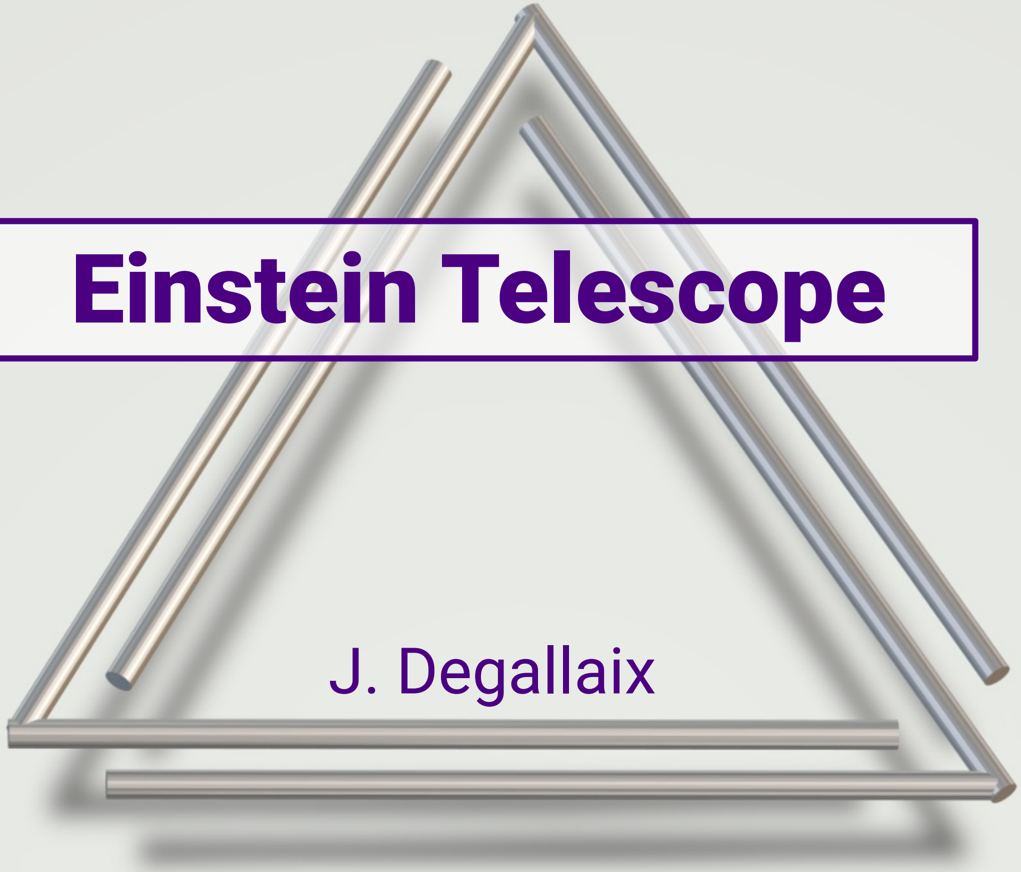
Einstein Telescope



J. Degallaix

ILANCE GW workshop – April 2022

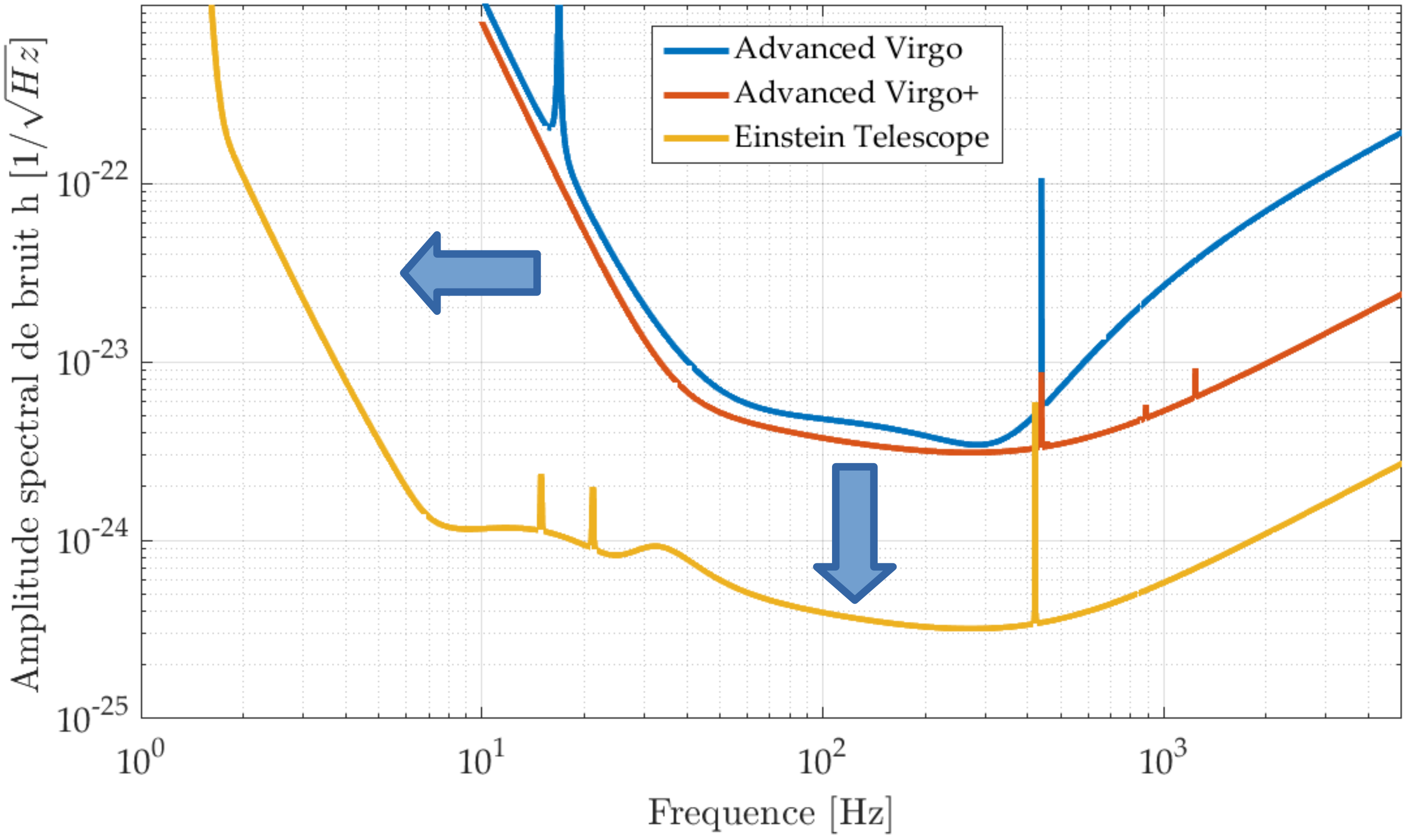
The agenda:

- status of the Einstein Telescope
- selected work on the instrument
- closing the gap : the post-O5 development

