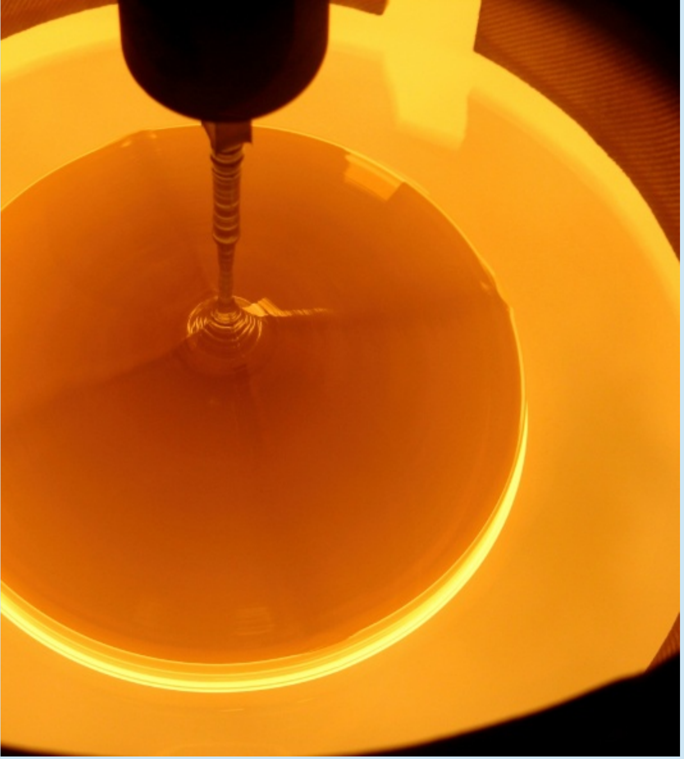
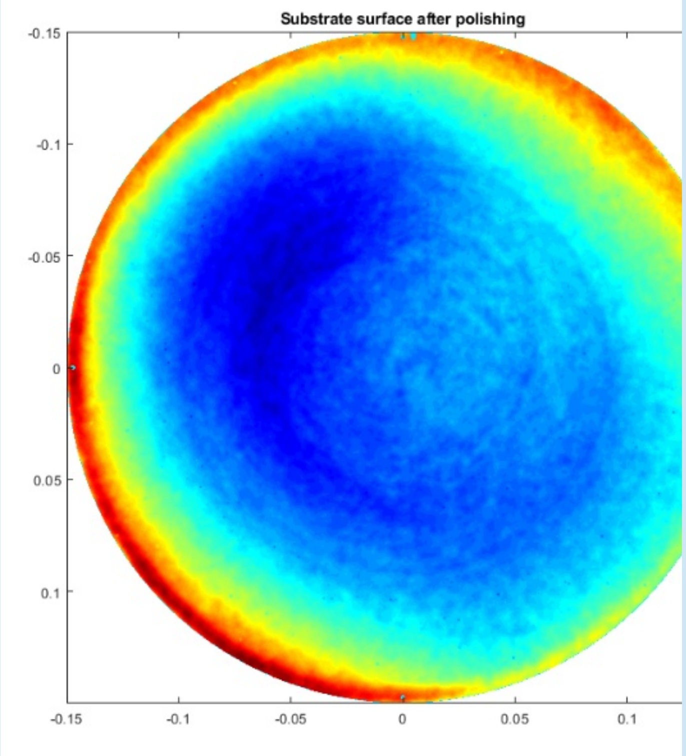




Einstein Telescope and cold Mirrors

Jérôme Degallaix

First DMLab Meeting: Scientific Kickoff

This presentation is about:

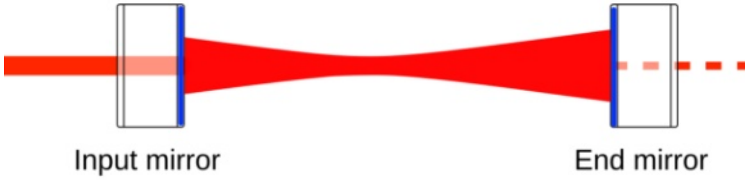
- the next generation European gravitational wave detector: the Einstein Telescope (ET)
- its overall technical design
- and one of the most critical part: the mirrors at room and cryogenic temperatures

At the heart of gravitational wave detectors...

