Ultra stable iso-static bonded optical mount design for harsh environments

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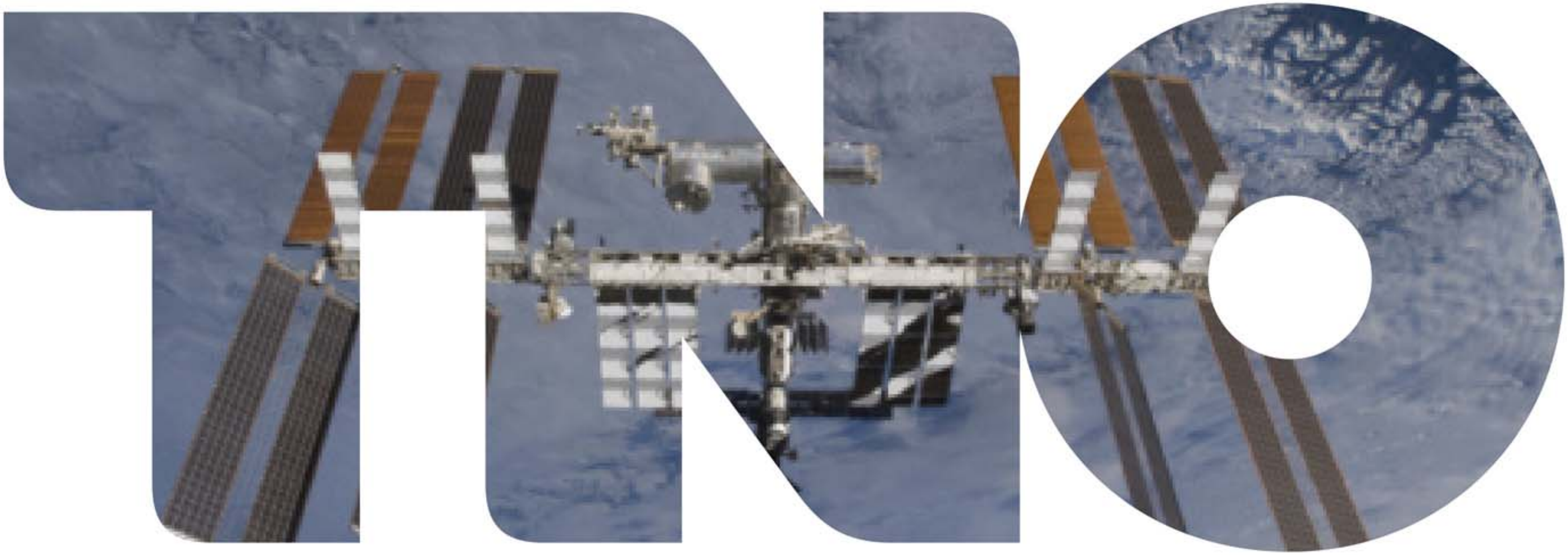



Outline

- Introduction
- Concept of Iso-static bonded optical mount design
  - Design
  - Analysis
  - Testing
  - Application of the mounting concept
  - GAIA WFS
  - TROPOMI
  - LISA PAAM
  - Euclid
- Conclusions

Mounting optics; driving requirements

- **Environmental Requirements**
  - Transport loads:
    - Mechanical: Launch loads
    - Thermal: Thermal survival loads
  - Cryogenic Operational temperatures
  - Vacuum, Zero gravity.

- **Performance Requirements**
  - Alignment
  - **Stability (over life time, incl. launch)**
  - **Allowable Wave Front Error at (cryogenic) operational temperature.**
  - Stress birefringence

