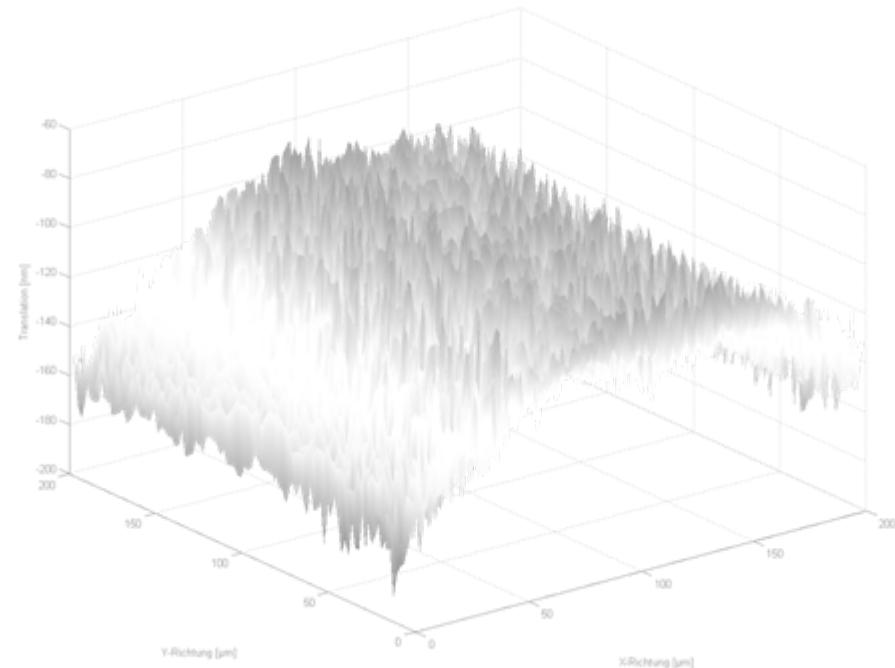
Nächste Schritte...



- **Fertigung des Aktors**
- **Performance Tests**
 - Translationsrauschen
 - Winkelrauschen
 - Ablagefehler bei Stellung des Winkels
- **Interferometerverifikation**
- **Closed-loop?**

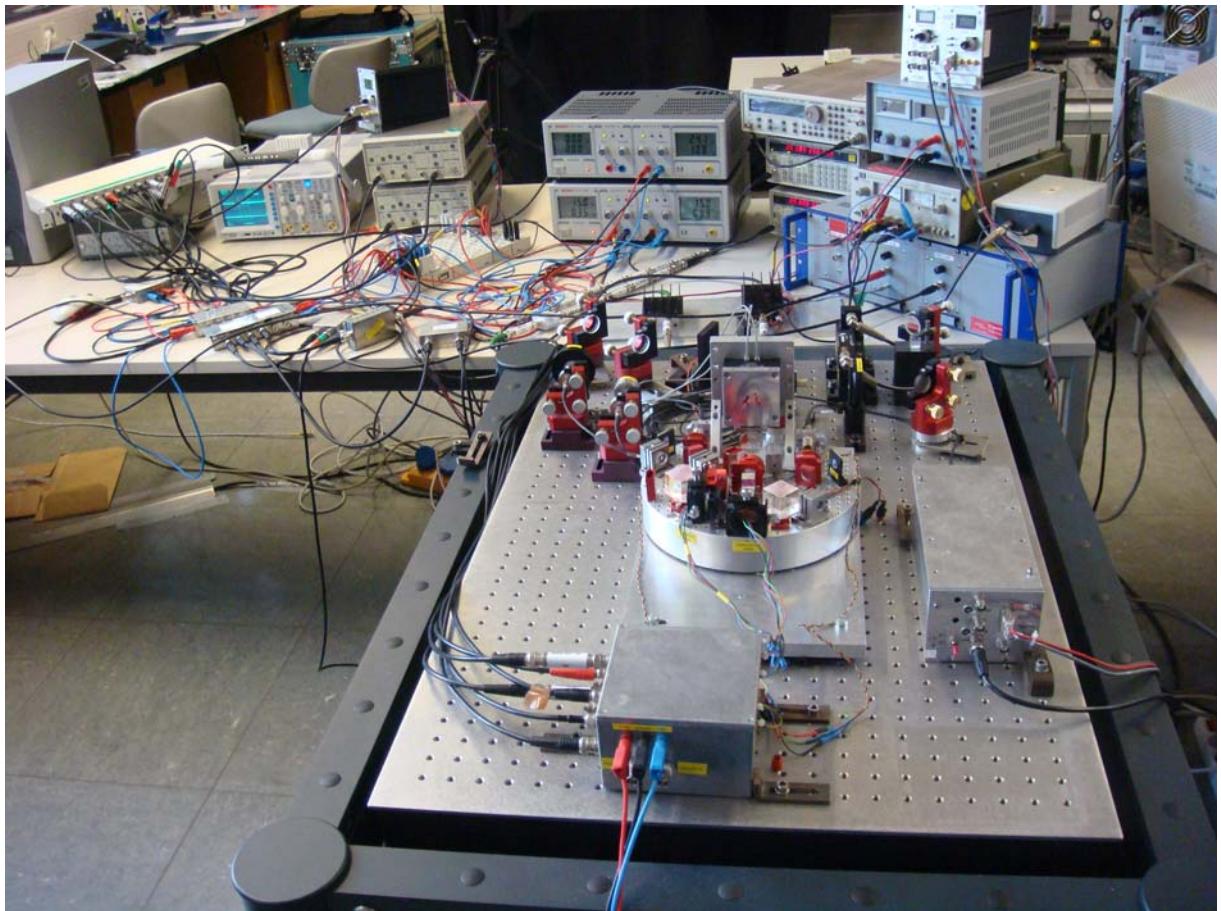
Profilometrie...

...erste Schritte...