The detector Virgo in Italy

… some outstanding mirrors

- forming the km long arm cavities
- where the gravitational wave signal is encoded to the phase of the light
- loosing light = loosing signal (and adding noise)

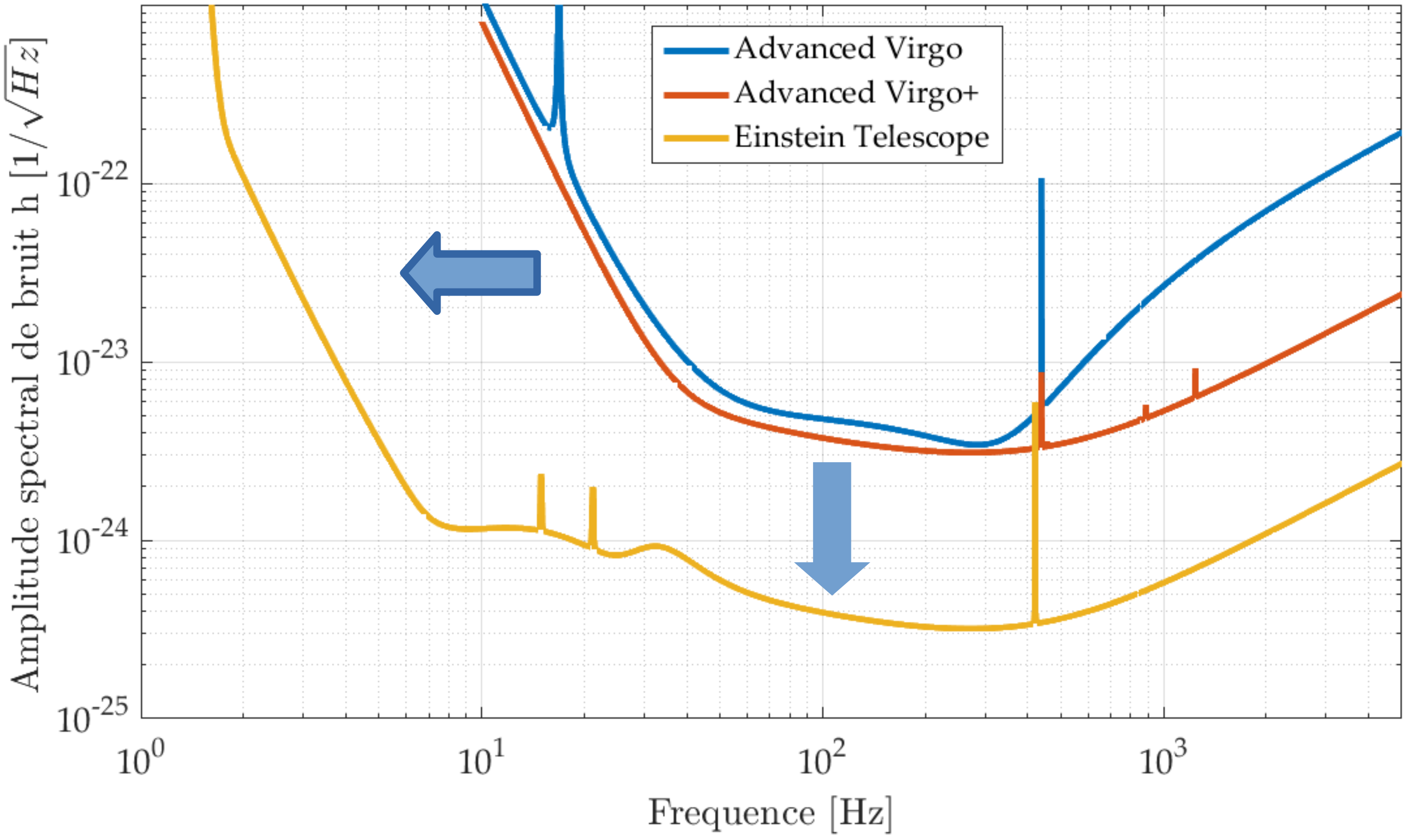


Very strong requirement on the amount of light lost per round trip: < 0.01 %