I.
Brief presentation and status

Goal of Einstein Telescope: to be 10 times more sensitive

compared to 2nd generation LIGO and Virgo



Goal of Einstein Telescope: to be 10 times more sensitive

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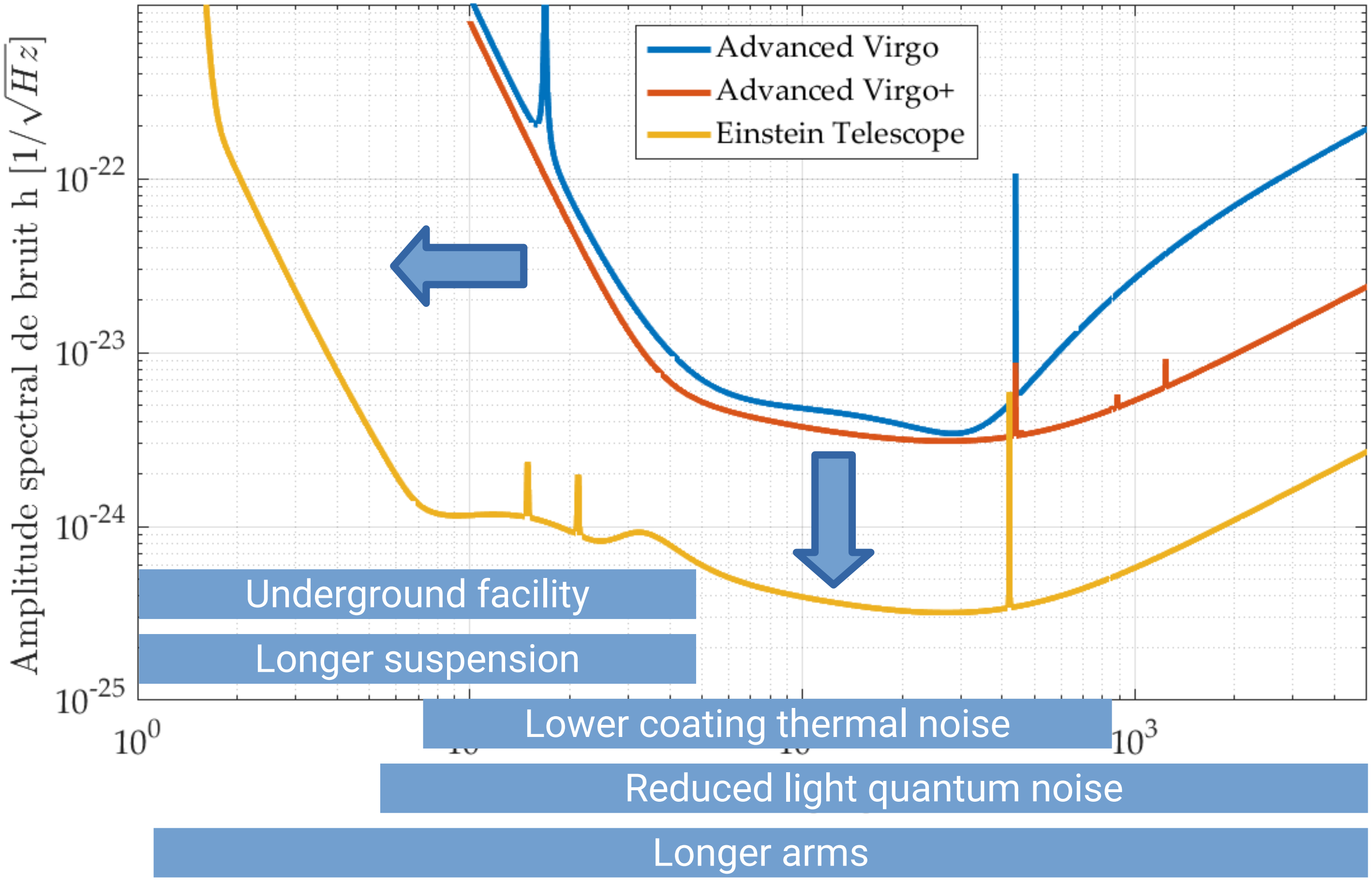
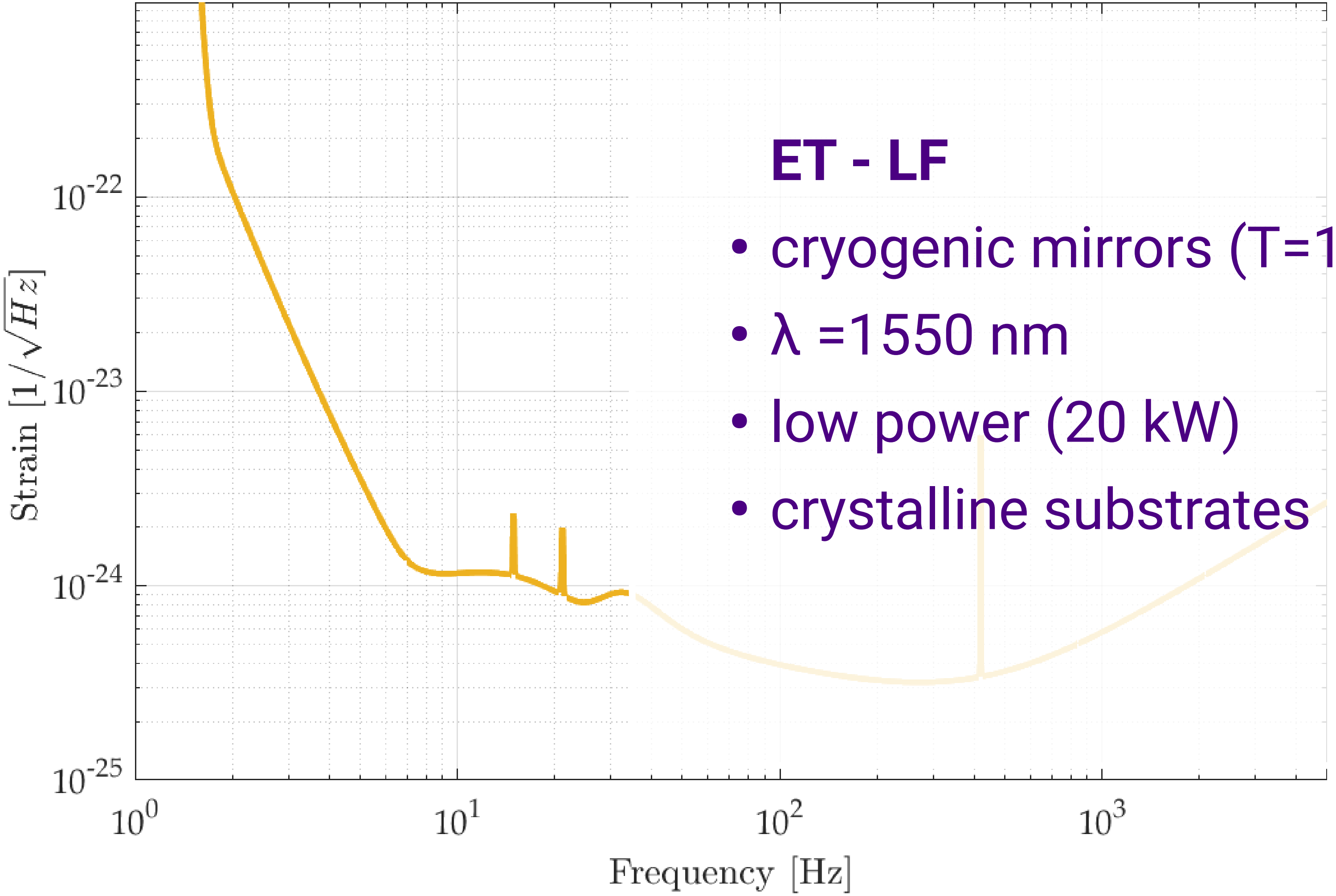