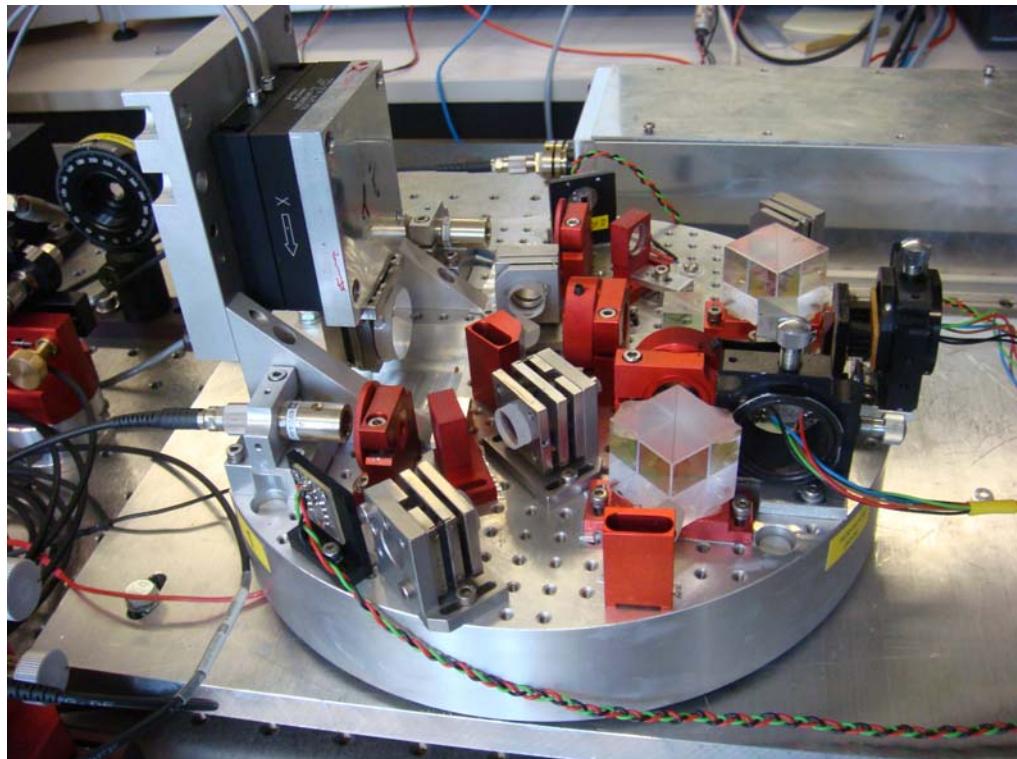
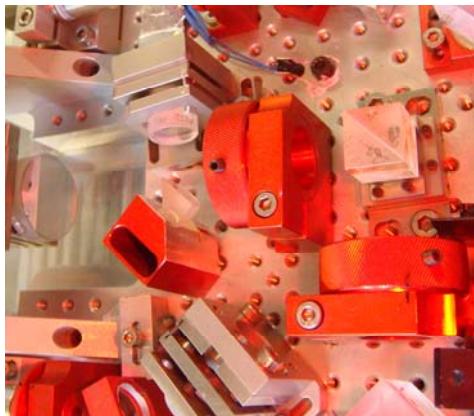
Aufbau des Profilometers

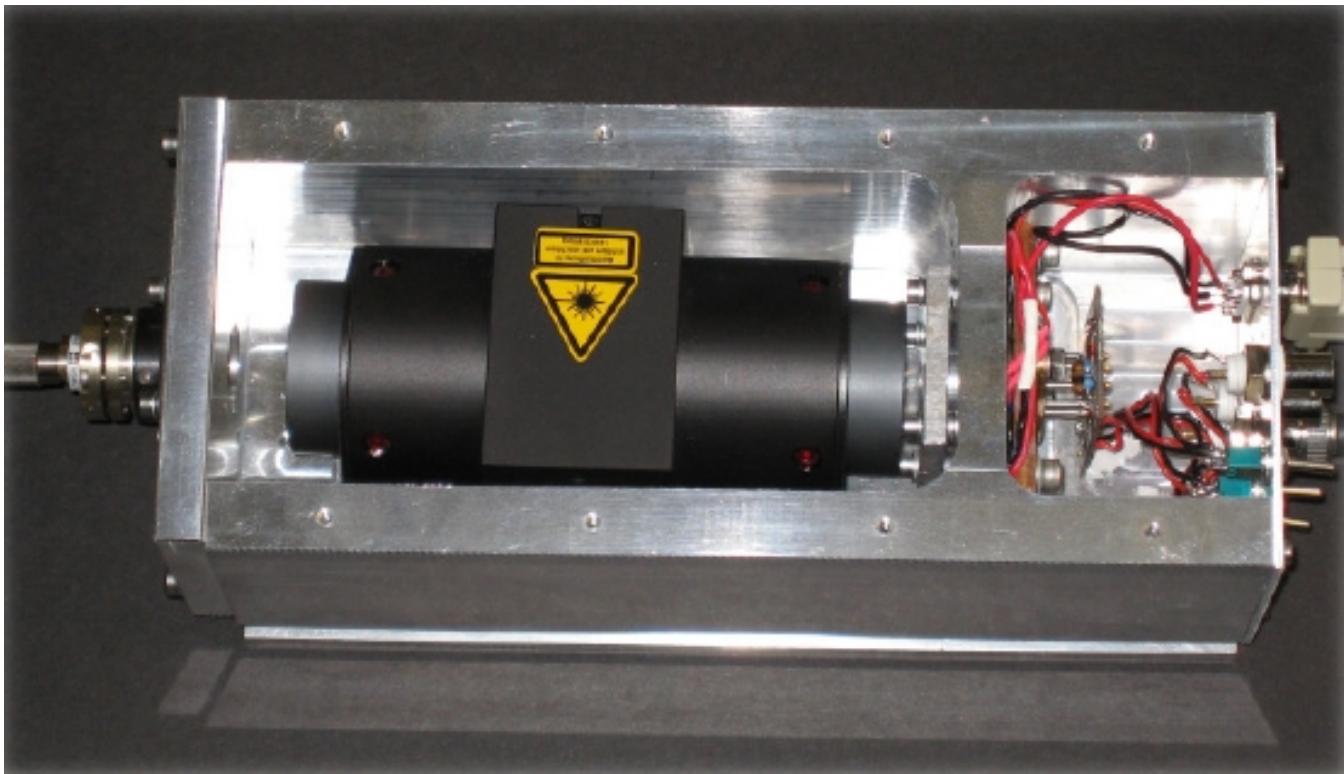
1. Interferometer
2. DBR-Laser
3. Heterodyn Frequenz Erzeugung
4. Aktuator
5. Daten- verarbeitung