State of the art substrates, polishing and coating

Goal of ET: to be 10 times more sensitive

compared to 2^{nd} generation LIGO and Virgo



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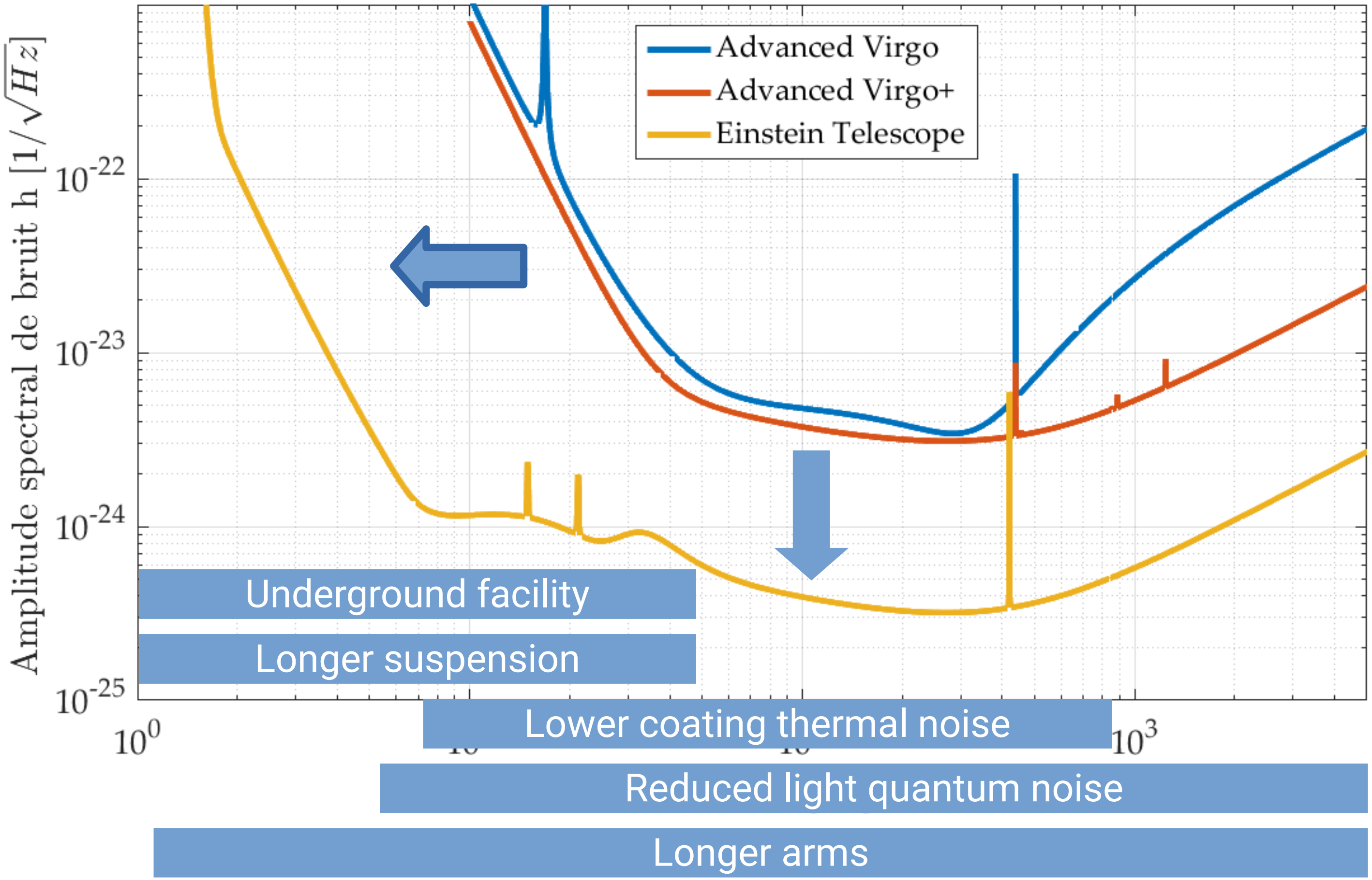
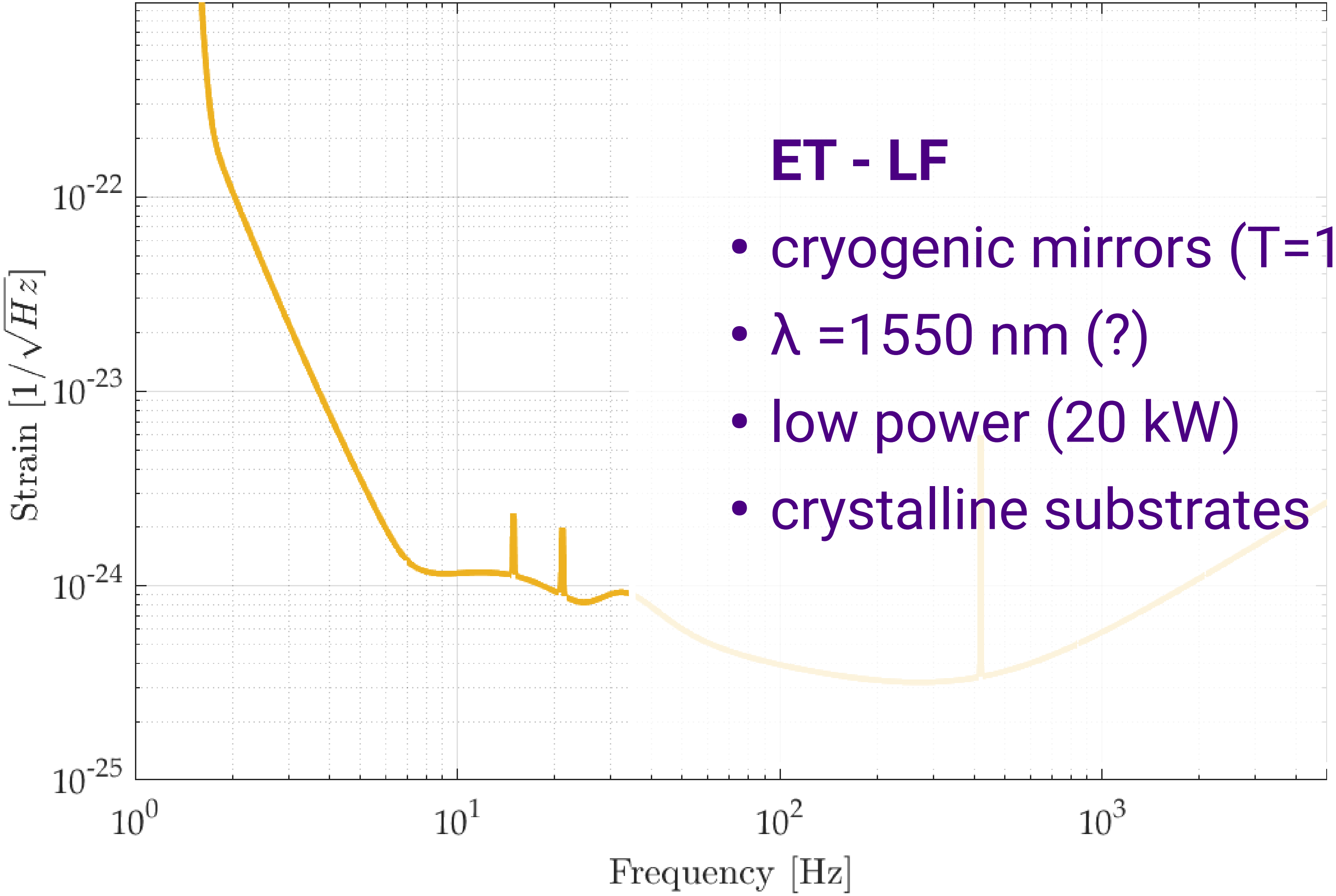


