University of Glasgow

IGR

GEO 600

Science & Technology Facilities Council

The Einstein Telescope

Stefan Hild for the ET Science Team

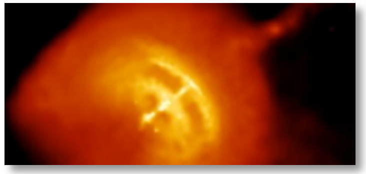
EINSTEIN TELESCOPE

LSC

LIGO-G1100435-v1

Overview of this presentation

- ET – the start of Gravitational Wave Astronomy



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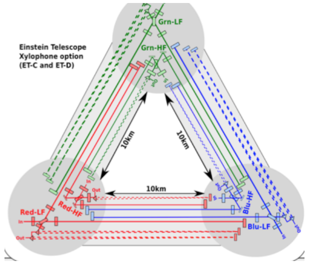
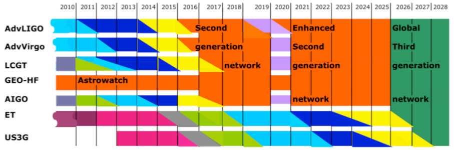
2G → 2.5G → 3G

- The Brute Force approach to achieve the 3rd Generation target sensitivity.

- The ET baseline design



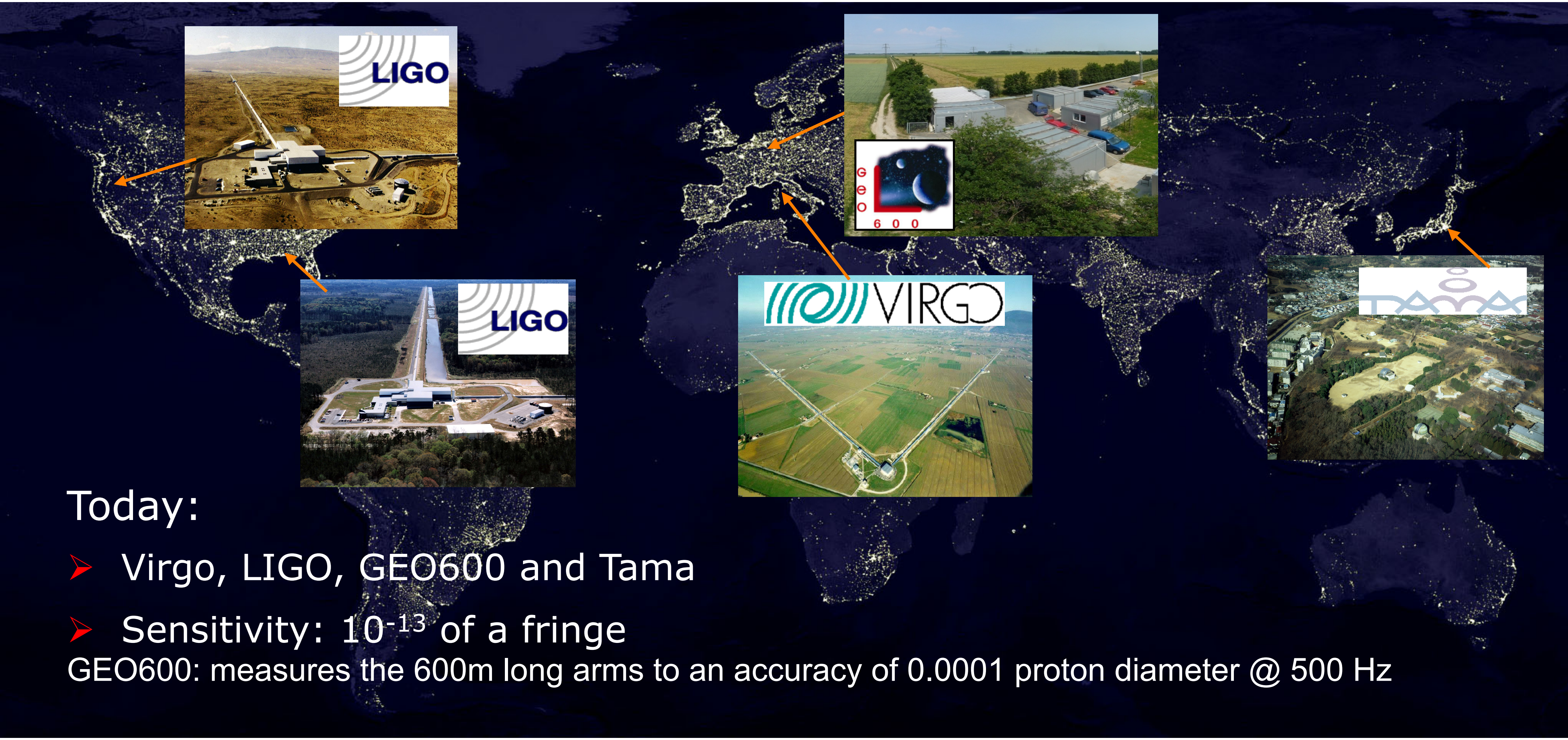
- Time line towards the Einstein Telescope



We have come a long way …

- The first Michelson interferometer: Experiment performed by Albert Michelson in Potsdam 1881.
- Measurement accuracy 0.02 fringe (expected Ether effect ~0.04 fringes)

… to today's network of GW detectors



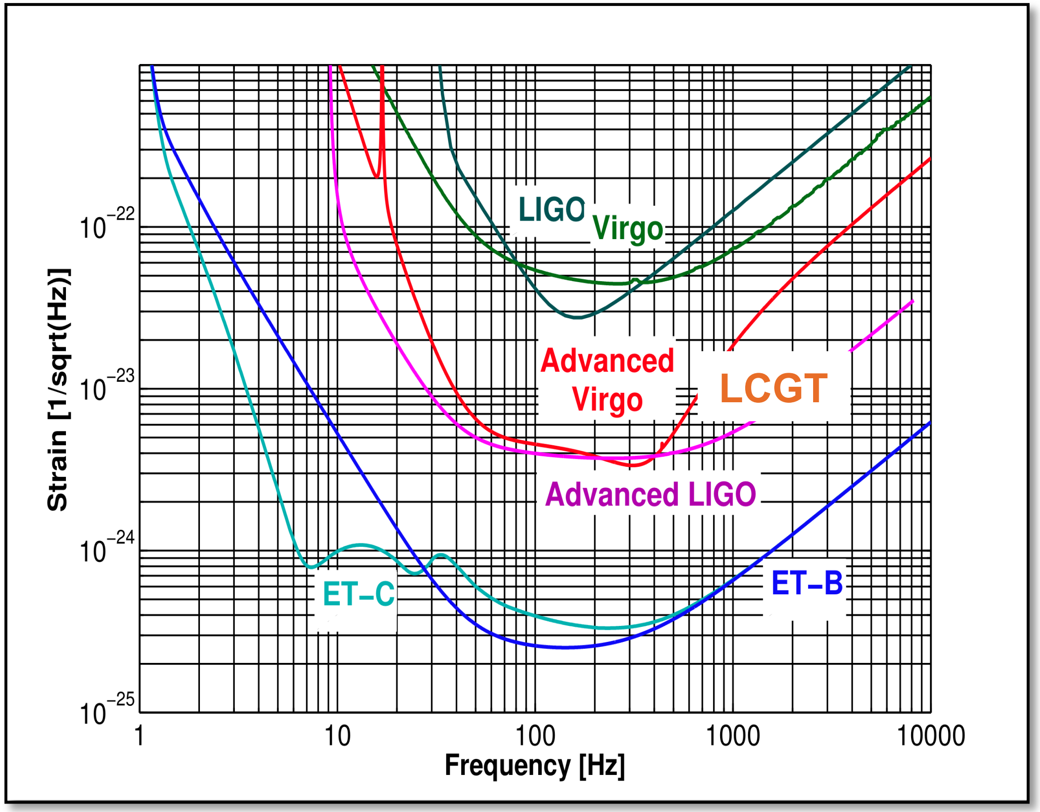
Today:

- Virgo, LIGO, GEO600 and Tama
- Sensitivity: 10^{-13} of a fringe

GEO600: measures the 600m long arms to an accuracy of 0.0001 proton diameter @ 500 Hz

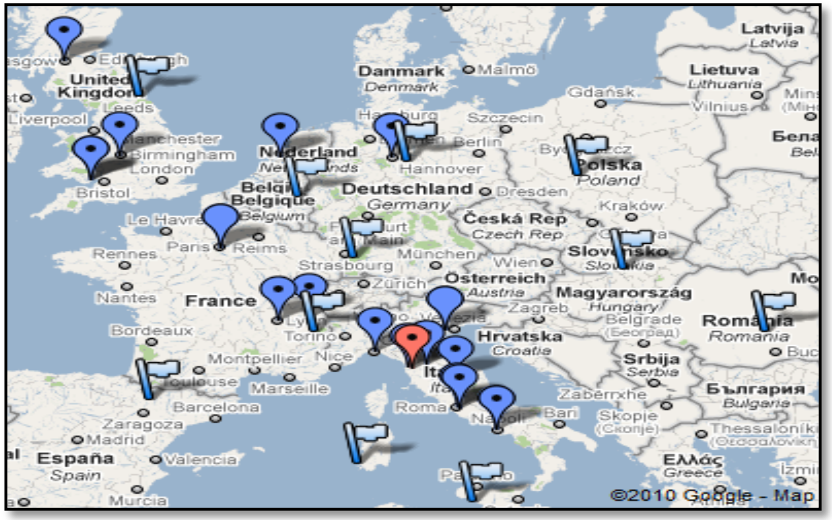
Status and future of GW observatories

- **1st** generation successfully completed:
  - Long duration observations (~1yr) in coincidence mode of 5 oberservatories.
  - Spin-down upper limit of the Crab-Pulsar beaten!
- **2nd** generation on the way:
  - End of design phase, construction started (Advanced LIGO project is nearly 50% complete)
  - 10 times better sensitivity than 1st generation. => Scanning 1000 times larger volume of the Universe
- **3rd** generation at the horizon:
  - FP7 funded design study in Europe
  - 100 times better sensitivity than 1st generation. => Scanning 1000000 times larger volume of the Universe



