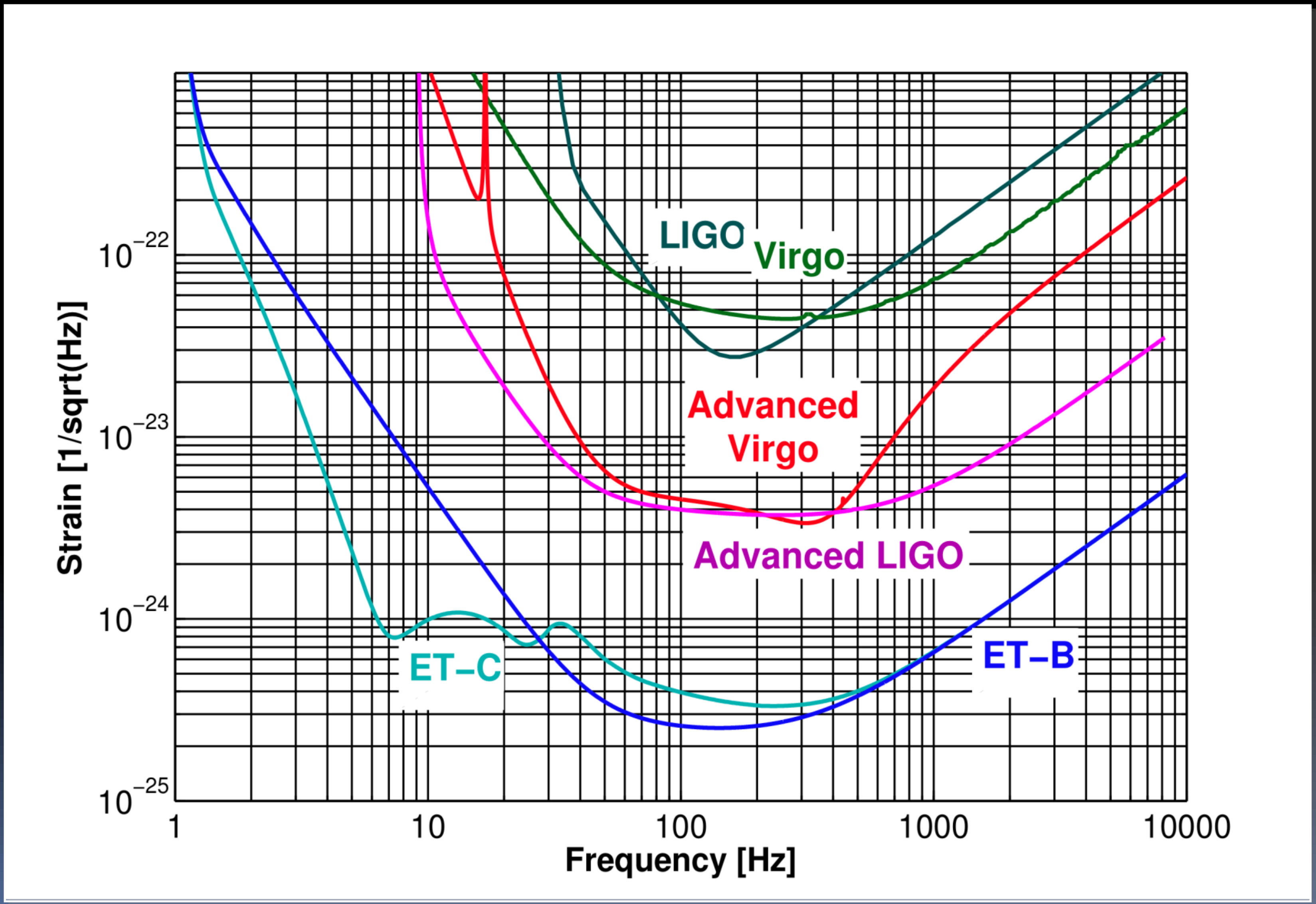
ET – THE EINSTEIN TELESCOPE

INSTRUMENTAL ASPECTS

Harald Lück
AEI Hannover

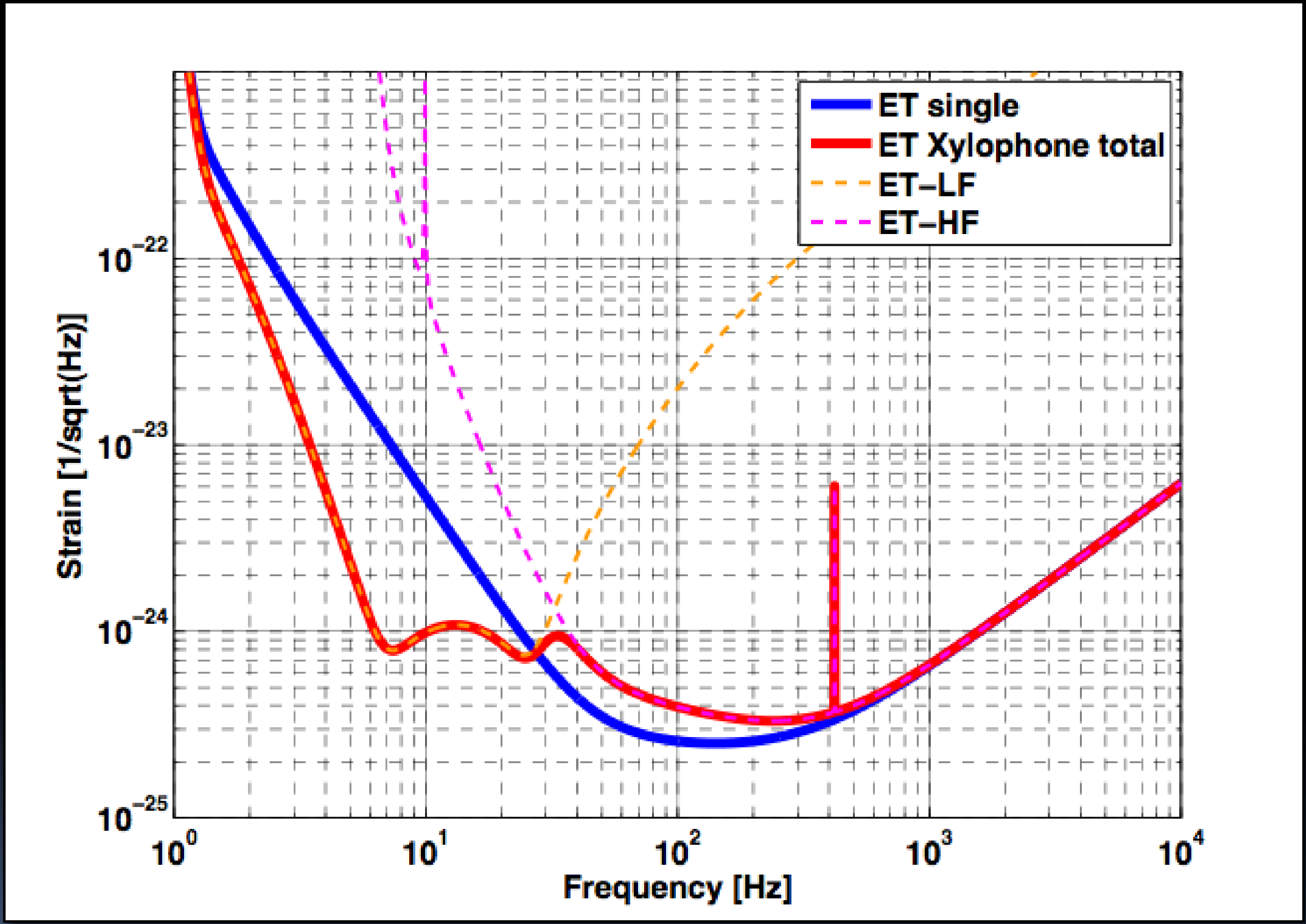
LIGO-G1000986-v1

The goal


LIGO
Virgo
Advanced
Virgo
Advanced LIGO
ET–C
ET–B
10^{-22}
10^{-23}
10^{-24}
10^{-25}
Strain [1/sqrt(Hz)]
1
10
100
1000
10000
Frequency [Hz]

„Xylophone“ concept

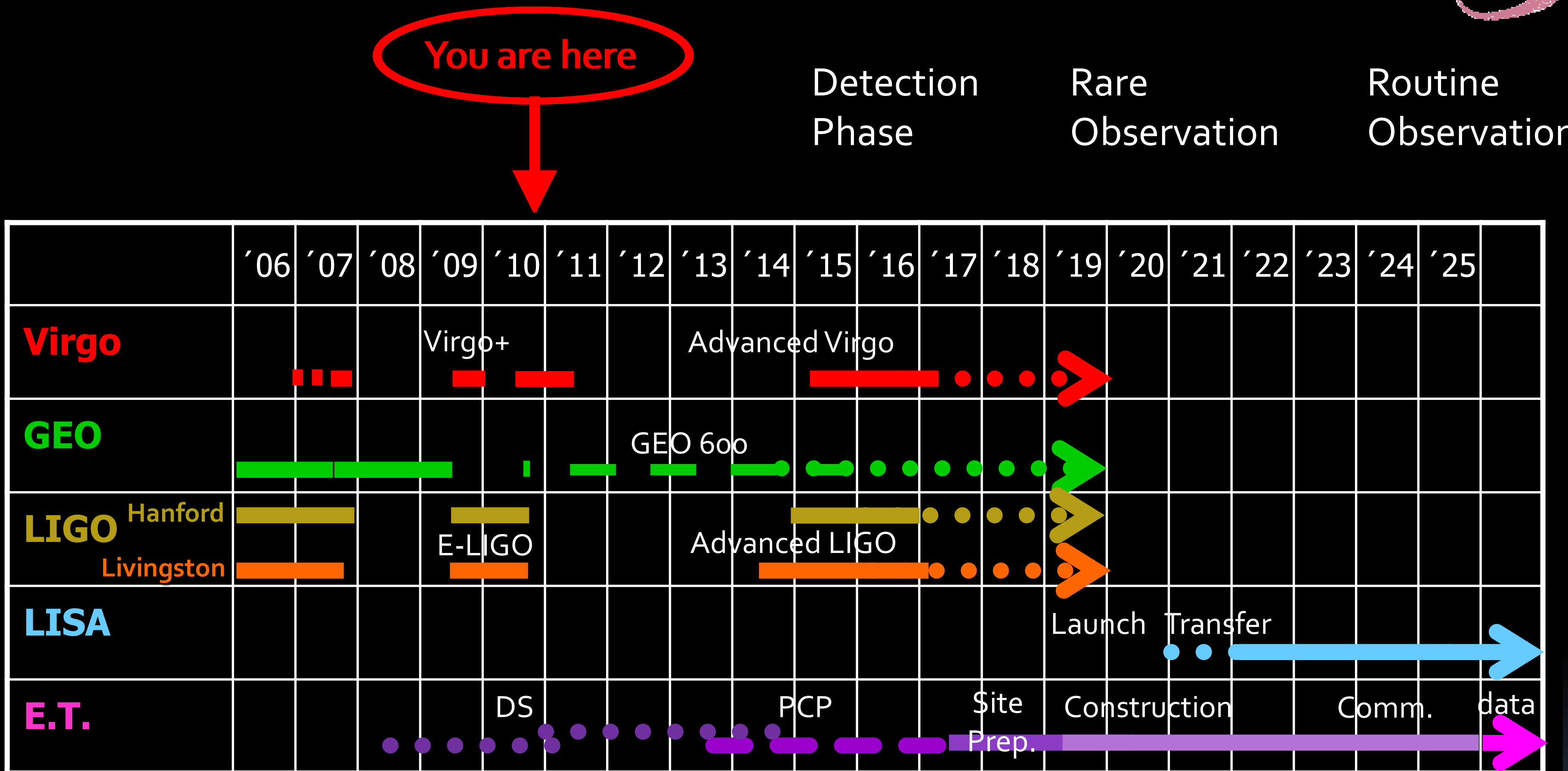
solves problem of high laser power and radiation pressure noise at low frequencies



- See also S.Hild, S.Chelkowski, A.Freise, J.Franc, R.Flaminio, N.Morgado and R.DeSalvo: 'A Xylophone Configuration for a third Generation Gravitational Wave Detector', CQG 2010, 27, 015003

EINSTEIN TELESCOPE

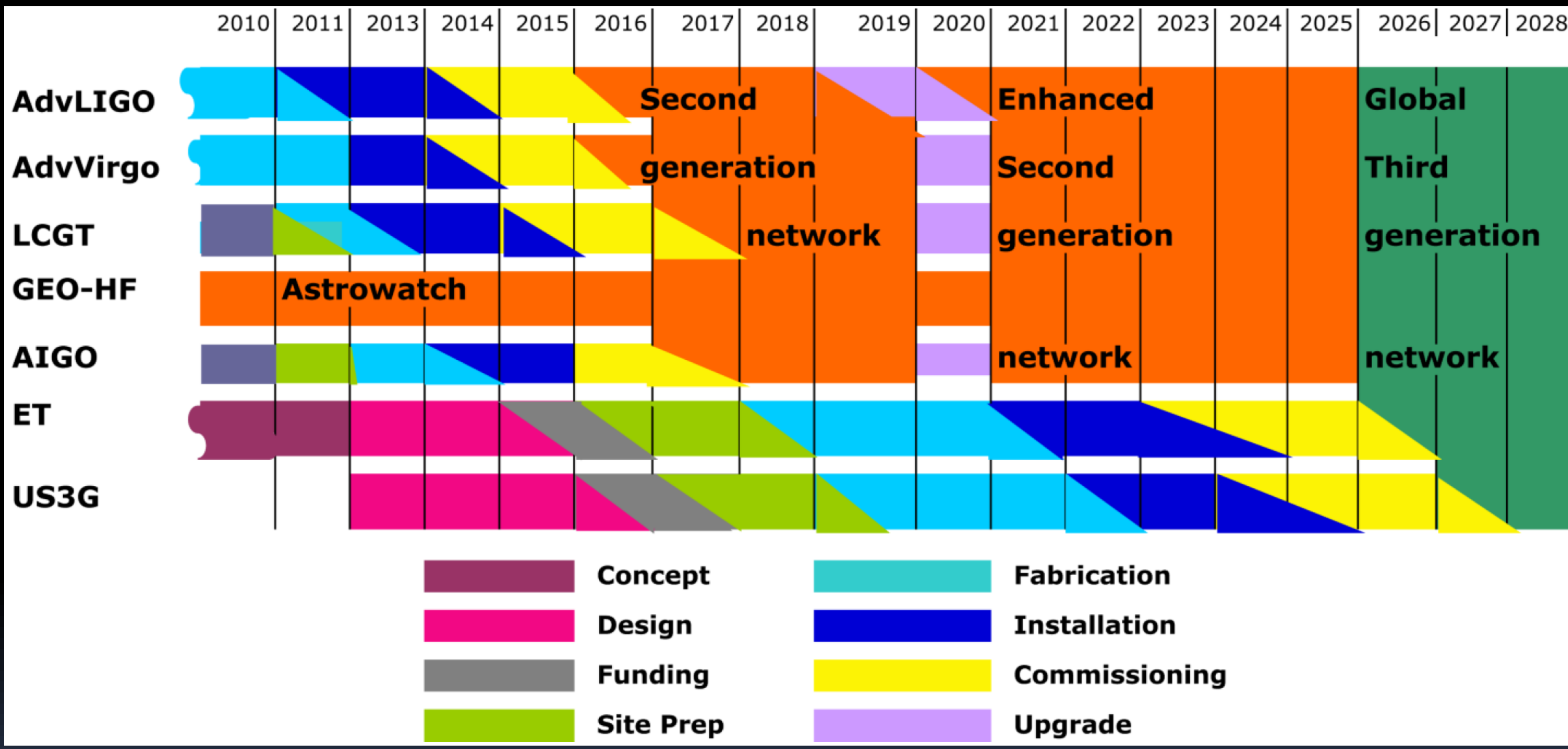
A LONG ROAD



1st Generation		2nd Generation	3rd Gen.