The challenge of increasing the bandwidth

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

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

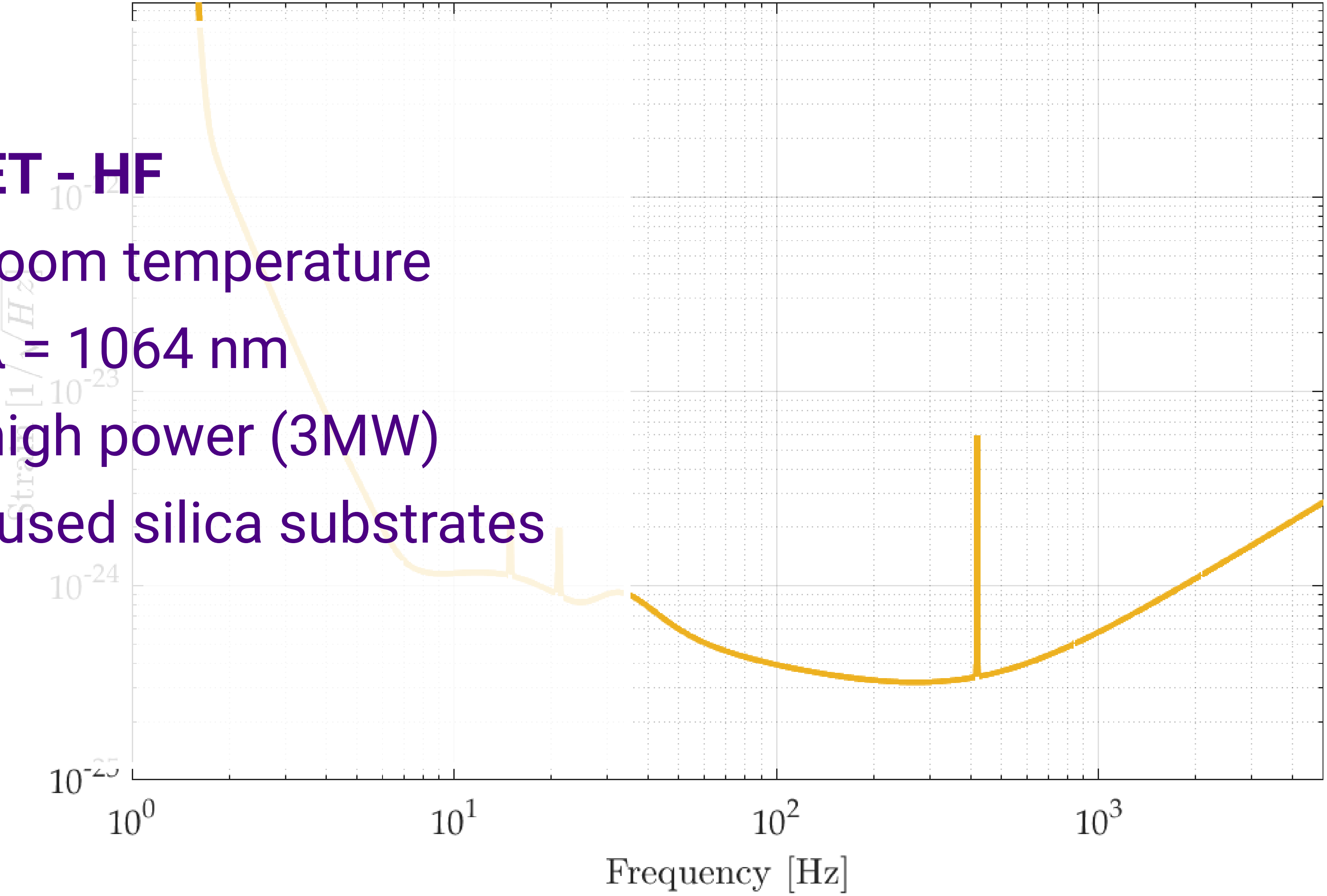
The xylophone strategy



ET - LF

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

The xylophone strategy



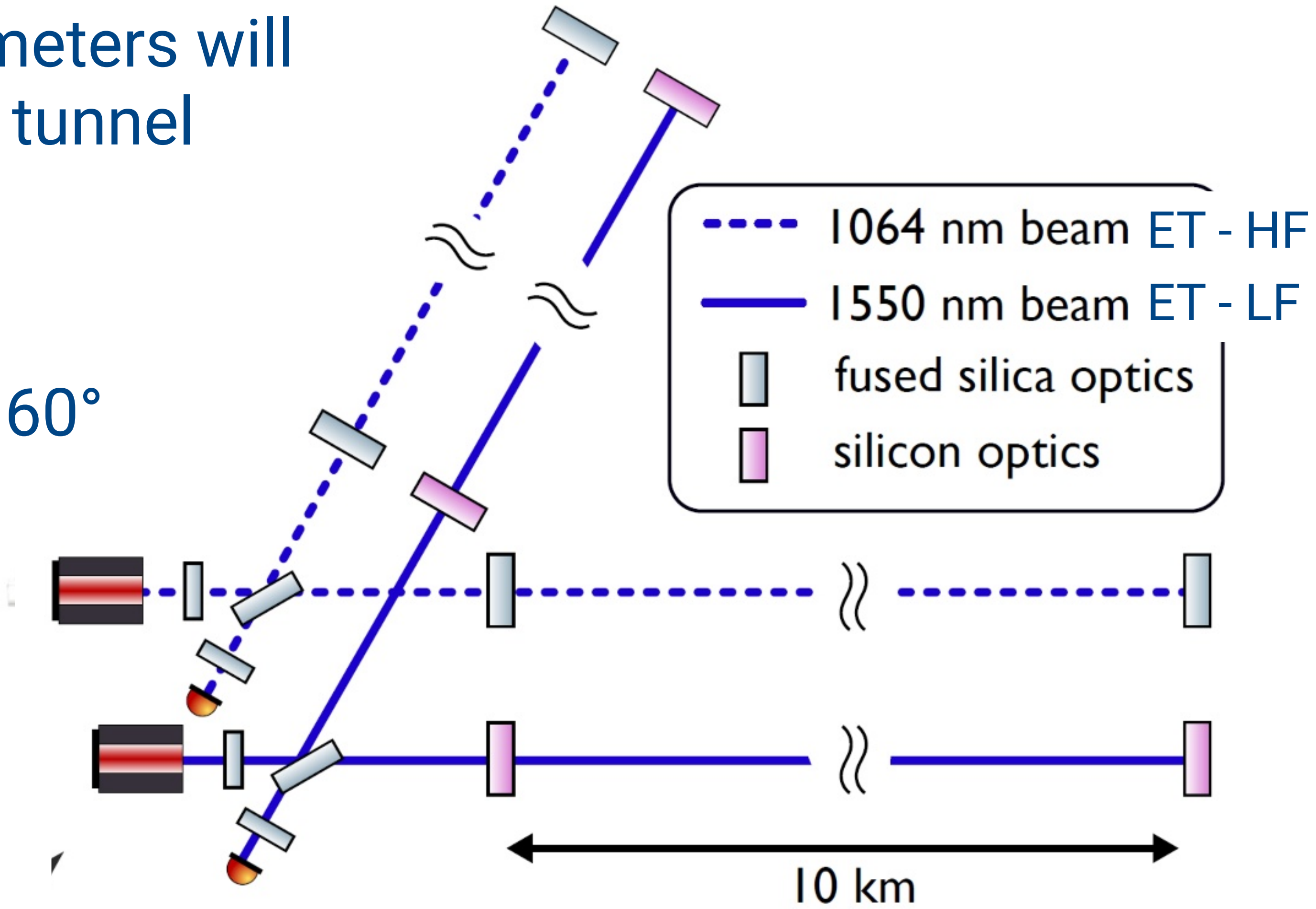
ET - HF

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

1 detector = 2 interferometers

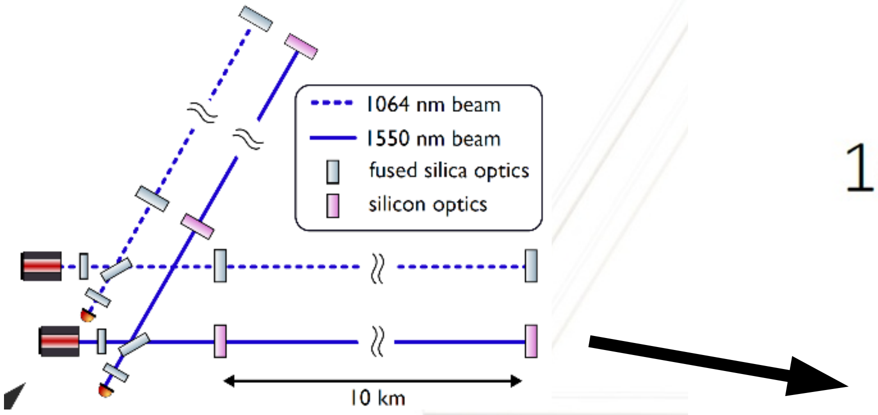
The 2 interferometers will share the same tunnel