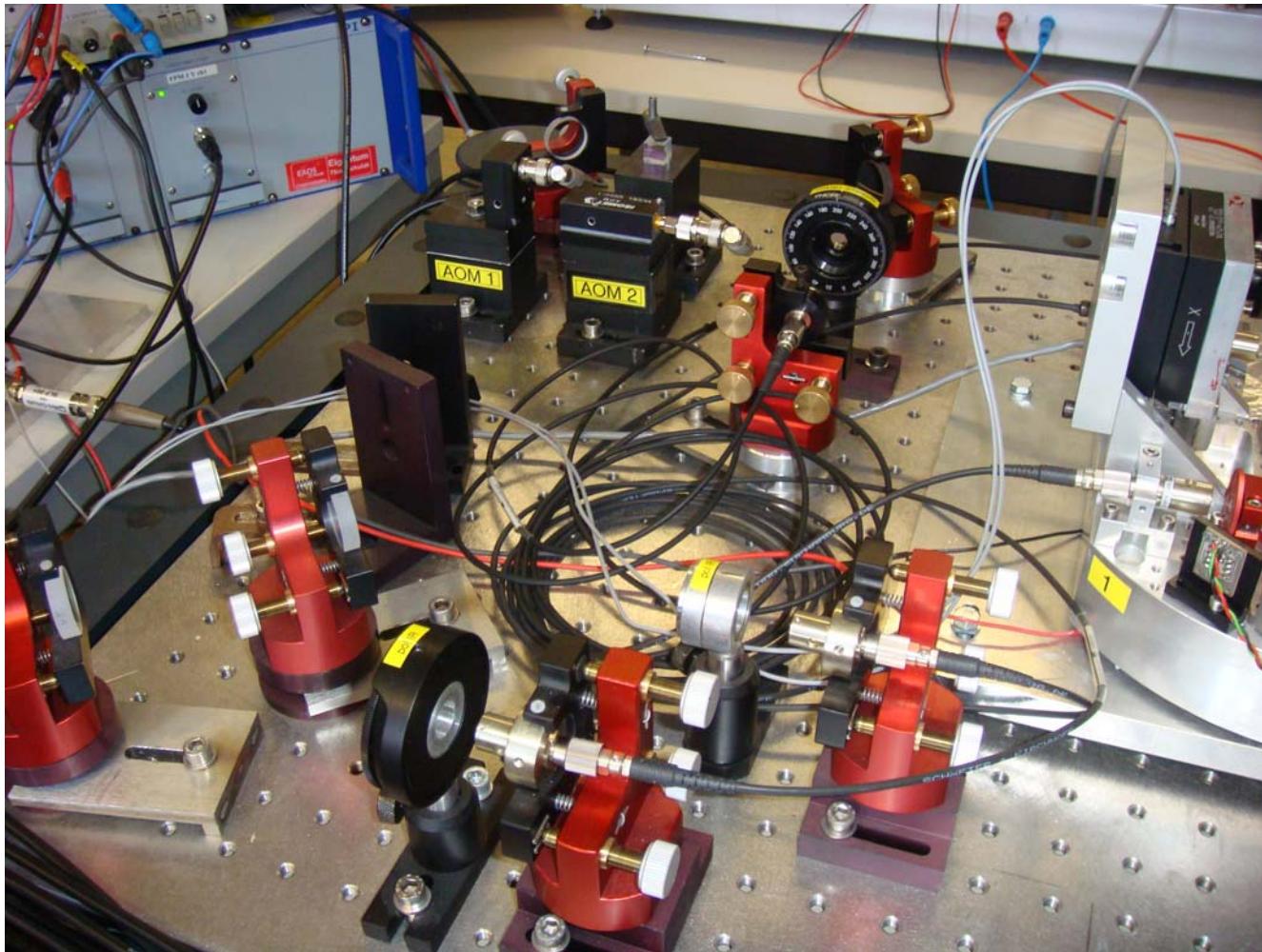
Aufbau des Heterodyn Interferometers

- Aktuator
- Hoch-symmetrischer Aufbau des Interferometers
- Quadrantendioden



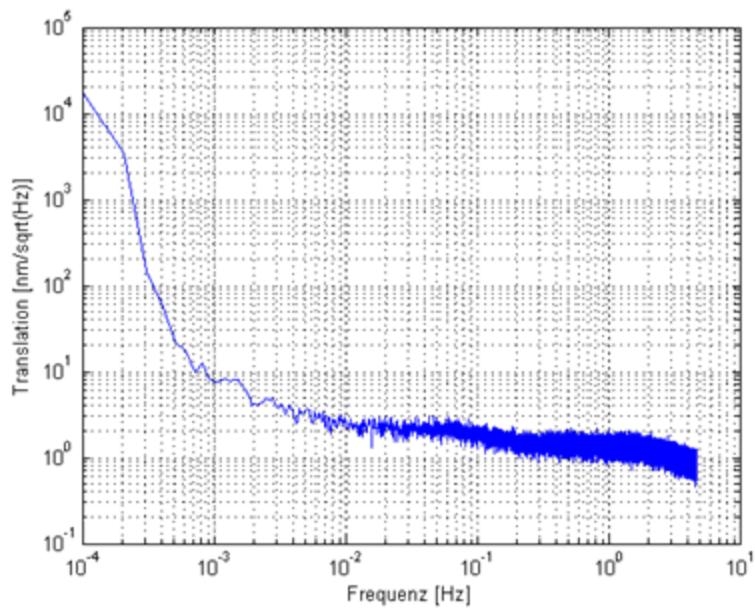
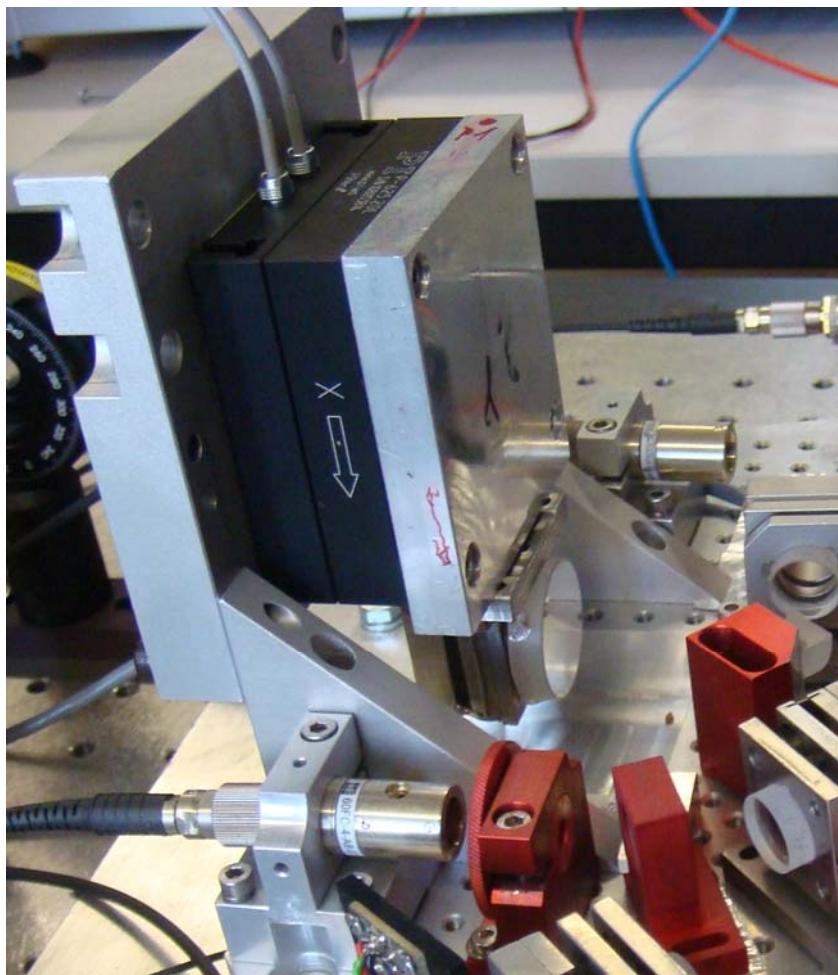


