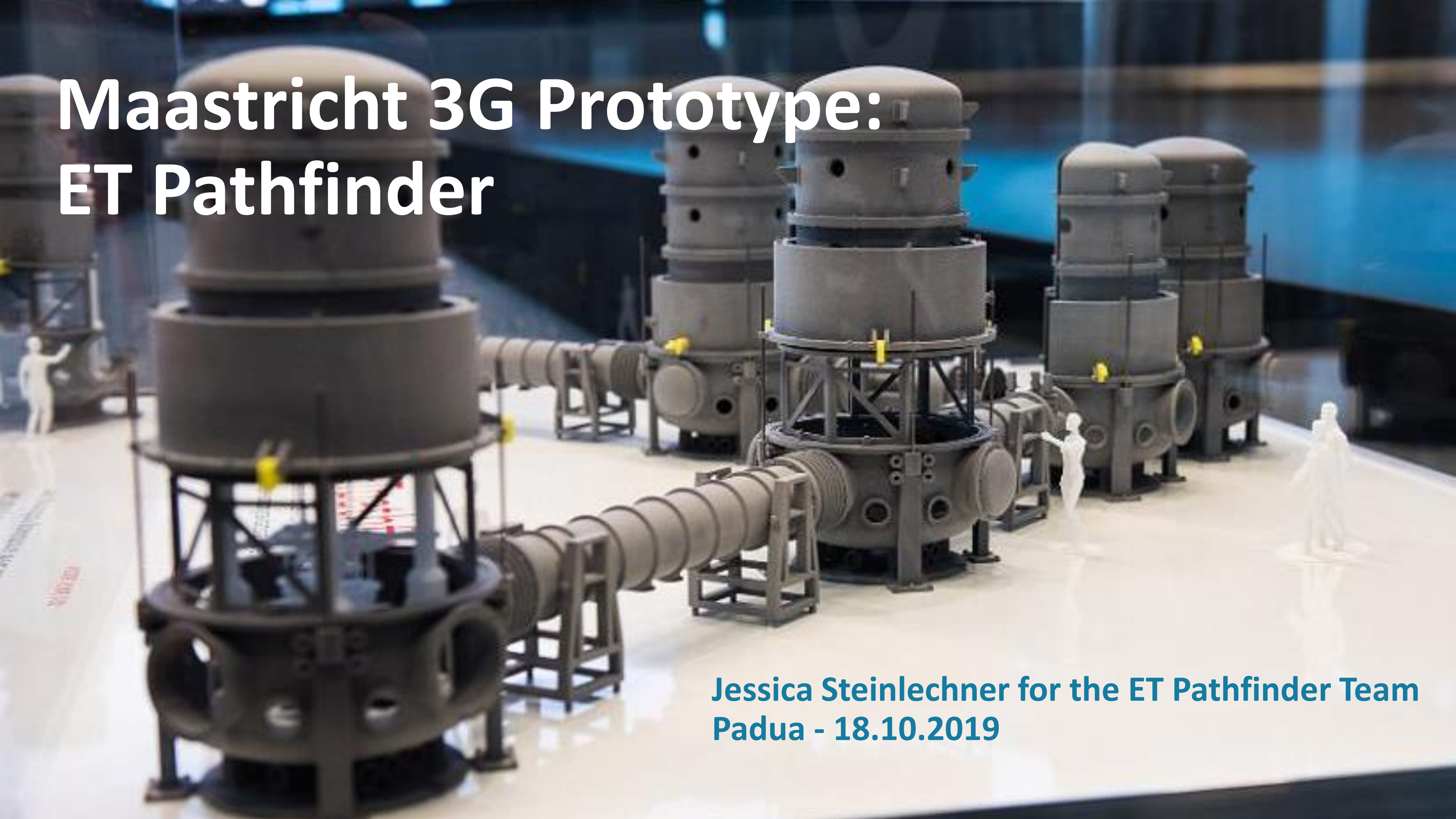
Maastricht 3G Prototype: ET Pathfinder



Jessica Steinlechner for the ET Pathfinder Team
Padua - 18.10.2019

The Maastricht Group: Who (and where) are we?

Maastricht University

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+ 2 PhD students and a 3rd starting soon!