The challenge of increasing the bandwidth

- conflicting requirement at low and high frequencies
  - high optical power required at high frequency to lower the shot noise
  - but high power also degrades the low frequency due to radiation pressure noise

- the sensitivity could be achieved by 2 interferometers dedicated to low frequency (ET-LF) and high frequency (ET-HF)

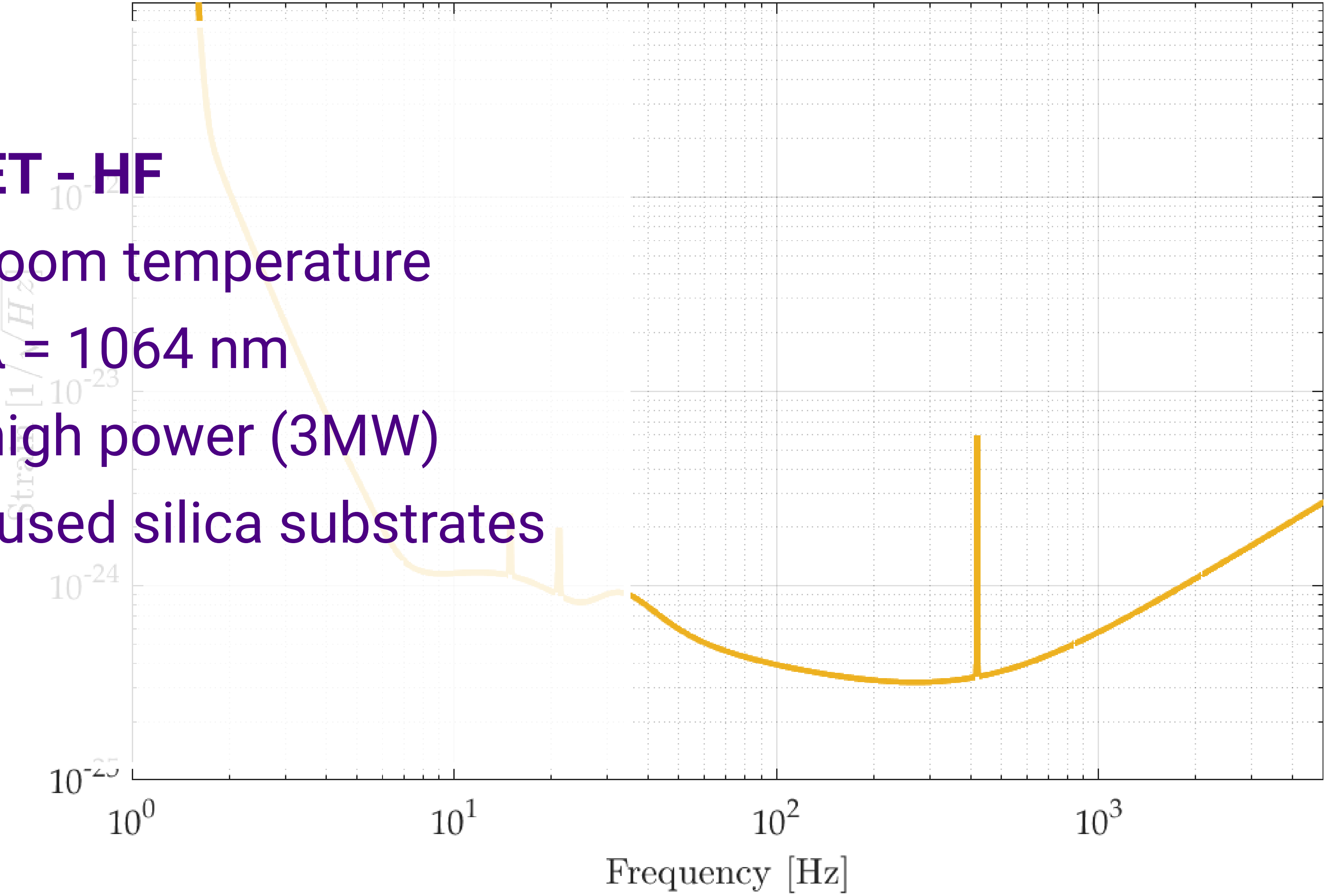
The xylophone strategy



ET - LF

- cryogenic mirrors (T=10-20K)
- λ =1550 nm (?)
- low power (20 kW)
- crystalline substrates