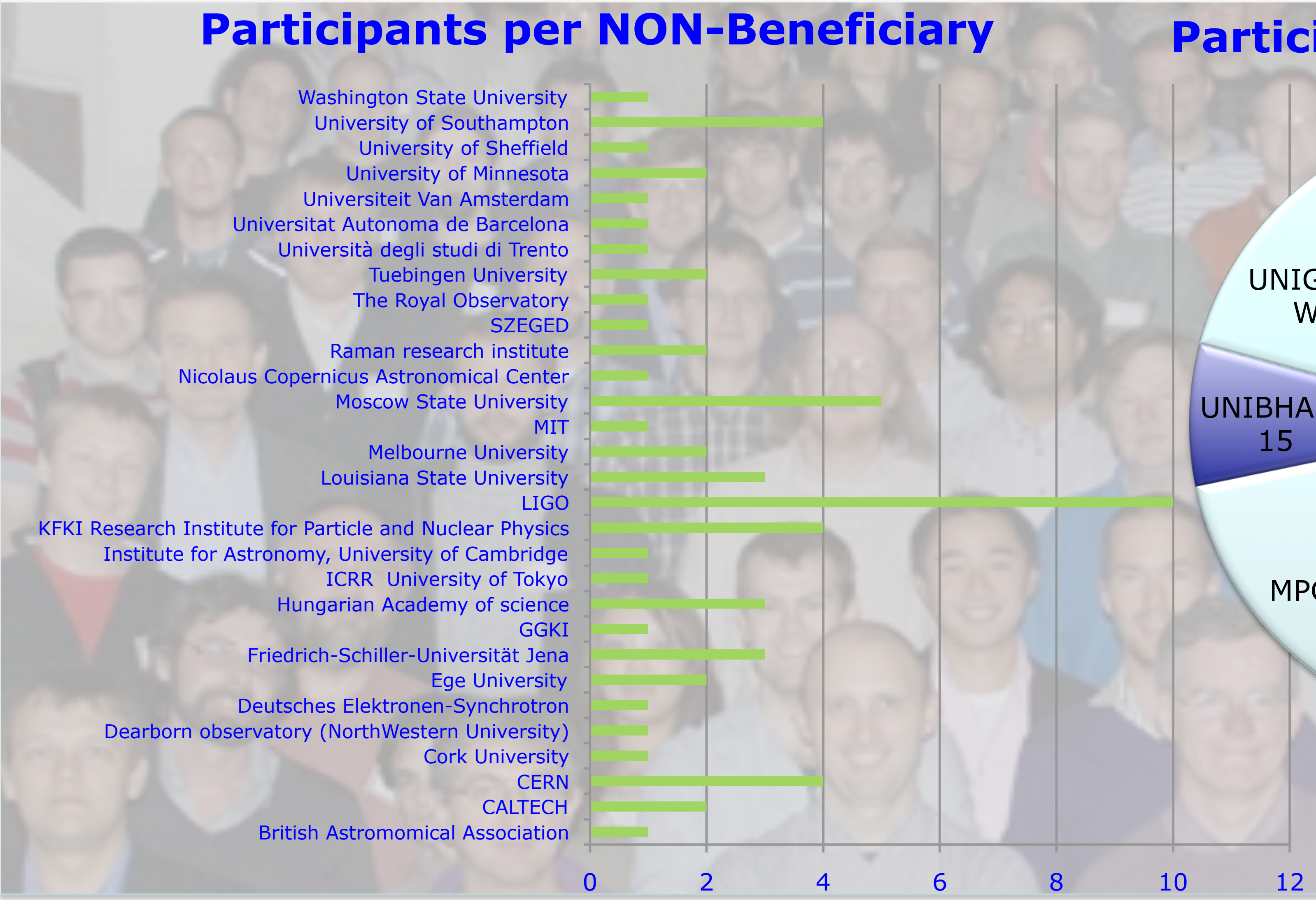
ET Design Study

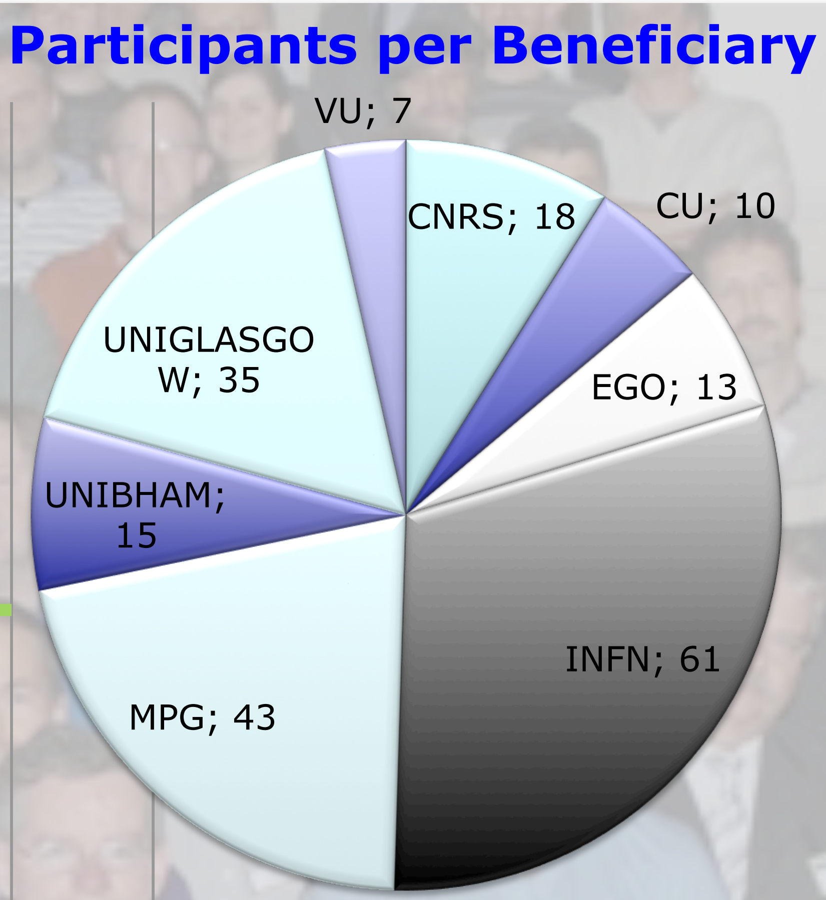
- The Einstein Telescope project aims to the realization of a third generation of GW observatory.
- The Einstein Telescope project is currently in its conceptual design study phase, supported by the European Community FP7 with about 3M€ from May 2008 to July 2011.
- The target of this design phase is to understand the feasibility of a new generation of GW observatory that will permit to gain one order of sensibility
- The main deliverable, at the end of these 3 years, will be a **conceptual design of such as infrastructure.**



Participant	**Country**
EGO	Italy/France
INFN	Italy
MPG	Germany
CNRS	France
University of Birmingham	UK
University of Glasgow	UK
Nikhef	NL
Cardiff University	UK

ET Science Team (~250 Scientists)

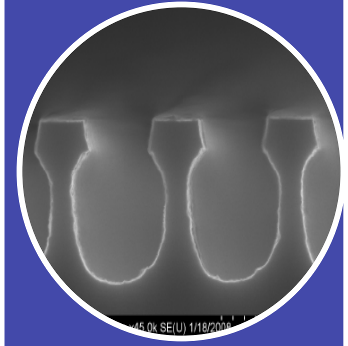




ET Work Package Structure

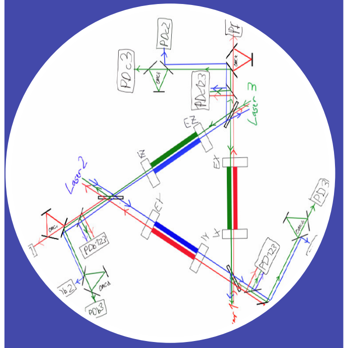
WP1:
Site and infrastructure

Chair: J.v.d. Brand
(Nikhef)



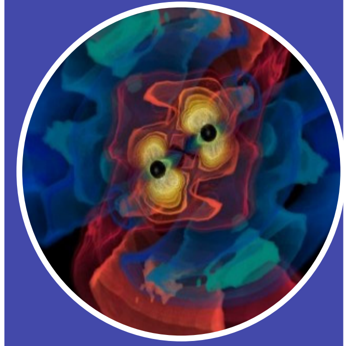
WP2:
Thermal noise of mirrors and suspensions / cryogenics

Chair: F. Ricci
(INFN)



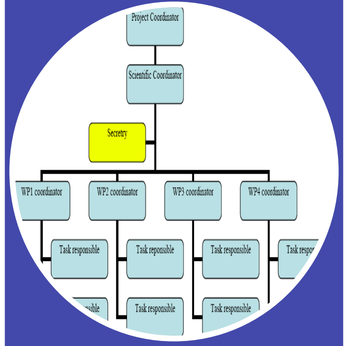
WP3:
Optical configuration

Chair: A. Freise
(Birmingham)



WP4:
Astrophysics issues

Chair:
Sathyaprakash
(Cardiff)



WP5:
Management

J. Colas, M. Punturo, H. Lueck

Fundamental Physics with ET

- Properties of gravitational waves
  - Testing GR beyond the quadrupole formula
    - Binary pulsars consistent with quadrupole formula; they don't measure properties of GW
  - How many polarizations are there?
    - In Einstein's theory only two polarizations; a scalar-tensor theory could have six
  - Do gravitational waves travel at the speed of light?
    - There are strong motivations from string theory to consider massive gravitons
    - Binary pulsars constrain the speed to few parts in a thousand
    - GW observations can constrain to 1 part in 10^{18}
- EoS of dark energy
  - Black hole binaries are standard candles/sirens
- EoS of supra-nuclear matter
  - Signature of EoS in GW emitted when neutron stars merge
- Black hole no-hair theorem and cosmic censorship
  - Are BH (candidates) of nature BH of general relativity?
- An independent constraint/measurement of neutrino mass
  - Delay in the arrival times of neutrinos and gravitational waves

Credits: Sathyaprakash + ET Science Team

Cosmology with ET

- Cosmography
  - Build the cosmic distance ladder, strengthen existing calibrations at high z
  - Measure the Hubble parameter, dark matter and dark energy densities, dark energy EoS w, variation of w with z
- Black hole seeds
  - Black hole seeds could be intermediate mass black holes
  - Might explore hierarchical growth of central engines of black holes
- Dipole anisotropy in the Hubble parameter
  - The Hubble parameter will be "slightly" different in different directions due to the local flow of our galaxy
- Anisotropic cosmologies
  - In an anisotropic Universe the distribution of H on the sky should show residual quadrupole and higher-order anisotropies
- Primordial gravitational waves
  - Quantum fluctuations in the early Universe could produce a stochastic b/g
- Production of GW during early Universe phase transitions
  - Phase transitions, pre-heating, re-heating, etc., could produce detectable stochastic GW

Credits: Sathyaprakash + ET Science Team

Astrophysics with ET

- Unveiling progenitors of short-hard GRBs
  - Understand the demographics and different classes of short-hard GRBs
- Understanding Supernovae
  - Astrophysics of gravitational collapse and accompanying supernova?
- Evolutionary paths of compact binaries
  - Evolution of compact binaries involves complex astrophysics
    - Initial mass function, stellar winds, kicks from supernova, common envelope phase
- Finding why pulsars glitch and magnetars flare
  - What causes sudden excursions in pulsar spin frequencies and what is behind ultra high-energy transients of EM radiation in magnetars
    - Could reveal the composition and structure of neutron star cores
- Ellipticity of neutron stars as small as 1 part in a billion (10μm)
  - Mountains of what size can be supported on neutron stars?
- NS spin frequencies in LMXBs
  - Why are spin frequencies of neutron stars in low-mass X-ray binaries bounded?
- Onset/evolution of relativistic instabilities
  - CFS instability and r-modes

