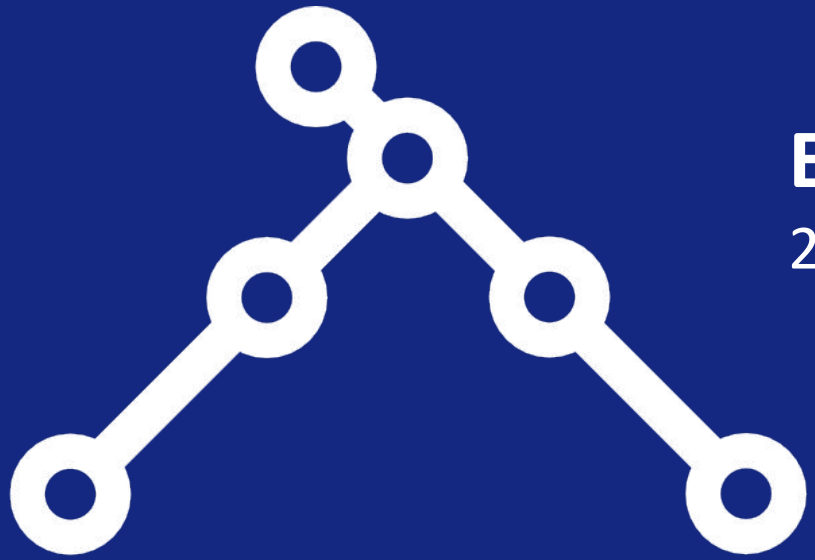


ETpathfinder workshop

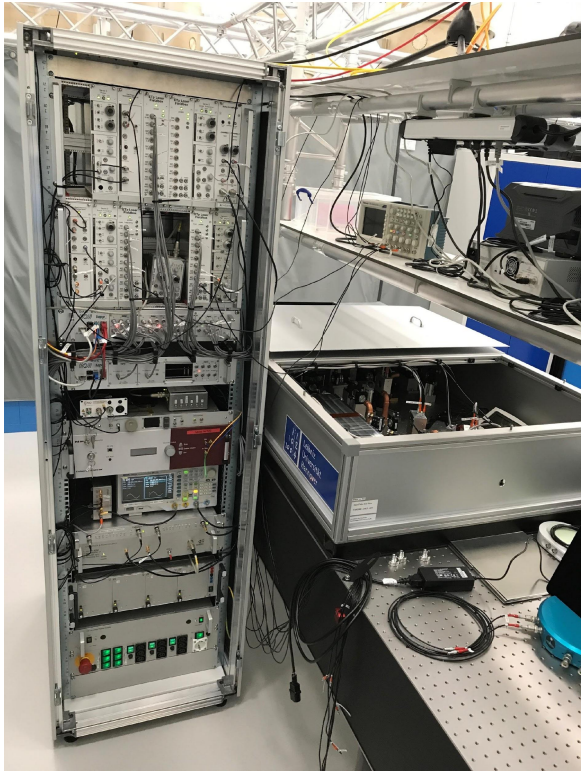
2025-06-03

WP6 Optics

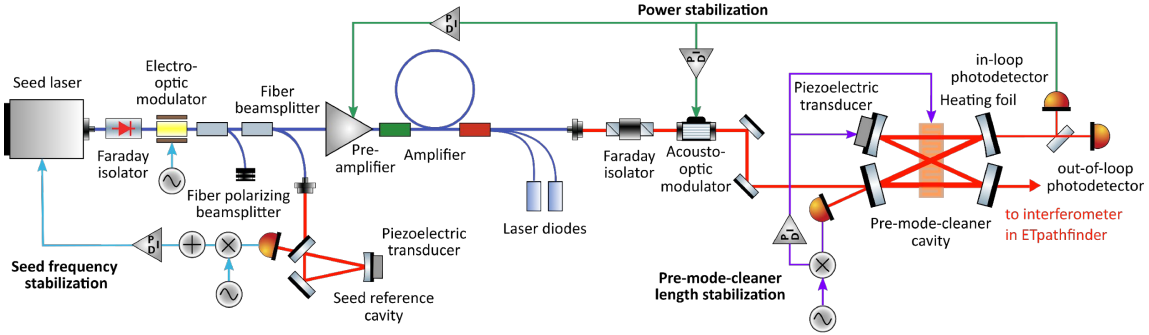
S. Steinlechner, M. Vervaeke
for ETpathfinder team

Interreg
EUROPESE UNIE
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

1550 nm Laser



- Pre-stabilized laser system arrived in April 2024 in Maastricht
- Current location: laser corner
- Will soon be moved next to vacuum system for aligning to input mode cleaner in beamsplitter tower