The xylophone strategy



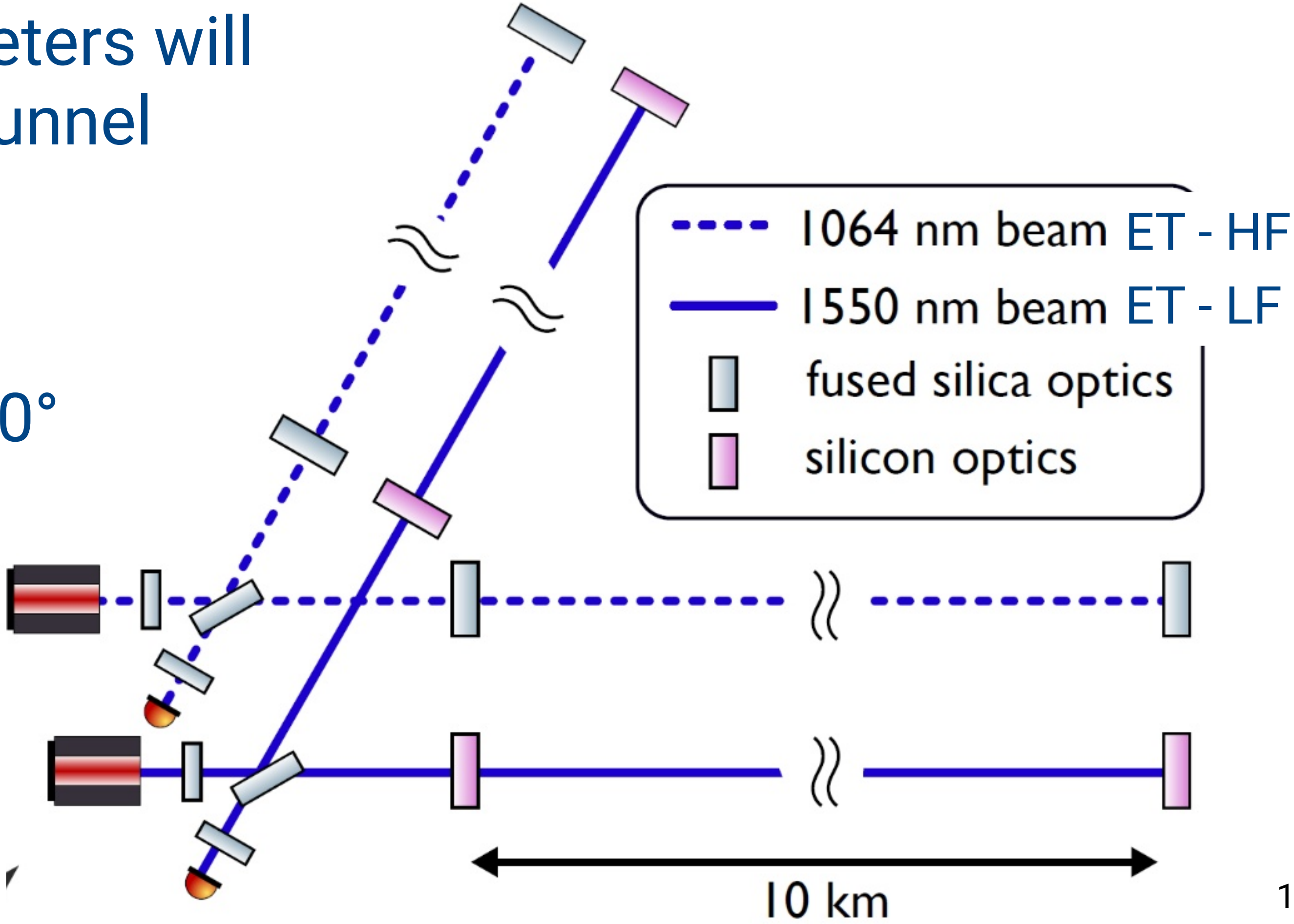
ET - HF

- room temperature
- λ = 1064 nm
- high power (3MW)
- fused silica substrates

1 detector = 2 interferometers

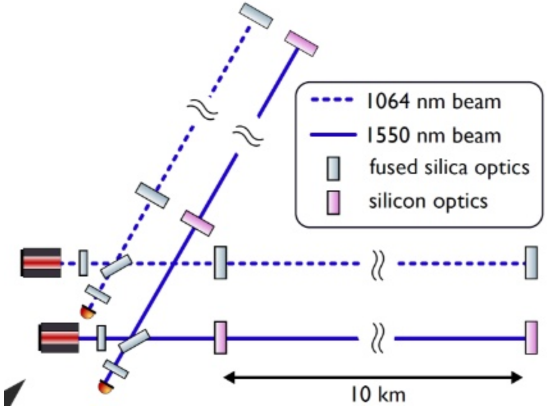
The 2 interferometers will share the same tunnel