Credits: Sathyaprakash + ET Science Team

More Details …

- For detailed information on the astrophysical motivation and benefits of 3rd generation detectors please have a look at:
  - Punturo et al: The third generation of gravitational wave observatories and their science reach, doi: 10.1088/0264-9381/27/8/084007
  - Einstein Telescope design study: Vision Document
    https://pub3.ego-gw.it/itf/tds/file.php?callFile=ET-031-09.pdf
  - Sathyprakash et al: Cosmography with the Einstein Telescope
    http://arxiv.org/abs/0906.4151

Please also see **the talk by Thomas Dent:** 'Fundamental physics and astrophysics with the Einstein Telescope', **Wednesday 14:45 Concert Hall**

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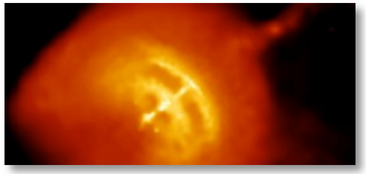

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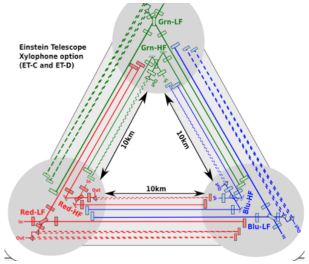

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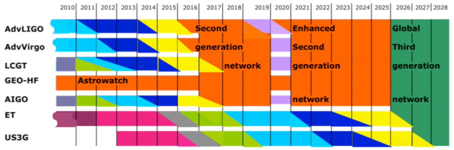
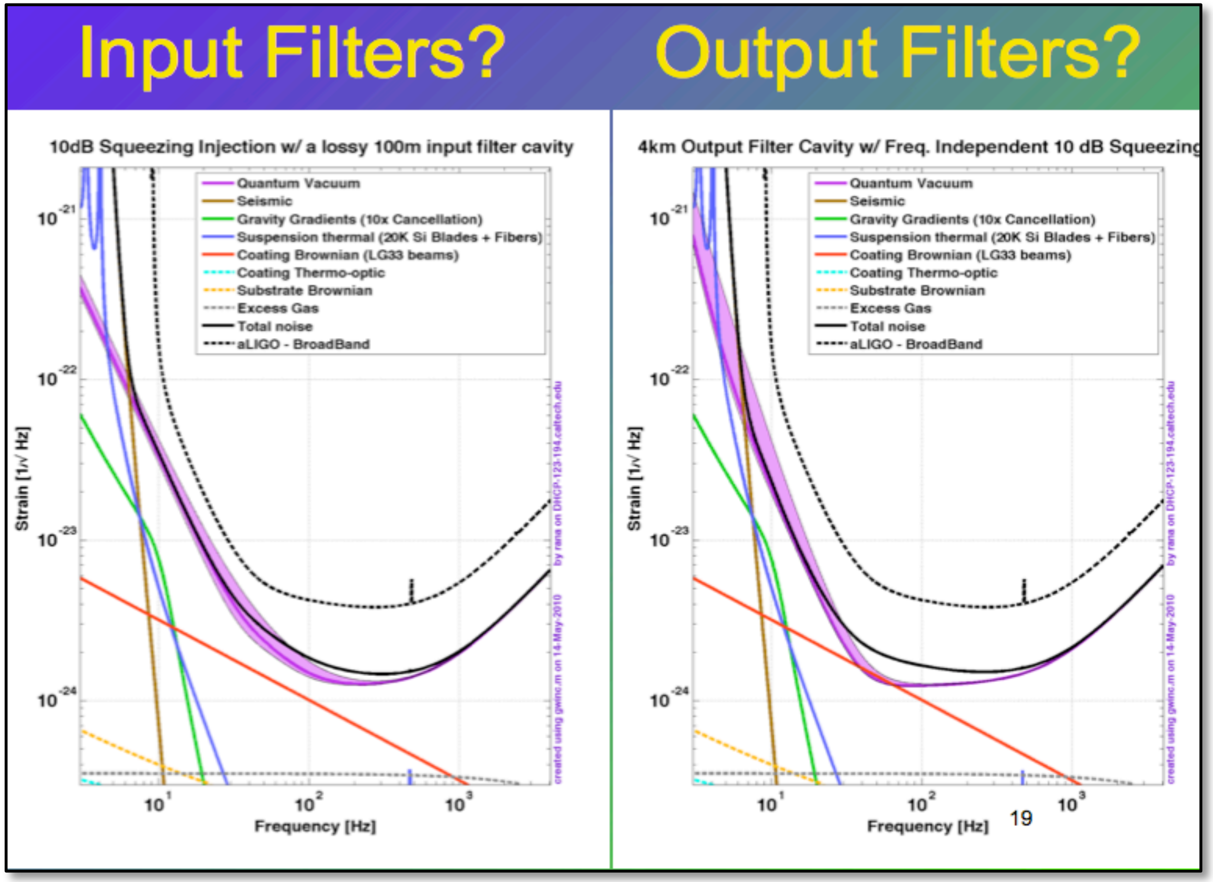