GW Detection is a prerequisite for building ET

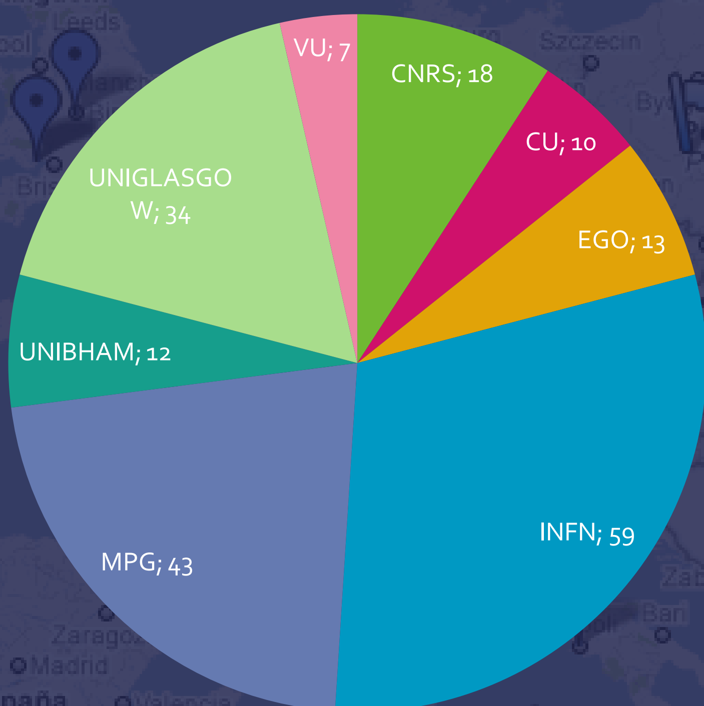
The GWIC roadmap



The Einstein Telescope

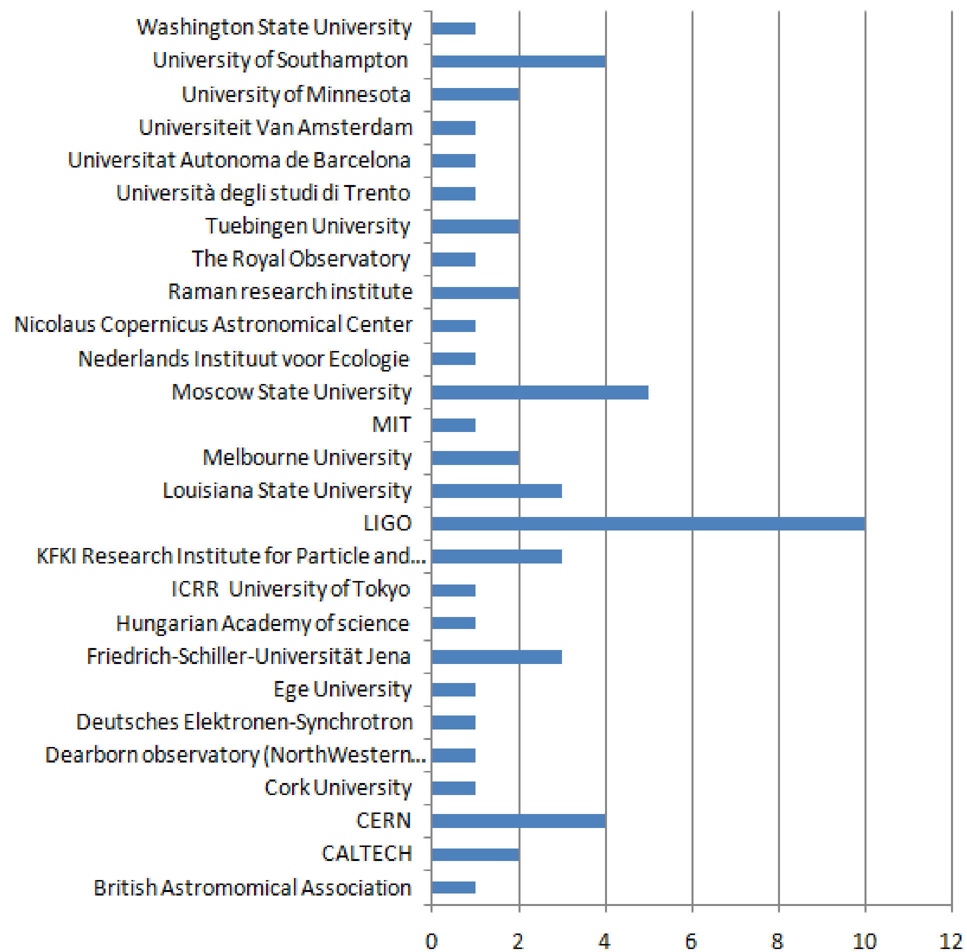
- The Einstein Telescope project is currently in its conceptual design study phase, supported by the European Union within FP7 with about 3M

Participants per Beneficiary



Science team total: 249

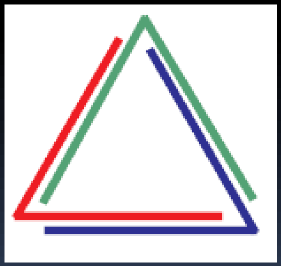
Participants per NON-Beneficiary



TECHNIQUES FOR ET

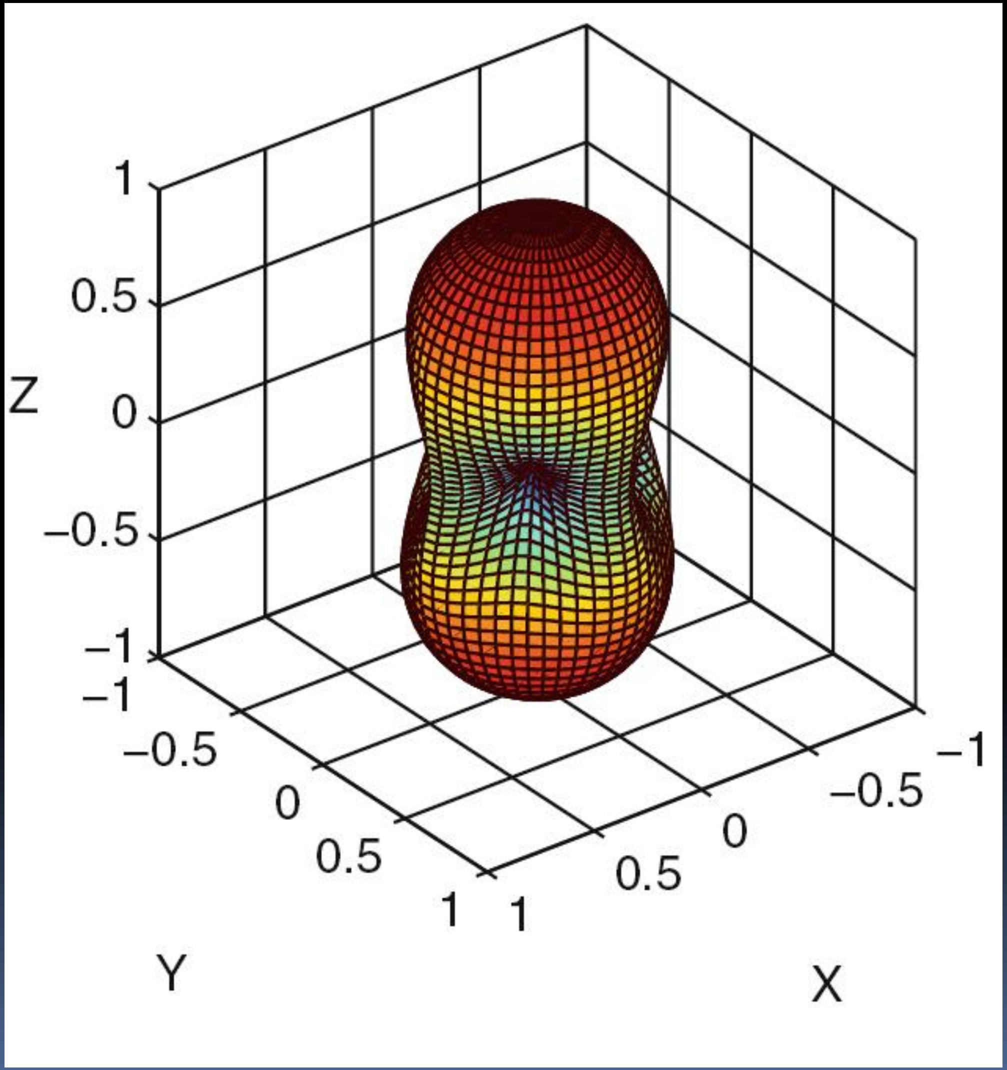
- **Basic assumptions:**
- ET will be a long lasting (decades) infrastructure
- Only mature techniques are foreseen as baseline design
- Subsequent upgrades to novel techniques will follow
- ET will be built underground, (see 'seismic slides')
- Overall tunnel length will be 30km
- ET will be built in a 'triple Michelson' arrangement

(CQG **26** 085012, 2009)



Antenna pattern

simple Michleson vs. triple Michelson



Freise et al. DOI 10.1007/s10714-010-1018-0

STARTING POINT: 2^{ND} GENERATION

We consider:

Michelson topology with dual recycling.

One detector covering the full frequency band

A single detector (no network)

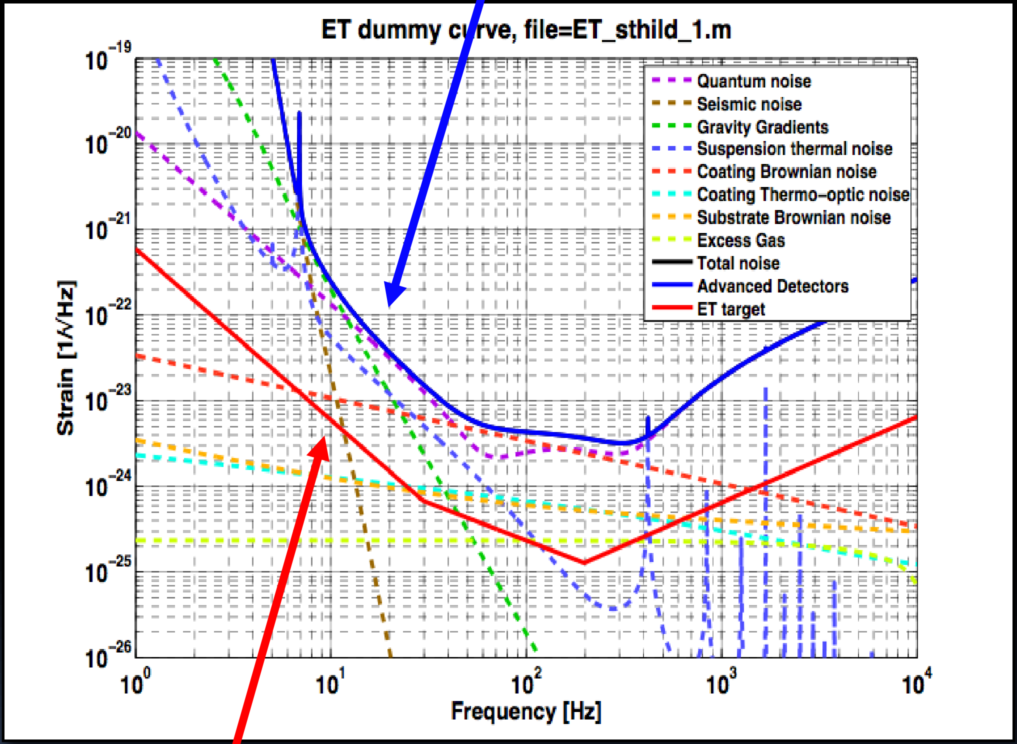
Start from a 2nd Generation instrument.

Each fundamental noise at least for some frequencies above the ET target.

=> OUR TASK:

All fundamental noises have to be improved !!

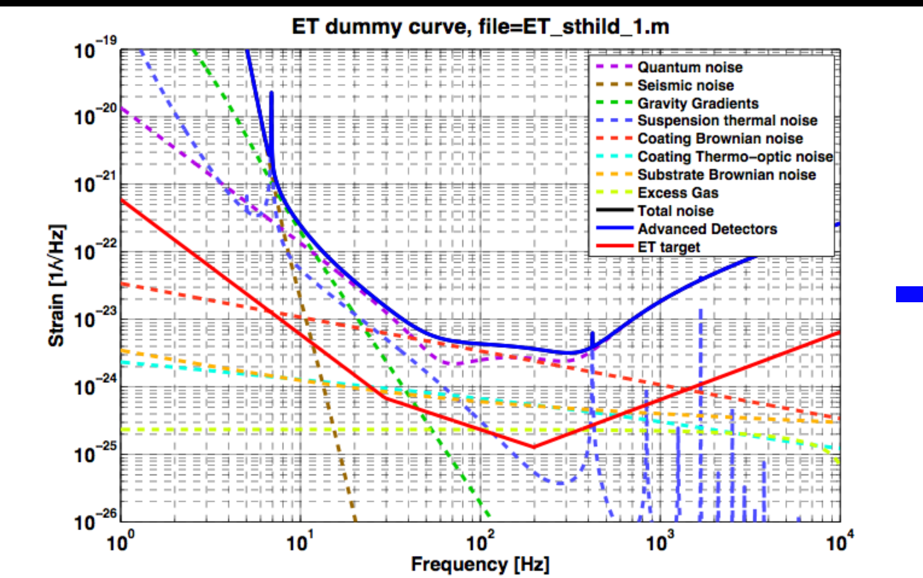
2nd Generation design sensitivity

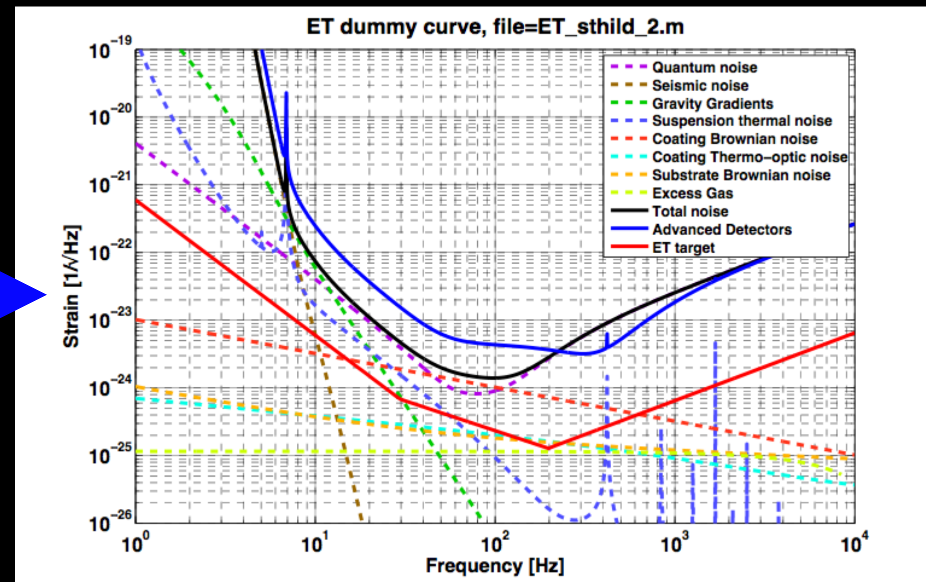


3G target sensitivity (approximated)