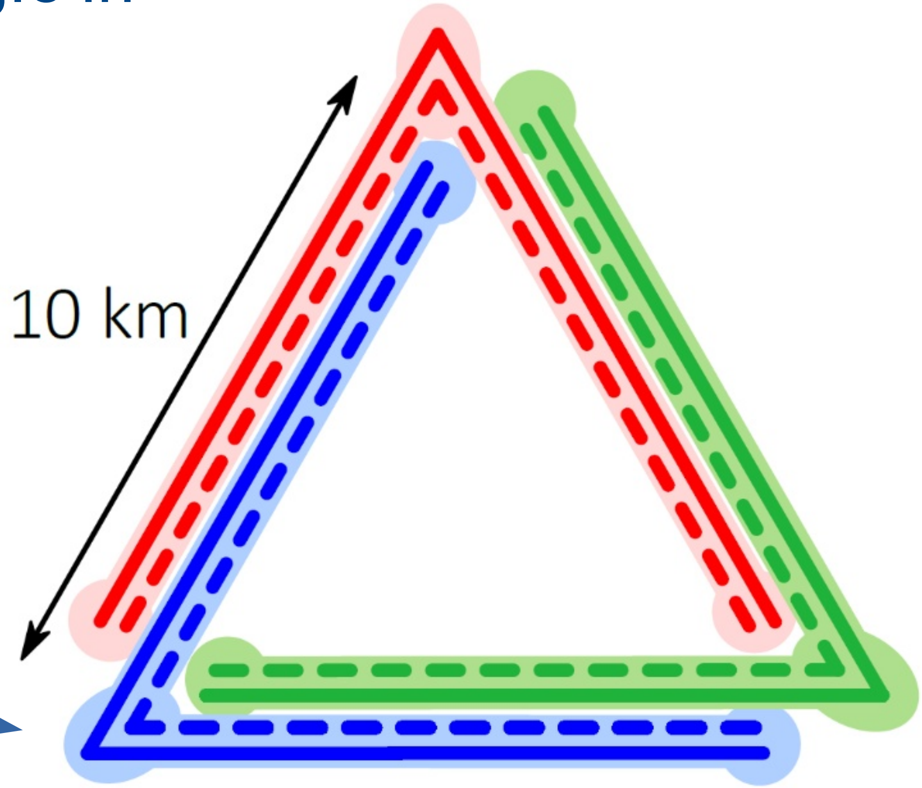
Michelson with 60° arm cavities

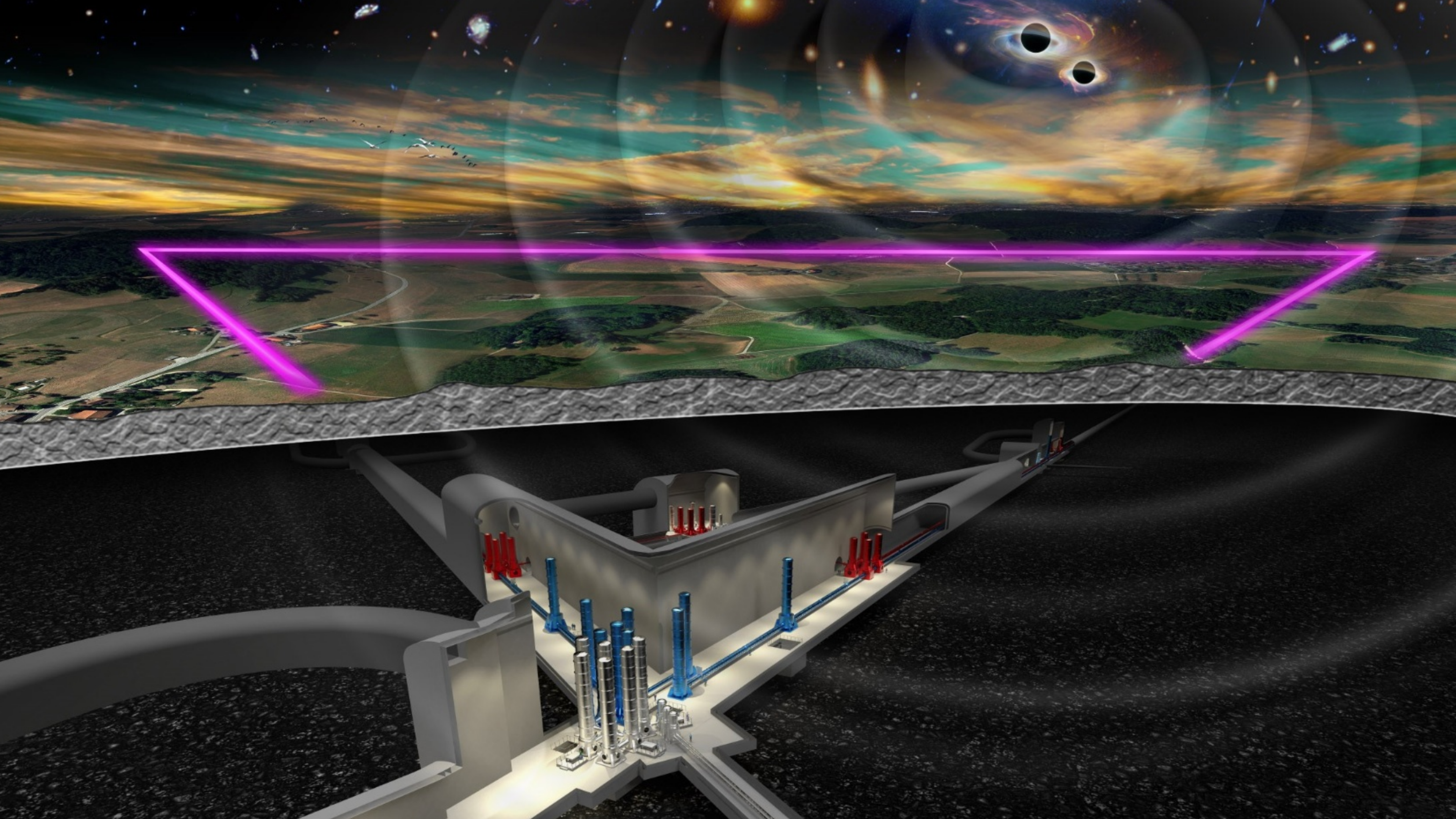