Git\niknus\ET_Pathfinder_Laser\Pictures\Drawings\Set-up

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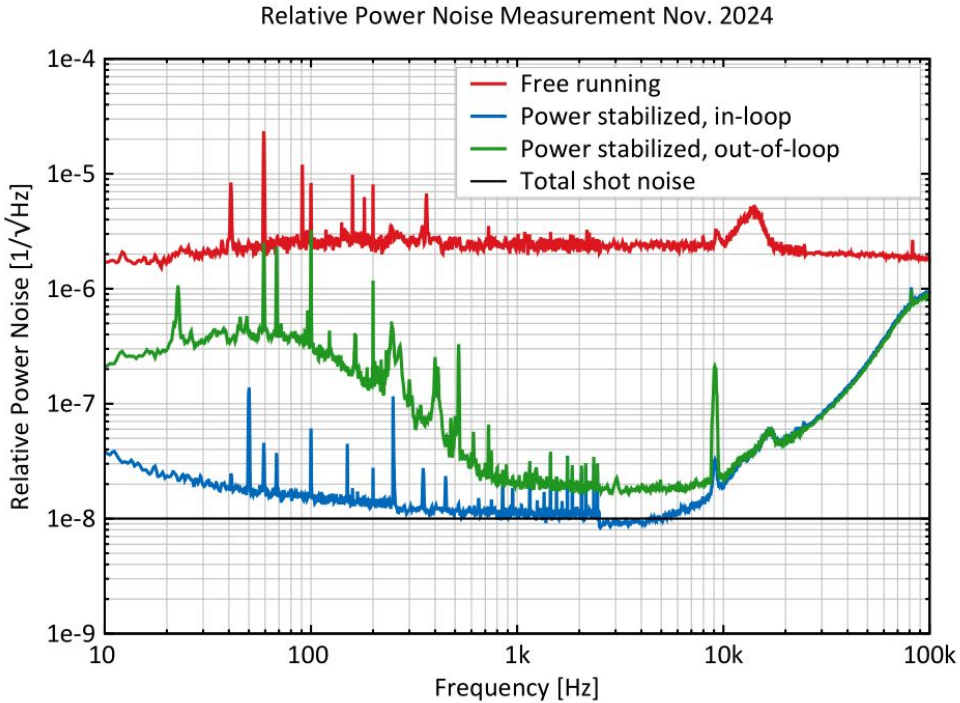
1550 nm Laser – Power Stabilization



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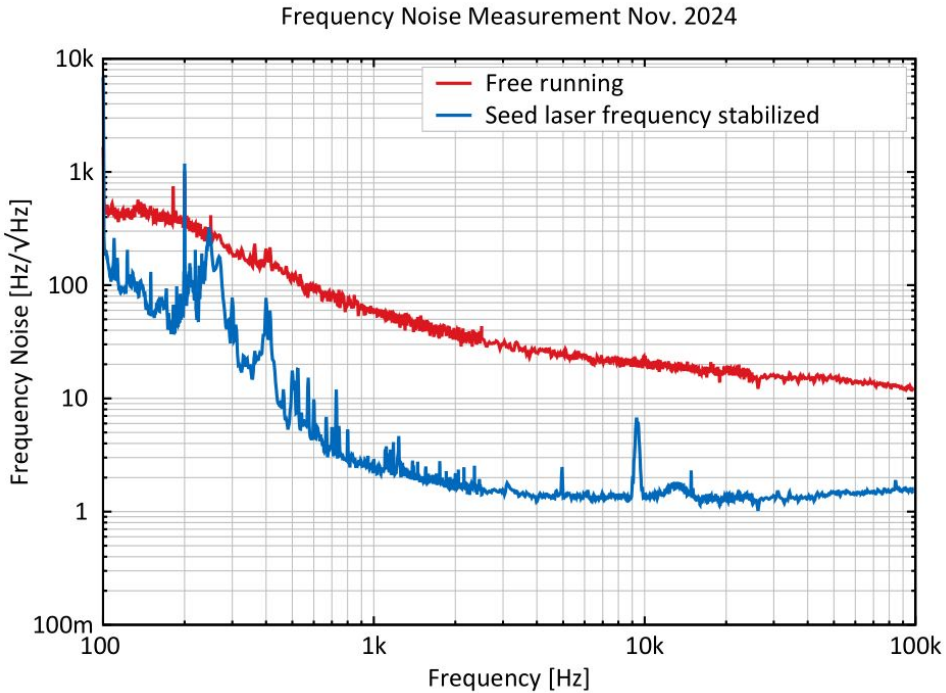
20250519_RPN_Slides_ETpathfinder_Workshop

Next steps:

- Remove increased out-of-loop noise at low frequencies
- Reduce out-of-loop noise to shot noise level
- Investigate relative power noise downstream of input mode cleaner in vacuum tower

1550 nm Laser – Frequency Stabilization of Seed Laser



Next step:

- Implement outer frequency stabilization control loop using input mode cleaner in vacuum tower as reference

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20250519_FN_Slides_ETpathfinder_Workshop

2090nm investigations

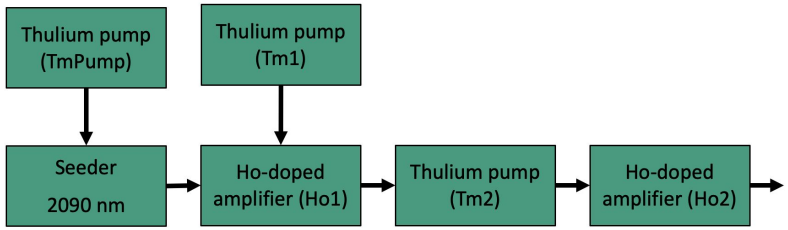
Status of 2090 nm laser

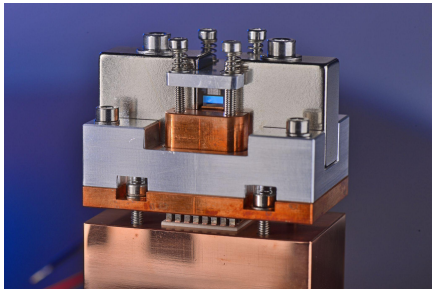
- NPRO:
  - Narrow linewidth operation at 2090 nm
  - Up to 50 mW output power