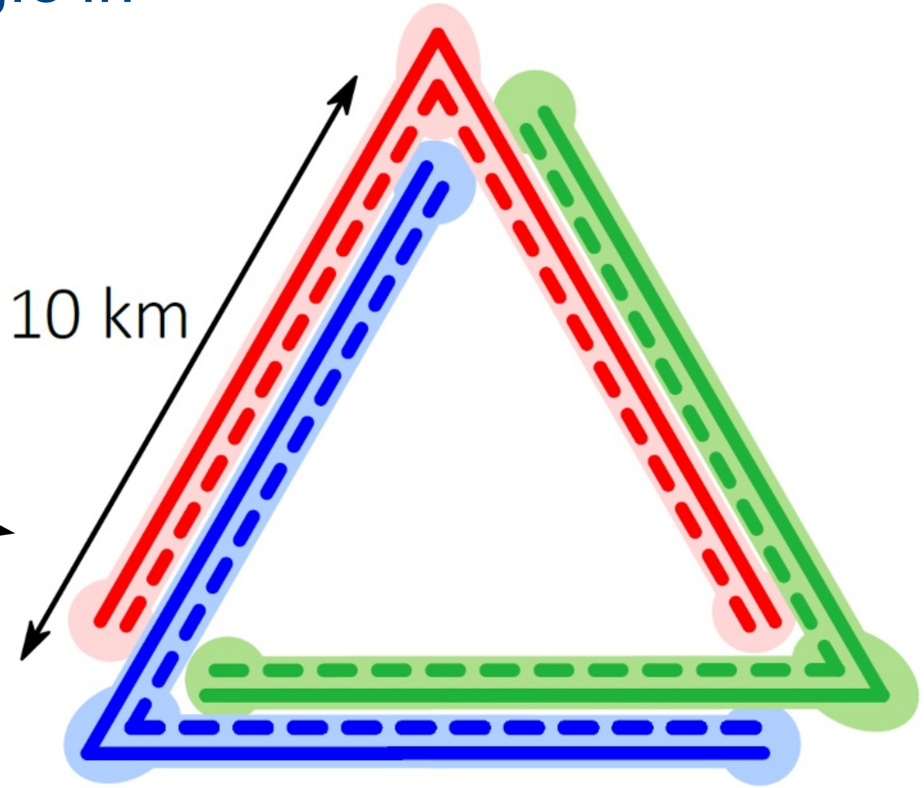
Michelson with 60° arm cavities



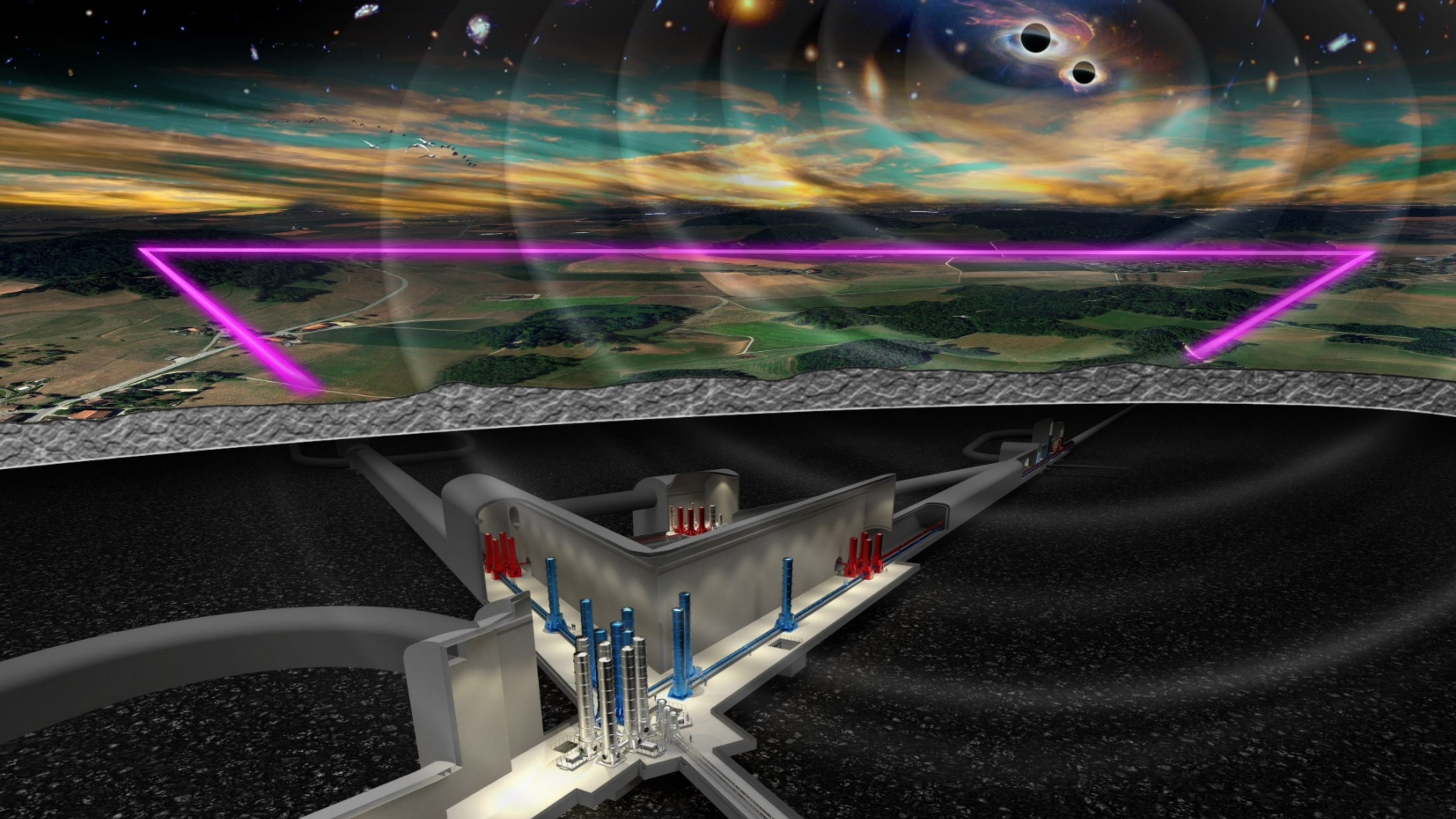
Not one but 3 detectors

3 detectors arranged in triangle in the same infrastructure

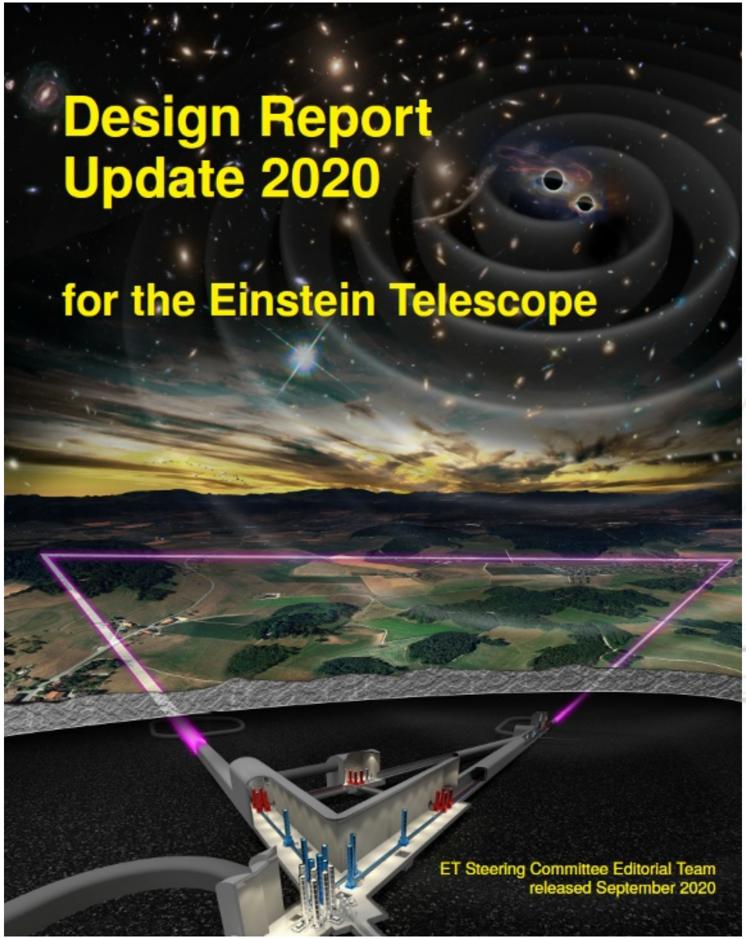




Advantages: high duty cycle and polarisation disentanglement



The key parameters