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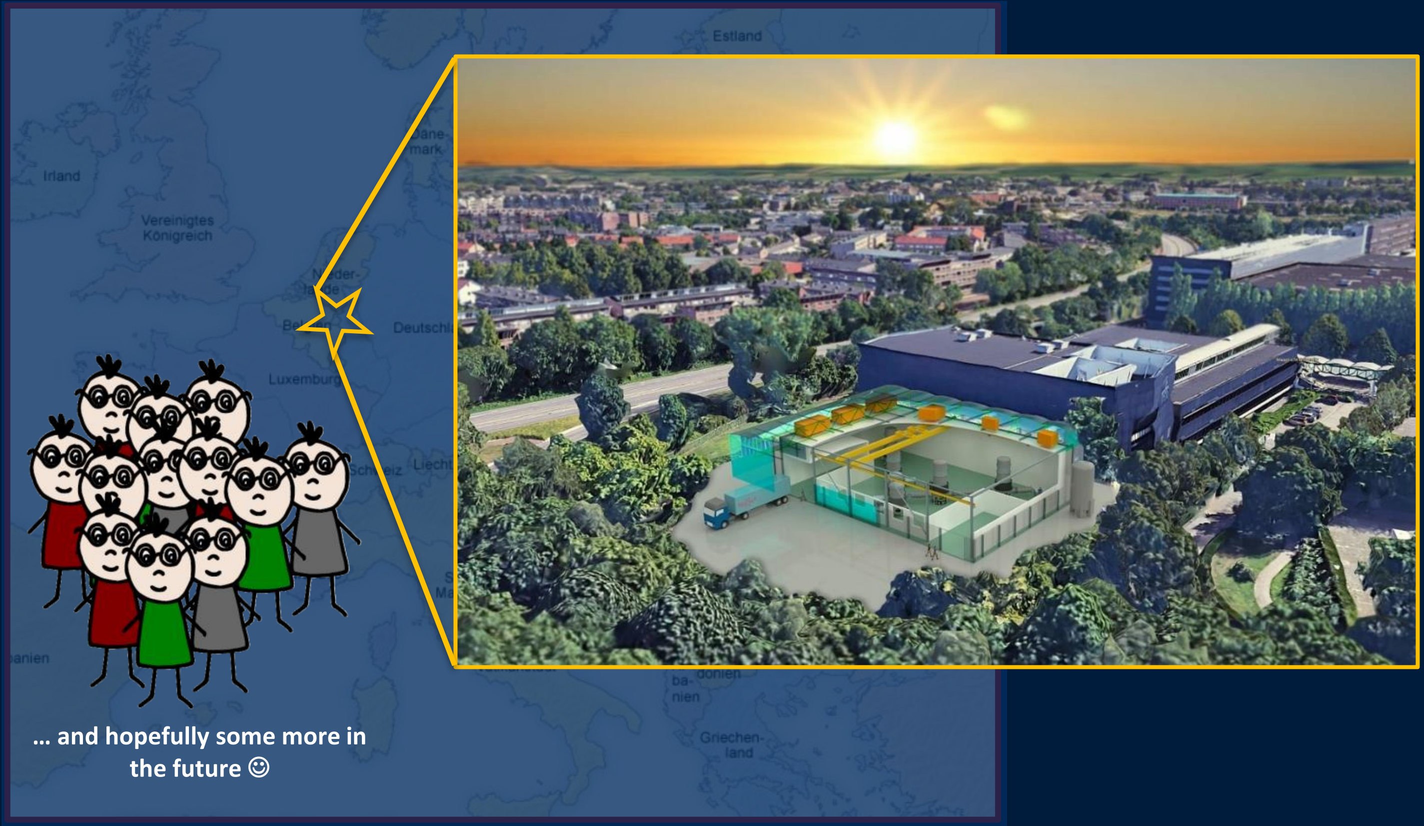
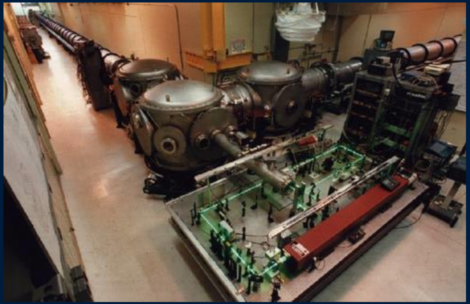
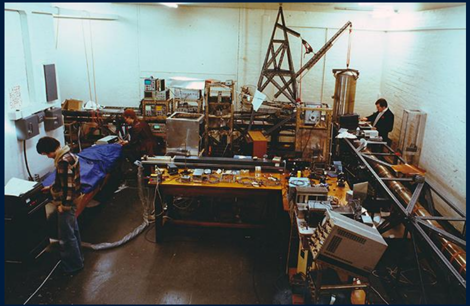


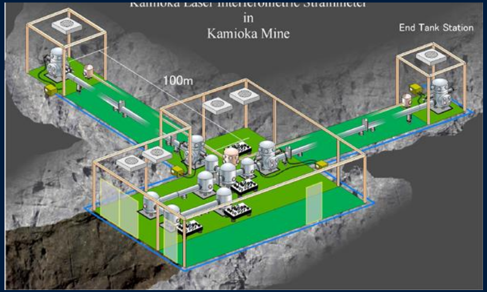
… and hopefully some more in the future ☺

Why do we need another prototype?

Prototype interferometers have been vital to develop GW detectors in the past decades:
Garching 30m, Glasgow 10m, Caltech 40m, MIT, Gingin, Stanford, CLIO, AEI …







Why do we need another prototype?

Table 1. Summary of the most important parameters of the ET-D high- and low-frequency interferometers as shown in figure 5. SA = superattenuator, freq. dep. squeez. = squeezing with frequency-dependent angle.

Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	Fused silica	Silicon
Mirror diameter/thickness	62 cm/30 cm	min 45 cm/TBD
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10%	20%
Quantum-noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Partial pressurefor H_2O, H_2, N_2	10^{-8}, 5×10^{-8}, 10^{-9} Pa	10^{-8}, 5×10^{-8}, 10^{-9} Pa
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \times 10^{-10}\,\mathrm{m}/f^2$	$5 \times 10^{-10}\,\mathrm{m}/f^2$
Gravity-gradient subtraction	none	none

Why do we need another prototype?