Courtesy:Stefan Hild

INCREASING THE ARM LENGTH



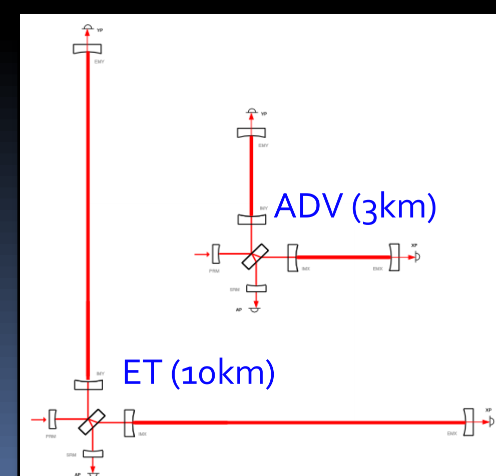


DRIVER: All displacement noises

ACTION: Increase arm length from 3km to 10km

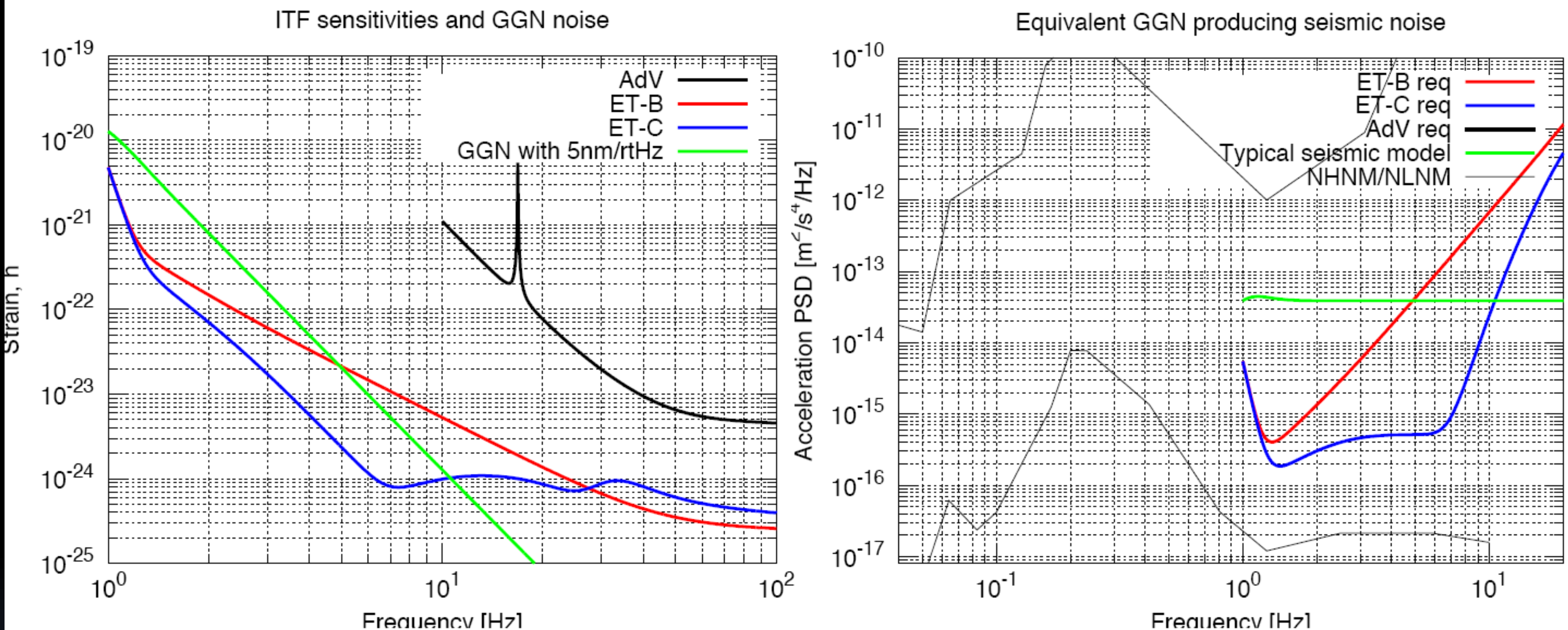
EFFECT: Decrease all displacement noises by a factor 3.3

SIDE EFFECTS:
- Decrease in residual gas pressure
- Change of effective Signal recycling tuning



Courtesy:Stefan Hild

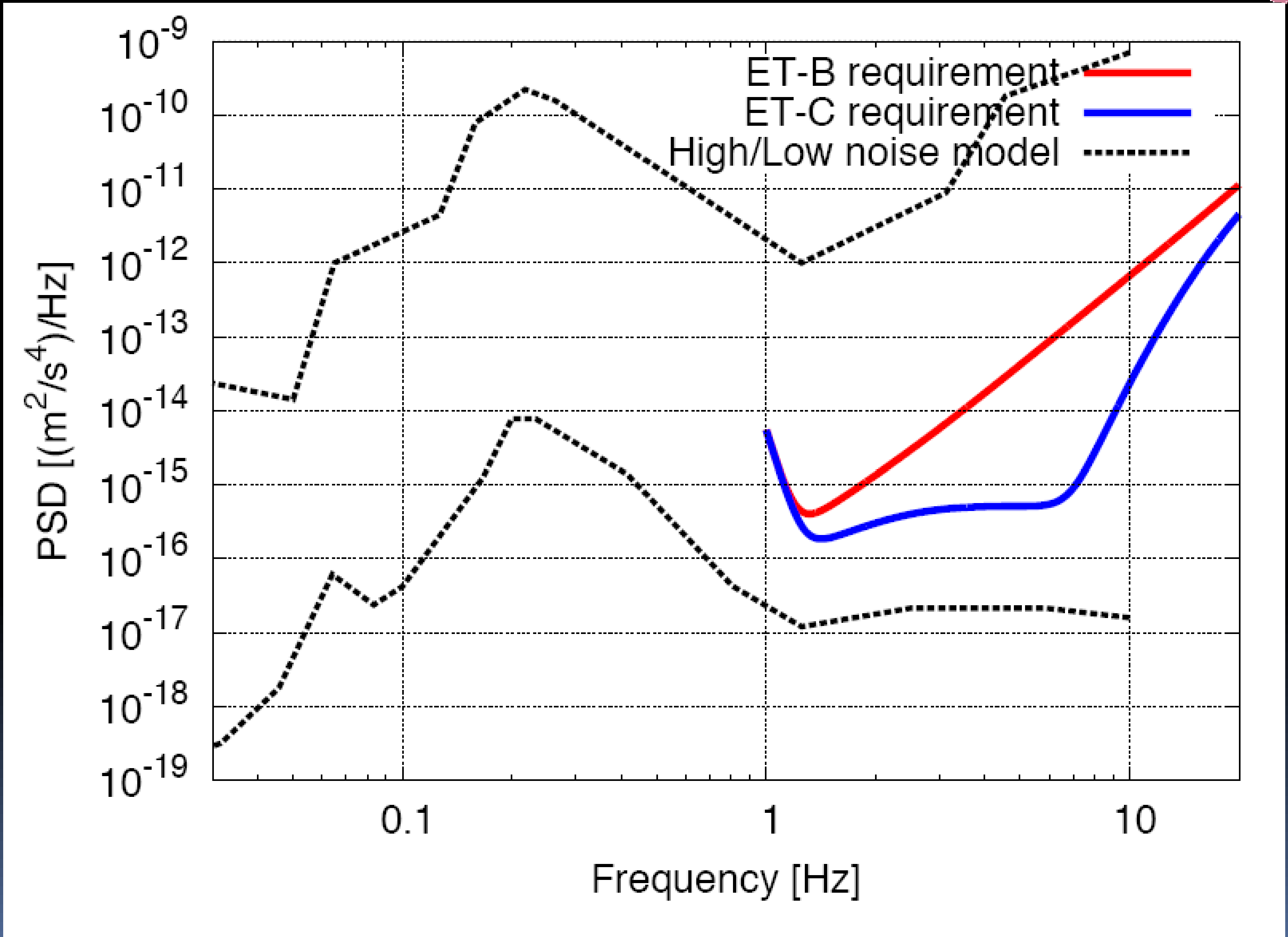
Gravity Gradient Noise



Assumptions: - Surface detector

- Isotropic body pressure waves
- Seismic spectrum: (5 nm/ f^2)/√Hz
- Saulson's model prediction of GGN (β = 0.6)

Credit: M. Beker, Nikhef



Credit: M. Beker, Nikhef

Seismic measurements

Credit: M. Beker, Nikhef

Data collected from these sites

3rd party data obtained and analyzed from these sites

Seismic measurements

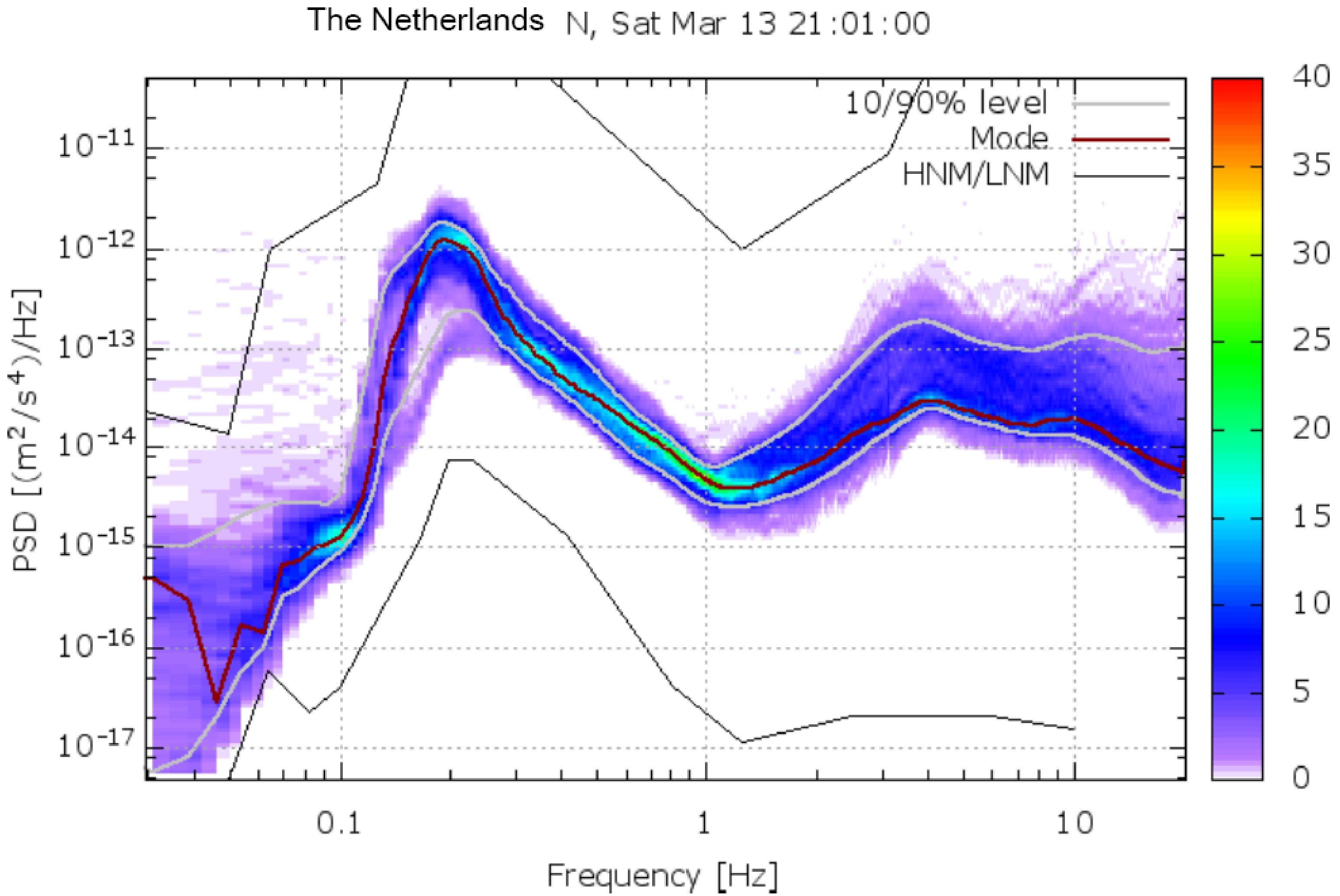
Data collected from these sites

3rd party data obtained and analyzed from these sites

Credit: M. Beker, Nikhef

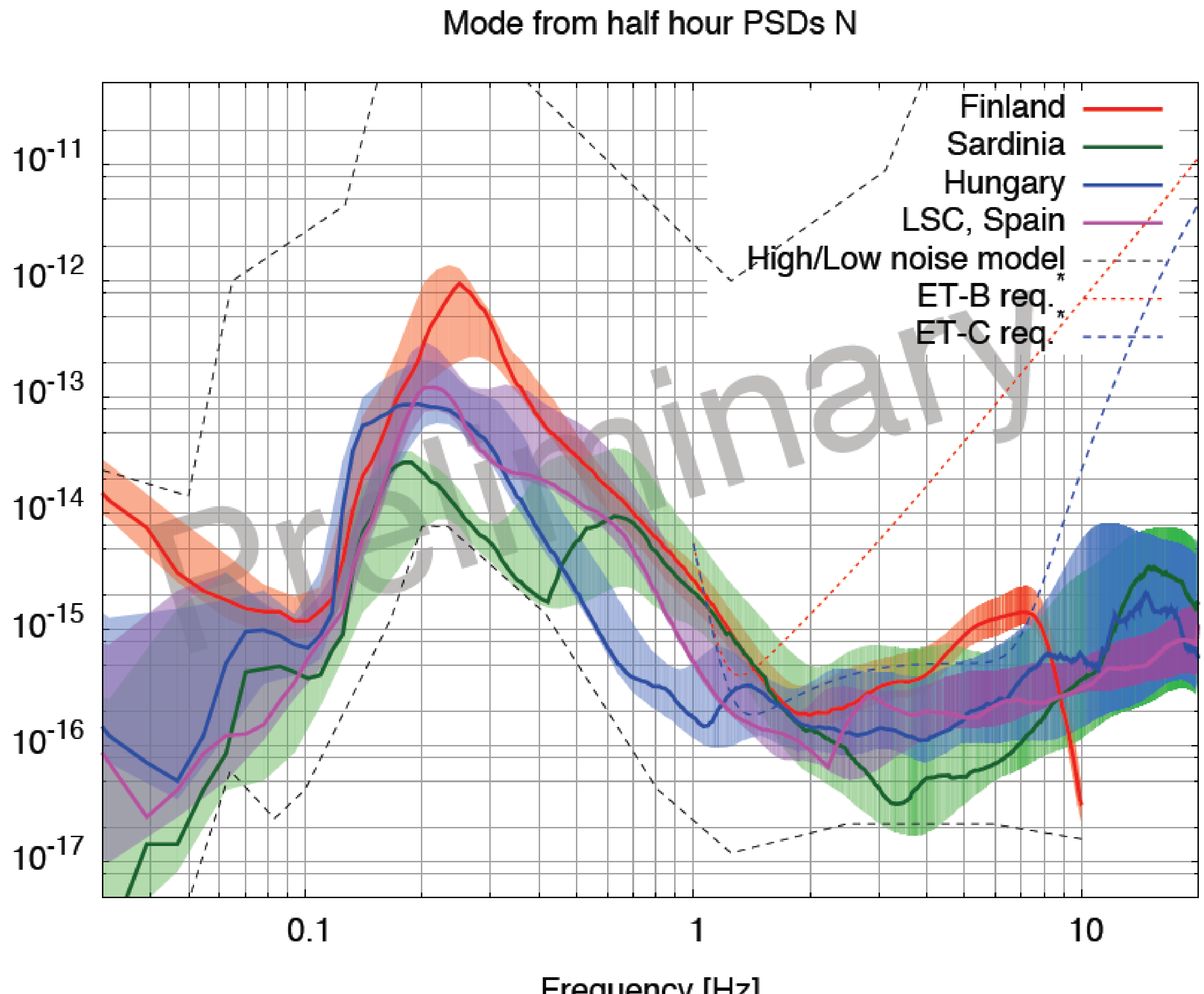
Seismic measurements

Characterization of sites is done using spectral variation plots of half hour averages