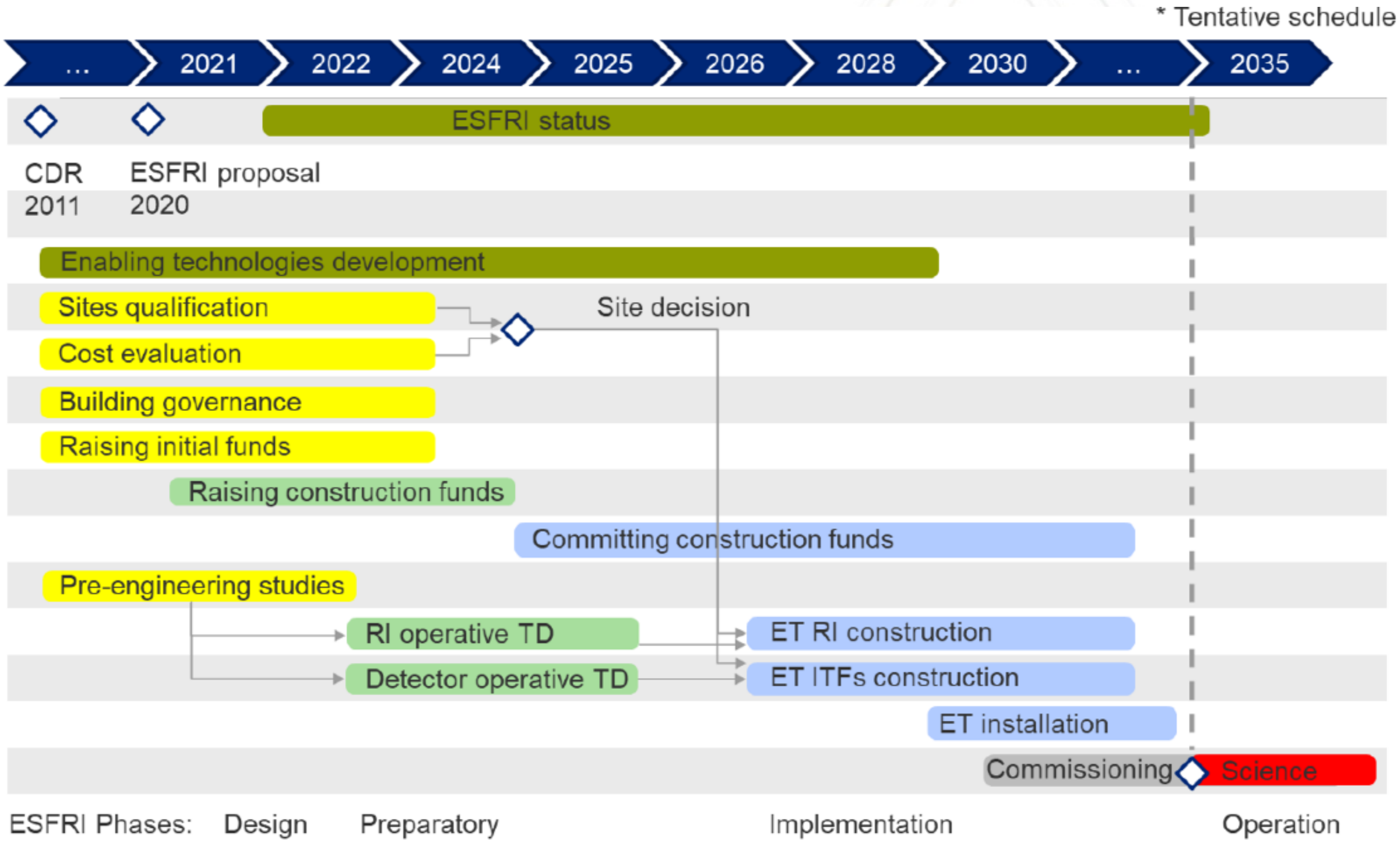


https://apps.et-gw.eu/tds/ql/?c=15418

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 (sapphire ?)
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

Since last year on the ESFRI* roadmap!

Proposed time line:



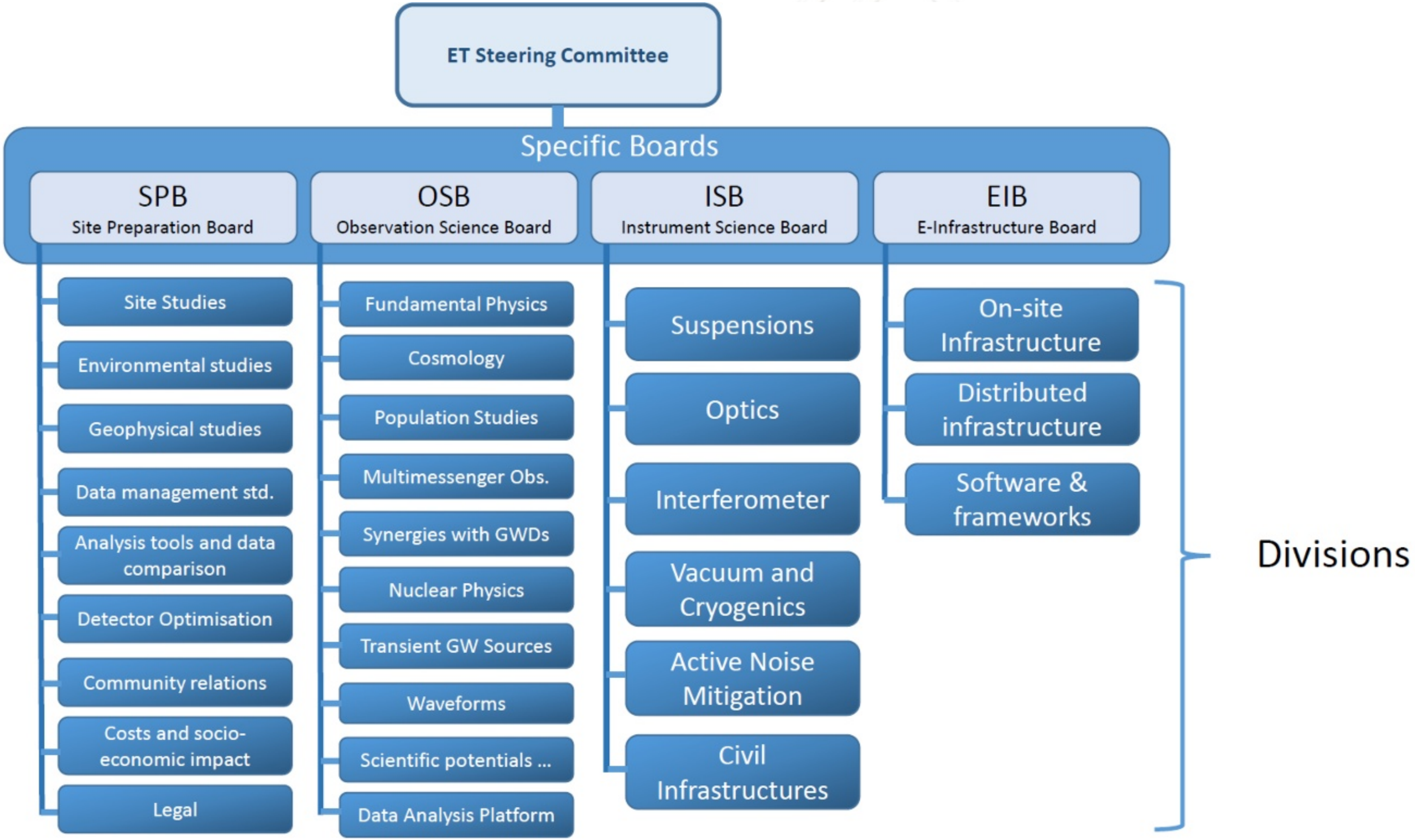
Strong dynamic in Europe...