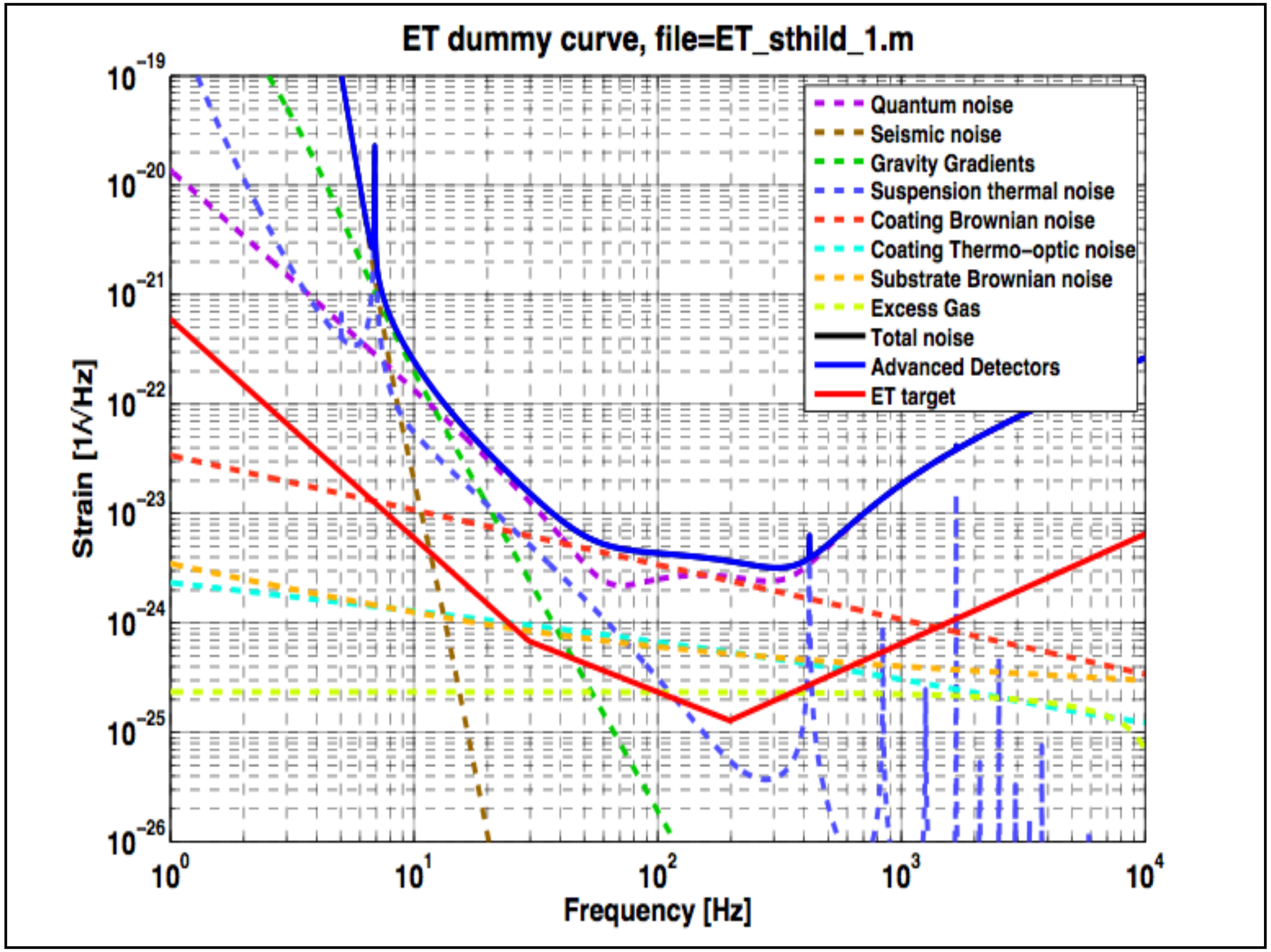
Enhancements of the Advanced Detectors

- People started to look into enhancements of the Advanced Detectors
  (see for example R. Adhikari's talk at GWADW 2010).
- Especially at high frequencies (and also in the mid-frequency range) improvements by a factor of a few seem potentially achievable.