Credit: M. Beker, Nikhef

Seismic measurements



Finland, 0 m

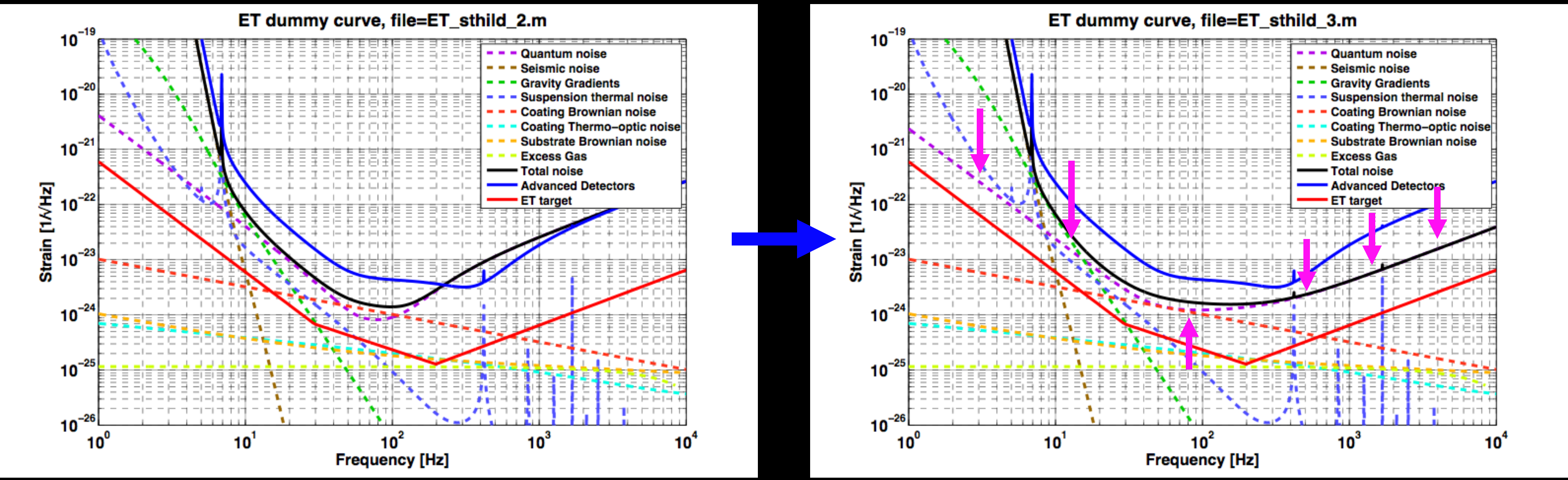
Sardinia, 185 m

Hungary, 400 m

LSC, Spain, 800 m

Credit: M. Beker, Nikhef

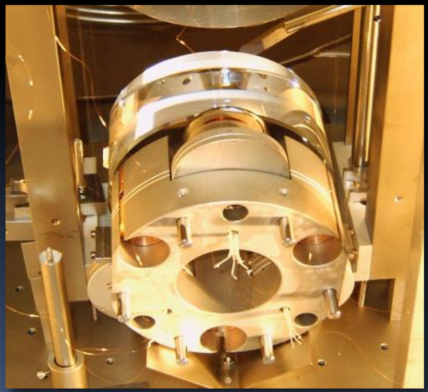
SIGNAL RECYCLING



DRIVER: Quantum noise

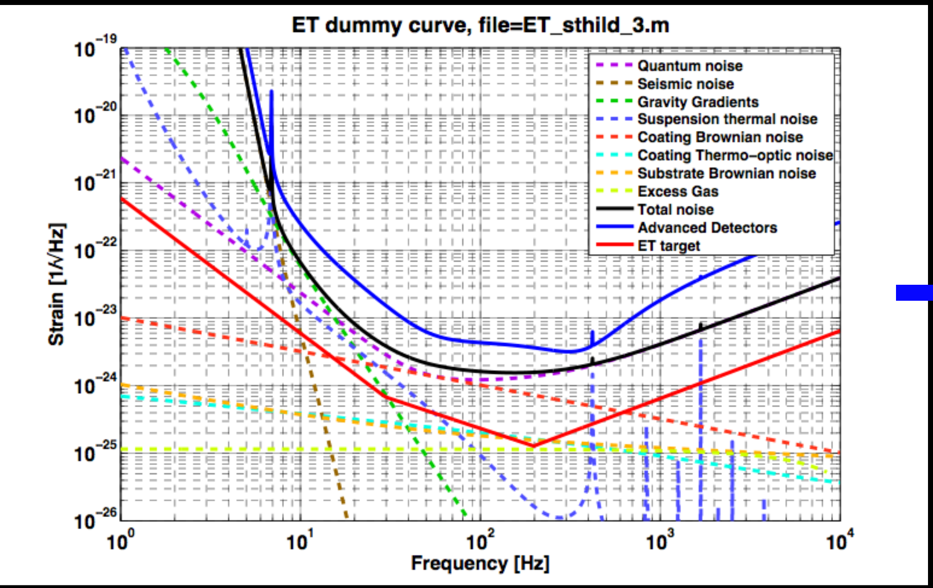
ACTION: From detuned SR to tuned SR (with 10% transmittance)

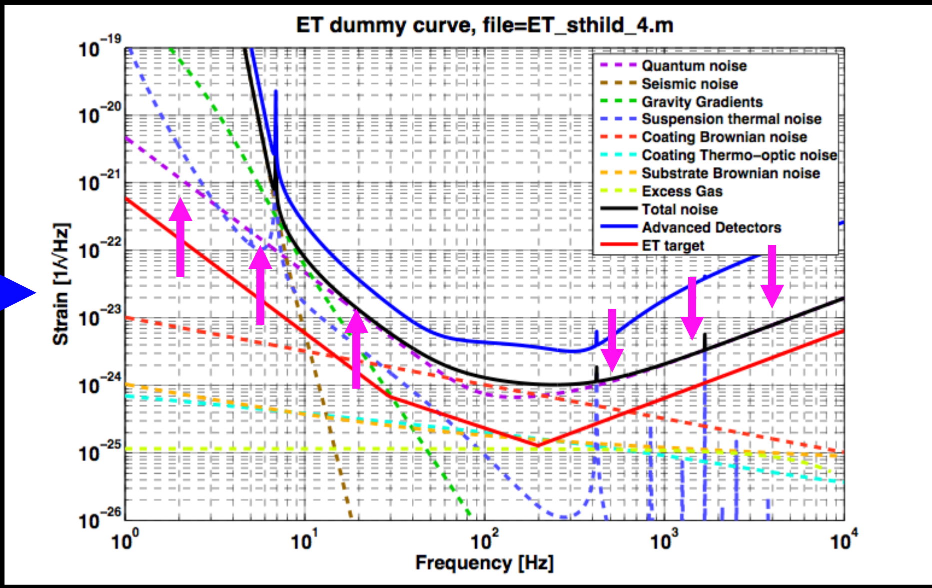
EFFECTS:
- Reduced shot noise by ~ factor 7 at high freqs
- Reduced radiation pressure by ~ factor 2 at low freqs
- Reduced peak sensitivity by ~ factor sqrt(2)   :(



Courtesy:Stefan Hild

MORE LASER POWER



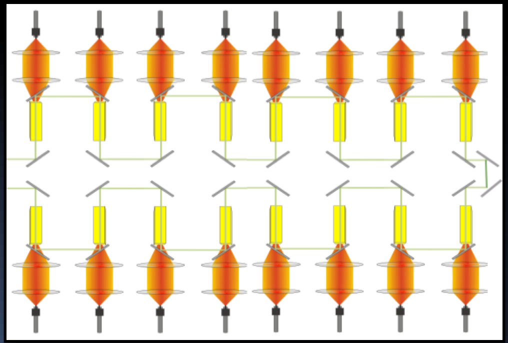


DRIVER: Shot noise at high frequencies

ACTION: Increase laser power (@ ifo input) from 125W to 500W

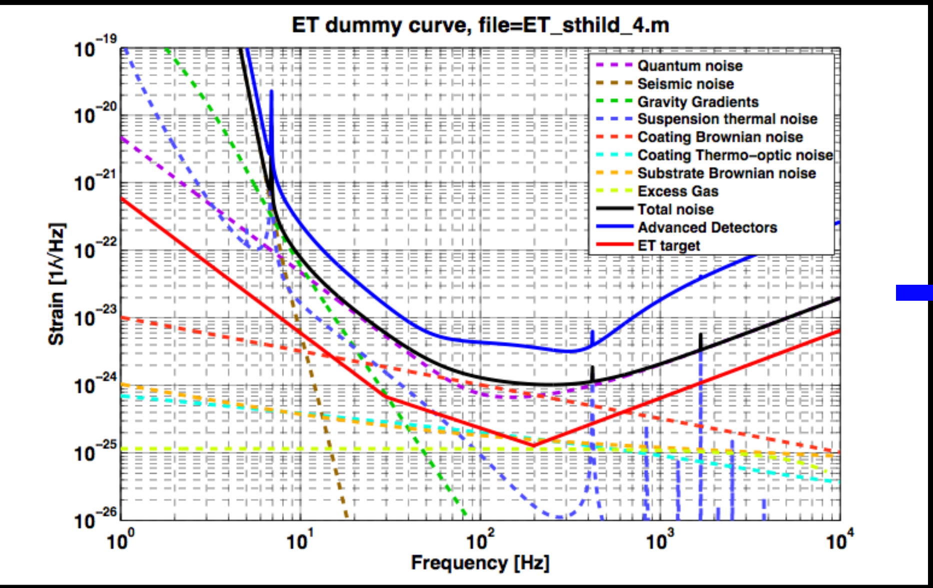
EFFECT: Reduced shot noise by a factor of 2

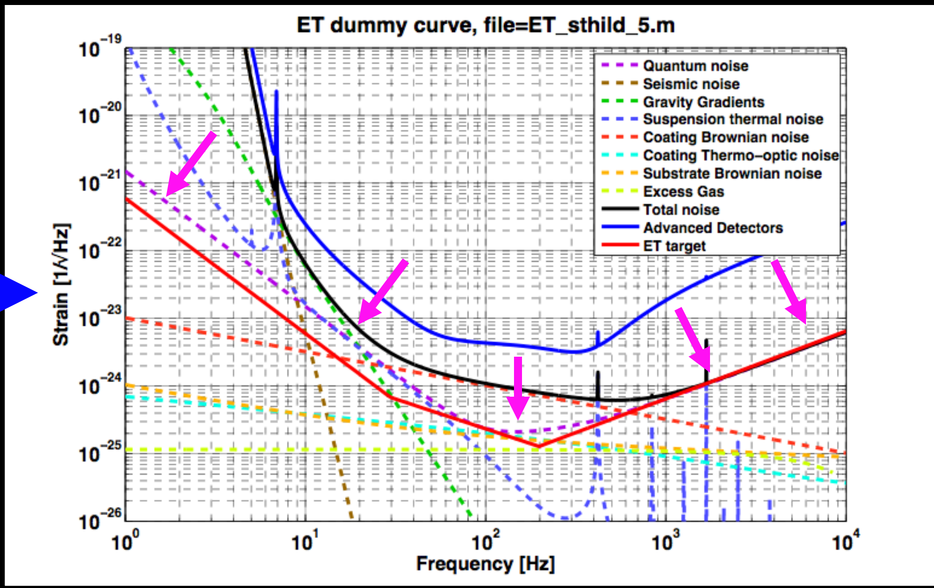
SIDE EFFECTS: Increased radiation pressure noise by a factor 2



Courtesy:Stefan Hild

QUANTUM NOISE REDUCTION



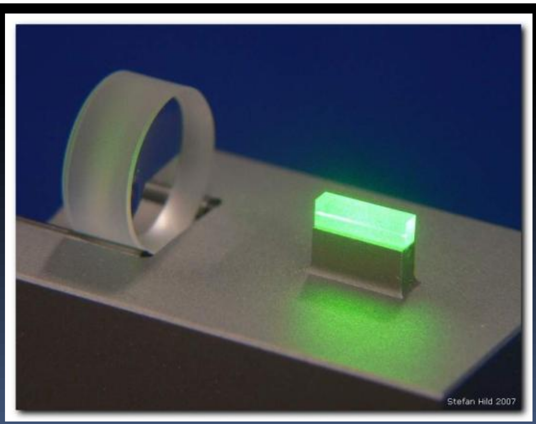


DRIVER: Shot noise at high frequencies

ACTION: Introduced 10dB of squeezing (frequency depend angle)

EFFECT: Decreases the shot noise by a factor 3

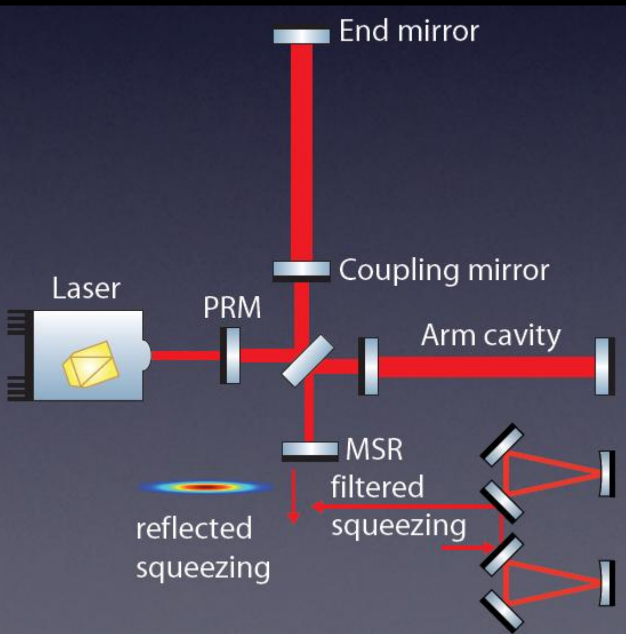
SIDE EFFECTS: Decreases radiation pressure noise by a factor 3

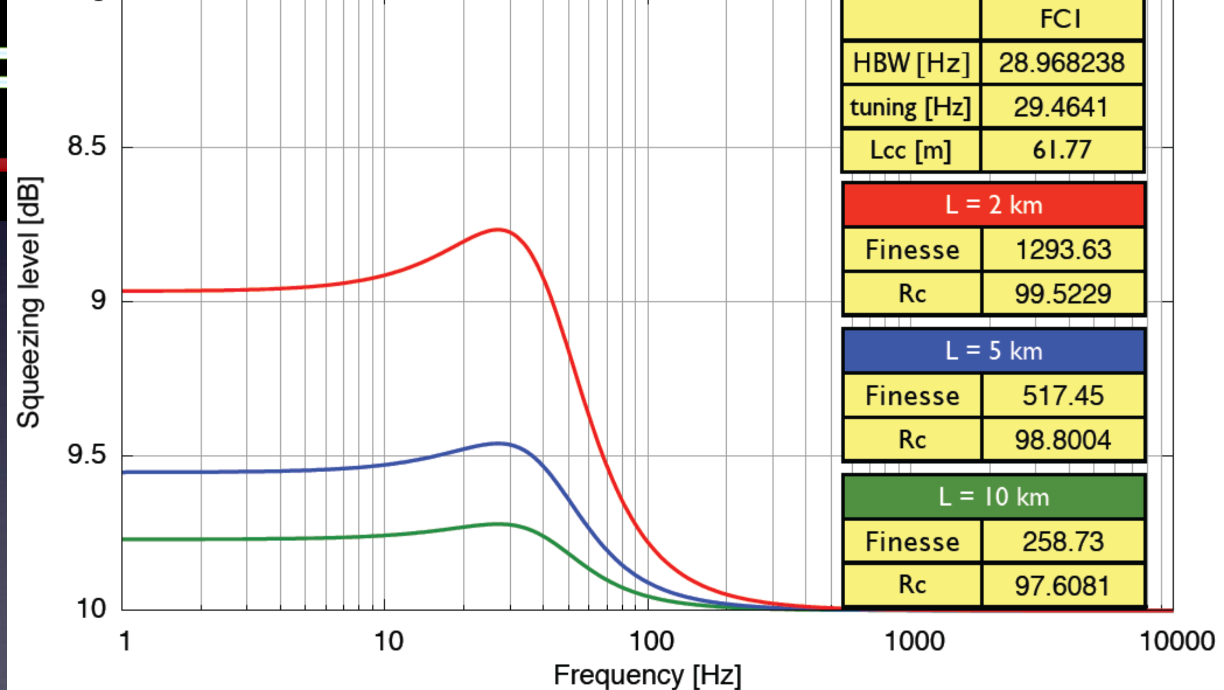


Courtesy:Stefan Hild

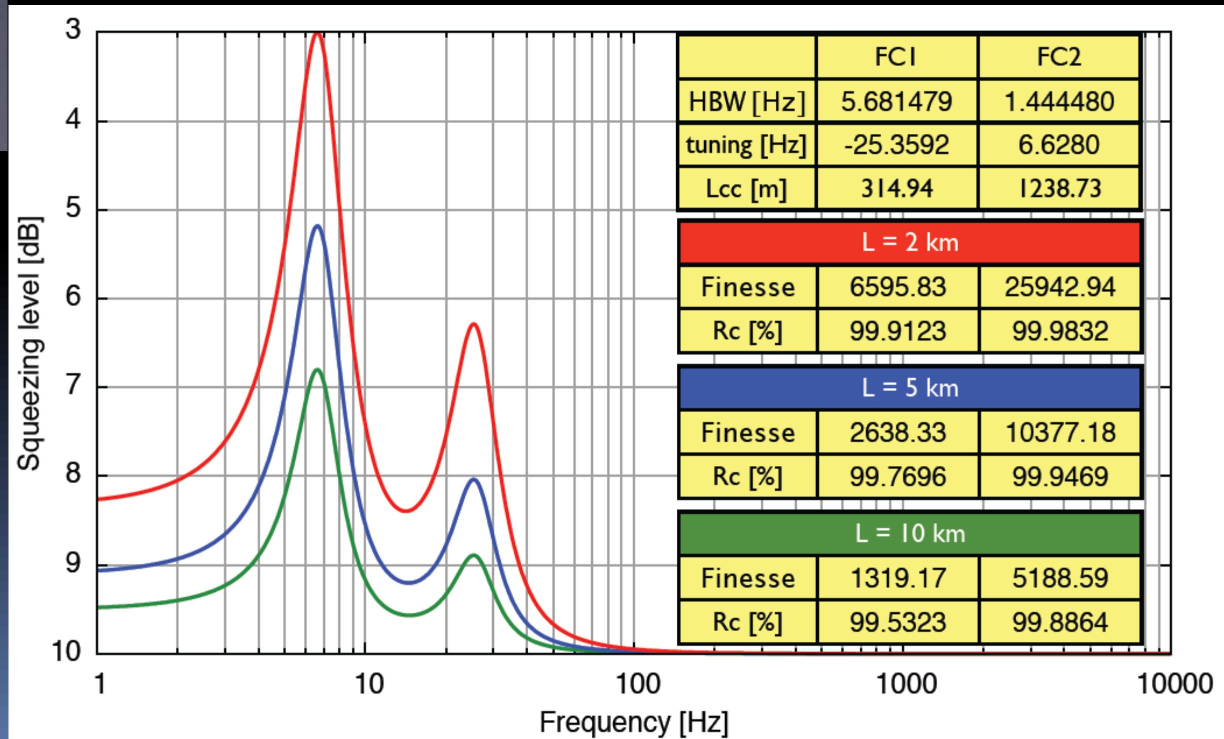
Detuned Squeezing requires filter cavities