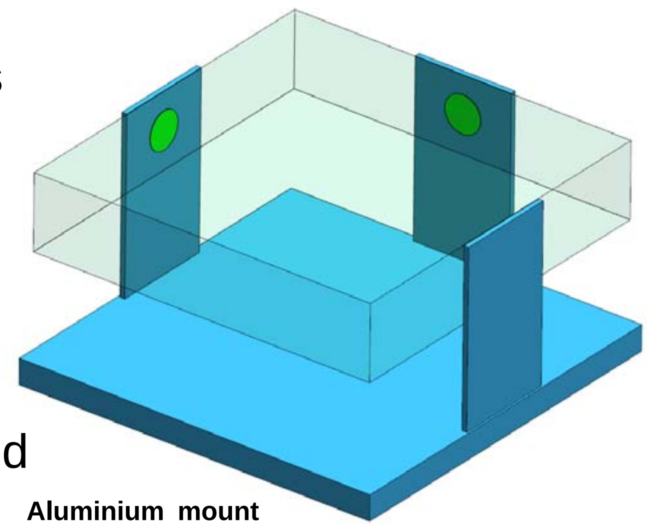
Iso-static bonded mount concept

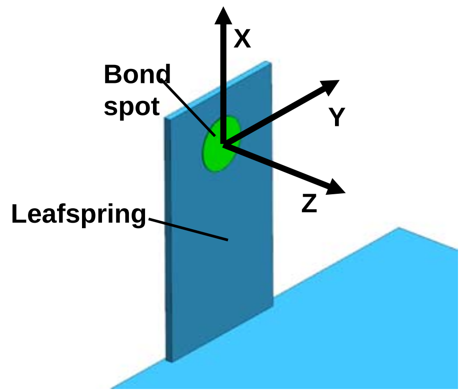
Iso-static design principle:

- Leaf spring has high tensile + shear stiffness but low bending stiffness
- Bond spot has high shear but low torsional stiffness

Each DOF of optical component is constrained once:

- Minimal and predictable forces and moments on optics.
- No bending introduced due to asymmetry in bonding spots or mount.

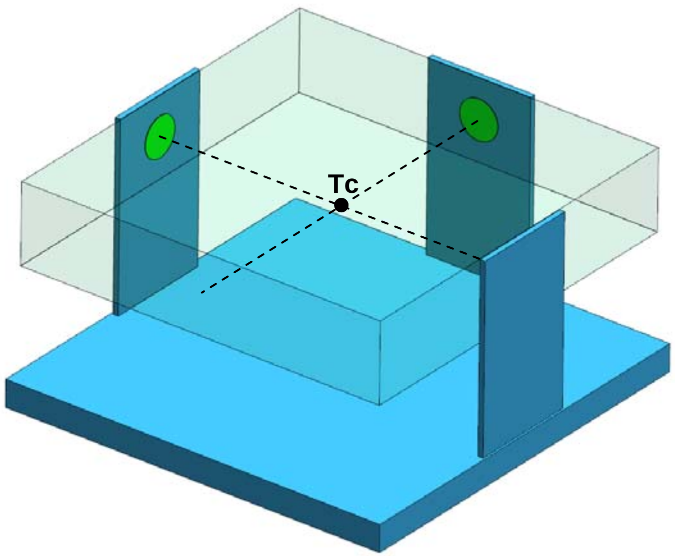


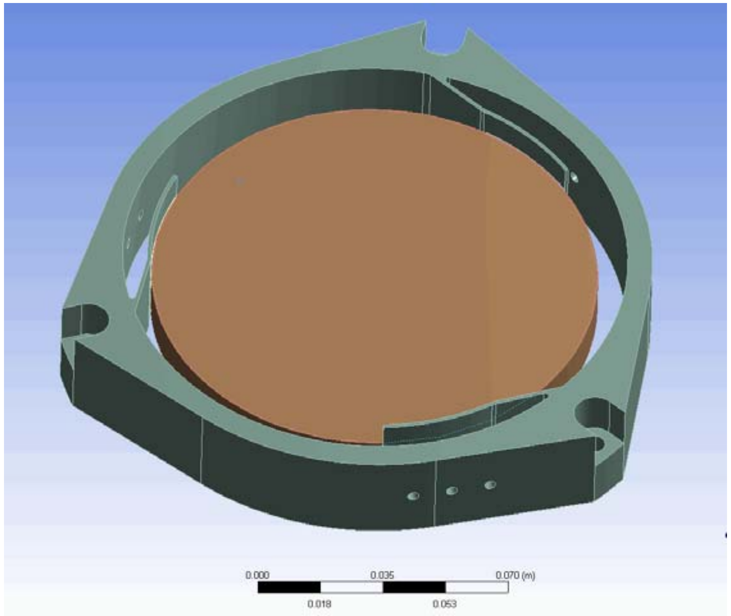


Iso-static bonded mount concept: advantages

- Defined and predictable Thermal Centre (TC) in all 3 translations.
- Large CTE difference between optical and mount material can be coped with, careful selection and dimensioning of adhesive mandatory.
- Mount design to a great extend independent of optical material.
- No CTE matched “intermediate” material mandatory, this avoids large amplification during Random Vibrations of intermediate iso static interface.
- Due to adhesive well damped “rigid” body modes of optics, (Q < 25)
- Alignment of component can be performed with (standard) external tooling and “locked” with bonding spots.
- CTE matching of materials works only as good as you knowledge of the material properties (5%) and works only “perfect” at **one** homogeneous temperature!