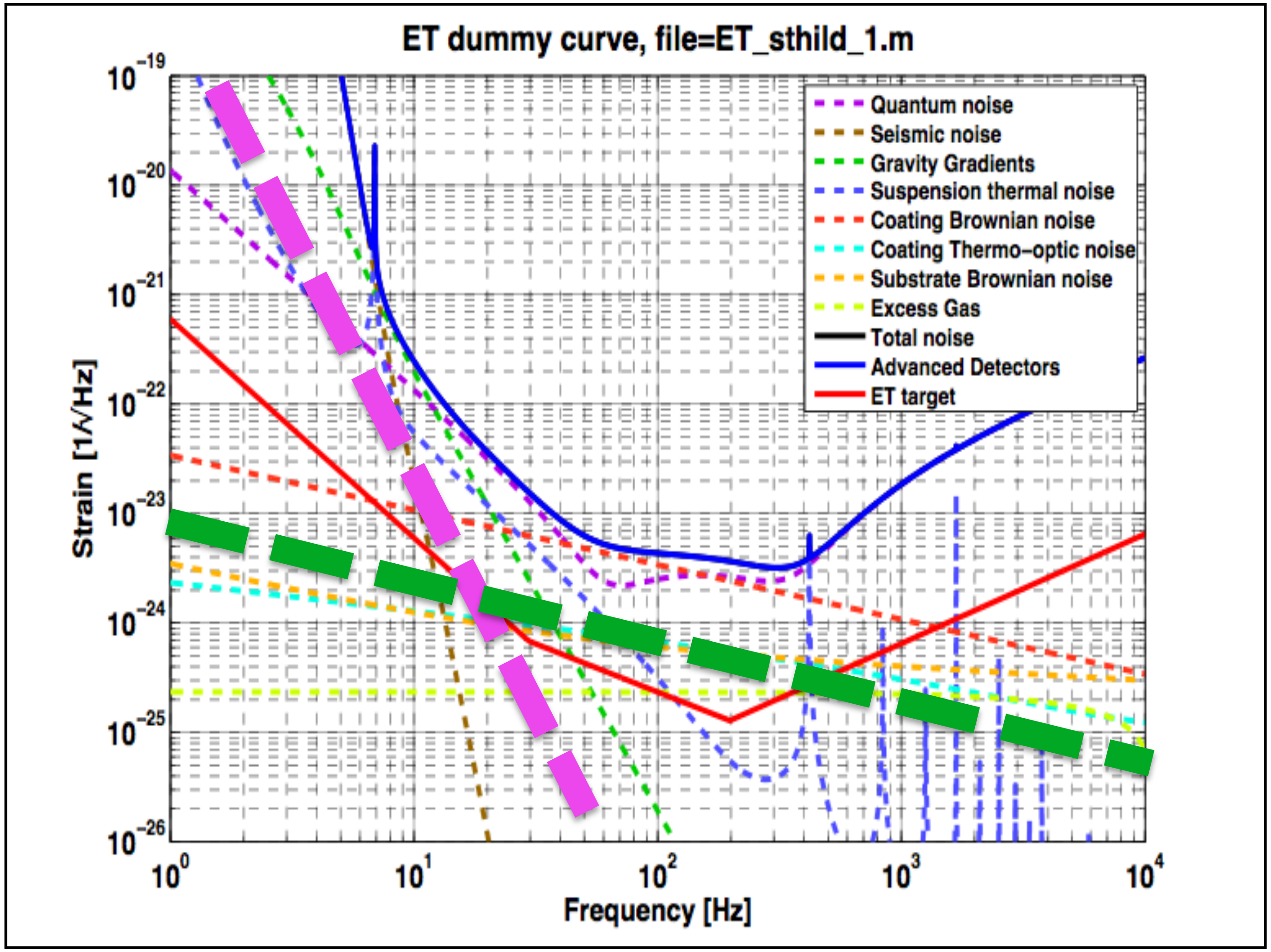
R.Adhikari: LIGO G100 0524

Facility limits of Advanced Detectors



Facility limits of Advanced Detectors

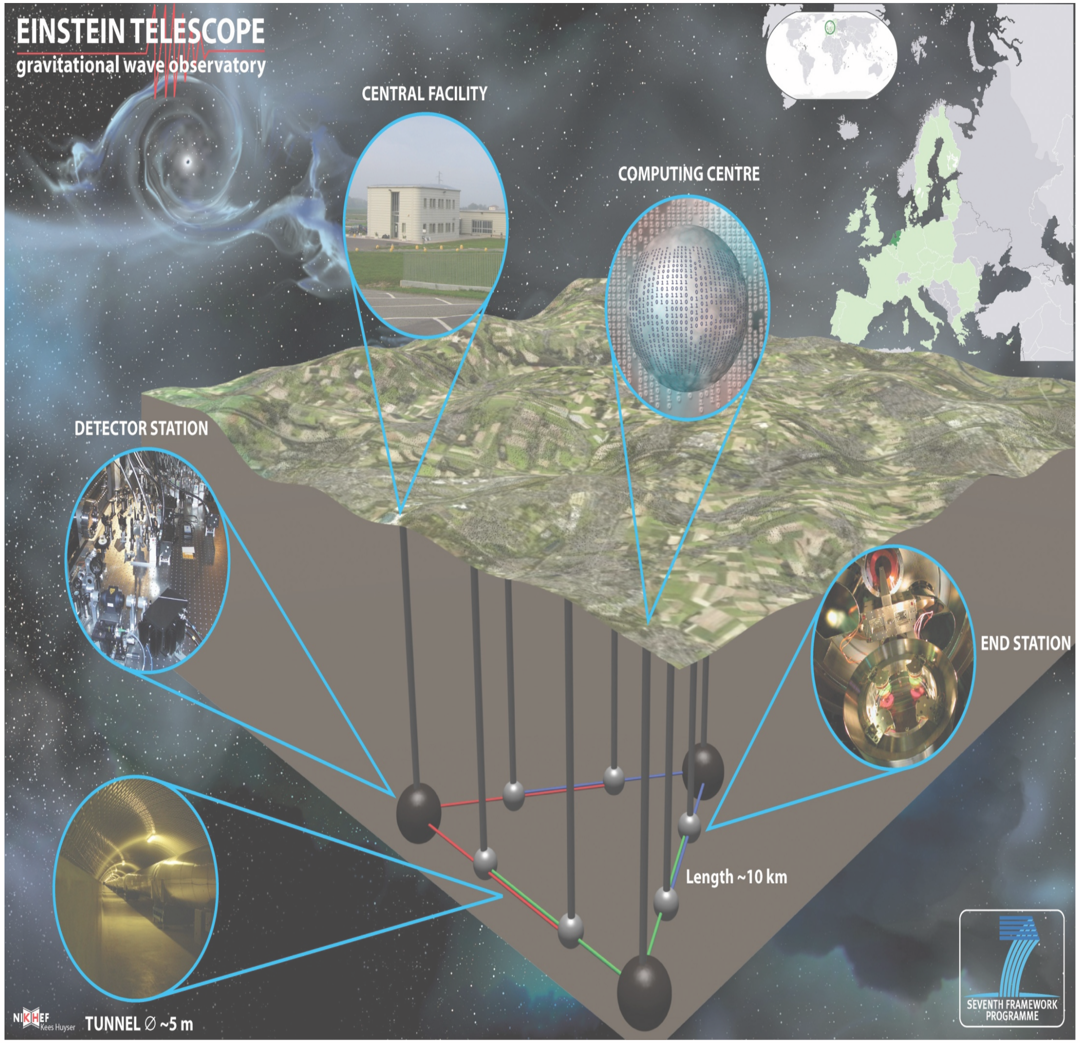
- However, using currently available technology we will hit the facility limits.
- At all frequencies:
  - Arm length
- At **low** frequencies:
  - Gravity Gradient Noise.
  - Perhaps also Seismic
- At **mid** frequencies:
  - Thermal noise



3rd generation

- To surpass the facility limits of the 2nd generation instruments, **3rd Generation 'lives' in new infrastructures.**

- Observatories like ET will be infrastructures that will stay **'on air' for decades,** hosting also future generations (3.5, 4 …) of Gravitational Wave detectors



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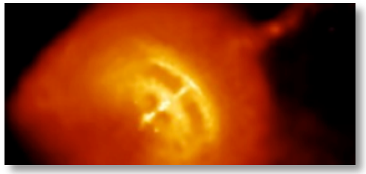

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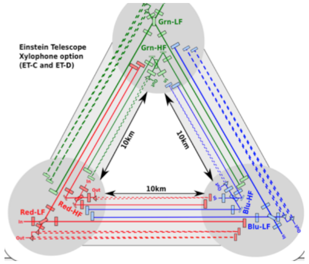

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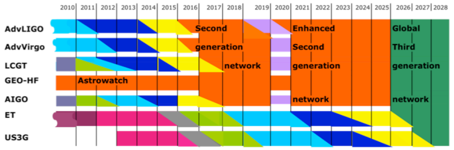
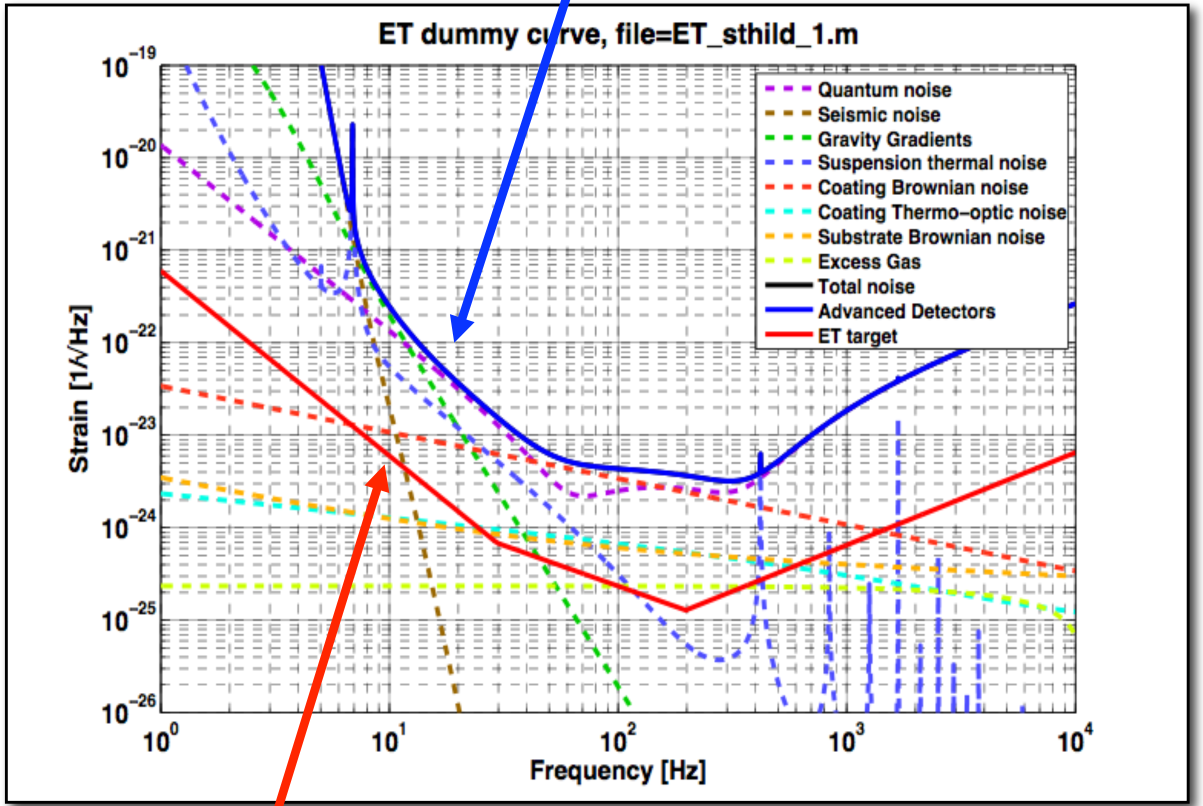


The starting point: 2nd Generation

- 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.