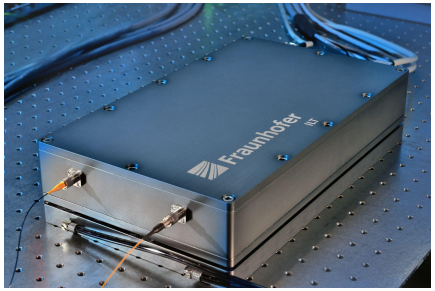
- Fiber amplifier:
  - Amplification to >10 W output power
  - Narrow linewidth, linear polarization
  - Power stability RIN at 100 Hz: $<10^{-5}$ $Hz^{-0.5}$

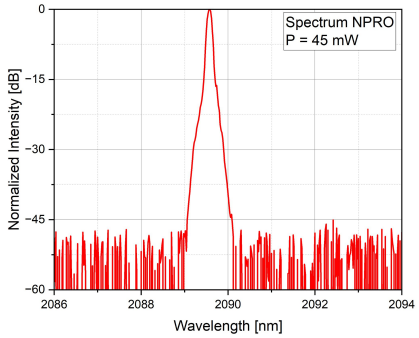
Current investigations:

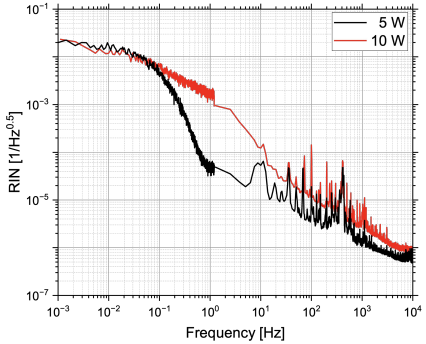
- Active power stabilization of NPRO seed laser
- Further development of thulium-doped pump laser Tm2 (Beam quality and power stability)
- Mode cleaner cavity design