Class. Quantum Grav. **28** (2011) 094013 — S Hild *et al*

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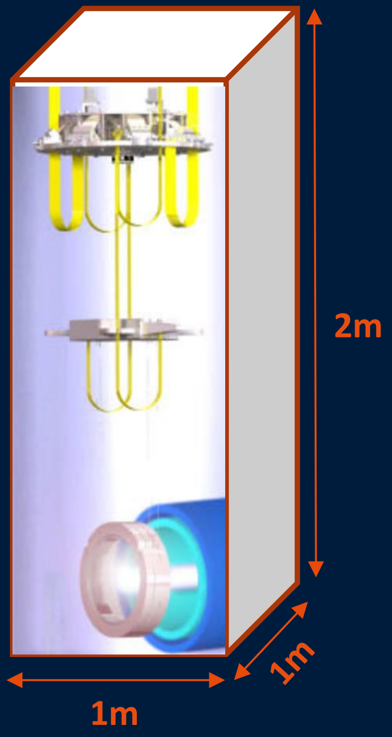
- Aspects that are better tested at A+ detectors or are not accessible to a prototype.
- Aspects could be tested in prototype but might be easier tested elsewhere
- Cryogenic, Silicon optics at 1550nm are key technologies that need testing at scale for ET

=> Main aim of Maastricht Prototype Interferometer

Main idea

- Starting of with a cryogenic payload volume of about 1x1x2m.

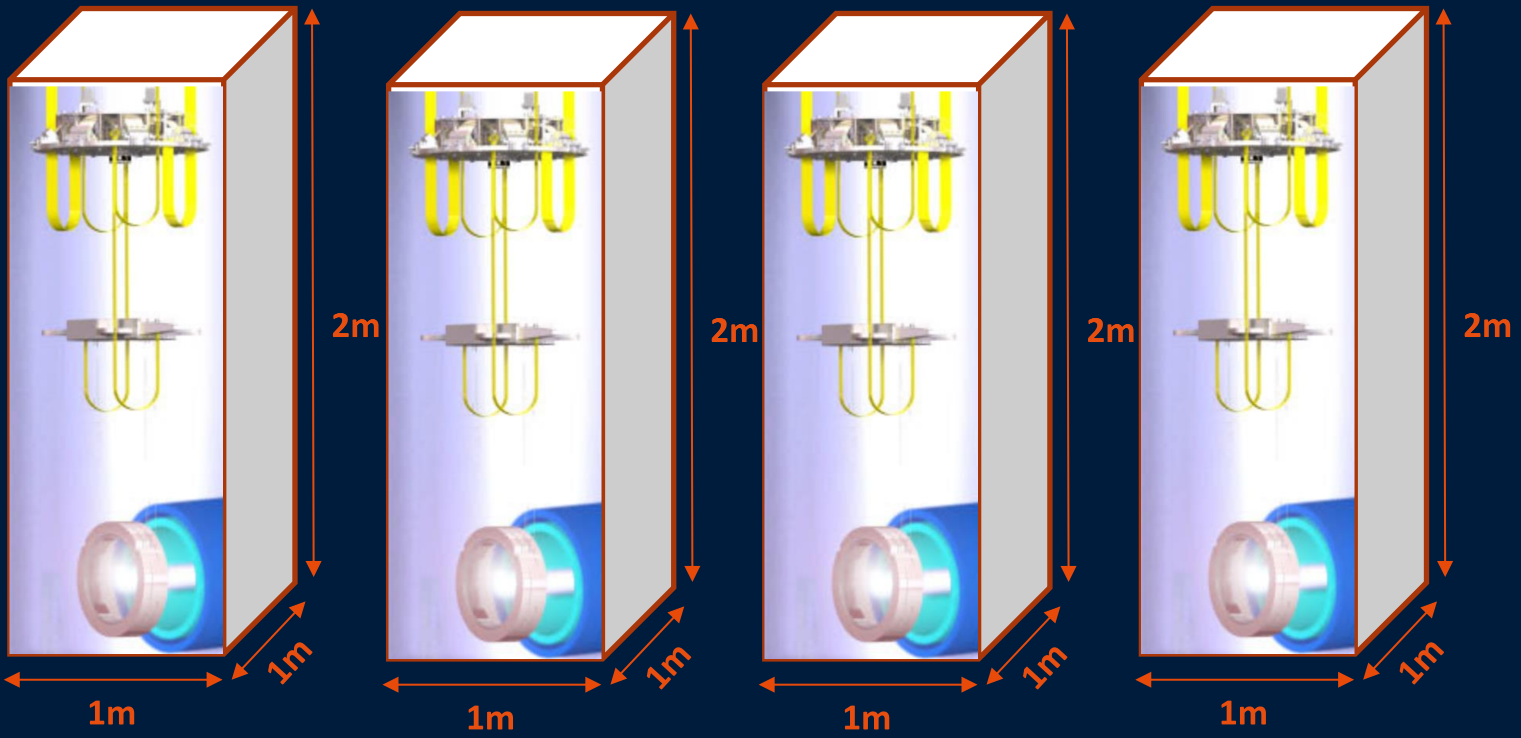


Main idea

- Starting of with a cryogenic payload volume of about 1x1x2m.