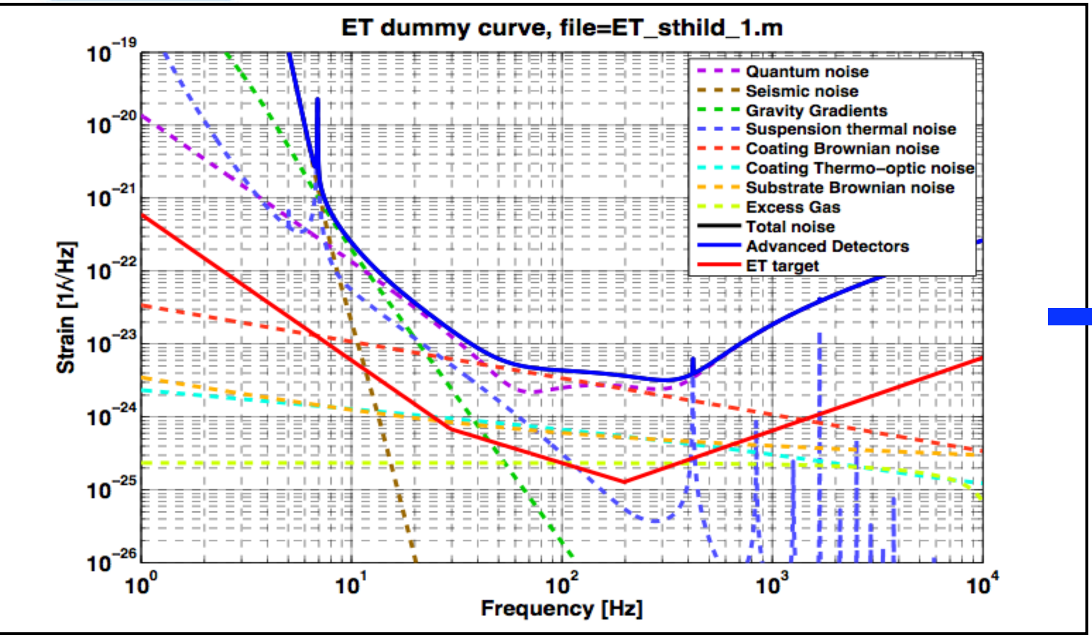
=> OUR TASK:
All fundamental noises have to be improved !!

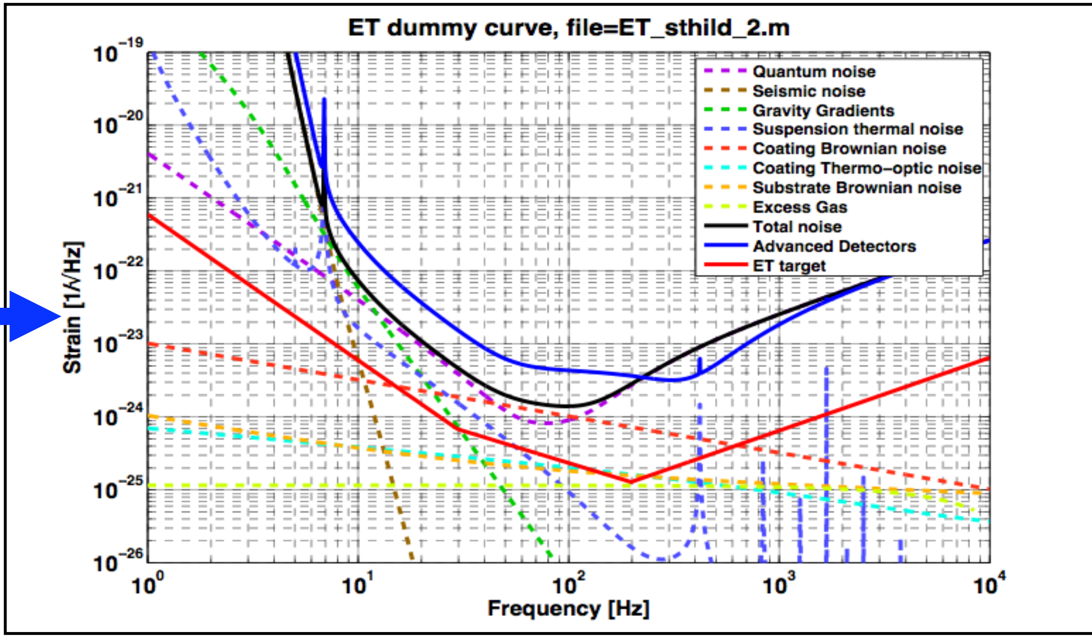
2nd Generation design sensitivity



3G target sensitivity (approximated)

Step 1: Increasing the arm length



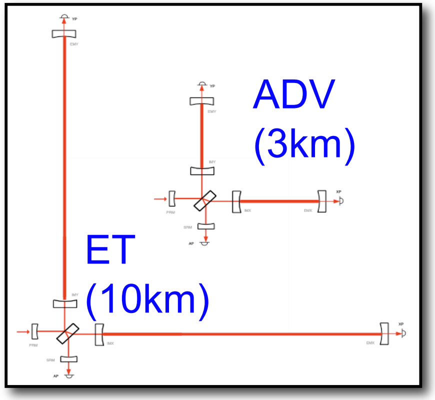


DRIVER: All displacement noises

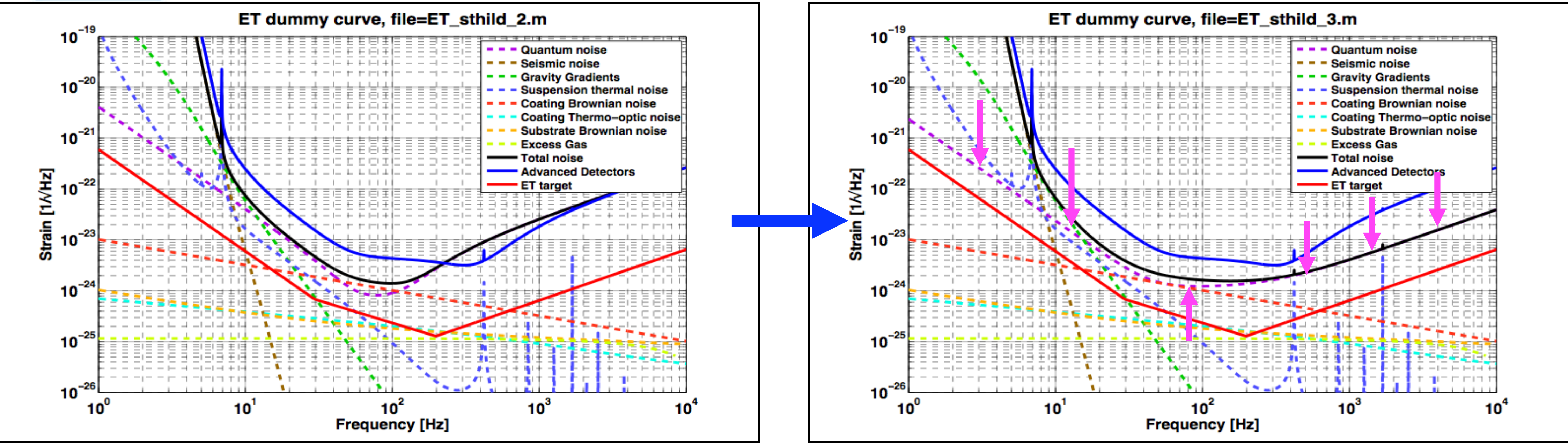
ACTION: Increase arm length from 3km to 10km