ET EINSTEIN TELESCOPE





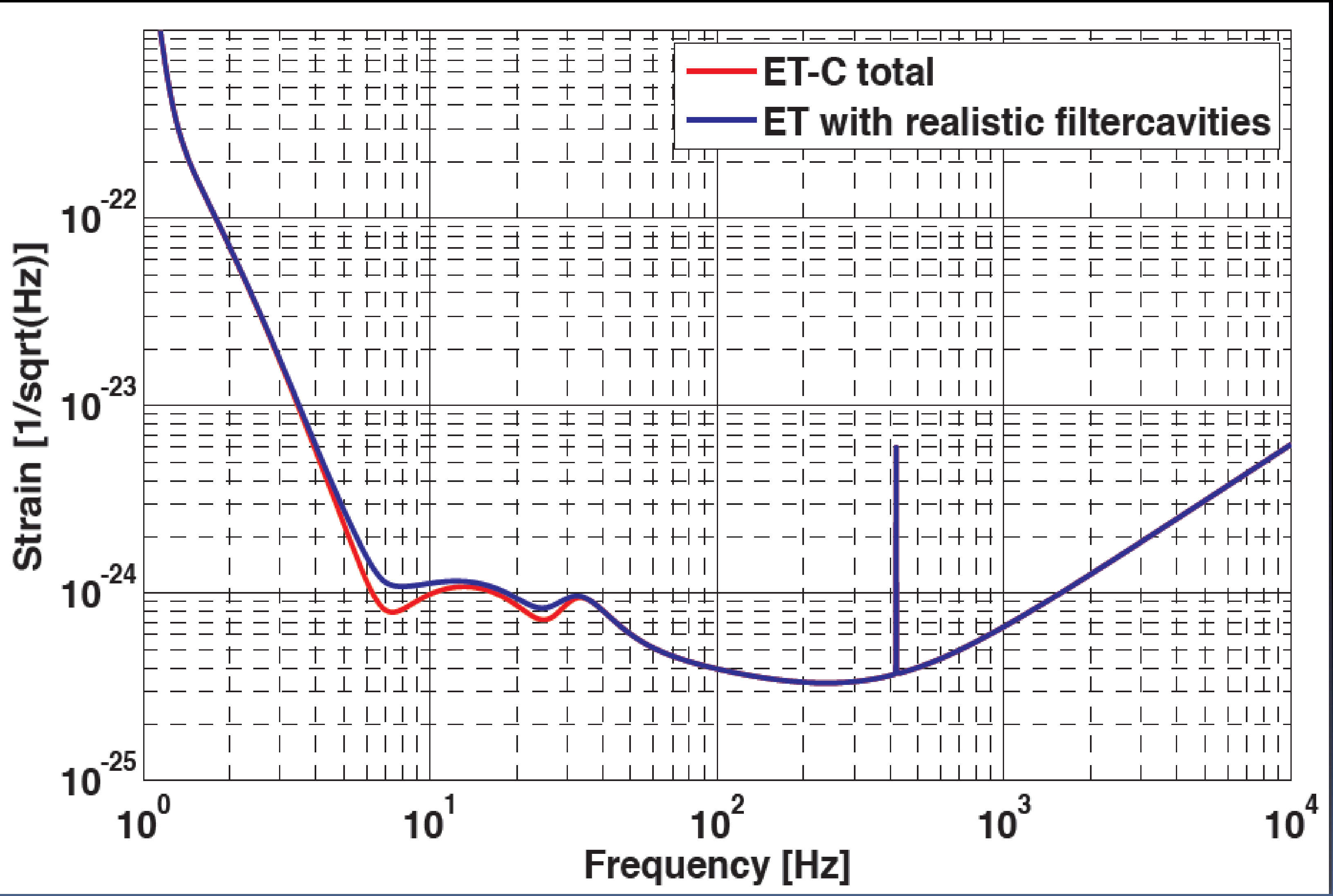
	FC1
HBW [Hz]	28.968238
tuning [Hz]	29.4641
Lcc [m]	61.77
L = 2 km	
Finesse	1293.63
Rc	99.5229
L = 5 km	
Finesse	517.45
Rc	98.8004
L = 10 km	
Finesse	258.73
Rc	97.6081



	FC1	FC2
HBW [Hz]	5.681479	1.444480
tuning [Hz]	-25.3592	6.6280
Lcc [m]	314.94	1238.73
L = 2 km		
Finesse	6595.83	25942.94
Rc [%]	99.9123	99.9832
L = 5 km		
Finesse	2638.33	10377.18
Rc [%]	99.7696	99.9469
L = 10 km		
Finesse	1319.17	5188.59
Rc [%]	99.5323	99.8864

Credit: André Thüring

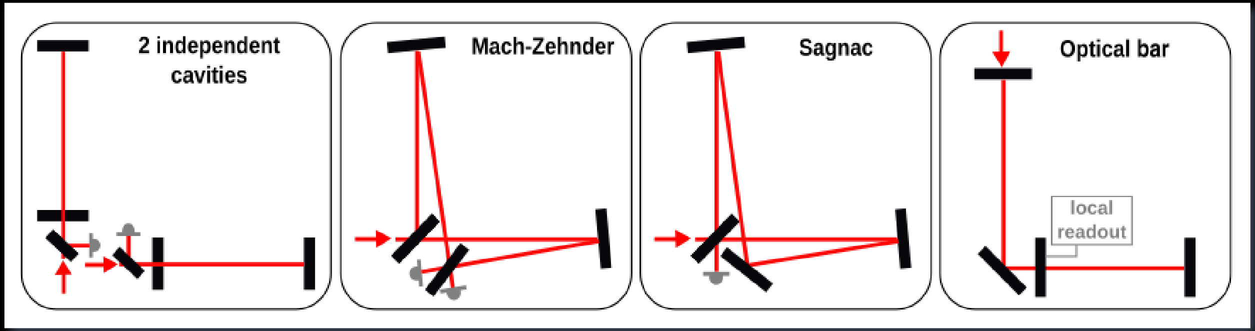
FILTER CAVITIES



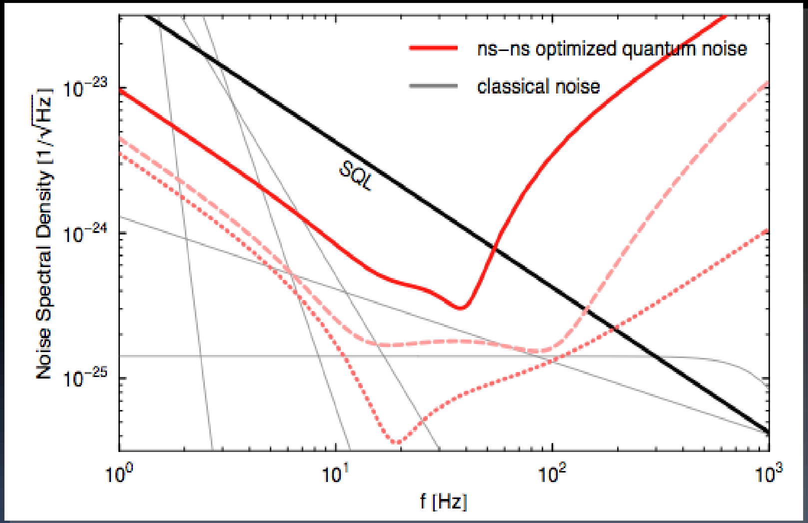
Credit: André Thüring [paper in preparation]

QND TECHNIQUES

NOT FORESEEN FOR INITIAL TOPOLOGY

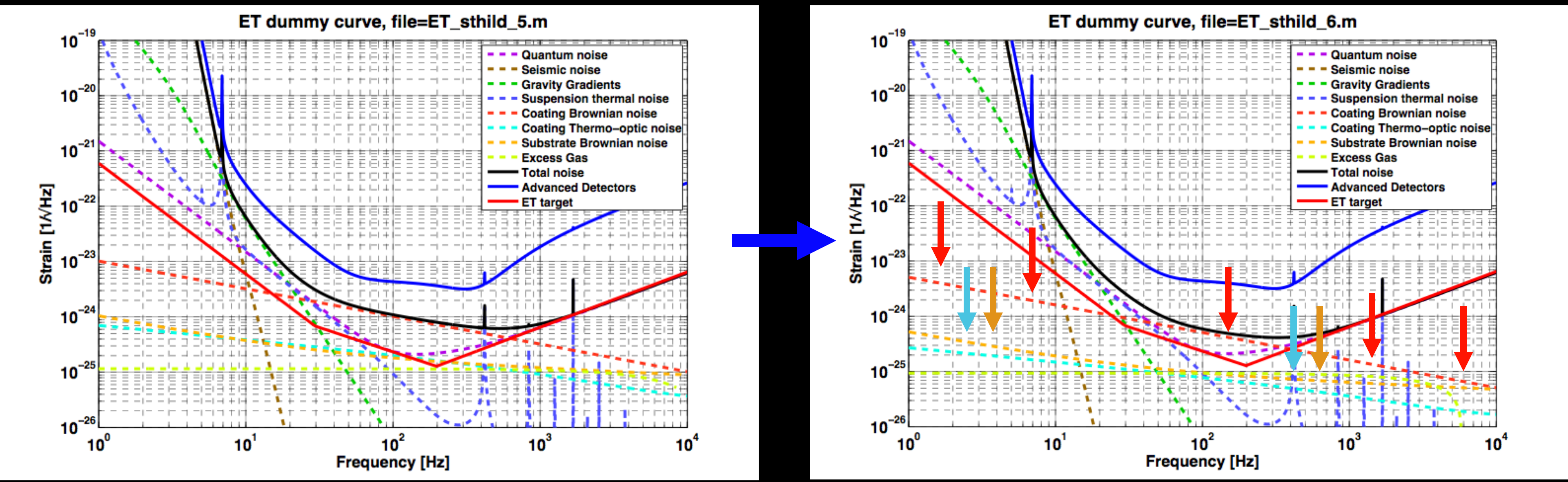


Detector topologies different than Michelson might offer even better quantum noise reduction, i.e. Dual Recycled Sagnac with arm cavities or Optical Bar / Optical Lever topologies.



Speedmeter sensitivity.
H. Mueller-Ebhardt et al:
https://pub3.ego-gw.it/itf/tds/file.php?callFile=ET-010-09.pdf

INCREASING THE BEAM SIZE



DRIVER: Coating Brownian noise

ACTION: Increase of beam radius from 6 to 12cm

EFFECT: Decrease of Coating Brownian by a factor 2

SIDE EFFECTS:

- Decrease of Substrate Brownian noise (~factor 2)
- Decrease of Thermo-optic noise (~factor 2)
- Decrease of residual gas pressure noise (~10-20%)

OR:

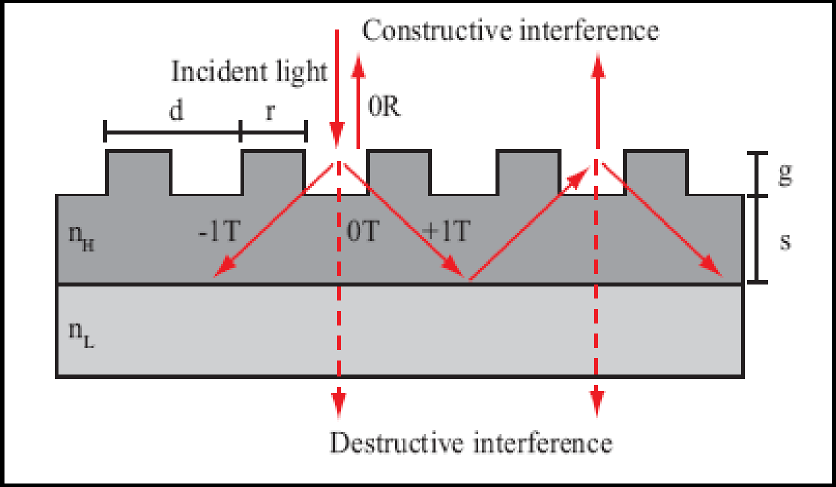
Courtesy:Stefan Hild

WAVEGUIDE COATINGS

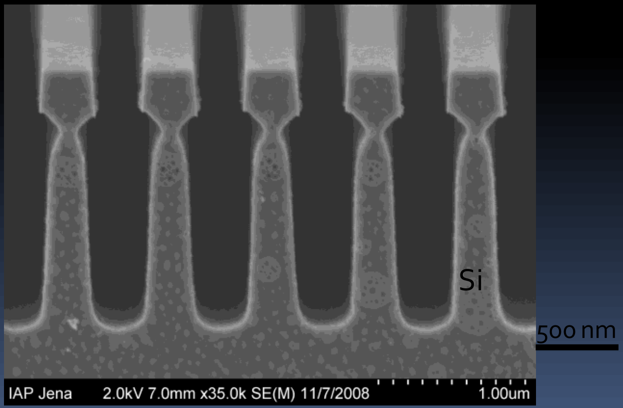
REDUCING MECHANICAL DISSIPATION

Waveguides may provide an elegant way to reduce coating Brownian noise.

Idea: replacing the dielectric (lossy, thick) multi-layer stack by a (low loss, thin) mono-crystalline silicon nano-structure or a (thin) single layer diffractive coating.