4x

to test low phase noise performance

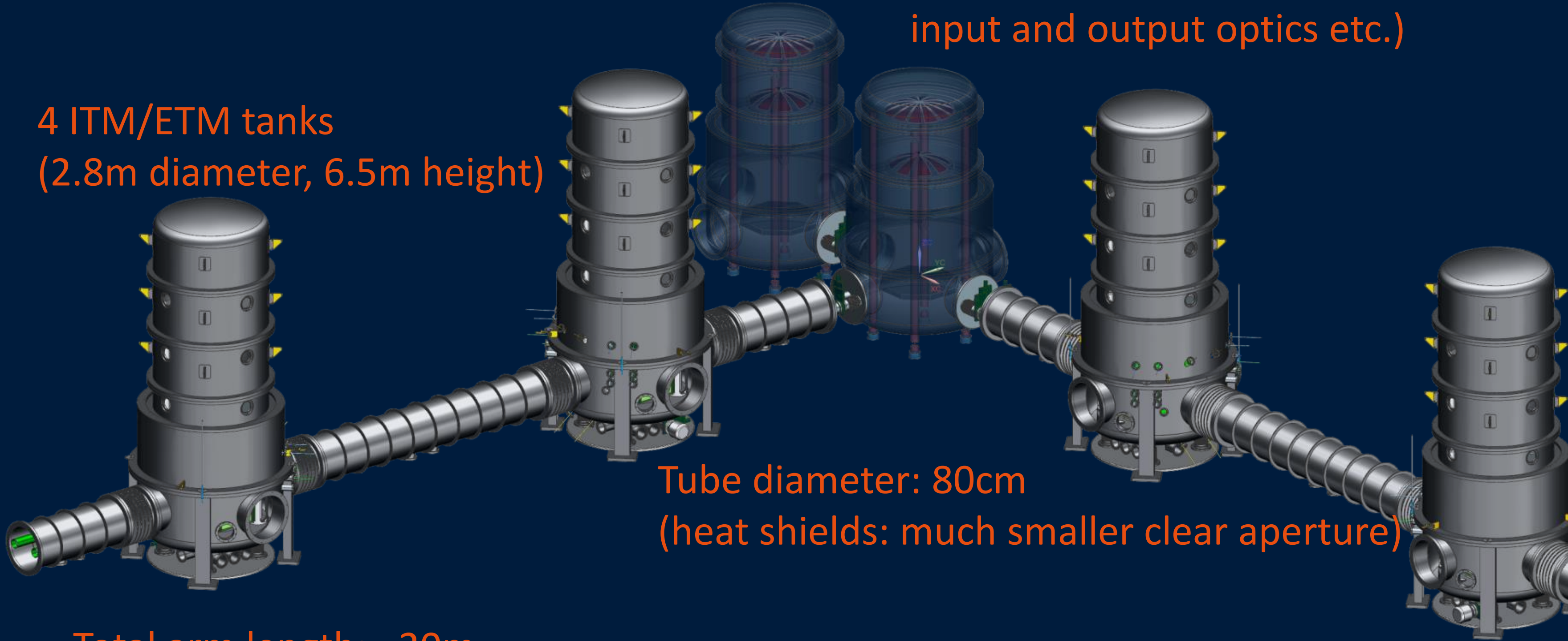


Total volume
about 180m³

Main idea

2 'warm' tanks
(suspended benches: BS,
input and output optics etc.)

4 ITM/ETM tanks
(2.8m diameter, 6.5m height)



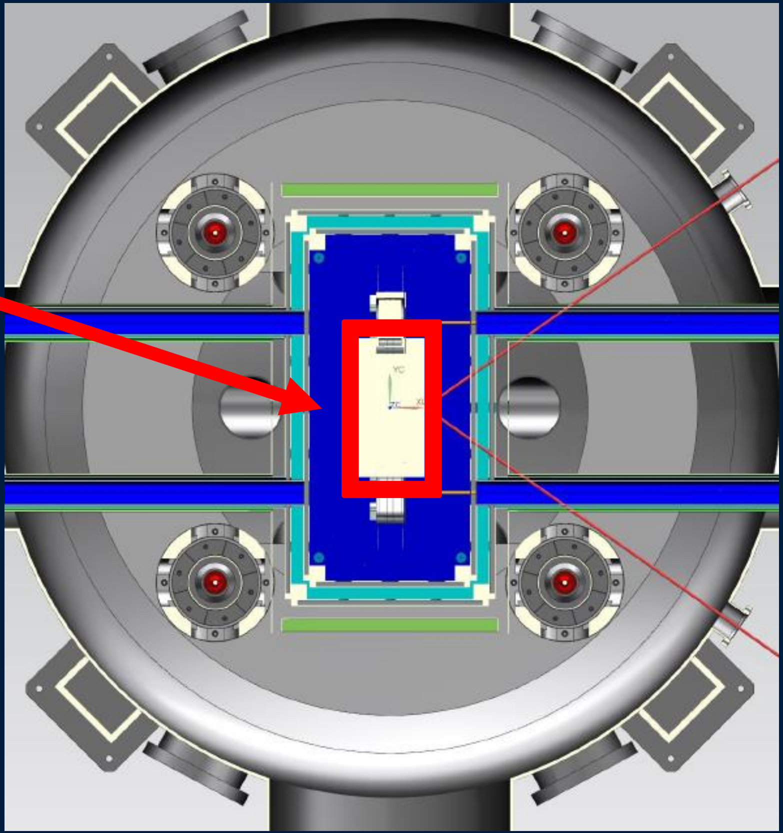
Tube diameter: 80cm
(heat shields: much smaller clear aperture)