First EU call successful this week

ET symposium in June (link)
Official start of the collaboration

* European Strategy Forum on Research Infrastructures

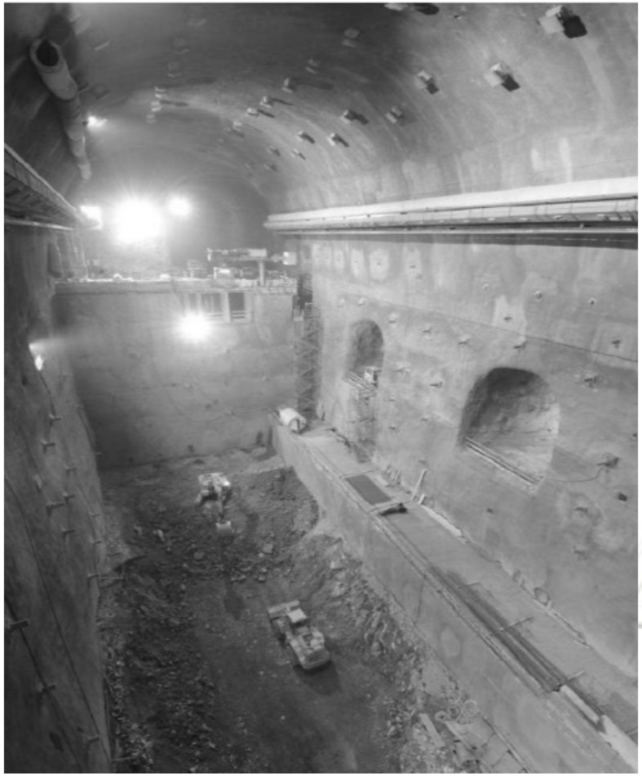
Organisation



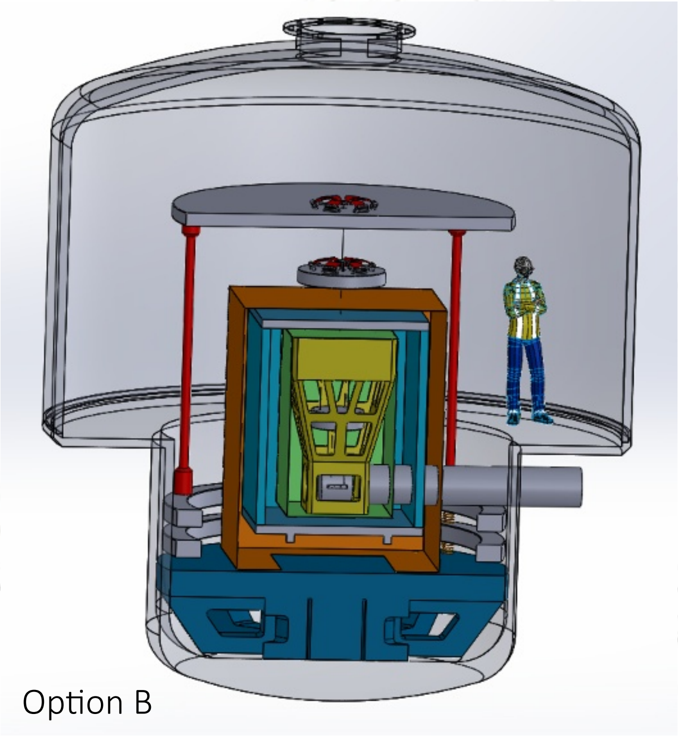
II.
The current instrumental work
(a selection with a French bias)

The WPs inside the Instrumental Science Board (ISB)

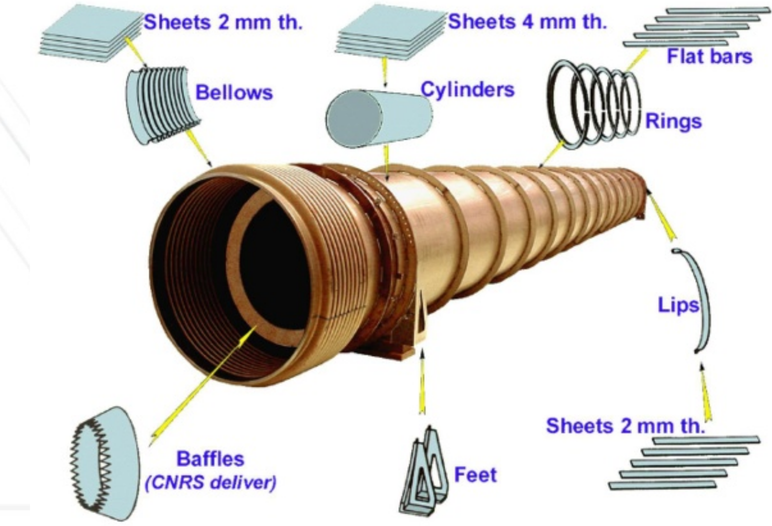
We start from almost a blank page (a personal selection)



Cavern shape ?
excavation method ?



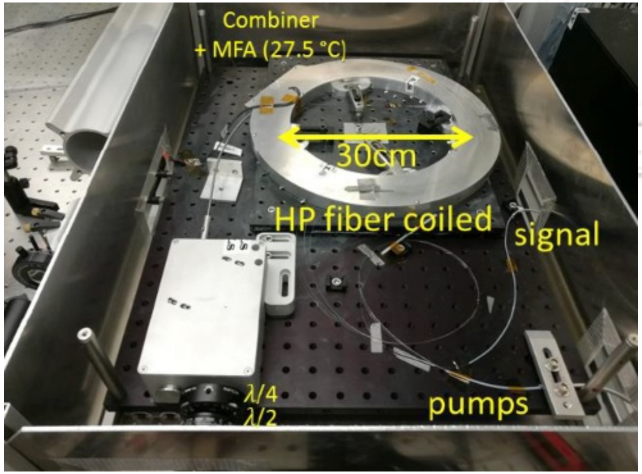
The challenge to reach low frequencies



120 km of vacuum pipe!
pipe design ? pumping strategy ?