Brückner et al., Optics Express 17 (2009) 163 – 169

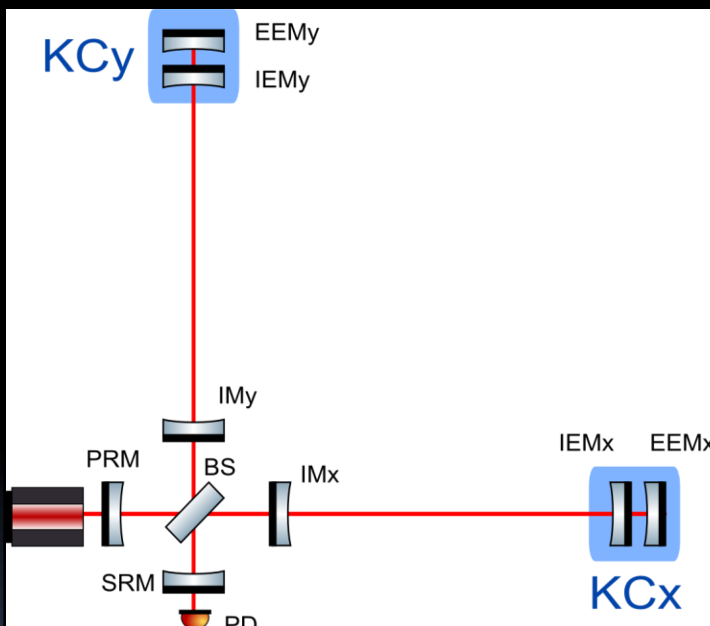


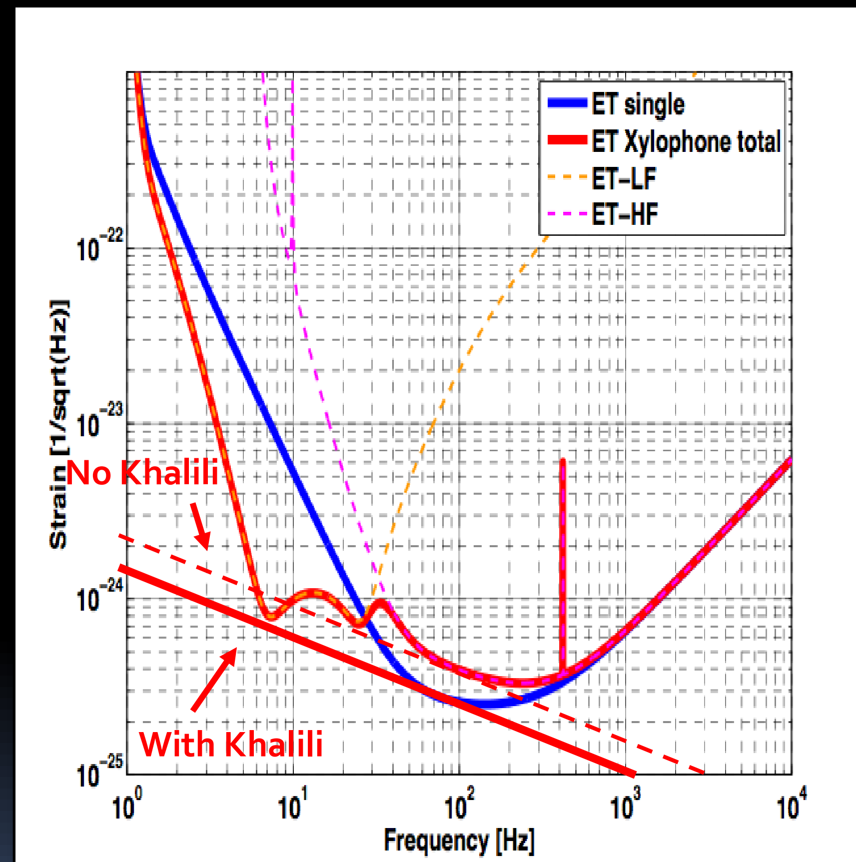
Brückner et al., Optics Letters 33 (2008) 264 - 266

OR:

END MIRROR (KHALILI) CAVITIES

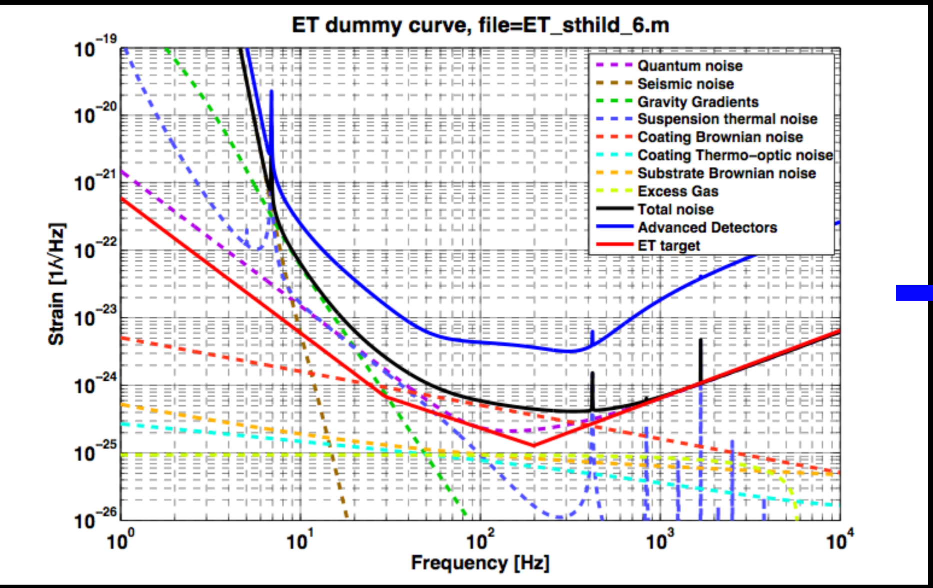
- "Khalili" cavities (F.Khalili *Physics Letters A*, **2005**, *334*, 67 - 72) allow to reduce the influence of coating Brownian noise.

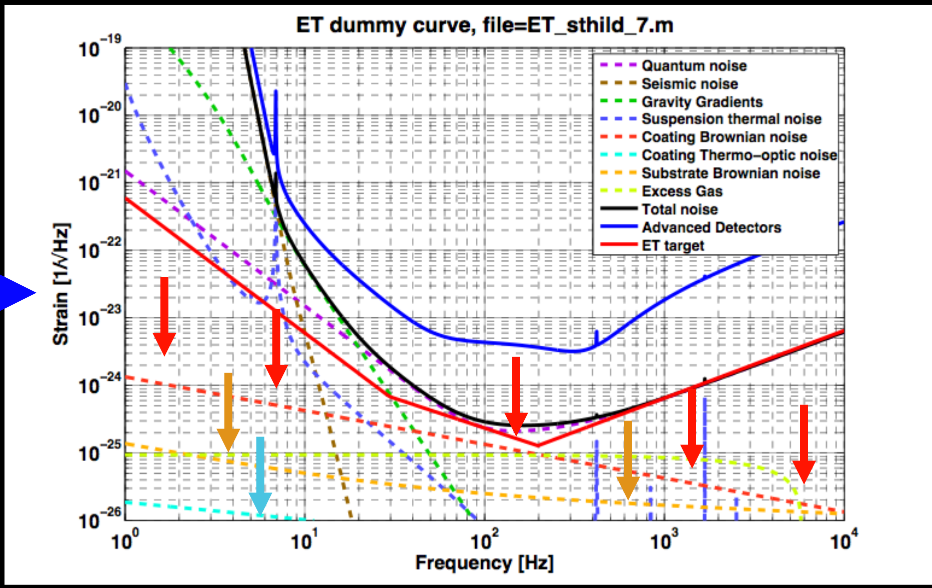




- Using Khalili-cavities as end mirrors, we can reduce the total mirror thermal noise of the whole interferometer by about a factor 1.5.

COOLING THE TEST MASSES



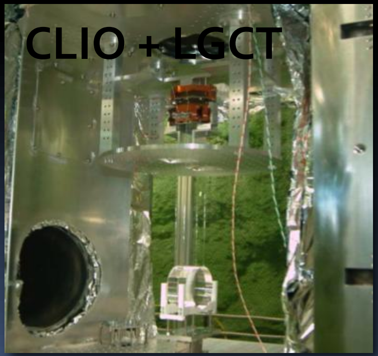


DRIVER: Coating Brownian noise

ACTION: Reduce the test mass temperature from 290K to 20K

EFFECT: Decrease Brownian by ~ factor of 4

SIDE EFFECTS:
- Decrease of substrate Brownian
- Decrease of thermo-optic noise



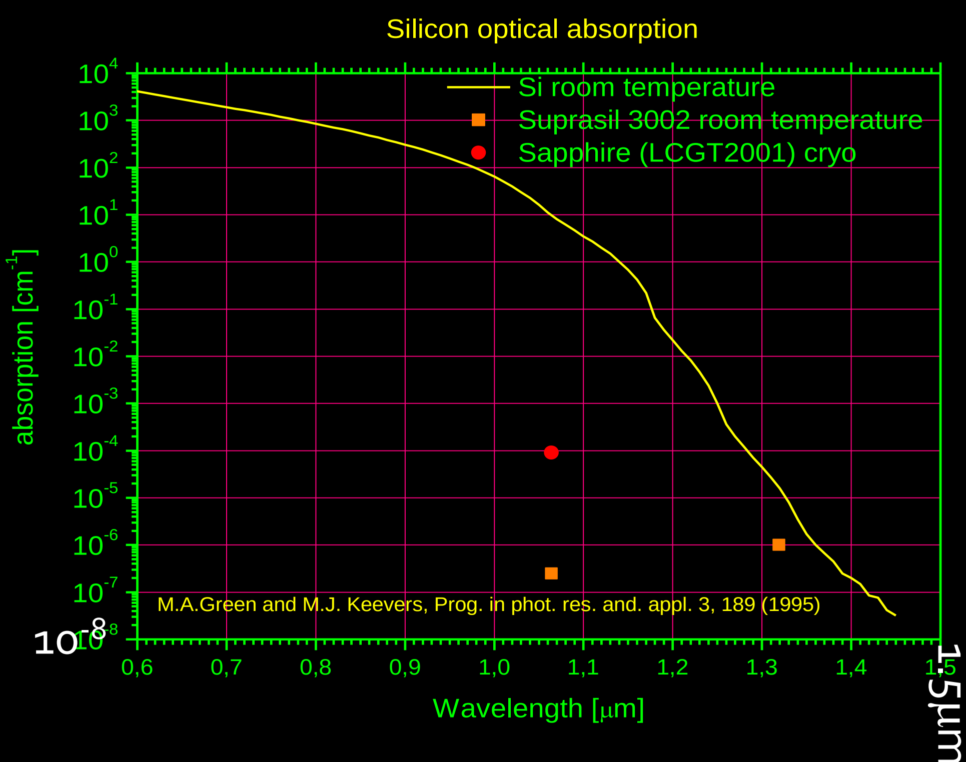
Kuroda 2008
LIGO-G080060

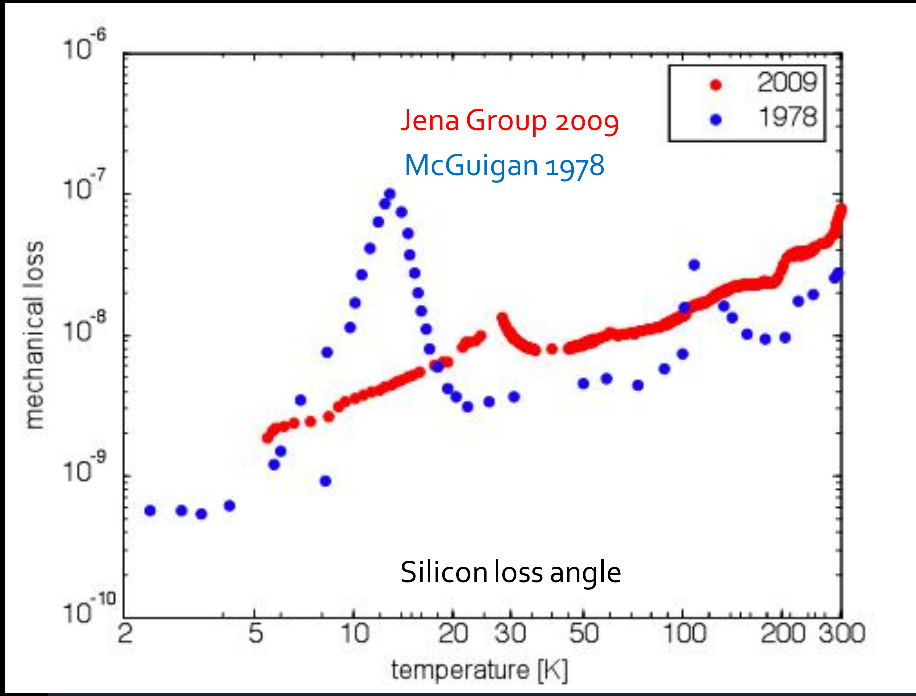
Courtesy:Stefan Hild

Requires “cryogenic material” ->silicon

Silicon

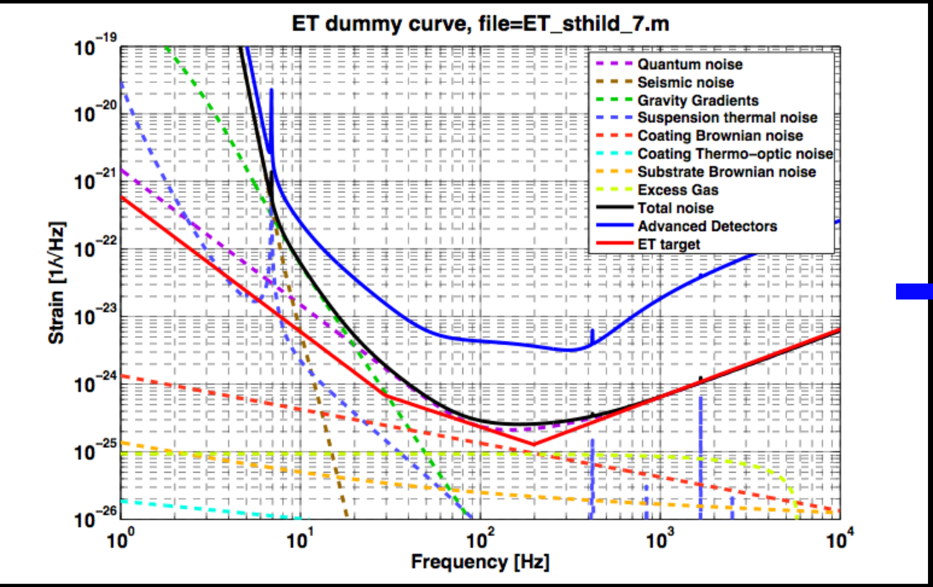
- Fused Silica unusable at cryo-temperatures
- Sapphire and Silicon best candidates
- Sapphire selected in LCGT
- Silicon under study in ET

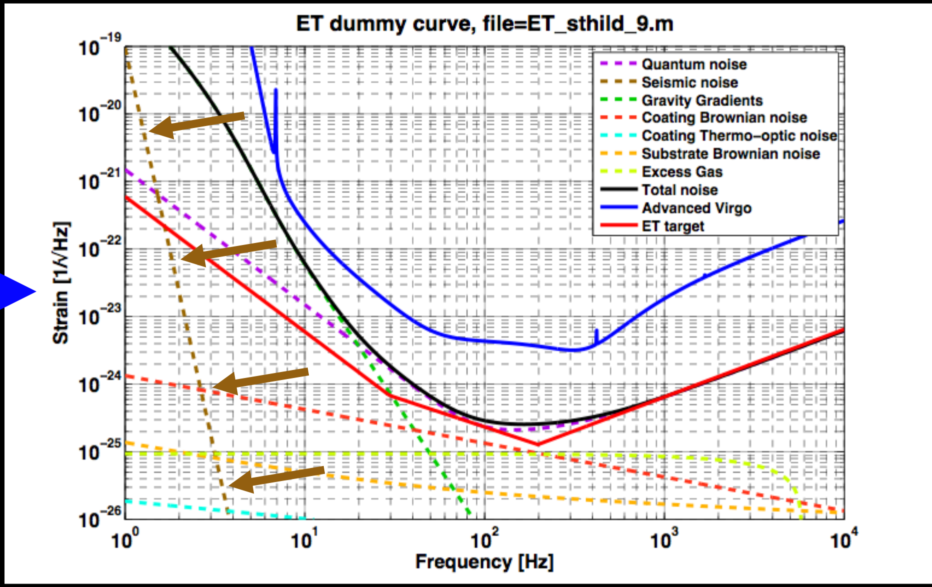




- Floating zone
  - high purity, up to 30 kOhms cm
  - < 200mm diameter
- Czochralski
  - more impurities, <300 Ohms cm
  - >300mm? ; bigger sizes in the ET era ?