Axial vs Tangential leaf spring orientation





- Residual leaf spring bending moment out of plane of optical component: Careful dimensioning of leaf springs mandatory for low WFE.

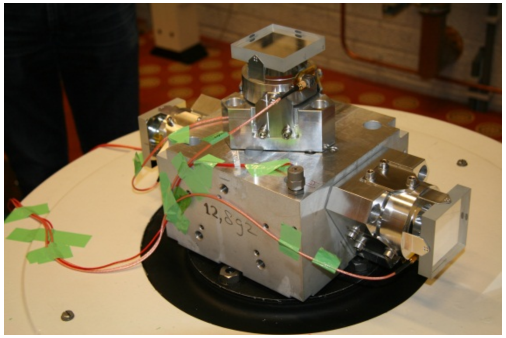
- Small rotation of component due to cool down
- Different envelopes
- Residual bending in plane of the component.

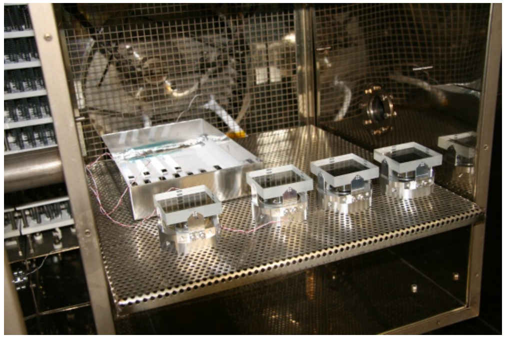

Analysis

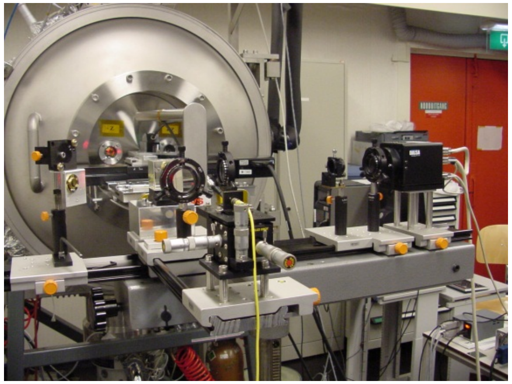
- Dimensioning done with analytical models.
- Adhesive selection based on Visco Plastic/Elastic Adhesive Properties in combination with (Thermal) environment.
- If needed: optimization done with FE analysis:
- Random Vibration analyses.
- Shock analyses.
- WFE and stability prediction under operational conditions.
- Stresses prediction in optics and mount, Visco Plastic/Elastic material properties have been measured and implemented in **in house developed FE Analyses tools**. For details see SPIE 8450-156 Jan de Vreugd et. al.

Environmental testing

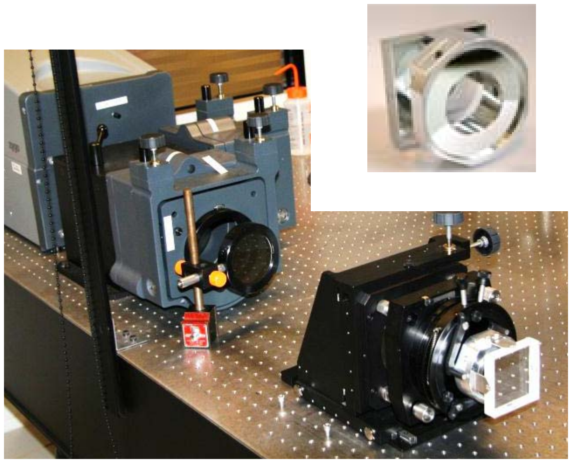
- A typical environmental test campaign for an optical mount consists of:
  - Random vibration testing
  - Shock testing
  - Thermal cycling in Vacuum or Dry N2