The laser

- 700W at 1064 nm, 5W at 1550 nm (2 um ?)
- specifications similar or better compared to ALIGO, Avirgo
- some challenges:
  - for ET-HF: coherent sum of beam to reach the power
  - for ET-LF: improve power stabilisation at low frequency



Fiber laser amplifier
for ET-HF

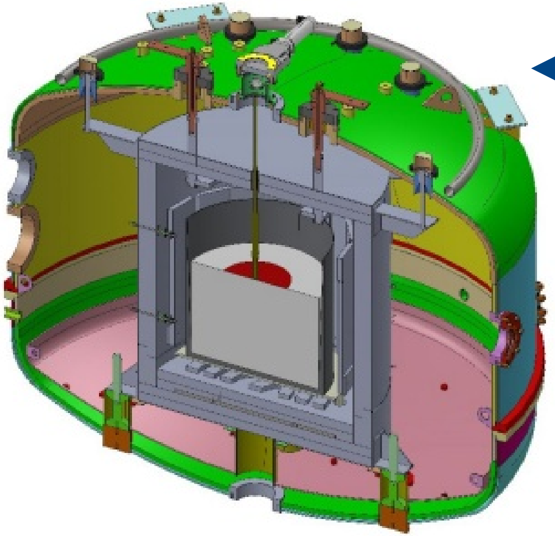
Injection and detection sides

- similar design to current detectors
- for ET-HF, the power handling is the critical part
- special attention to reduce the loss to benefit fully from the squeezing

- calibration with Newtonian calibrator (geometry ?) and photon calibrator (1 or more beams ?)

Crystalline substrates

- strong dynamic in Lyon to push for large sapphire substrates

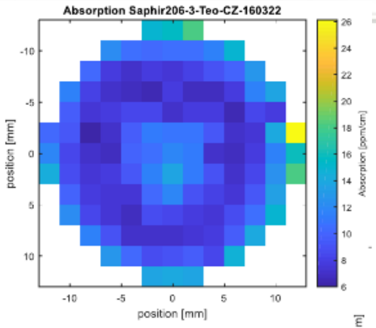


Unique oven to melt 500 kg of alumina

Tests in progress

+ fiber production

- Study absorption vs growth parameters on smaller samples



Best (and latest) results:
~ < 15 ppm/cm
at 1064 nm

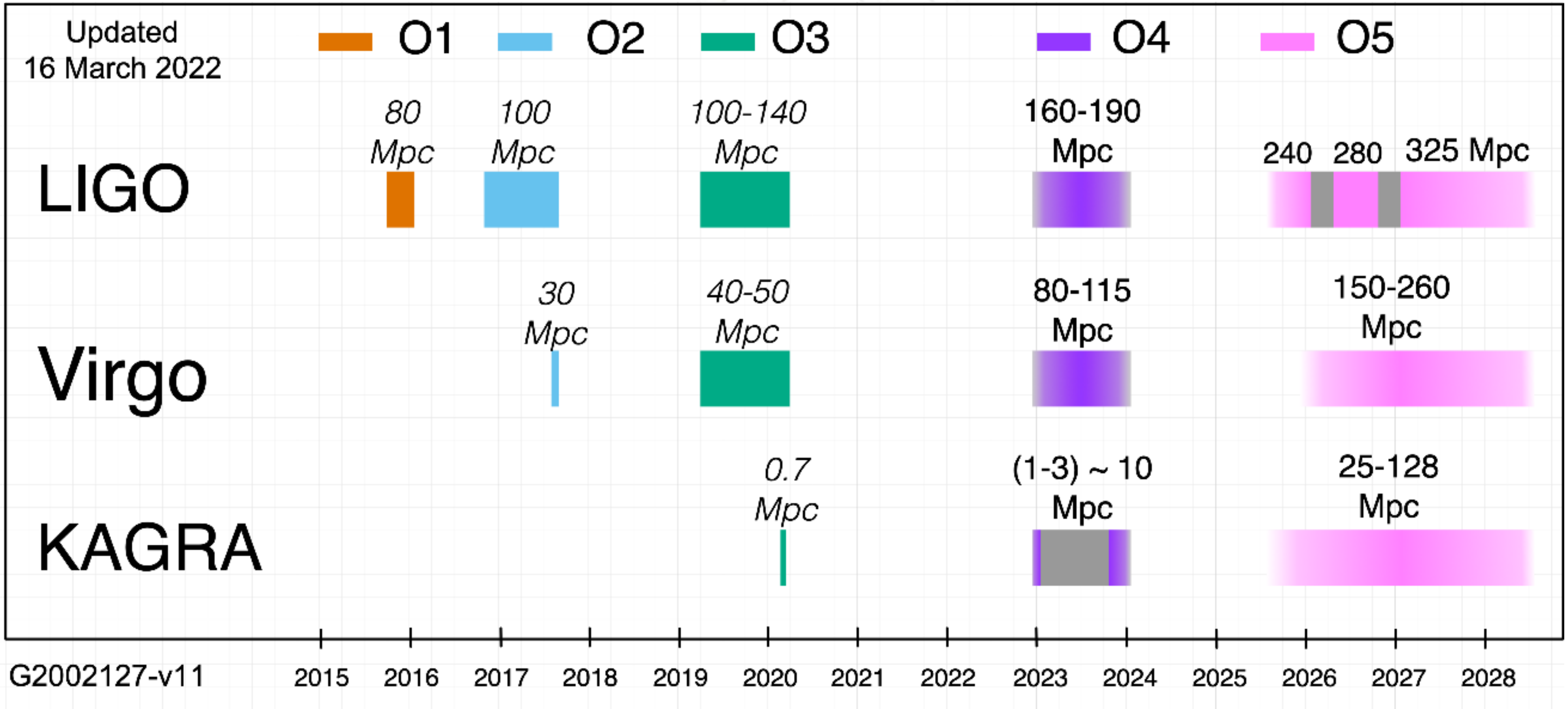
What about the coating ?

- research right now focusing on large coating for O5
- material candidate to replace Ti:Ta2O5 → Ti:GeO2
- further reduction in coating loss angle for post O5

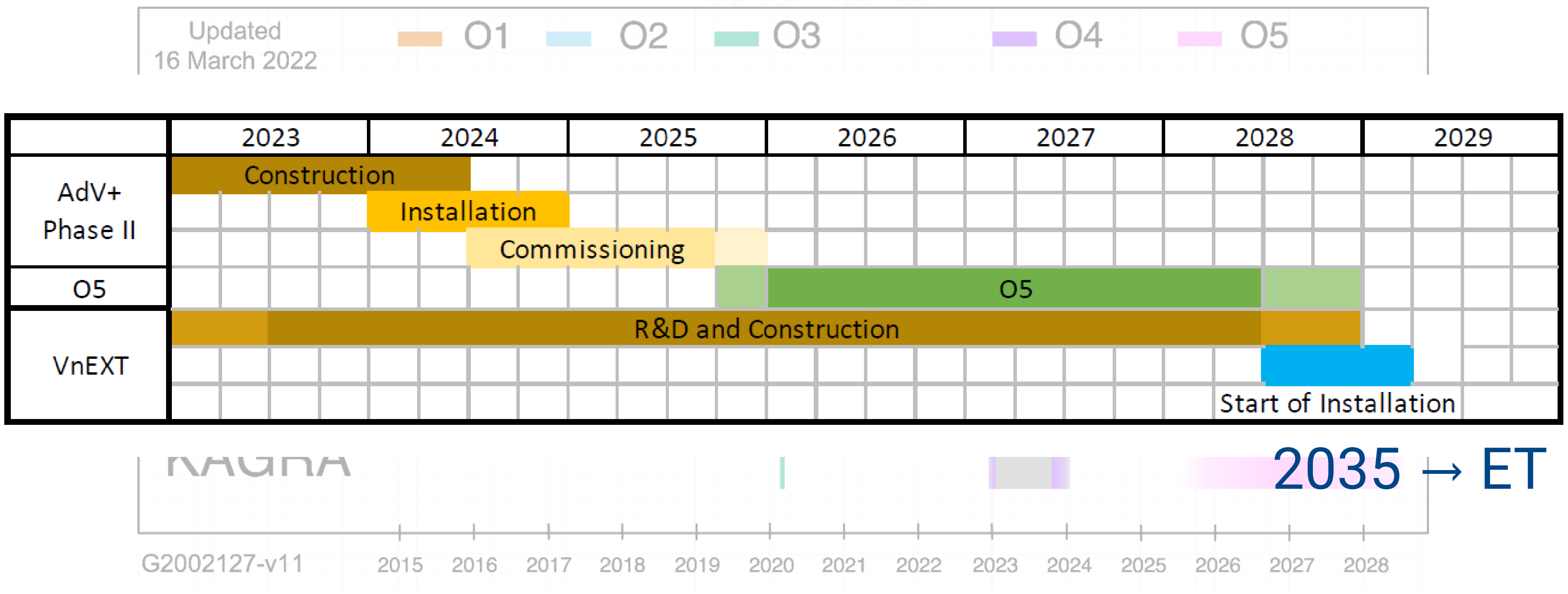
- ET will benefit in all the coating development for LIGO/Virgo
- dedicated cryogenic coating ?
- crystalline coating ?