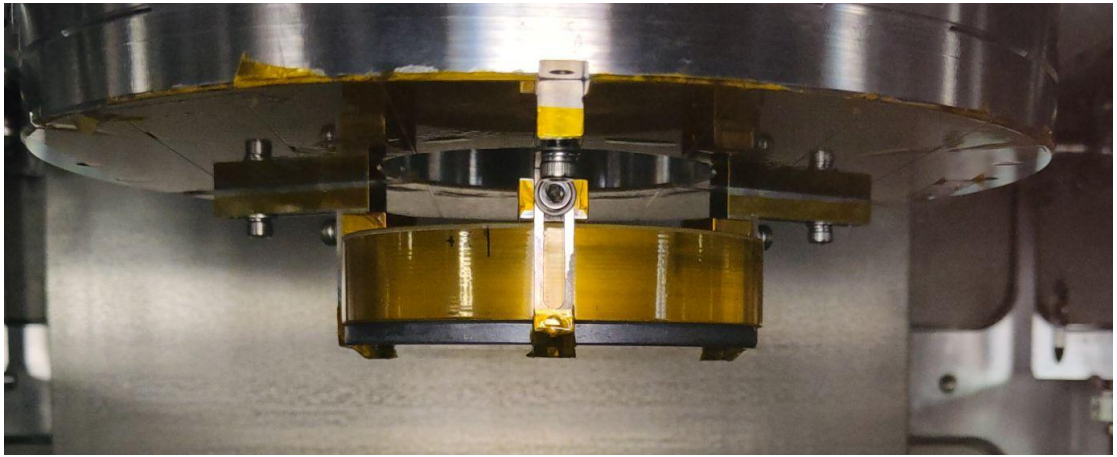




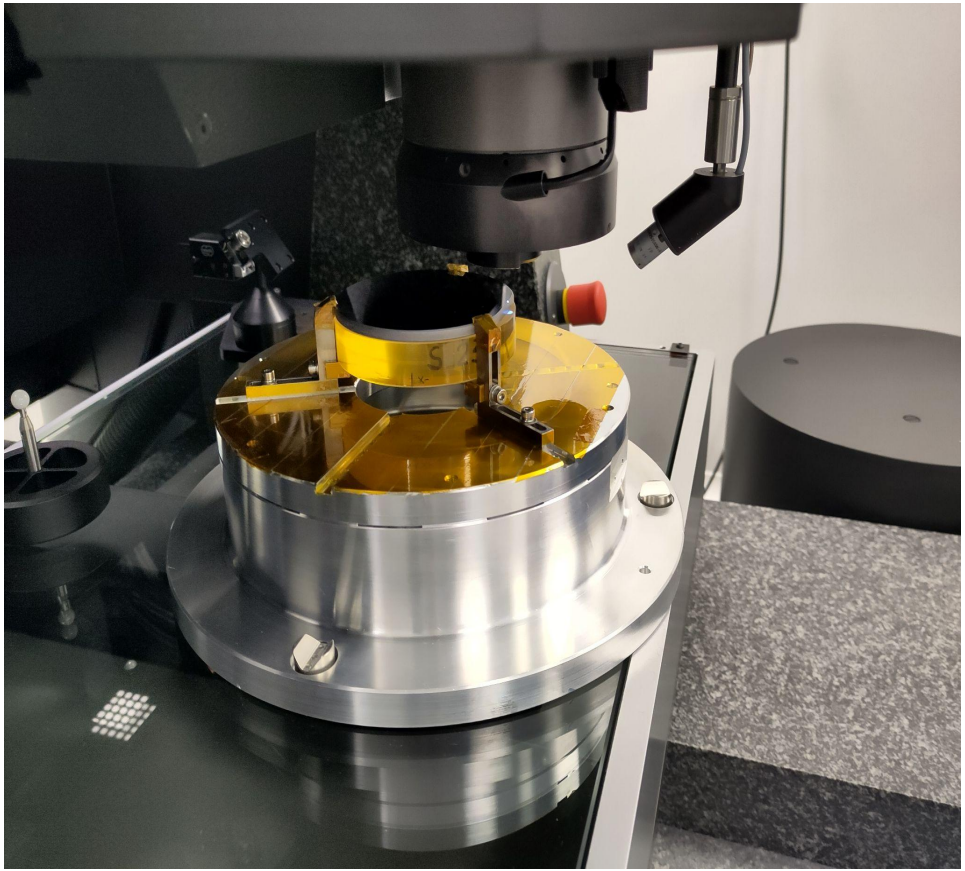


VUB B-PHOT: ongoing acceptance testing ion beam figuring

- Up to D200mm optics through the loadlock
- 5-axis ion gun motion
- Integrated removal function analyser
- Fully 24/7 operation
- Loadlock through cleanroom ISO7
- Plasma cleaning in the loadlock

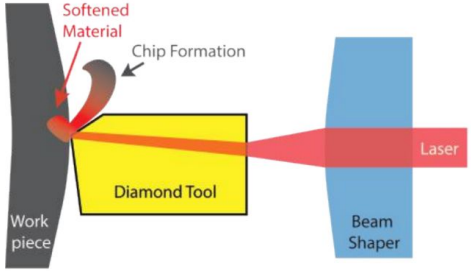


VUB B-PHOT: ongoing acceptance testing ion beam figuring

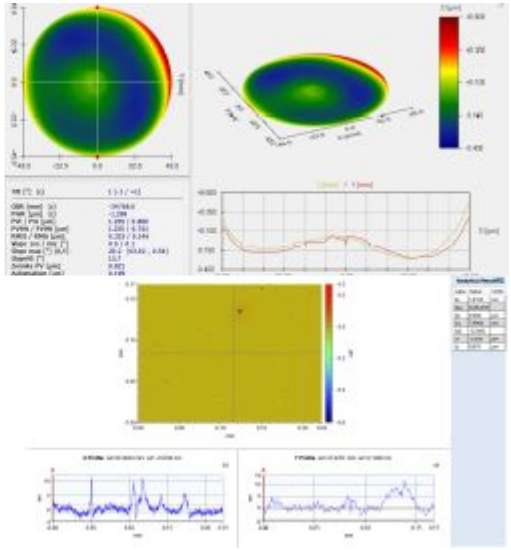


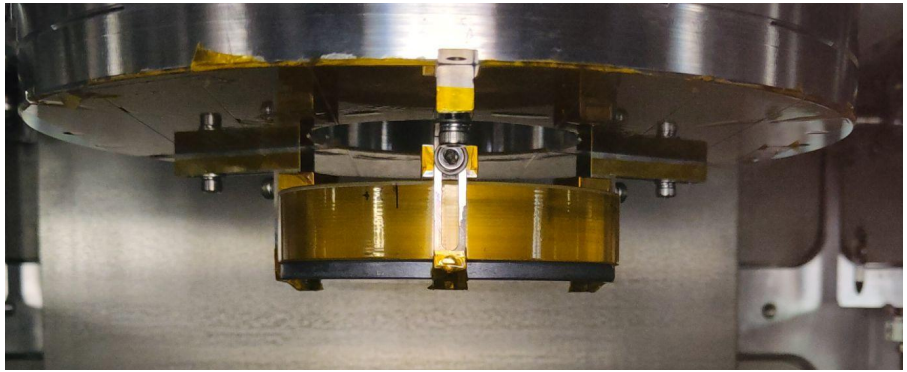
Start of first experiments: May 30th
(Silicon CZ flat)

VUB B-PHOT: ongoing acceptance testing ion beam figuring



- Preshape:
  - Laser-assisted diamond turning Si
  - PV: 0.8µm (can be improved)
  - Sa: 6.3nm
  - SiO2 based post-polishing





VUB B-PHOT: ongoing acceptance testing ion beam figuring

- CZ Si test figuring
  Started May 30th EOB

VUB B-PHOT: ongoing acceptance testing ion beam figuring

Next step (as of May 30th 2025):

- Ion beam figuring
- Outlook do drop PV error quickly
- Based on process simulations
- Very first results June 2nd EOB