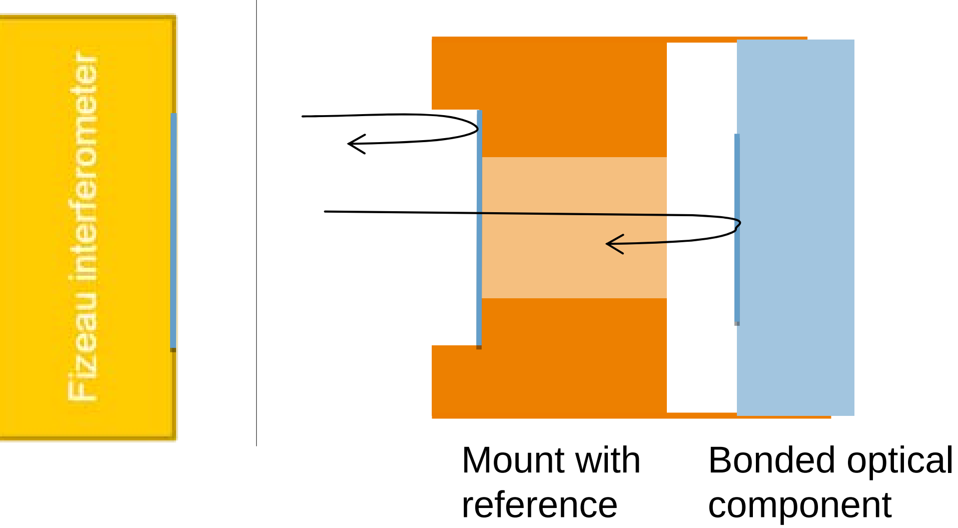




Stability verification by test

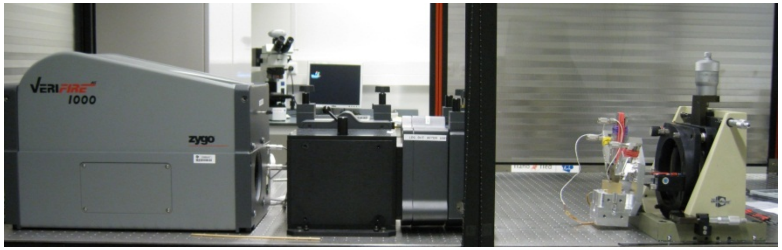


- Zygo Verify interferometer for stability measurement
  - Tip/tilt stability
  - WFE
- Relative measurement between
  - Diamond turned reference on mount
  - Reflective coating on optics
- 0.5 µrad accuracy achievable

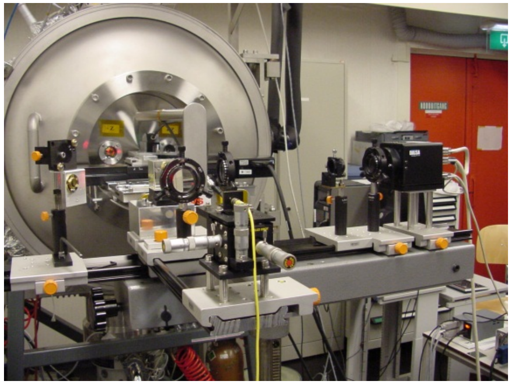


WFE verification by testing

- WFE measurement under operational conditions:
  - Vacuum
  - Cryogenic



- Down to 90 K at TNO test facility and aperture of 100 mm.



- Down to 4 K and aperture of 150 mm at **NOVA Astron**, Dwingelo, The Netherlands.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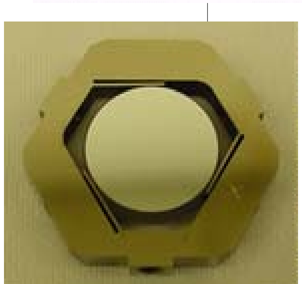
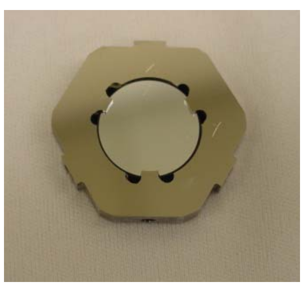
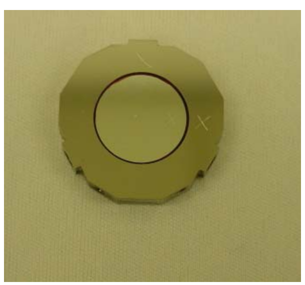
Application: GAIA WFS mounts



Iso-static leafspring



Mechanical mounting



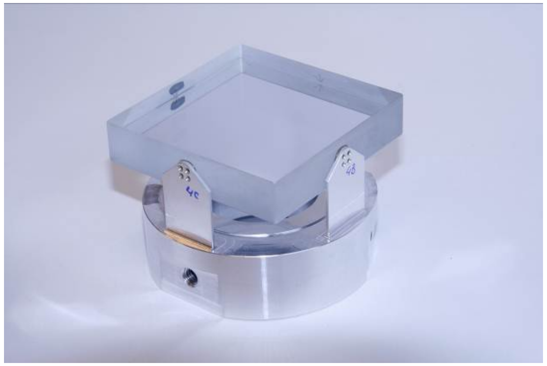
Continuous bond ring

- Various concepts breadboarded
- Leafspring design met all requirements:
  - WFE < 3nm rms
  - Tip/tilt stability < 50 µrad
- Verification testing:
  - Random vibration, 30 grms
  - Thermal cycling, 100K to 350K
  - Stability < 9 µrad
  - WFE at cryogenic vacuum conditions < 24 nm PV