Total arm length: ≈20m
Cavity length: 9.34m (due to heat shields in front of ITMs and behind ETMs)

Test Masses

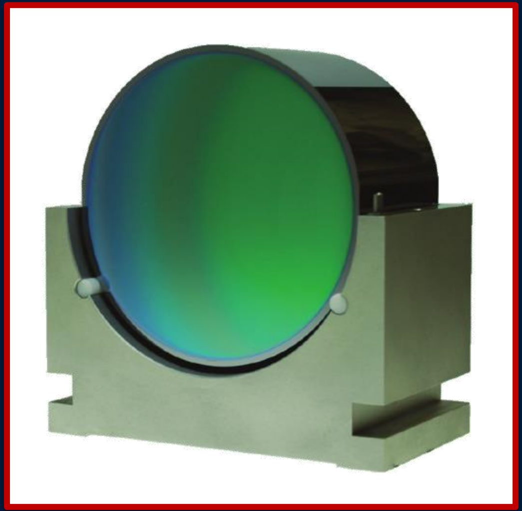
System designed to test silicon mirrors (100kg or more) at 10K in the long run.

For scale this 45cm by 22.5cm (~82kg).



Problem: Could we buy silicon mirrors of such dimensions and with the right properties right now?
– probably not yet ...

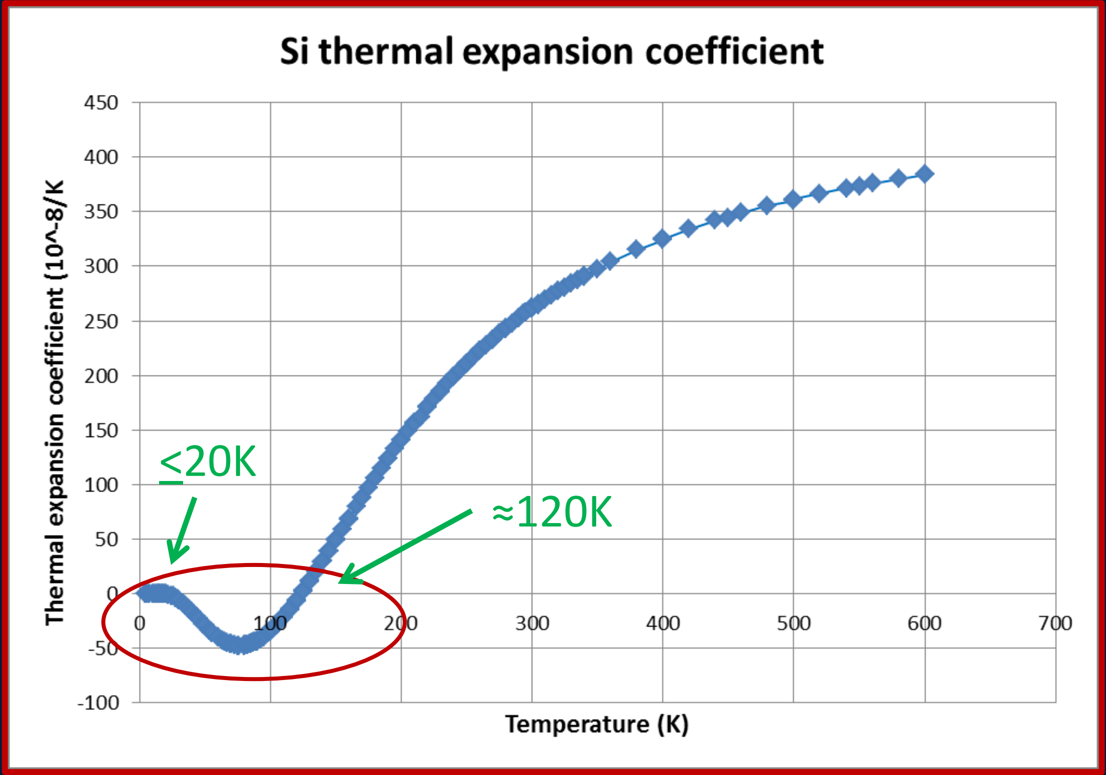
Which parameters should be tested?



Which parameters should be tested?