Heterodyn Frequenz Erzeugung



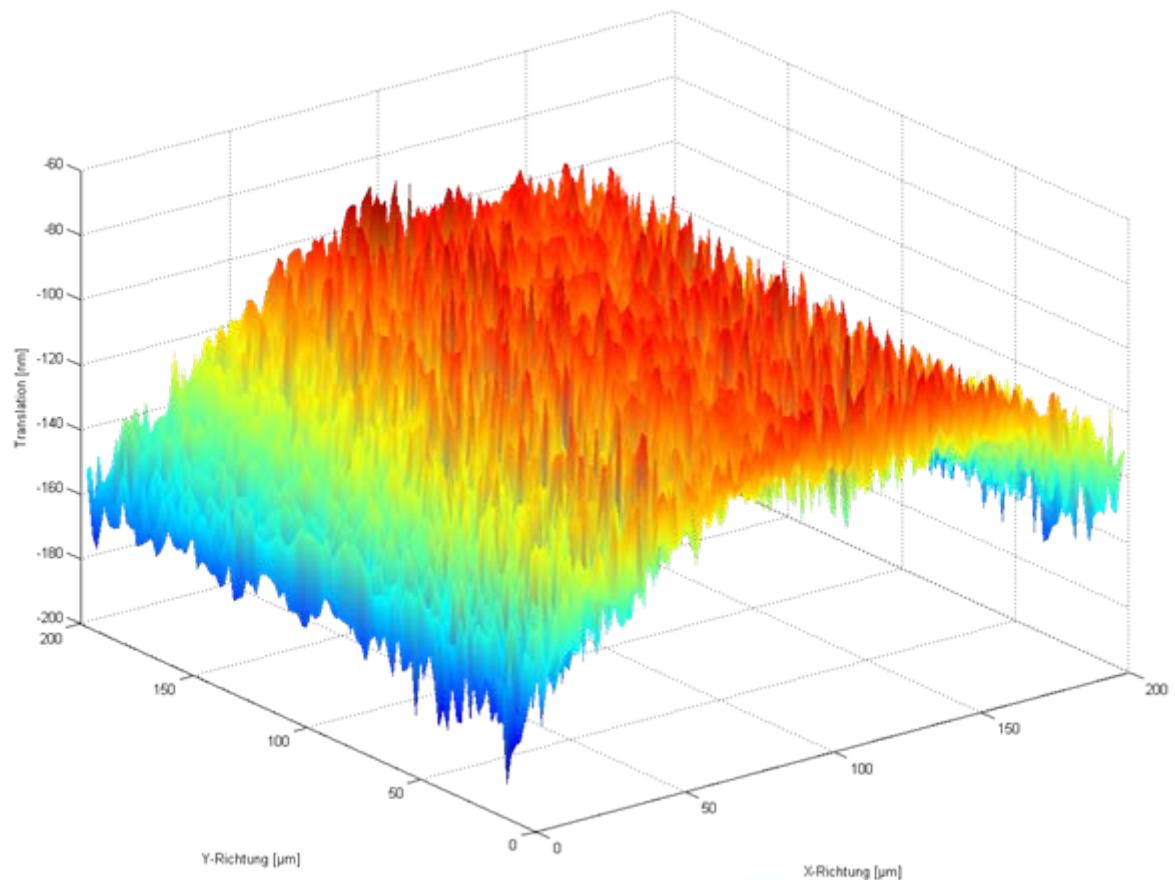
All the space you need

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3D Profil eines Spiegels

- 200 µm x 200 µm
- 100 Schritte in x- und y-Richtung



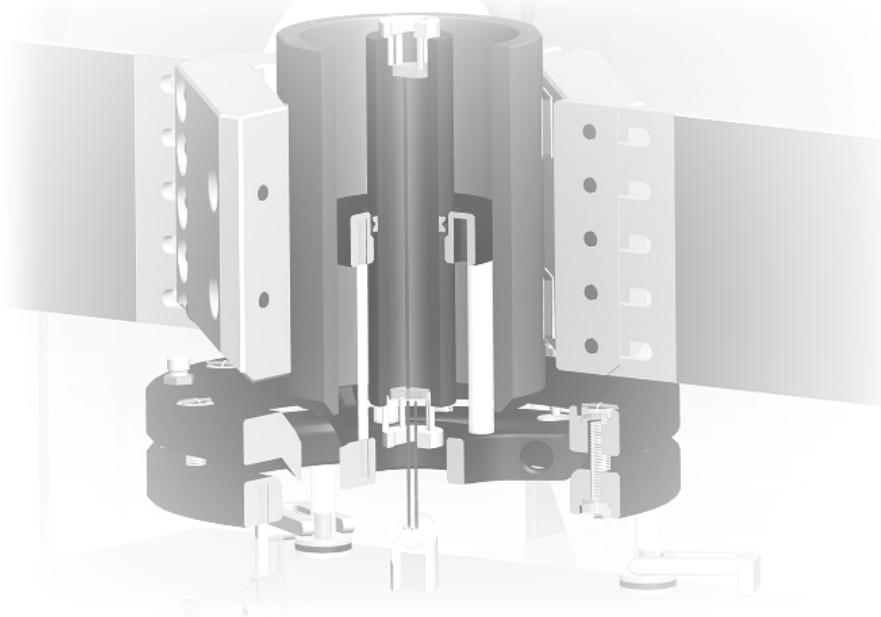
Nächste Schritte...



- Optimierung des mechanischen Aufbaus
- Aktuation des Messstrahls für einen flexiblen Sensorkopf
- Fokussierung des Messstrahls
- Kombination mit einer taktilen Messmaschine zur Erweiterung des Messbereichs
- Vergleich mit Aalen

Anwendung...