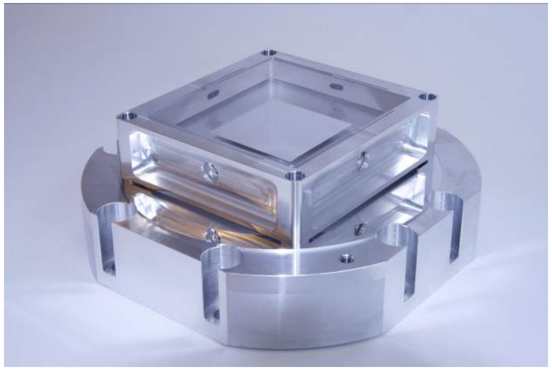
Application: TROPOMI mounts

- Fused silica components bonded to an aluminium mount
- Bond spot optimized to overcome local CTE difference (23 ppm vs. 0.5 ppm)

- Verification by test of breadboard 1:
  - Random vibration 14.4 grms
  - Thermal cycling -50 °C and +45 °C
  - No mechanical degradation
  - Tip Tilt Stability below 5 µrad



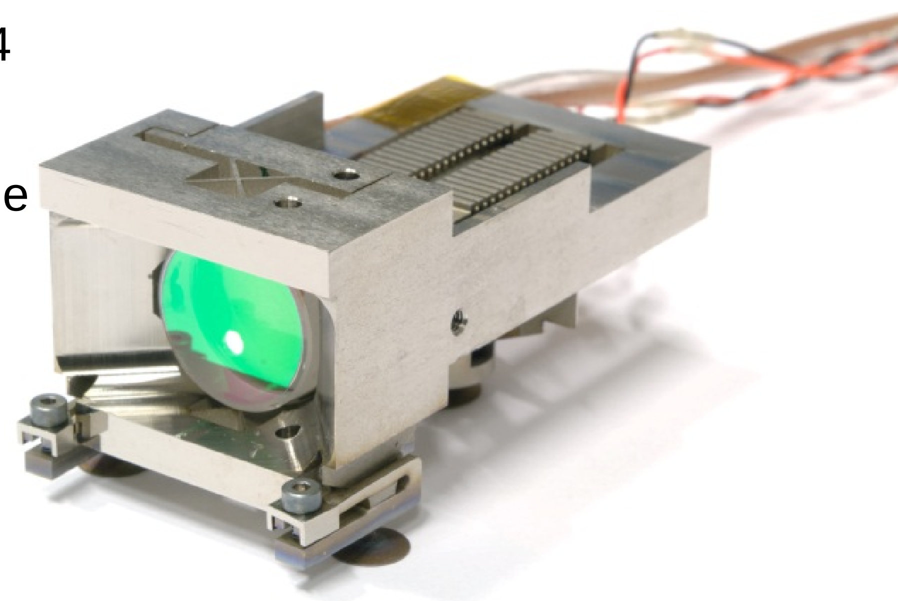
Breadboard 1: 70x70 mm, 0.2 kg