Not one but 3 detectors

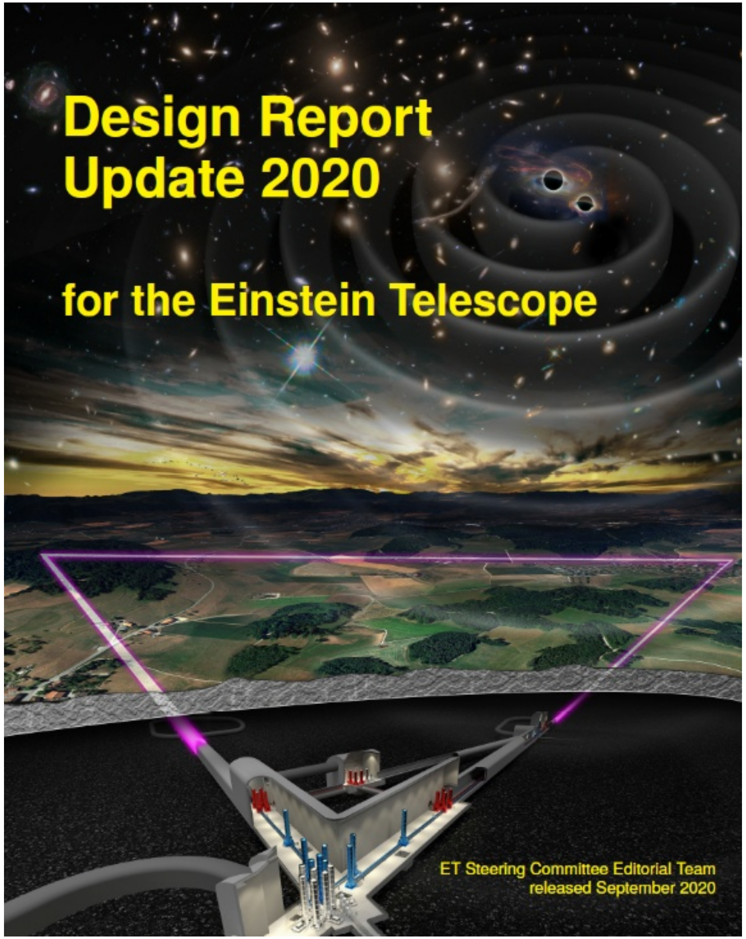
3 detectors arranged in triangle in the same infrastructure