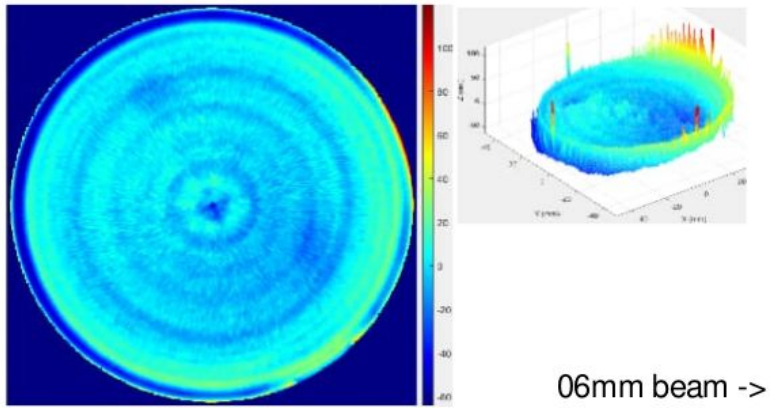
Challenge:

Roughness 0.1 nm spec => only with post-polishing with dedicated slurry composition

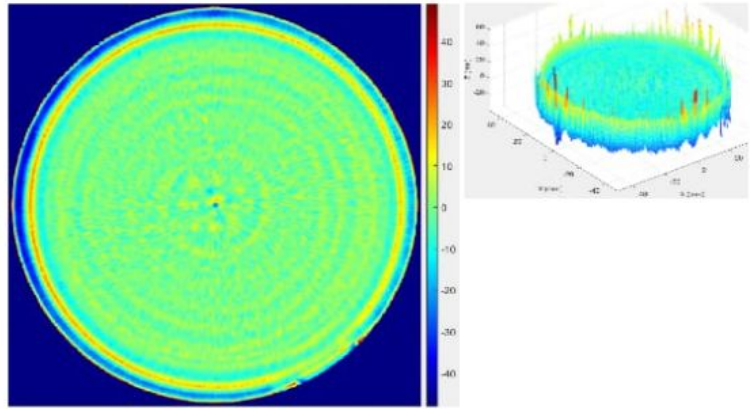
Results after iterative processing

	Beam: 09	Beam: 06	
PV $_{(OS)}$:	270	126	nm
PV $_{(CA)}$:	80	58	nm
rms $_{(OS)}$:	17	8.4	nm
rms $_{(CA)}$:	6.1	4.4	nm
Duration:	4H27	2H28	hours