Zero crossings of CTE at ~120K and ~20K

→ two interesting options for operating temperatures due to low TE noise

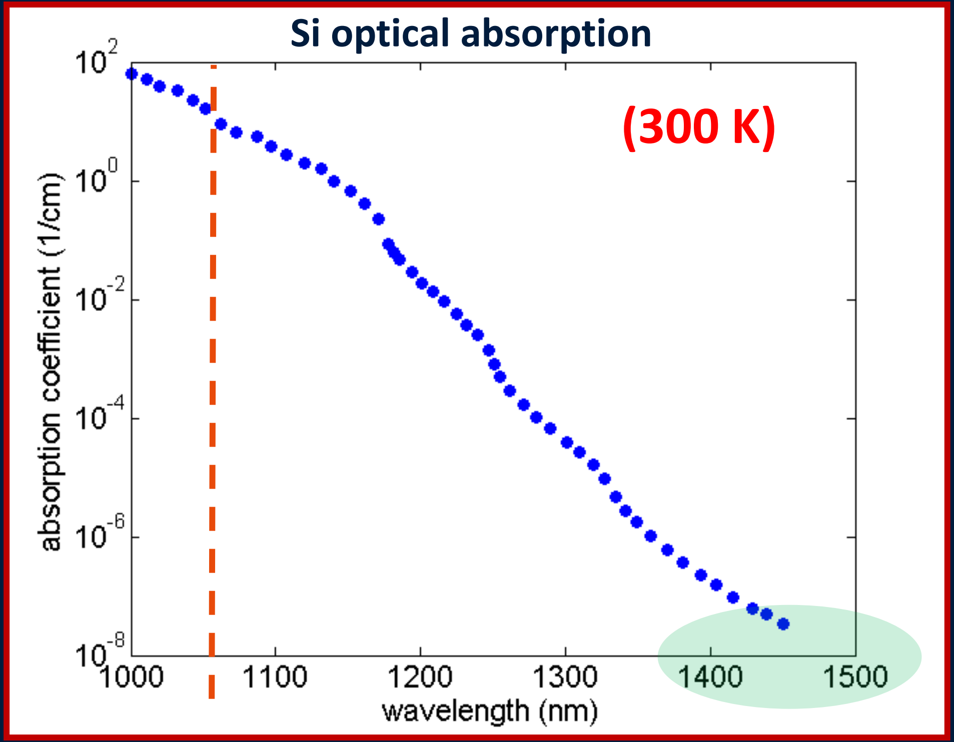


https://trc.nist.gov/cryogenics/materials/Silicon/Silicon.htm

Which parameters should be tested?

Optical absorption low at wavelengths above ~1500nm

→ cSi bulk absorption low at 1550nm and 2000nm



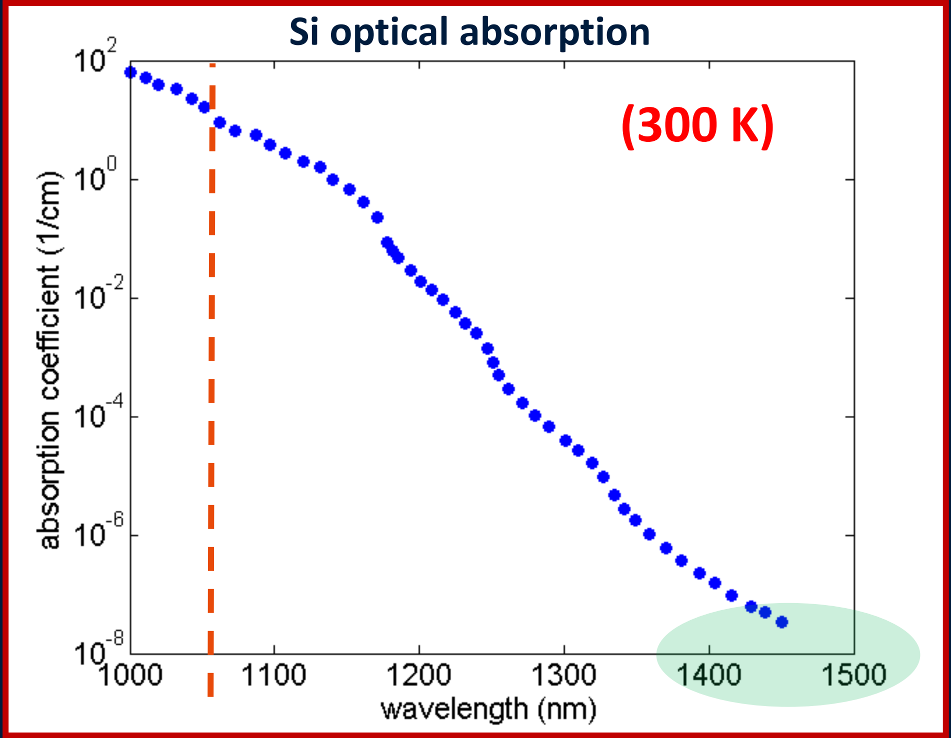
[Keeves et al., J. Appl. Phys.]

Which parameters should be tested?

Optical absorption low at wavelengths above ~1500nm

cSi bulk absorption tested at 1550nm and around 2000nm → no strong reason for one or the other wavelength

<u>Coatings</u> are a possible motivation for 2µm: absorption of aSi (and e.g. SiN) lower than at 1550nm (see P. Murrays talk)



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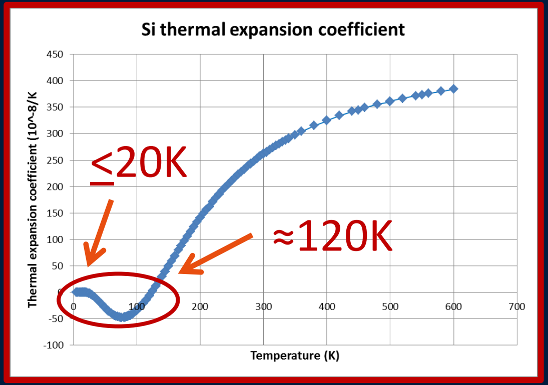
Which parameters should be tested?