The key parameters



Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×300 m	2×1.0 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	TEM_{00}	TEM_{00}
Beam radius	12.0 cm	9 cm
Scatter loss per surface	37 ppm	37 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	factor of a few

https://apps.et-gw.eu/tds/ql/?c=15418

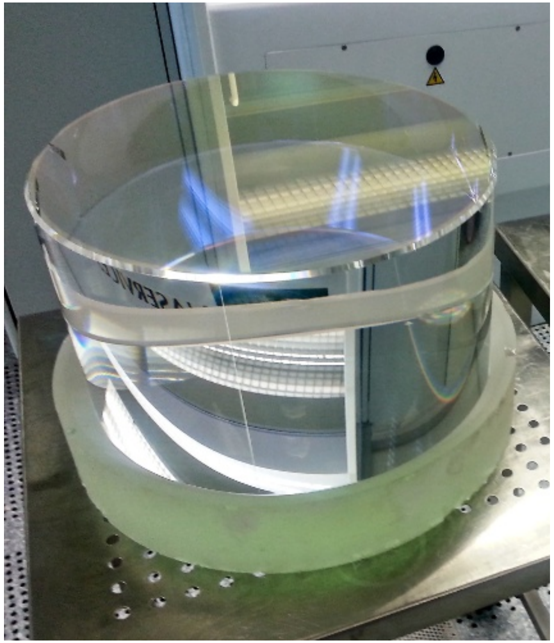
Part I
Room temperature mirrors for ET-HF
(à la Virgo/LIGO)

The king: fused silica

THE test mass substrate for the room temperature first and second generations of gravitational wave detectors

A well justified choice:

- outstanding optical properties
- available in large size
- polishing and coating well mastered

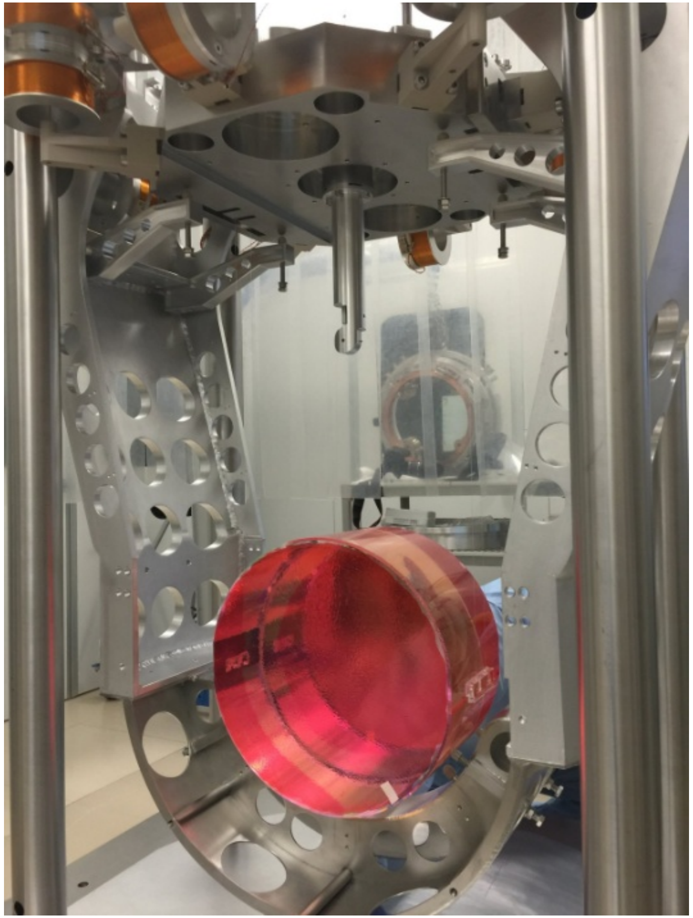


The king: fused silica

Some more properties particularly relevant to GW detectors:

- very low bulk thermal noise
- possibility of monolithic suspension

Reduction of the mirror displacement due to thermal noise



Part II
Cryogenic mirrors for ET-LF
(AKA the cool solution)

Which substrate material ?

- fused silica presents excess bulk thermal noise at low temperature

- candidate substrates:
  - silicon (λ > 1300 nm)
  - sapphire (λ > 400 nm)

- to be available in diameter 450 mm, 200 kg
  - difficulties to find such ingot with the required optical properties
  - R&D for cryogenic coating in progress

Serious issues to take care of...

- cooling without transmitting vibration noise
  - soft links to bring the cooling power, integrated to the suspension
- managing a growing ice layer
  - very low water partial pressure (10^{-12} mbar)
  - cryo-panels around the mirrors
- cooling power
  - largely dominated by the cryo-traps (ET-LF and ET-HF)

Outside the usual expertise of the GW community

- so far only KAGRA (Japanese project) has experiences with cold mirrors
- looking for collaboration / expertise
  - strong involvement of KIT in ET
  - discussion with CERN
- the DM lab will smooth the exchange between French and German labs in this domain

Conclusion

- currently setting up the collaboration, design of the Einstein Telescope
- next generation of gravitational wave detectors to revolutionize the view of our Universe
- a European global effort and many opportunities of collaboration, the mirrors are only one of them
- the project will strongly benefit from the DMlab