09mm beam ->

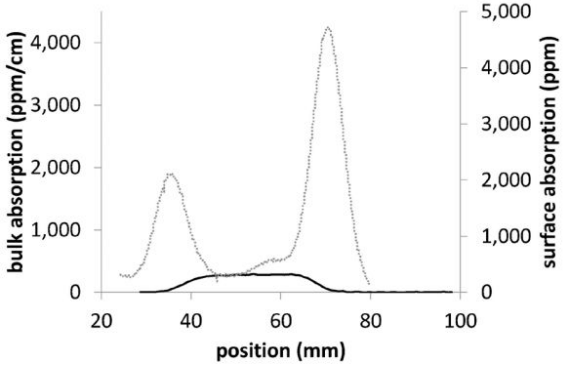


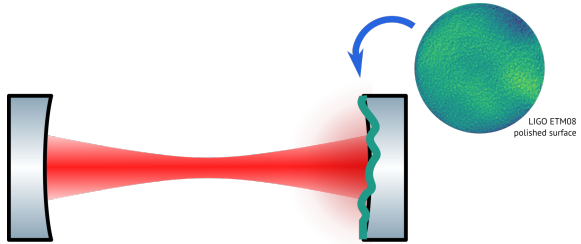
06mm beam ->

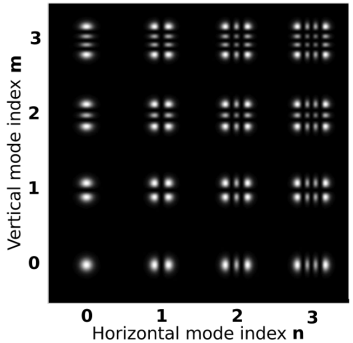


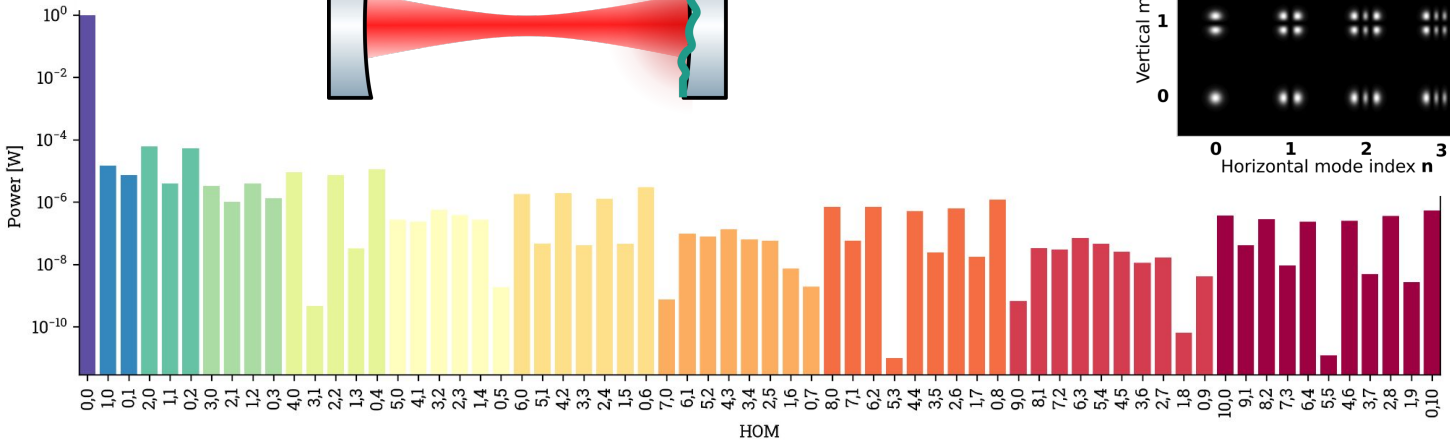
Investigation of Zeiss mirrors

- Two mirrors produced to full specifications by Zeiss
- We now have the option to procure (up to) 6 more (go for 2 for now?)
- need to make sure we are decently happy with them
  - analyse surface map data provided by Zeiss
  - analyse surface absorption at LMA (with third sample, w/o flats)

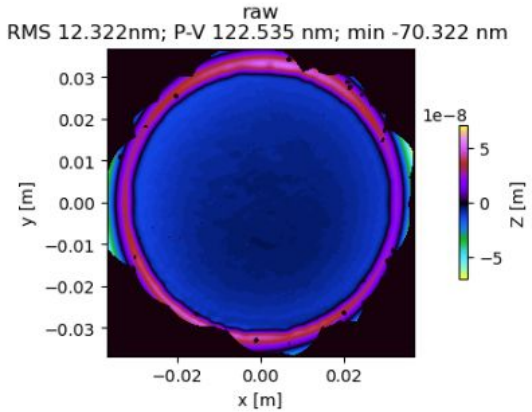


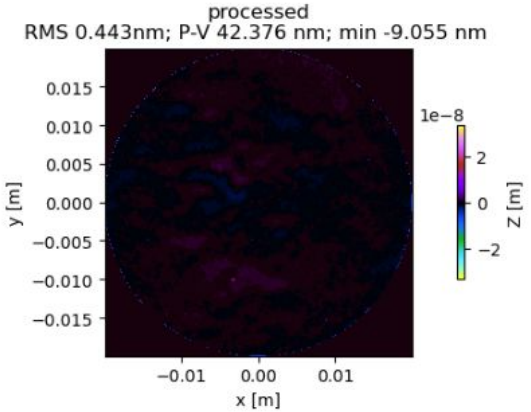


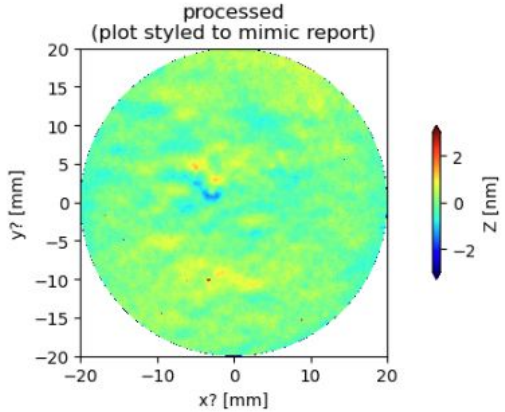


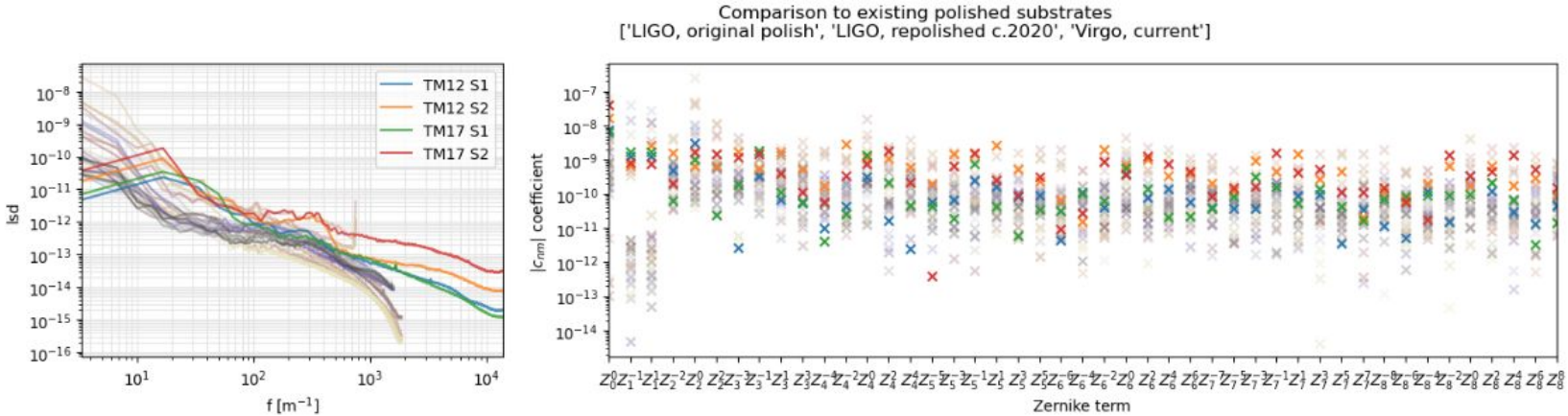


Looking into surface maps (all preliminary!)