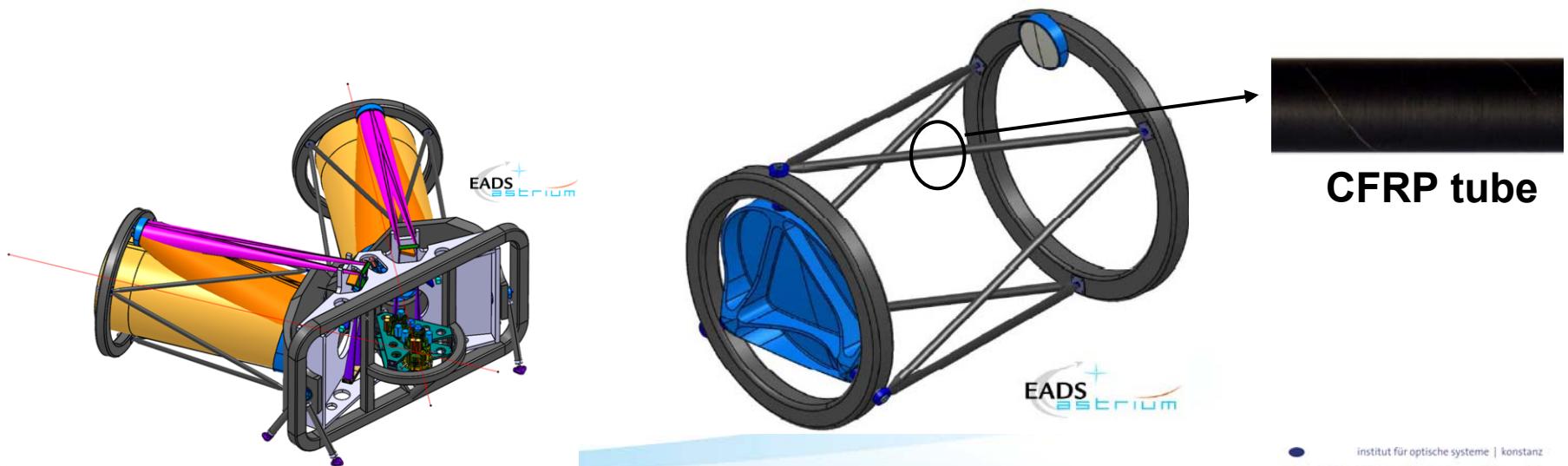
...Dilatometer...



All the space you need

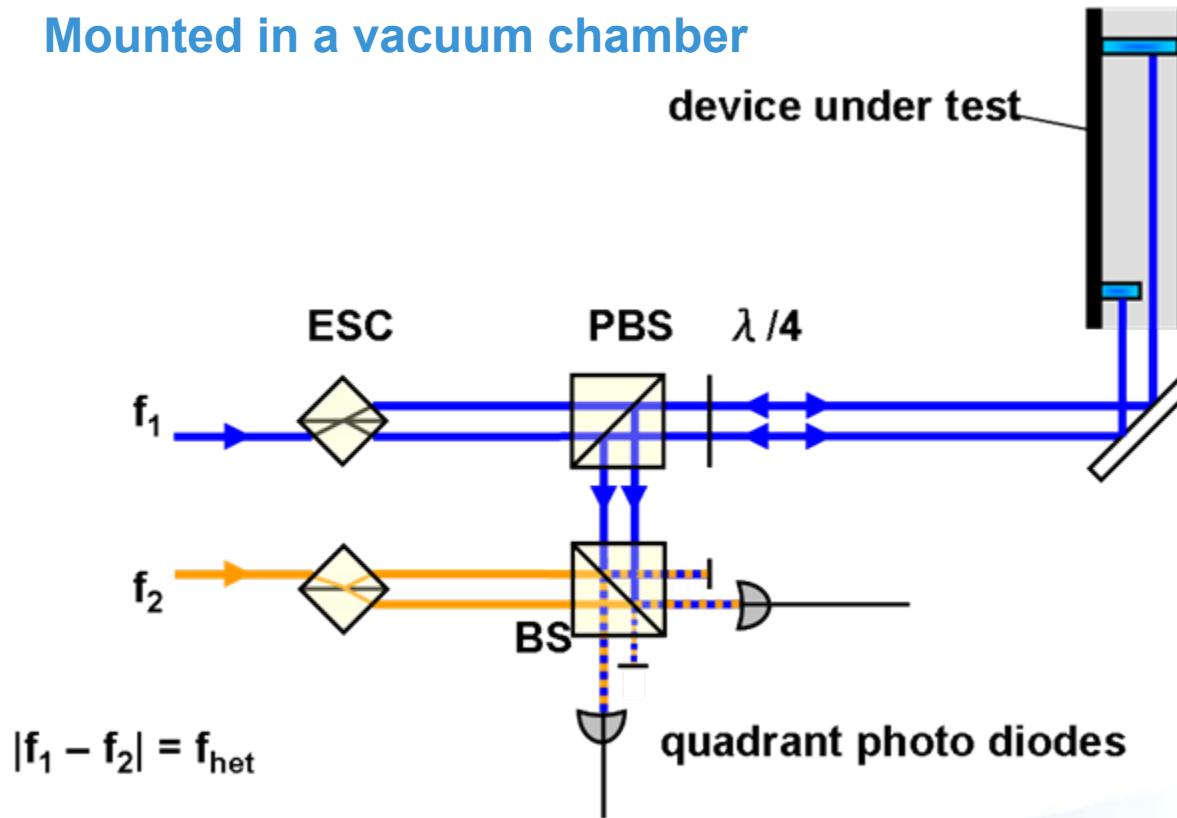
-47-

- **Telescope characteristics & requirements:**
 - Current spacer material: **Carbon-Fiber Reinforced Plastic**
 - Length stability requirement: $10 \text{ pm}/\sqrt{\text{Hz}} @ 1 \text{ mHz}$
 - External temperature -60°C , internal temperature $\approx 20^\circ\text{C}$ to provide an ideal temperature for the metrology performance
- Coefficient of thermal expansion can be at most $0.2 \cdot 10^{-6} \text{ K}^{-1}$ to achieve the measurement requirements



Experiment Setup

- **Heterodyne Interferometer**
 - Heterodyne high symmetric interferometer
 - Mounted in a vacuum chamber



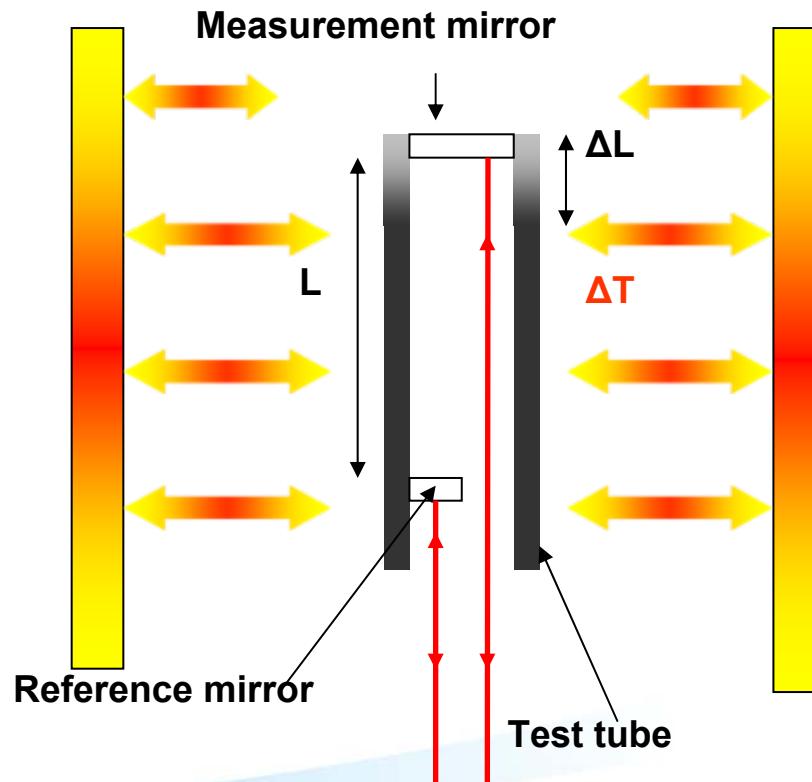
cf. C.-M. Wu, S.-T. Lin, and J. Fu; Optical and Quantum Electronics **34**:
1267 (2002)