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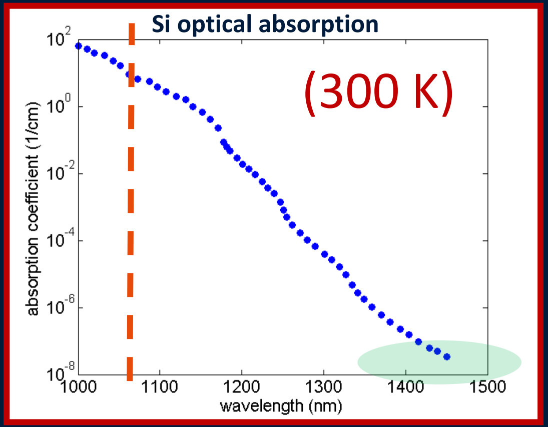

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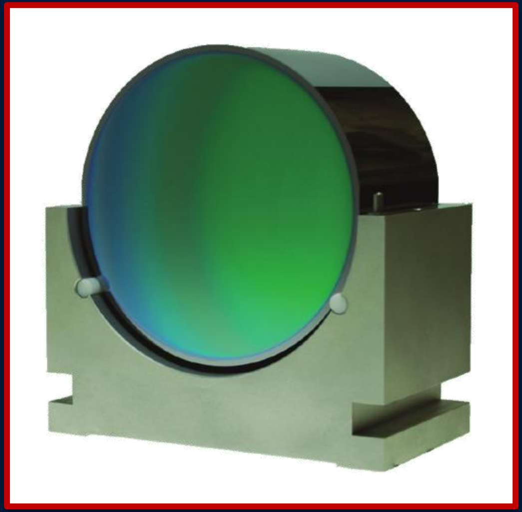
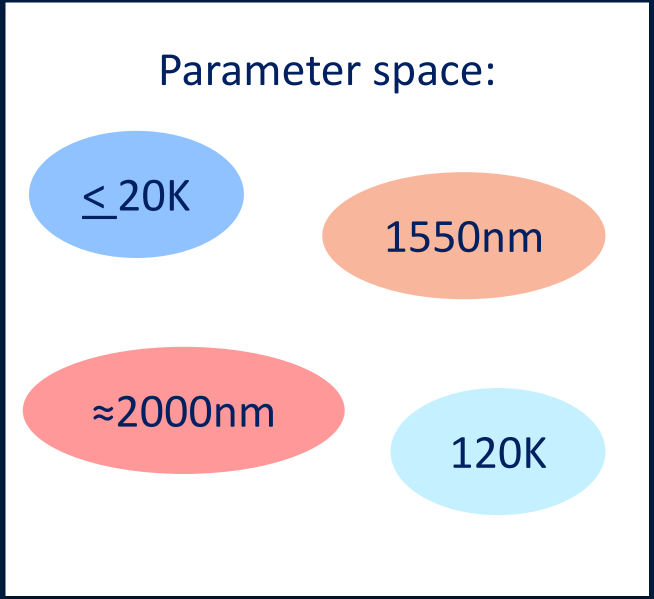
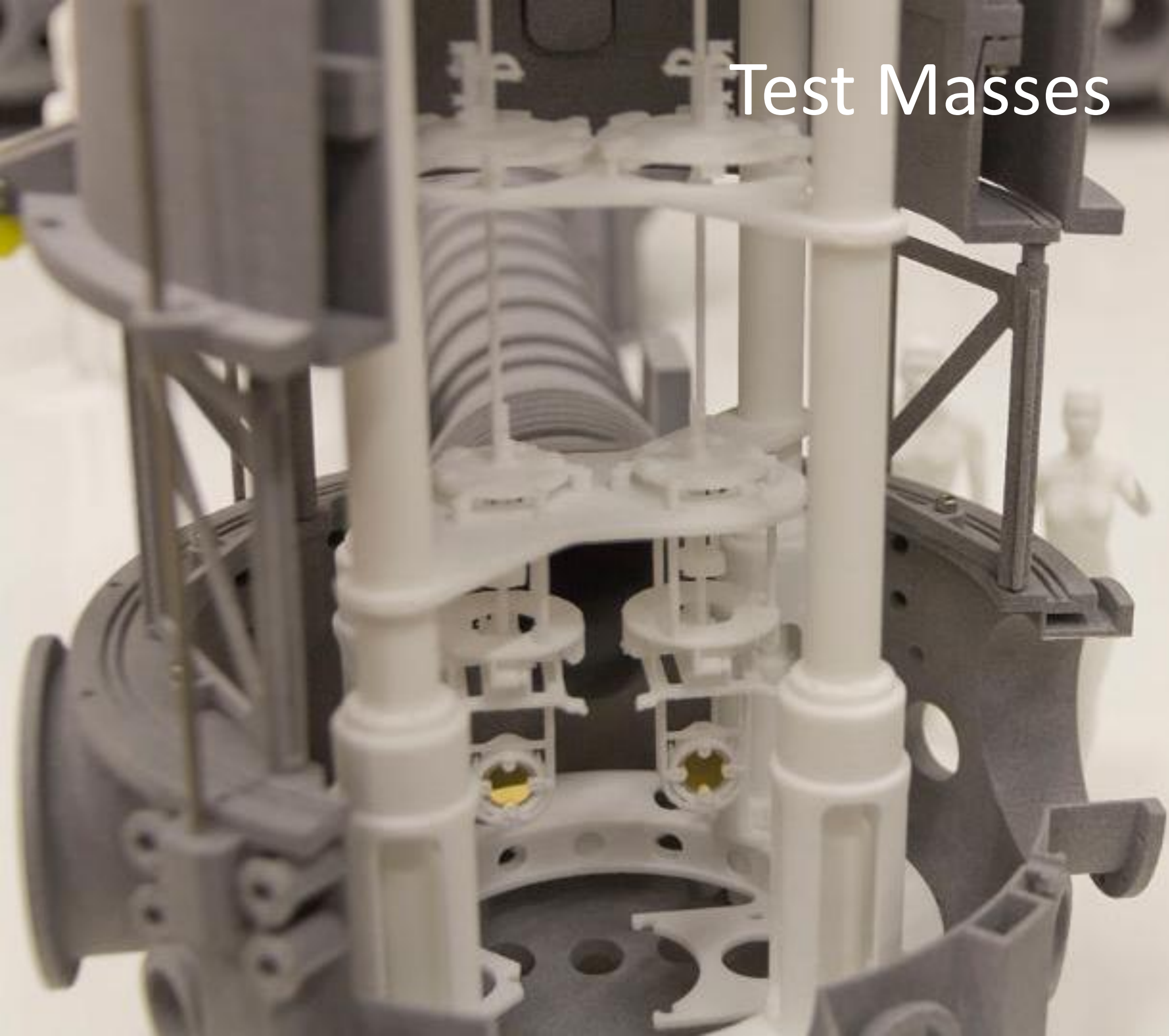