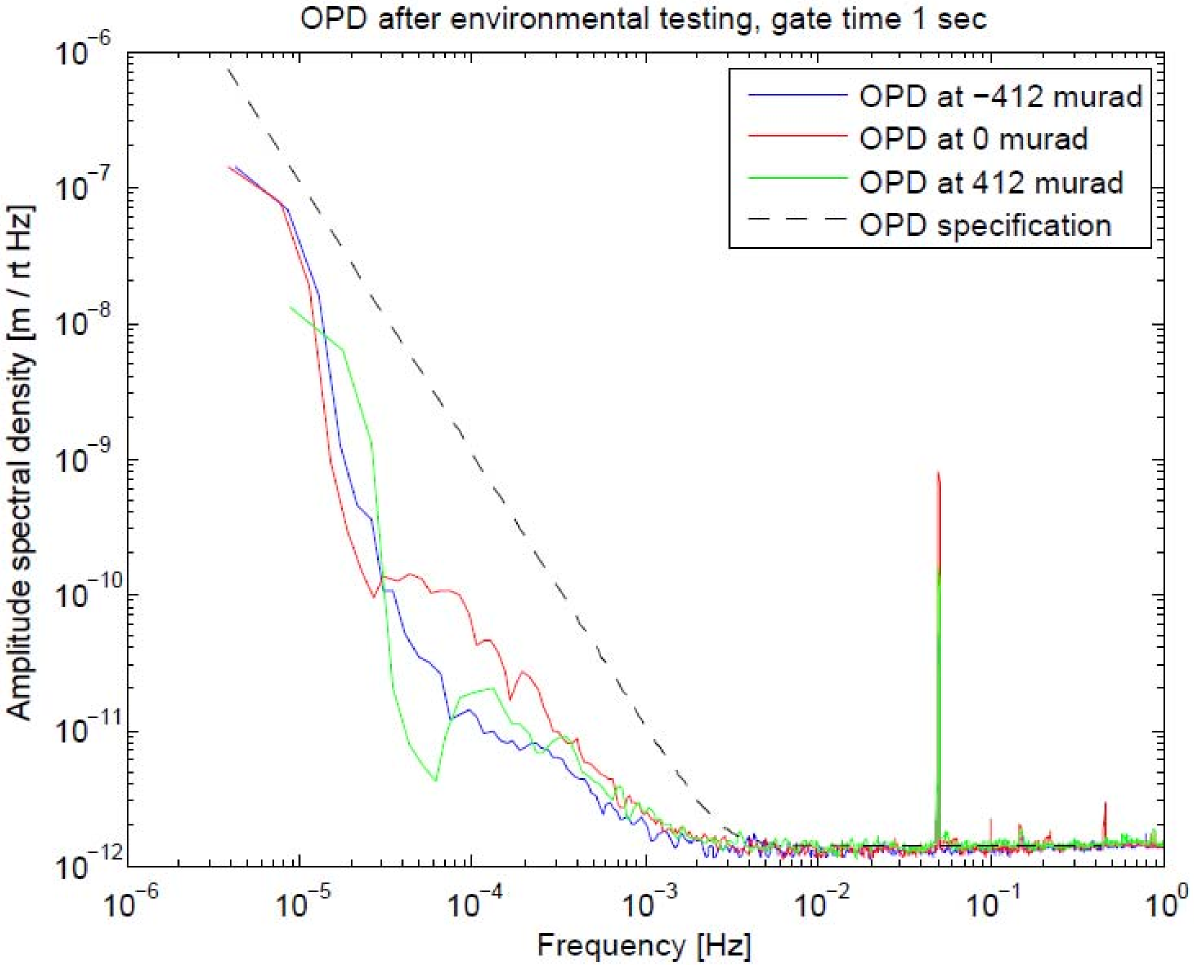
Breadboard 2: 95x95 mm, 0.5 kg

Application: LISA PAAM

- Scan mechanism with picometer stability over hours.
- Bonded Iso static mirror mount implemented.
- Critical requirements.
- Pointing stability over lifetime < 4 micro radians, (incl Launch)
- Piston stability in picometer range during measurement of hours



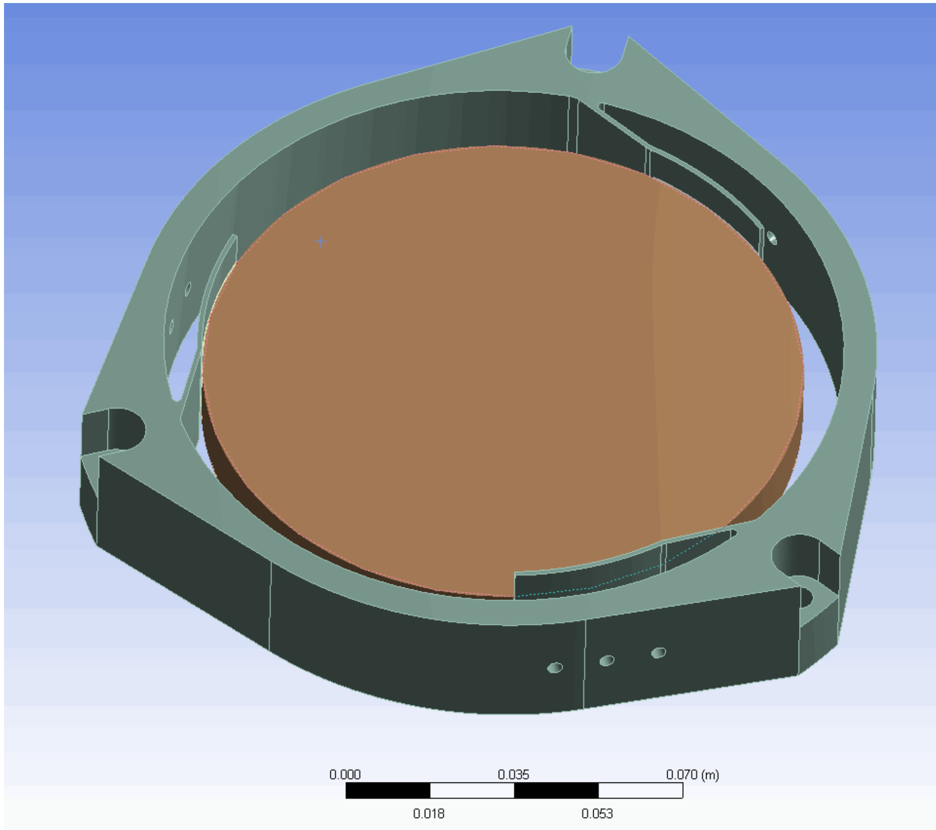
PAA Mechanism Piston stability measurement