All the space you need

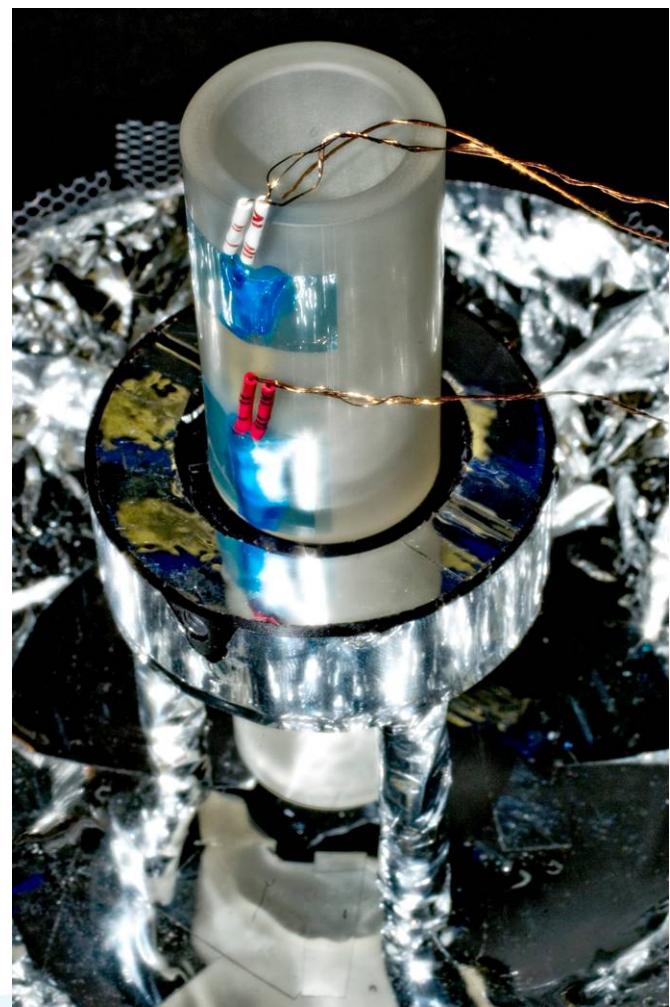
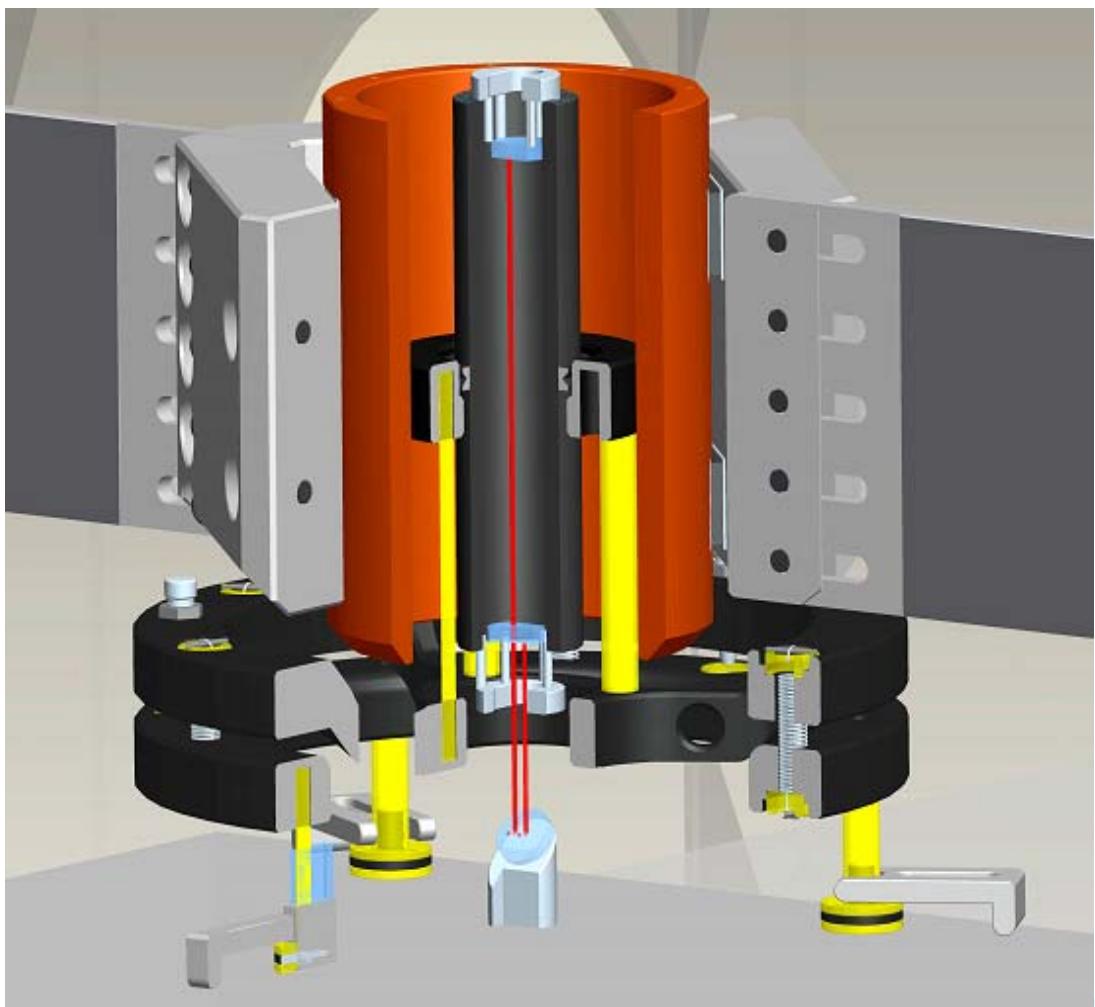
Experiment setup