III.
Bridging the gap between O5 and E.T.
(inspired from VIR-0391A-22)

The stage


Updated
16 March 2022
O1
O2
O3
O4
O5
LIGO
80 Mpc
100 Mpc
100-140 Mpc
160-190 Mpc
240
280
325 Mpc
Virgo
30 Mpc
40-50 Mpc
80-115 Mpc
150-260 Mpc
KAGRA
0.7 Mpc
(1-3) ~ 10 Mpc
25-128 Mpc
G2002127-v11
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028

The stage

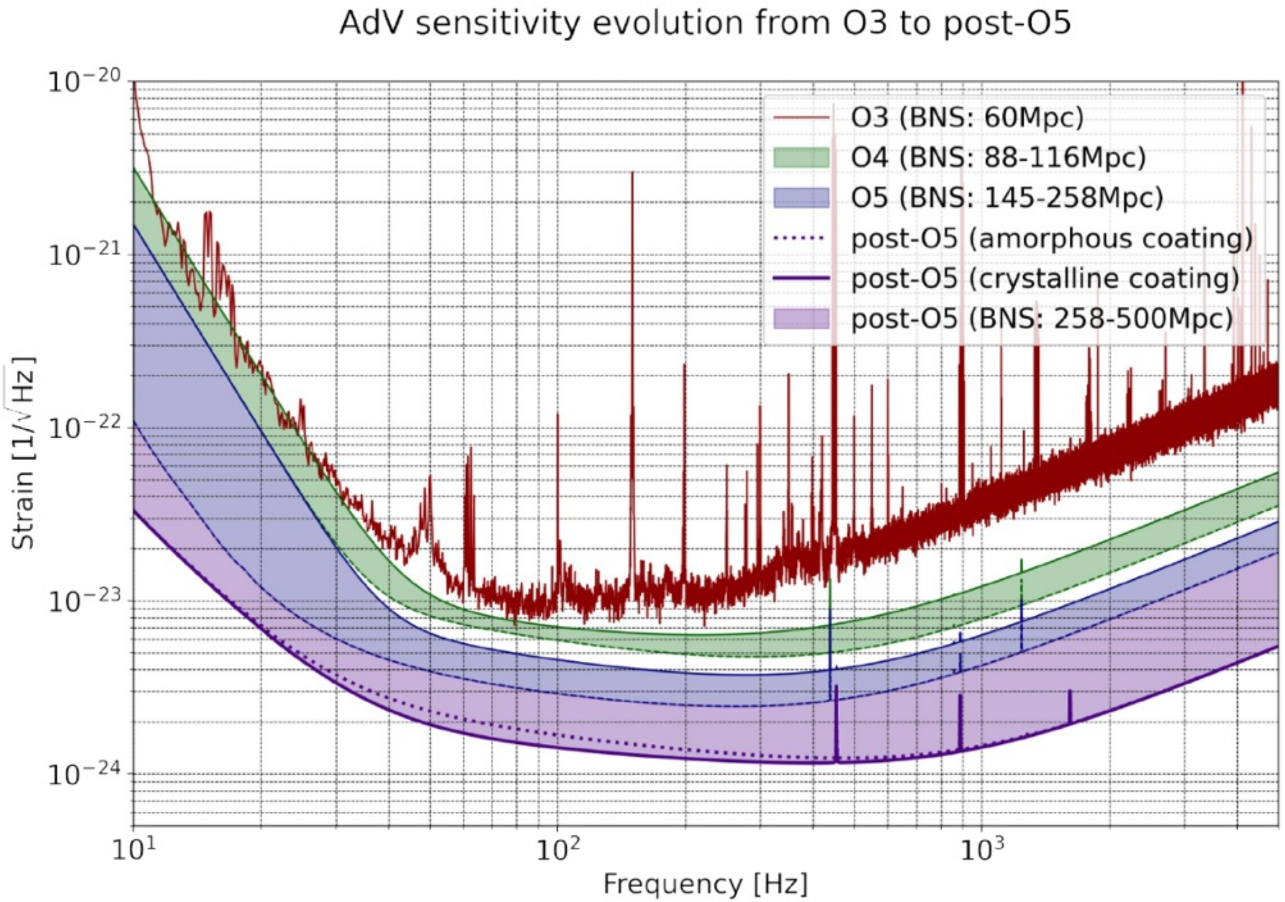

Updated
16 March 2022
O1
O2
O3
O4
O5
2023
2024
2025
2026
2027
2028
2029
AdV+
Phase II
Construction
Installation
Commissioning
O5
O5
VnEXT
R&D and Construction
Start of Installation
2035 → ET
G2002127-v11
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028

Comparison of Parameters

Parameter	O4 high	O4 low	O5 high	O5 low	VnEXT_low
Power injected	25 W	40 W	60 W	80 W	277 W
Arm power	120 kW	190 kW	290 kW	390 kW	1.5 MW
PR gain	34	34	35	35	39
Finesse	446	446	446	446	446
Signal recycling	Yes	Yes	Yes	Yes	Yes
Squeezing type	FIS	FDS	FDS	FDS	FDS
Squeezing detected level	3 dB	4.5 dB	4.5 dB	6 dB	10.5
Payload type	AdV	AdV	AdV	AdV	Triple pendulum
ITM mass	42 kg	42kg	42 kg	42 kg	105 kg
ETM mass	42 kg	42kg	105 kg	105 kg	105 kg
ITM beam radius	49 mm	49 mm	49 mm	49 mm	49 mm
ETM beam radius	58 mm	58 mm	91 mm	91 mm	91 mm
Coating losses ETM	2.37e-4	2.37e-4	2.37e-4	0.79e-4	6.2e-6
Coating losses ITM	1.63e-4	1.63e-4	1.63e-4	0.54e-4	6.2e-6
Newtonian noise reduction	None	1/3	1/3	1/5	1/5
Technical noise	“Late high”	“Late low”	“Late low”	None	None
BNS range	90 Mpc	115 Mpc	145 Mpc	260 Mpc	500 Mpc

Fafone et al, Virgo Week April 2022

Sensitivity forecast



Fafone et al, Virgo Week April 2022

Conclusion

- Great amount of R&D to prepare the post-O5 and the Einstein Telescope
- Numerous joint R&D with KAGRA
- Ilance is a unique opportunity to strengthen our collaboration