Measurement performed by Albert Einstein Institute, Hannover.

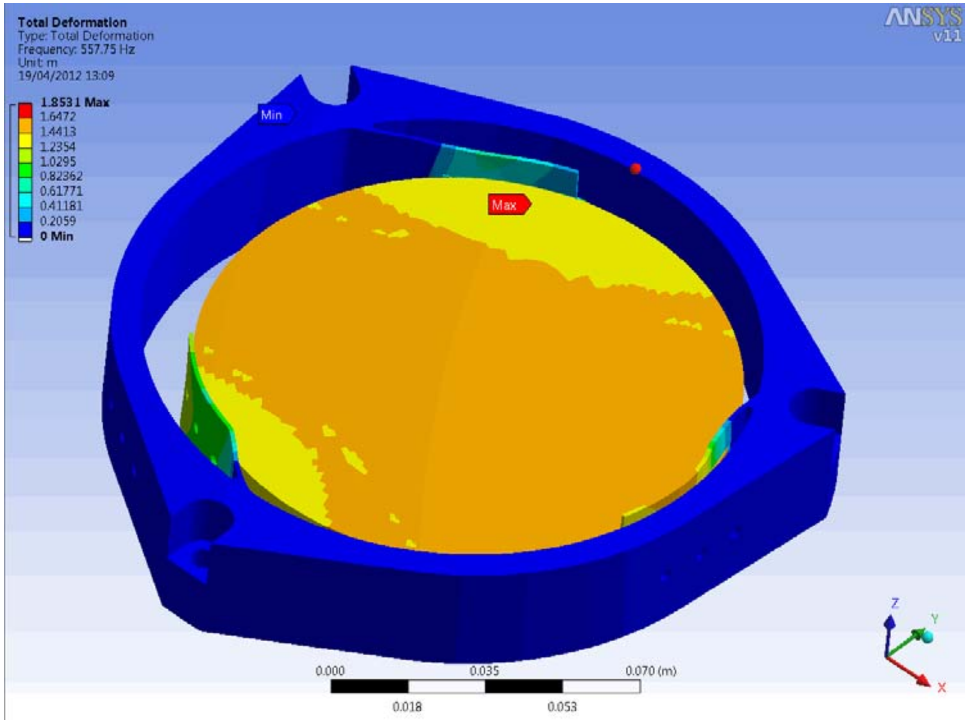
Application: Euclid Cryogenic mount for large optics

- Driving Requirements:
  - 0.5 kg CaF_2 blanks D = 125 mm t = 10 mm
  - 60 g quasi static launch loads
  - 120 K to 313 K Thermal survival range
  - WFE < 68 nm P-V at 140 K
  - Angular stability over life time (including launch and cool down to 140 K) goal: < 25 micro radian.