- **CTE Measurement**
 - ΔL from the Interferometer
 - $\Delta T \rightarrow$ Temperature \rightarrow direct measurement using Pt100 sensors

$$\text{CTE} = \alpha = \frac{\Delta L}{L} \cdot \frac{1}{\Delta T}$$



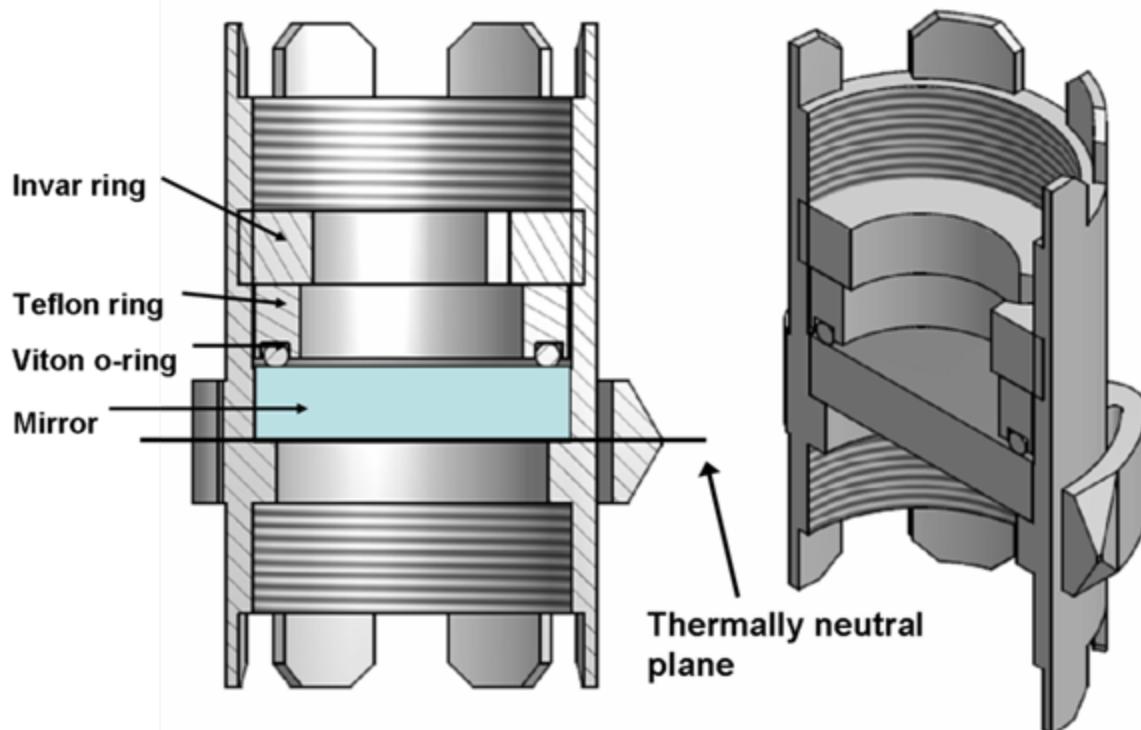
Measurement setup



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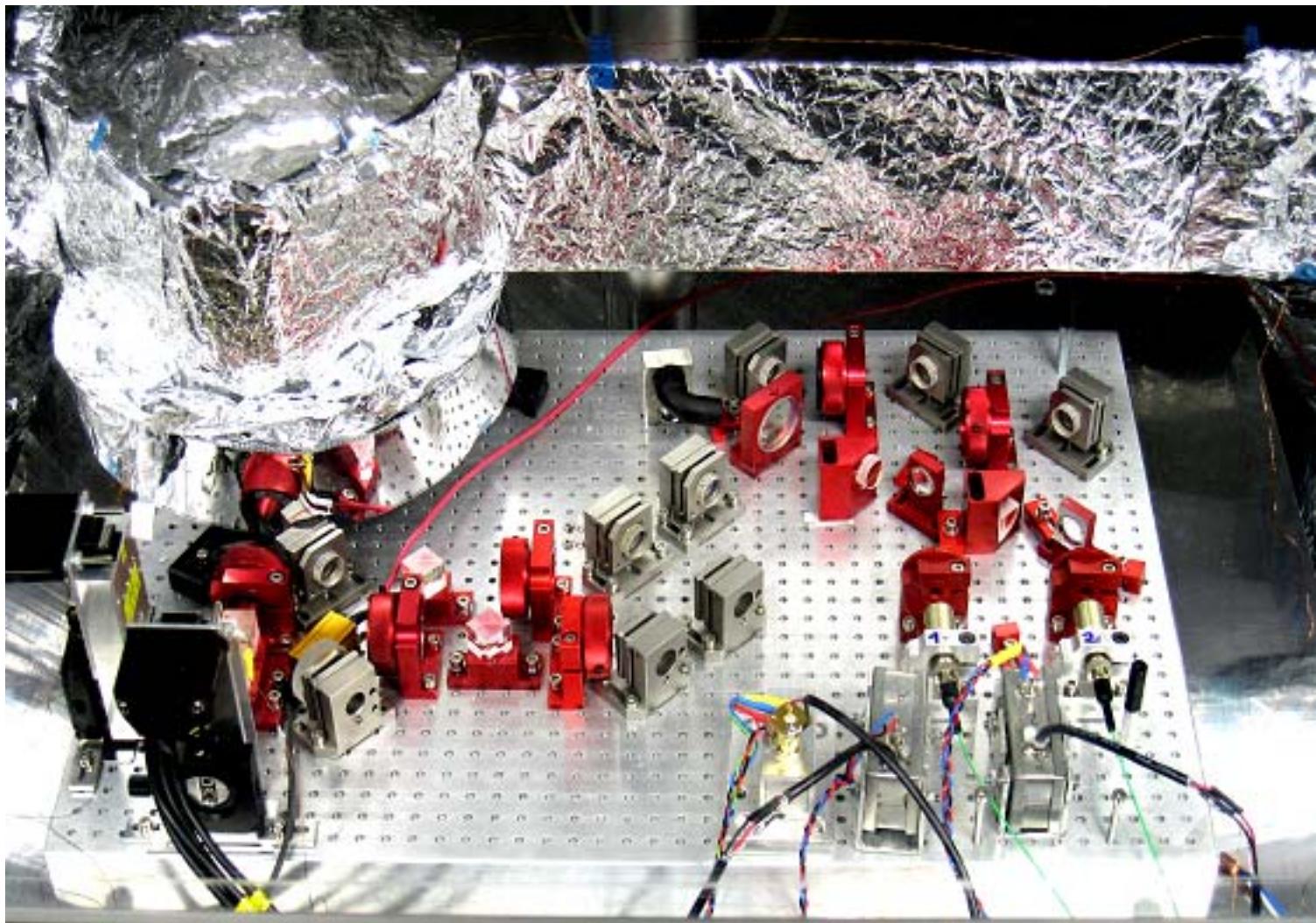
Measurement setup