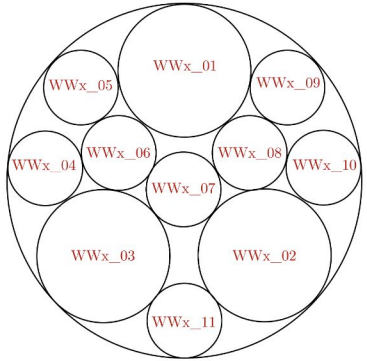


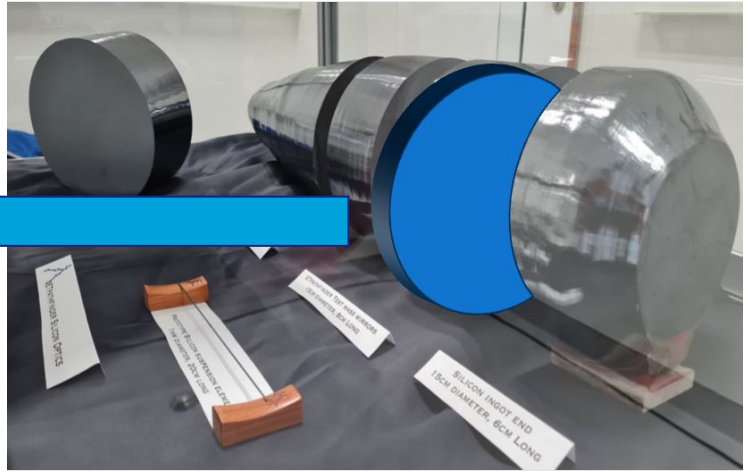






Silicon Characterization

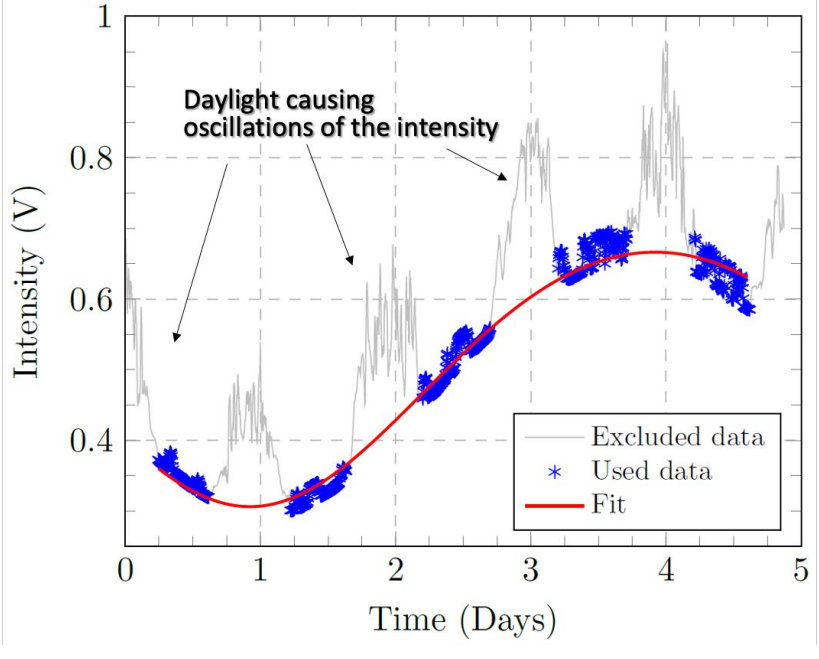




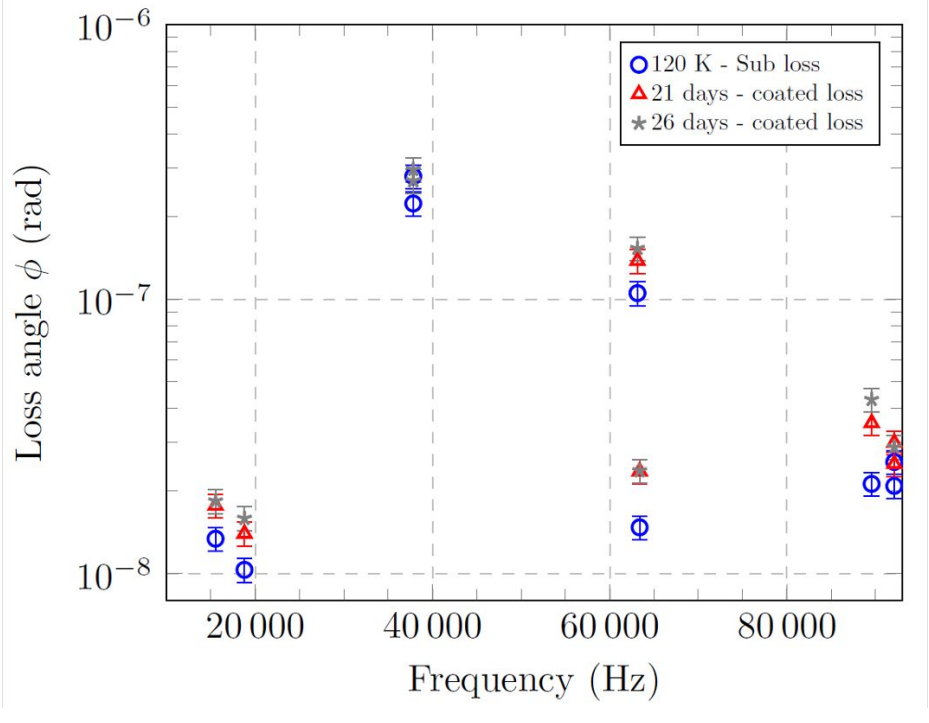
Temperature-dependent measurement of mechanical loss of silicon samples cut from our ingots (50mm x 5mm disks) show quite low loss and clear loss dip at around 120K.
Setup cannot (yet?) go to the very low temperatures, i.e. <20K where we expect the loss again to become very low.