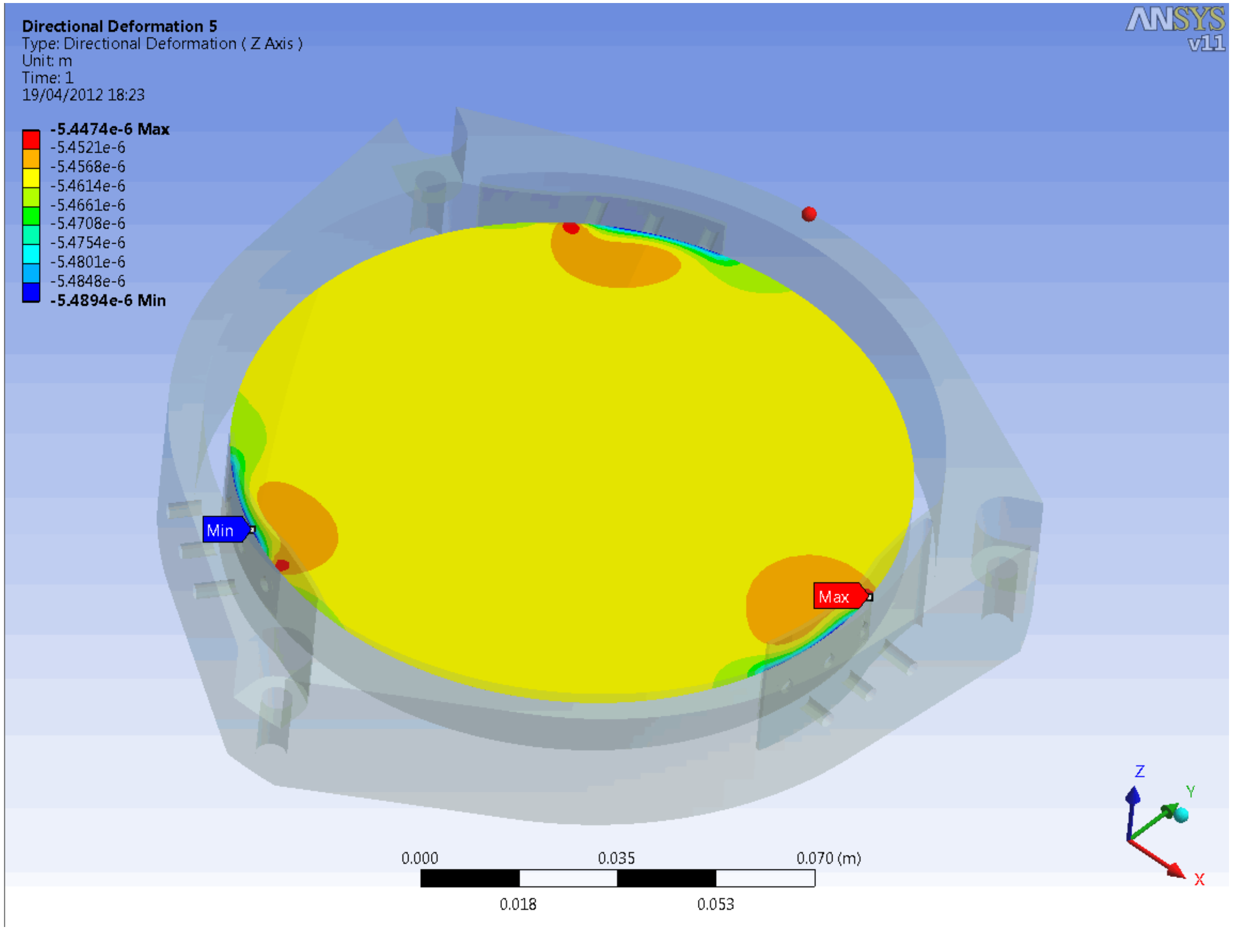


Application: Euclid Cryogenic mount for large optics

- Bonded tangential leaf spring mount.
- Optimized adhesive and leaf spring dimensions and properties for:
  - High stiffness and stability (First mode > 550 Hz)
  - Low stresses in Glass due to launch and cool down (< 4 MPa)
  - Low WFE
- Design ready for manufacturing and testing.



Application: Euclid Cryogenic mount for large optics



Predicted Surface deformation < 42 nm P-V

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Conclusions

- The iso static bonded mount concept can be implemented for various application, main advantages:
  - High stability up to 1 micro radian over life time including launch.
  - Low and predictable WFE.
  - Simple and cost effective design
  - Alignable up to 1 micro radian with external tooling
  - Supported by TNO developed analyses and experimental verification methods.
  - Design, Analyses and Test infrastructure, for WFE measurements at cryogenic temperatures in cooperation with NOVA Astron, Dwingelo, The Netherlands.
- **TNO can in house characterise your adhesives and implement the material models in your FE tools.**

Acknowledgements

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- Astrium EADS
- Dutch Space, Leiden, The Netherlands
- Albert Einstein Institute, Hannover, Germany
- NOVA Astron, Dwingelo, The Netherlands

TNO likes to thank all of them for their contribution!

Thanks for your attention!

Questions?