- **Mirror clamps**
 - Does not influence the measurement
 - Very low thermal expansion (**Invar® CTE \approx 1,8 ppm/K**)
 - To feature a thermally neutral plane at the reflective surface
 - Avoid mechanical damage



Measurement setup

HT
WZL



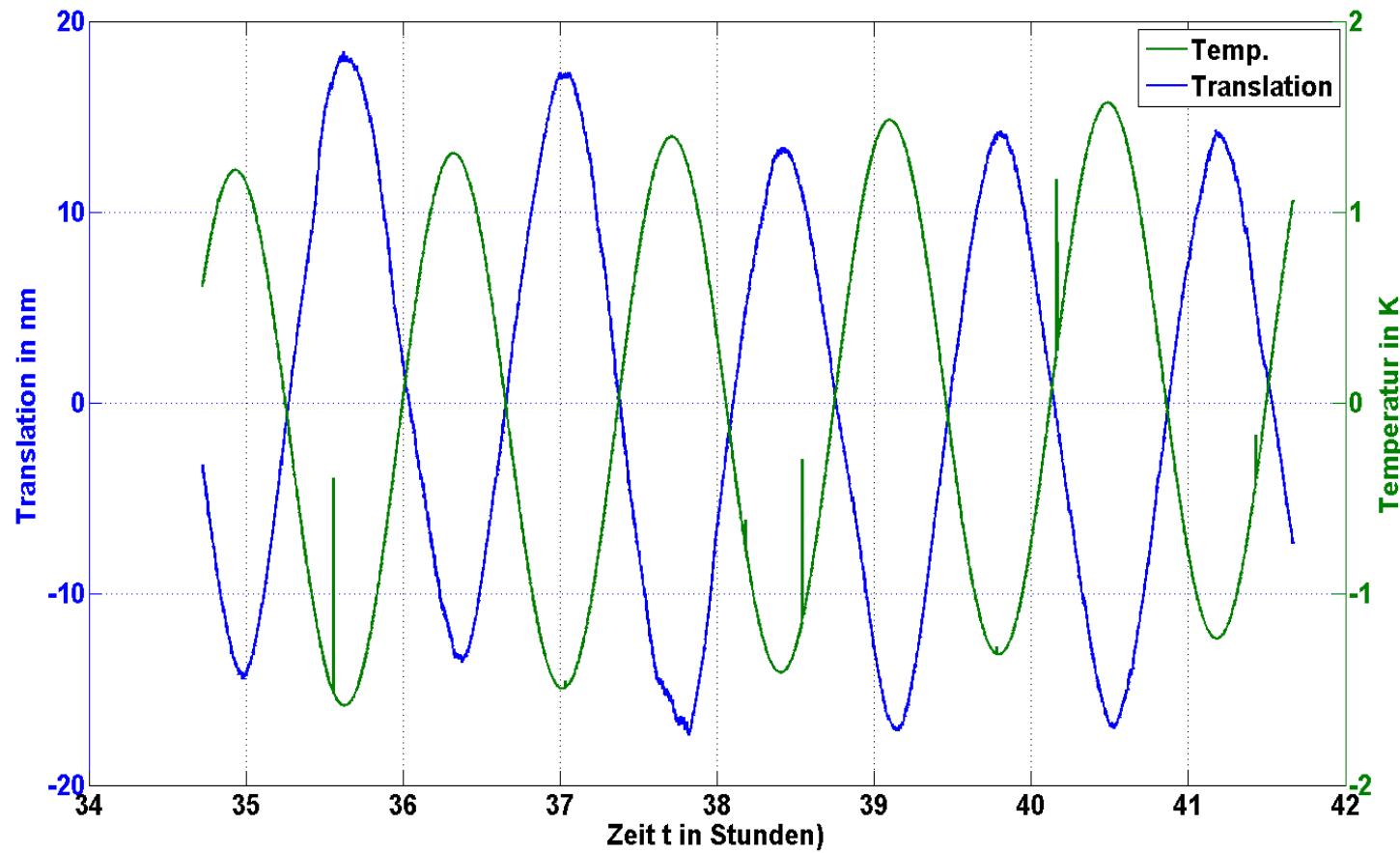
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Measurements and Results

•Amplitude

$$\text{CTE} = -(9,9 \pm 0,1) \cdot 10^{-8} \text{ K}^{-1}$$



- **Compact Laser Interferometer for Translation and Tilt Metrology**
T. Schultdt, M. Gohlke, D. Weise, U. Johann, A. Peters, C. Braxmaier
Int. J. Optomechatronics **1**, 168-179 (2007)
- **Picometer and nanoradian optical heterodyne interferometry for translation and tilt metrology of the LISA gravitational reference sensor**
T. Schultdt, M. Gohlke, D. Weise, U. Johann, A. Peters, C. Braxmaier
Class. Quantum Grav. **26** 085008 (2009)
- **Interferometry based high-precision dilatometry for dimensional characterization of highly stable materials**
J. Cordero, T. Heinrich, T. Schultdt, M. Gohlke, S. Lucarelli, D. Weise, U. Johann, C. Braxmaier
accepted Meas. Sci. Technol.
- **Sub-nanometer heterodyne interferometry and its application in dilatometry and industrial metrology**
T. Schultdt, M. Gohlke, D. Weise, U. Johann, A. Peters, C. Braxmaier
submitted to Int. J. Optomechatronics
- **Ultra-stable integration technologies for optical components using baseplates made of Zerodur**
S. Ressel, M. Gohlke, W. Kronast, U. Mescheder, T. Schultdt, D. Weise, U. Johann, C. Braxmaier
in preparation for Appl. Optics

Zusammenfassung



- **Interferometer**
 - pm- und nrad-Auflösungsbereich für LISA
 - ...und weitere Anwendungen
- **Kompaktifizierung des Aufbaus**
 - Design
 - Aufbau- & Verbindungstechnologie
- **Aktoren:**
 - Strahlstellung
 - Verifikation
- **Anwendungen**
 - Erste Schritte zur Charakterisierung von optischen Oberflächen
 - Dilatometrie

- **Aufbau des kompakten Sensorkopfs**
 - Performance Tests
 - Environmental Tests
- **Fertigung und Tests des Spiegels → Kooperation Furtwangen**
 - Performance Test der Strahlkontrolle
 - Dynamiktest des Interferometers
- **„Profilometrie“ über Stellung des Laserstrahls**
 - Aufbau der Aktorik
 - Entwicklung der Bildverarbeitung
 - Vergleich → Kooperation Aalen