SUSPENSIONS





DRIVER: Seismic noise

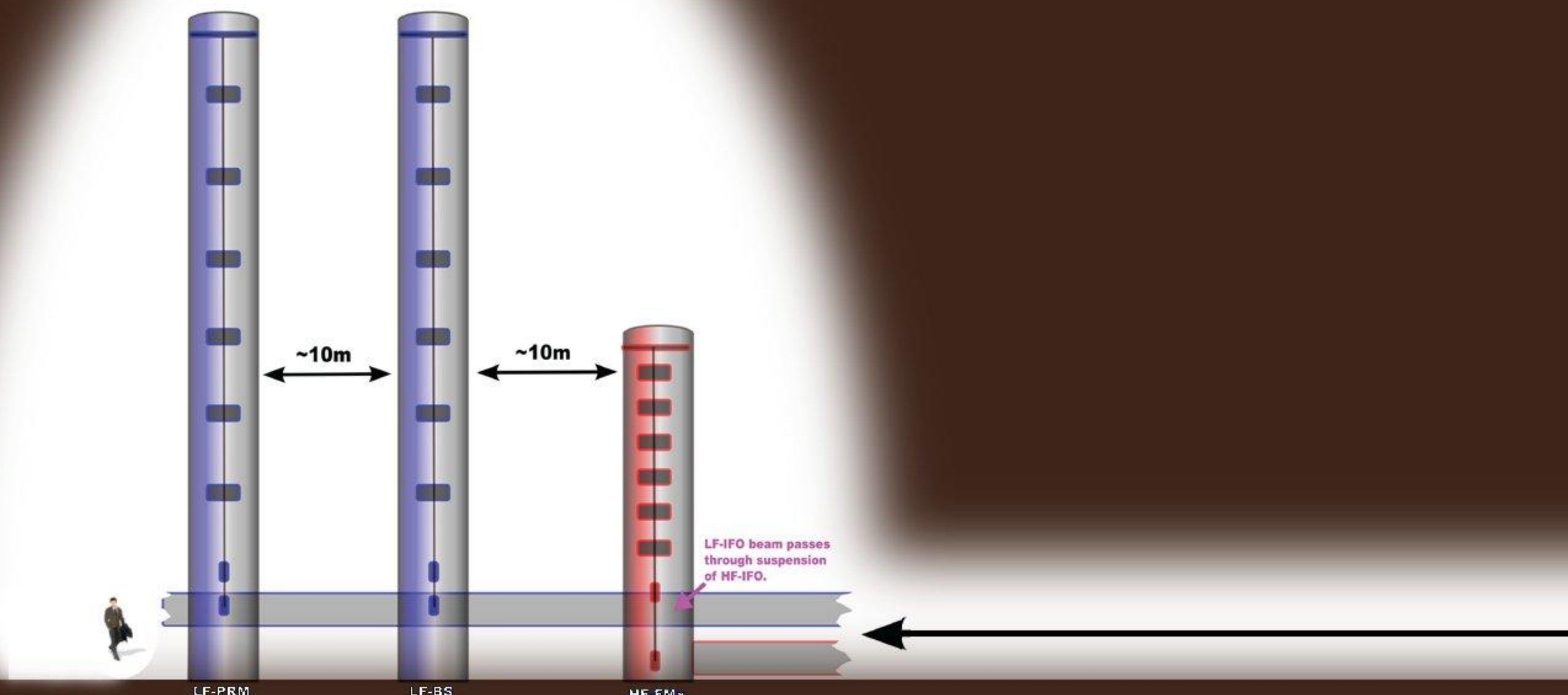
ACTION: Build a 17m Virgo-Style Superattenuator

EFFECT: Decrease seismic noise by many orders of magnitude
or pushes the seismic wall from 10 Hz to about 1.5 Hz

S.Brachini: http://gw.icrr.u-tokyo.ac.jp/gwadw2010/program/2010_GWADW_Braccini.ppt

Courtesy:Stefan Hild

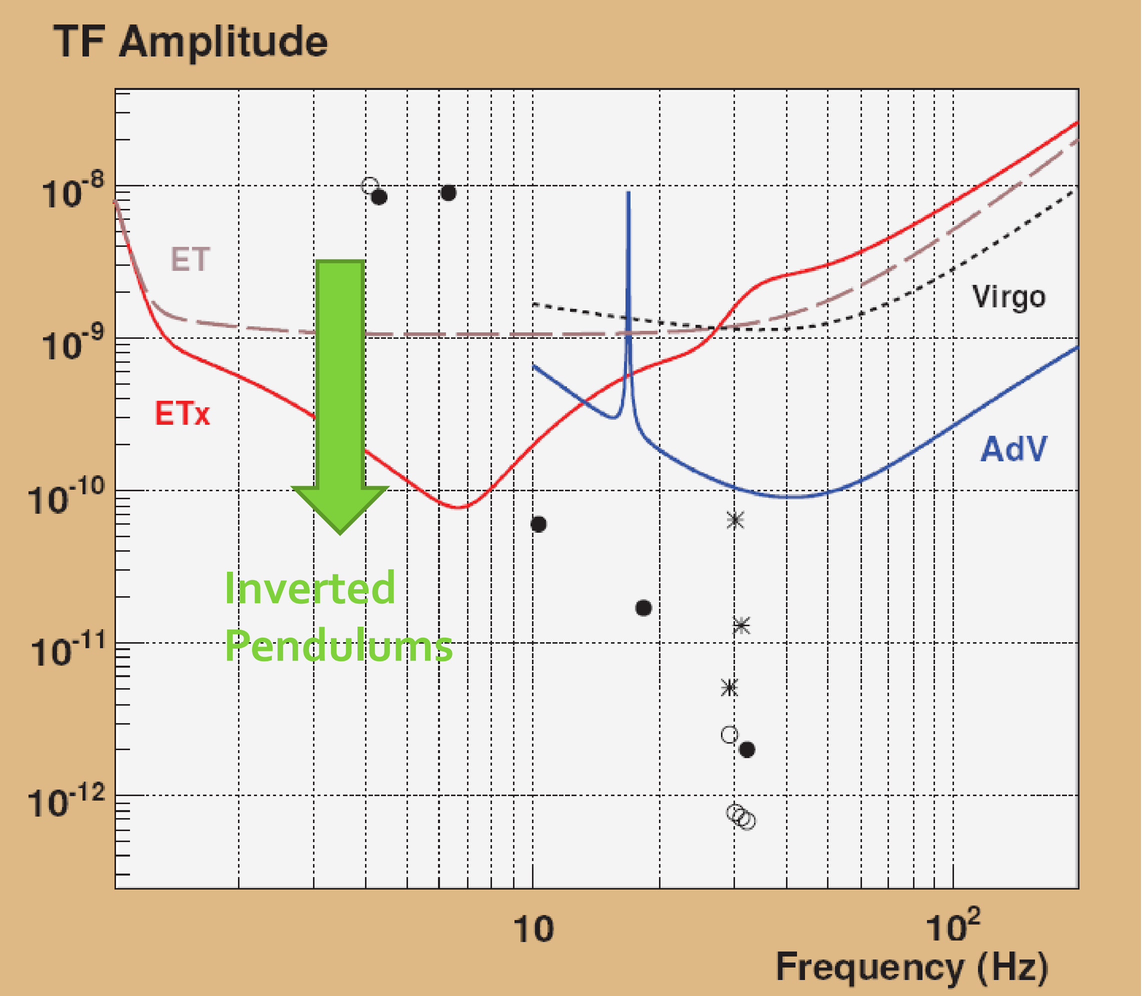
SUSPENSION TOWERS

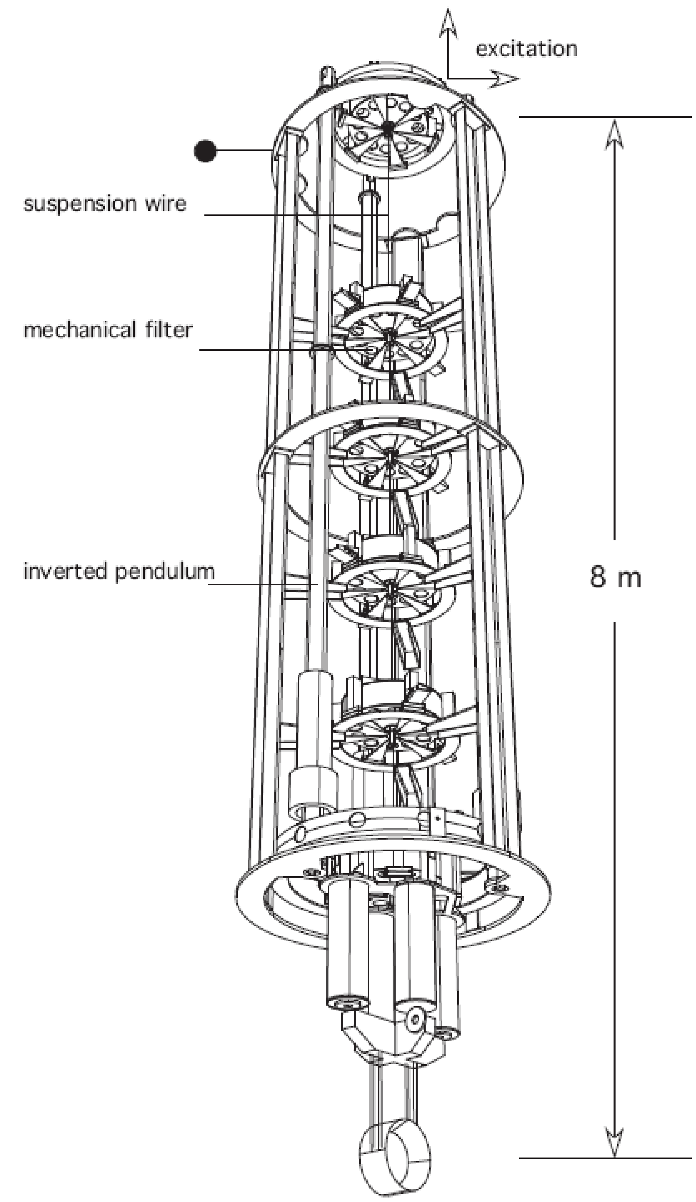


Most of the drawing: Stefan Hild

Virgo SA performance

*Braccini et al., ASTROPARTICLE PHYSICS , **33** (3),pp. 182-189 , (2010)*





'Xylophone': cool & hot

20K 300K

For mo
S.
J.F
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Co
Ge
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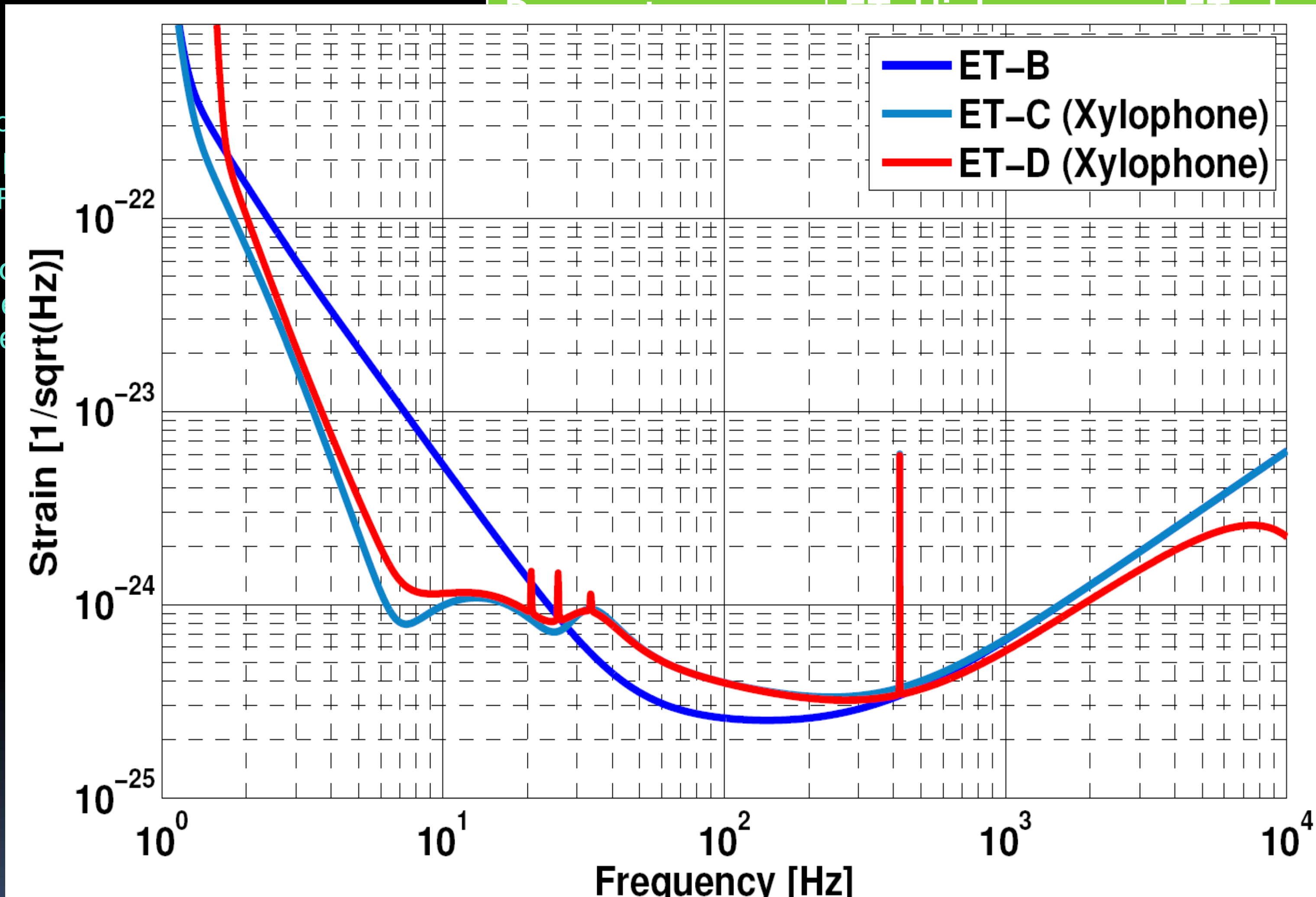
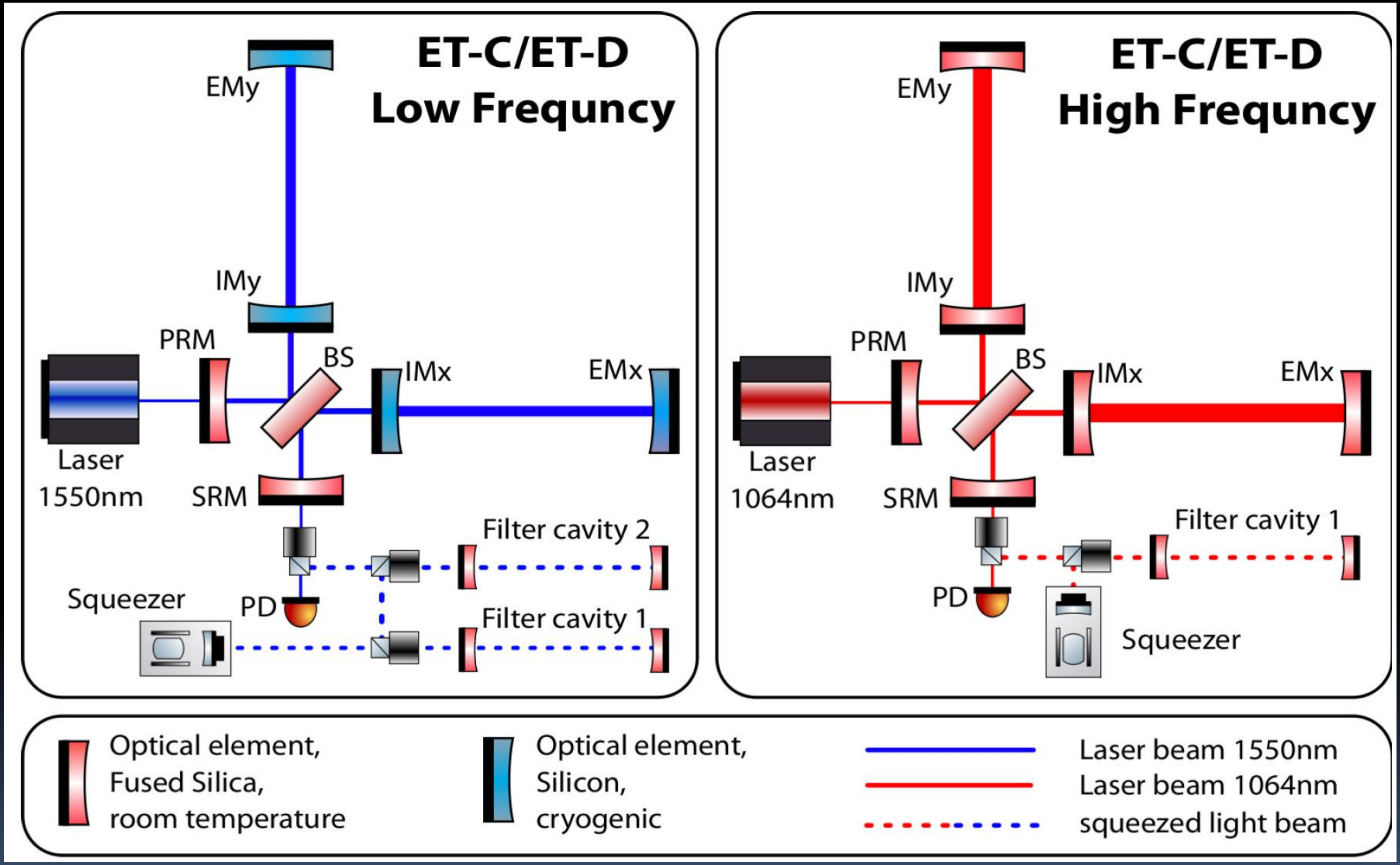


		cy
		ɔmm
		600mm)
		(0.6 rad)
Beam Radius	72 mm	120 mm
Suspension	Short SA	SA 20m