Ice investigation

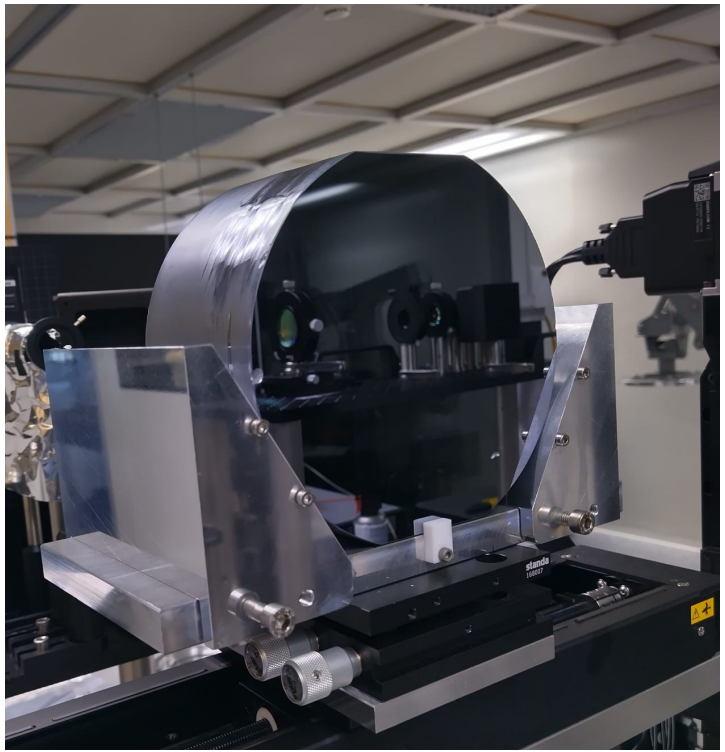
- From the fit we derived a growth rate of 42 nm/day
- Final ice thickness of ~1.1 µm.



- Ice growth on sample's surface for 26 days.
- Mechanical loss checked after 21 and 26 days.
- The total loss increased of 1.5 on average considering all modes.



Absorption loss and Coatings at LMA



To further check the surface quality of cutting and polishing, a dummy substrate polished by Zeiss has been sent to LMA to check optical absorption of surface and bulk material.

LMA just received the sample and tested the new mount.

Everything ready to start the measurement!

Absorption loss and Coatings at LMA

Considering ETpathfinder sensitivity, testing new coating materials is not a priority.

Photo_IN2P3_Patrick_Dumas_Fev2019

Mirrors will be SiO_2/Ta_2O_5 coating
(current GW detectors have $SiO_2/TiO_2:Ta_2O_5$)

Coating deposition will be done in the Veeco Spector IBS machine:

- ➔ One mirror at the time
- ➔ Extra care needed to meet requirements for "identical" mirrors

NGF: Optics Consortium

- Investigation of polishing steps: sawing, grinding, laser assisted SPDT & MRF polishing, wet-etching on crystal structure, ion beam figuring
- Development of metrology for surface-quality characteriation
  ⟶ aims: meet optical ET surface-quality requirements without excess surface absorption; track down source of surface absorption

- Characterisation of low-absorption magnetically purified Czochralski silicon
- Bonding of silicon: investigation of mechanical and optical properties of the bond
  ⟶ aim: find ways of reaching test-mass size required for ET

- Coating development: Explore effect of coatings on silicon (surface) quality

Partner:

- Cosine (consortium lead)
- SRON
- VSL
- TNO
- NOVA
- Maastricht University

Work Packages:

- WP1000 ‘Mirror polishing development’ ⟶ Boris Landgraf (cosine)
- WP2000 ‘Characterization silicon absorption’ ⟶ Jessica Steinlechner (MU)
- WP3000 ‘Metrology system development’ ⟶ Ramón Navarro (NOVA)
- WP4000 ‘Bonding method development’ ⟶ Marloes Bistervels (cosine)
- WP5000 ‘Coating development’ ⟶ Jessica Steinlechner (MU)
- WP6000 ‘Optics valorization’ ⟶ Ramón Navarro (NOVA)

Questions & Tasks

- single cavity experiment
  - timelines from cryo, suspension, vacuum, controls
  - planning of layout (e.g., which side to use), required components
  - build-up of required aux suspensions, optics, detectors
  - key measurements?
- availability and ambitions of people for assembly and commissioning