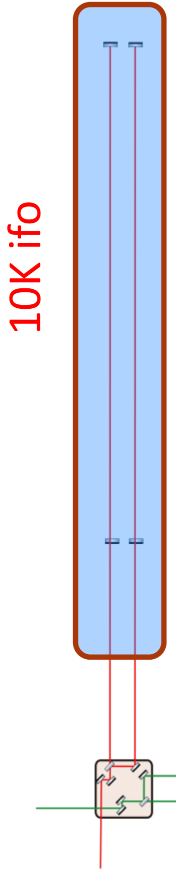
Test Masses



Initial phase (Phase 1):
2 small mirrors in each cryostat
Small mirrors = 15cm diameter, 3kg

→ We can operate 2 independent interferometers with a total of 8 cryogenic test masses.

Two Interferometers



Option 1: arrange these 2 interferometers as 2 'L'

Option 2: use each arm of the vacuum system for one interferometer

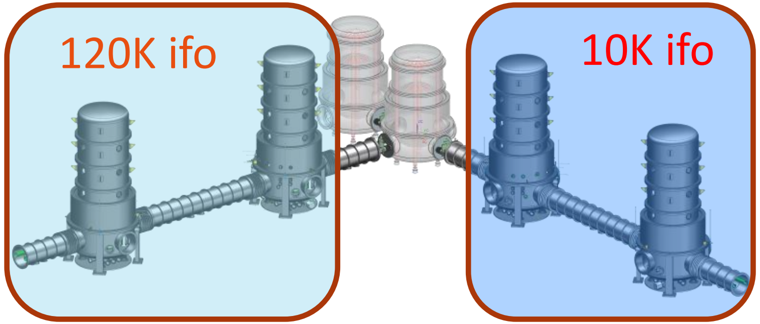
→ operate the two arms (and hence interferometers) at <u>different temperatures</u>: one at 120K and one at 10K.

→ allows to run the two interferometers at <u>different wavelength</u>: one at 1550nm and one around 2um

<u>**Potentially allows to explore test the full matrix of temperatures and wavelengths currently discussed.**</u>

For example:

operate one ifo as in ET-D-LF config (10K, 1550nm, low power) and one in Voyager/CE config (120K, 2um, high power).



Science Goals

- Low phase noise interferometry with cryogenic silicon mirrors of up to ~100kg
- Providing a flexible testbed to explore the full matrix of cryogenic temperatures and laser wavelength
- Investigating the interplay of thermal noise, quantum noise and control noises in the sub 10Hz region
- Various tests of cryogenic plants (liquids vs cryo-coolers; stable control of mirror temperature; contamination handling of mirror surfaces; low power actuators etc.)
- Loads of other interesting topics (Thermal compensation; adaptive modematching; Parametric Instabilities; etc)

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What would you like seen being test or investigated in this prototype? --- Please let us know!

Partners and Funding

1. *Nikhef*
2. *Maastricht University*
3. *Eindhoven University of Technology*
4. *University of Leuven*
5. *Ghent University*
6. *University of Antwerp*
7. *University of Hasselt*
8. *University of Liège*
9. *Vrije Universiteit Brussel*
10. *Université catholique de Louvain*
11. *Fraunhofer Institute for Laser Technology (ILT)*
12. *RWTH Aachen University*
13. *University of Twente*
14. *Flemish Institute for Technological Research (VITO), Mol*
15. *Netherlands Organisation for Applied Scientific Research (TNO), Delft*

Also input from Glasgow, AEI, Perugia …

Location: **Maastricht**

€14.5m capital investment (Interreg, institutions, governments, provinces)

Committed manpower of 100+ man years (scientists and engineers) over the next 5 years

Collaboration with relevant local and national industry partners