'Xylophone' parts

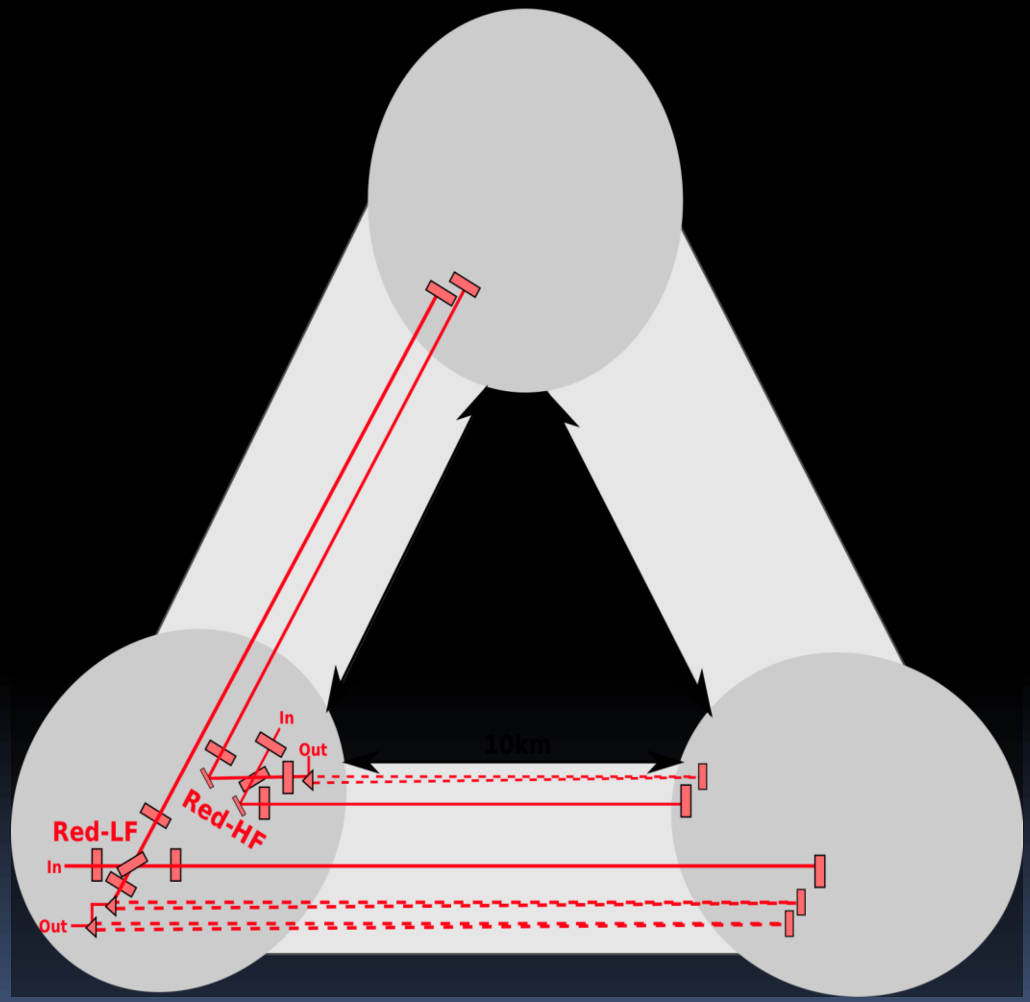


ET Note: ET-02-10

ET EINSTEIN TELESCOPE

INSTALLATION OF ET

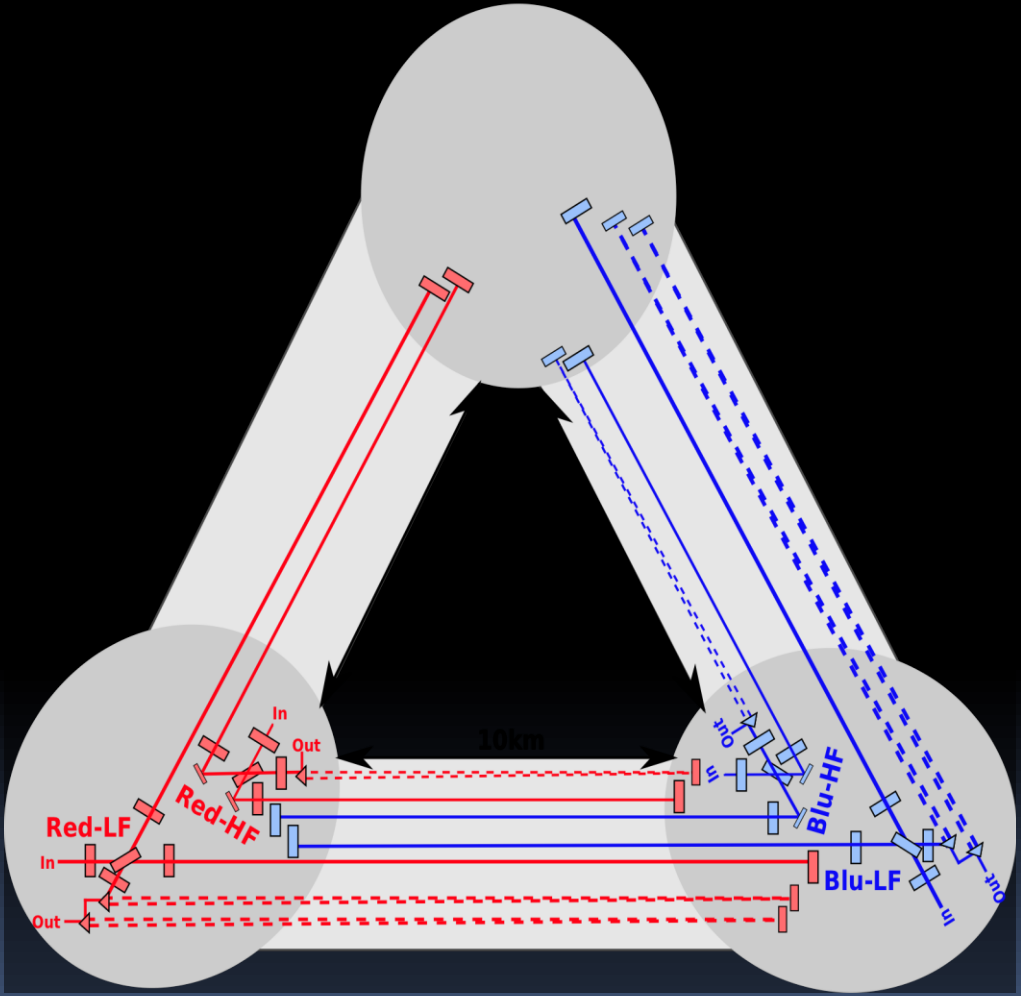
For efficiency reasons
build a triangle.
Start with a single
xylophone detector.



INSTALLATION OF ET

For efficiency reasons build a triangle.
Start with a single xylophone detector.

Add second Xylophone detector to fully resolve polarisation.

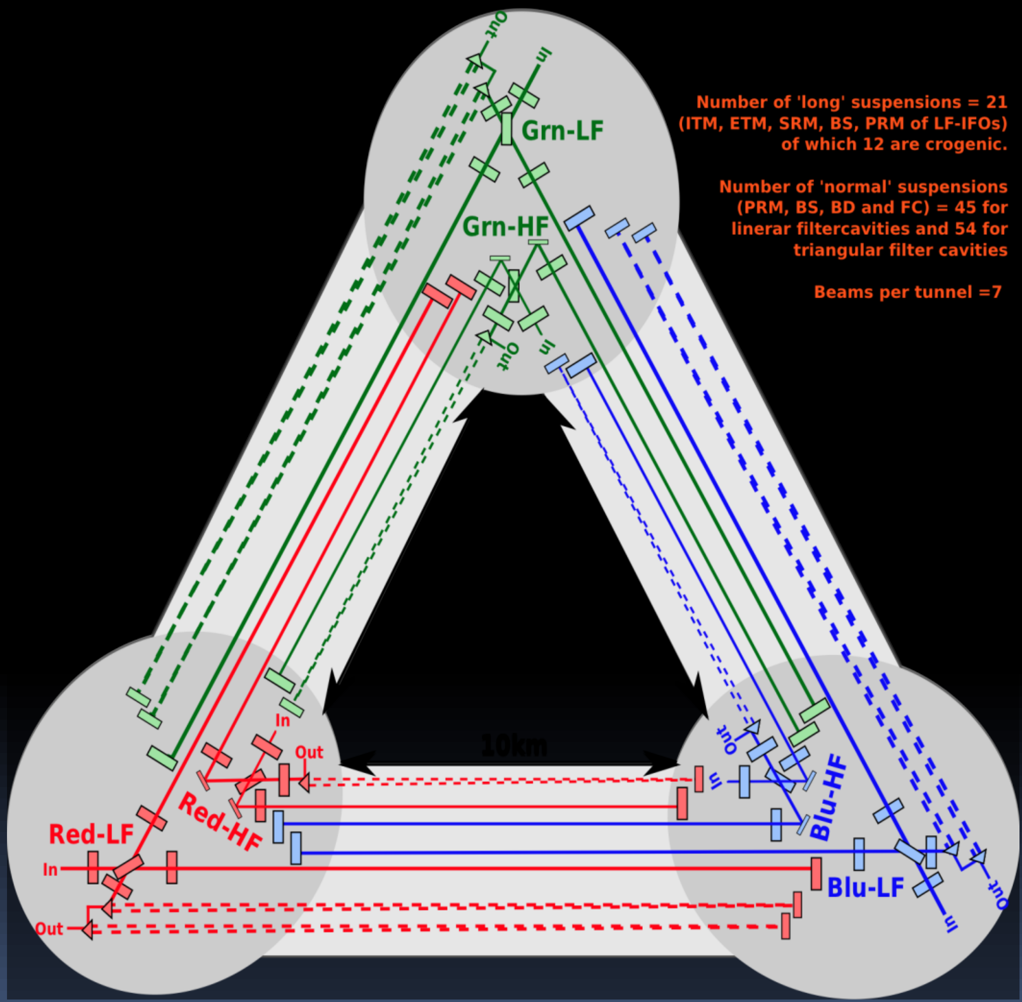


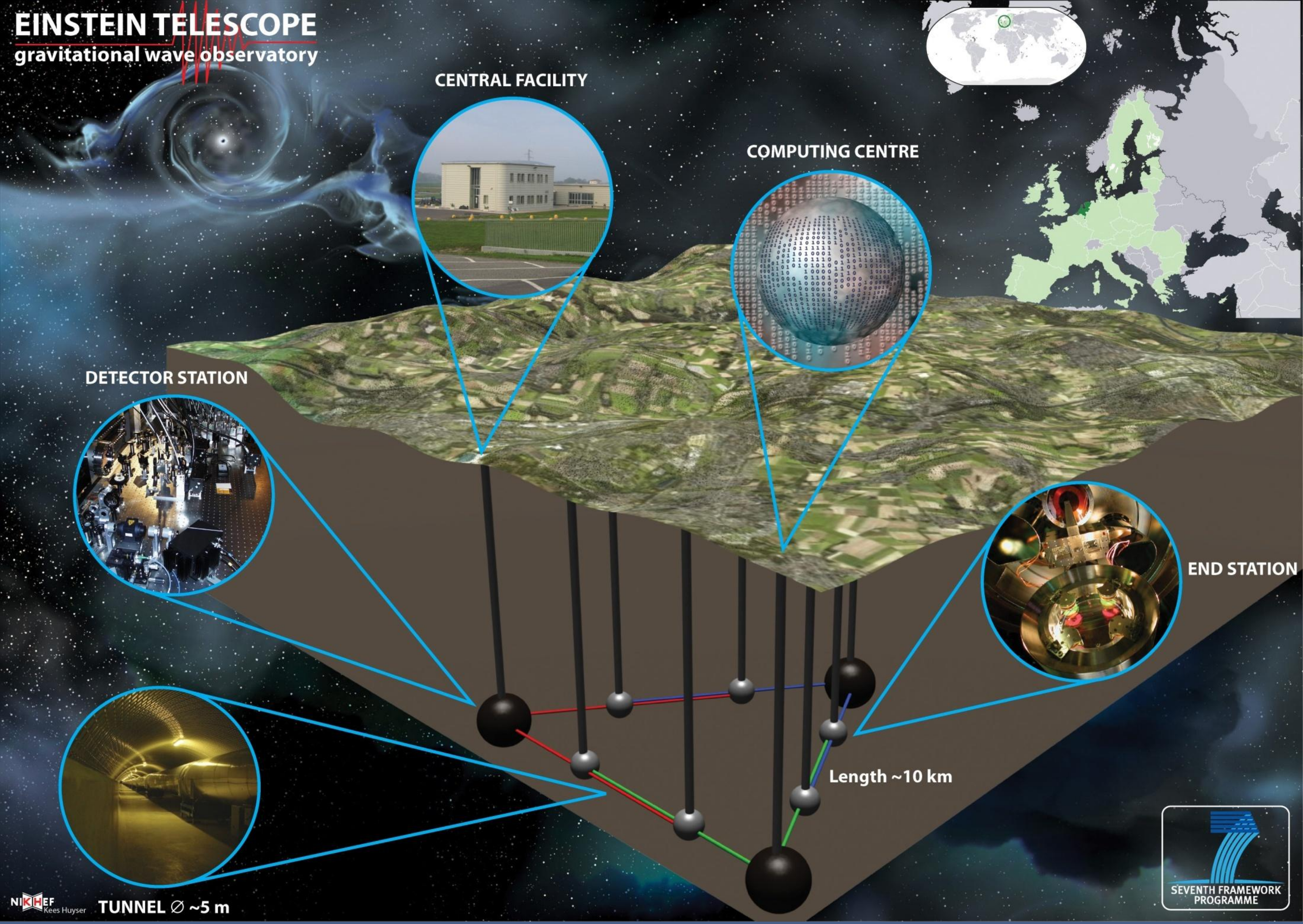
INSTALLATION OF ET

For efficiency reasons build a triangle.
Start with a single xylophone detector.

Add second Xylophone detector to fully resolve polarisation.

Add third Xylophone detector for redundancy and null-streams.




EINSTEIN TELESCOPE
gravitational wave observatory
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
END STATION
Length ~10 km
TUNNEL ∅ ~5 m
NIKHEF
Kees Huyser
SEVENTH FRAMEWORK
PROGRAMME