EFFECT: Decrease all displacement noises by a factor 3.3

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



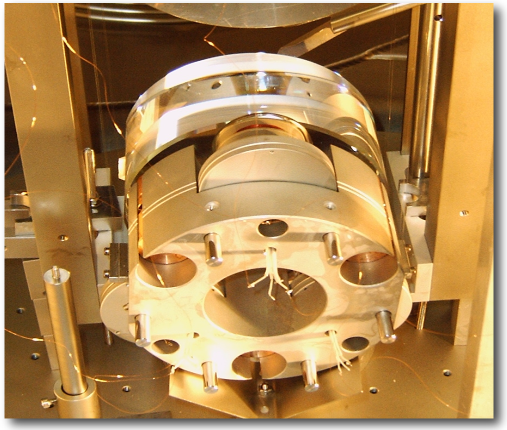
Step 2: Optimising signal recycling



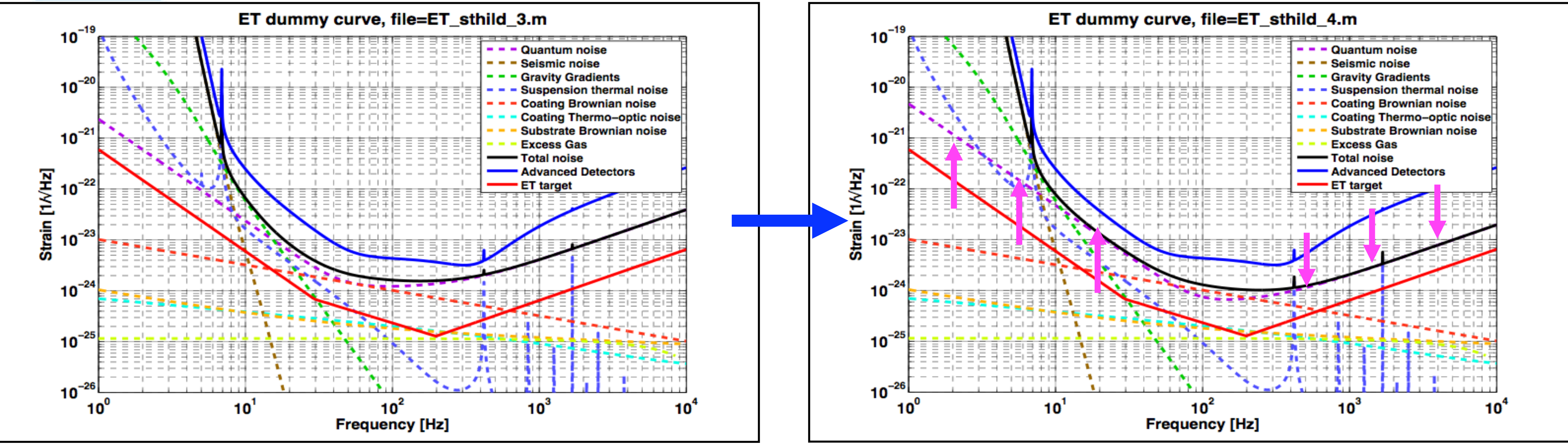
DRIVER: Quantum noise

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) :(



Step 3: Increasing the laser power

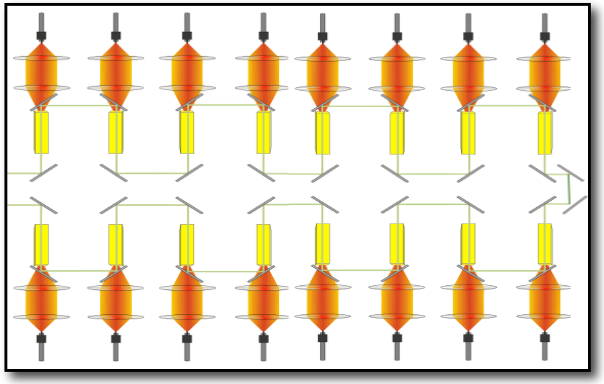


DRIVER: Shot noise at high frequencies

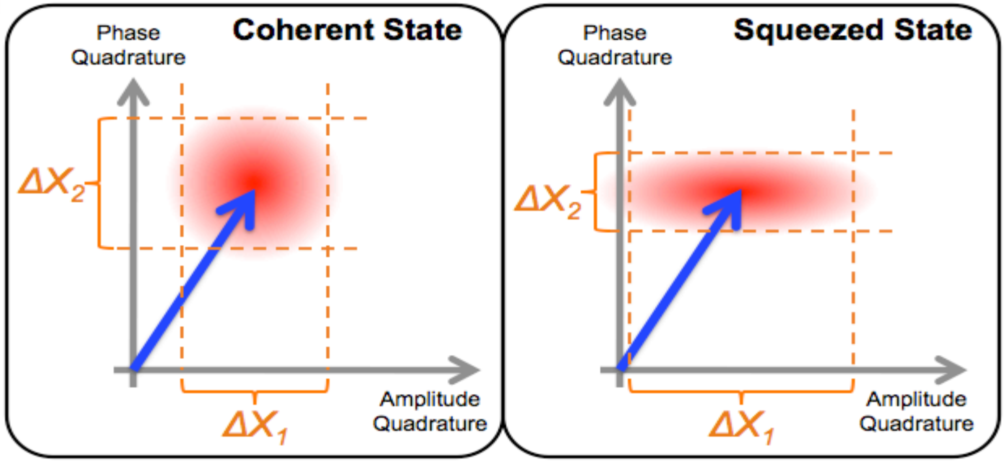
ACTION: Increase laser power (@ ifo input) from 125W to 500W

EFFECT: Reduced shot noise by a factor of 2

SIDE EFFECTS: Increased radiation pressure noise by a factor 2



Injection of Squeezed Light

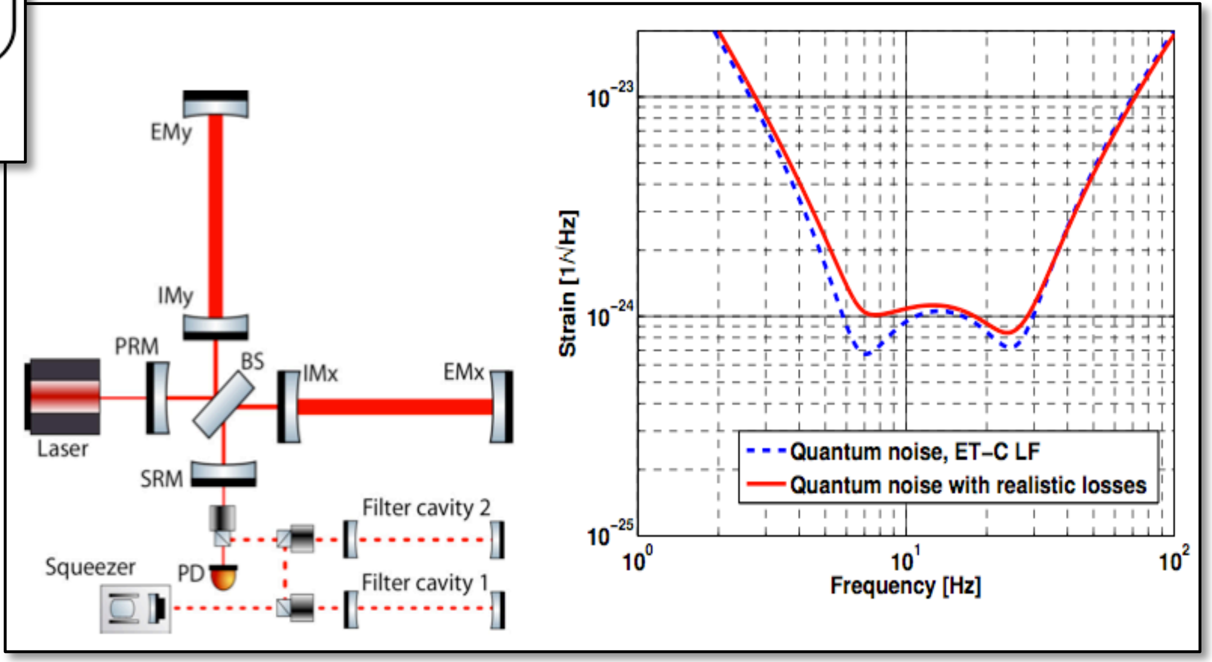


Heisenberg uncertainty principle: there is a minimal area of ball

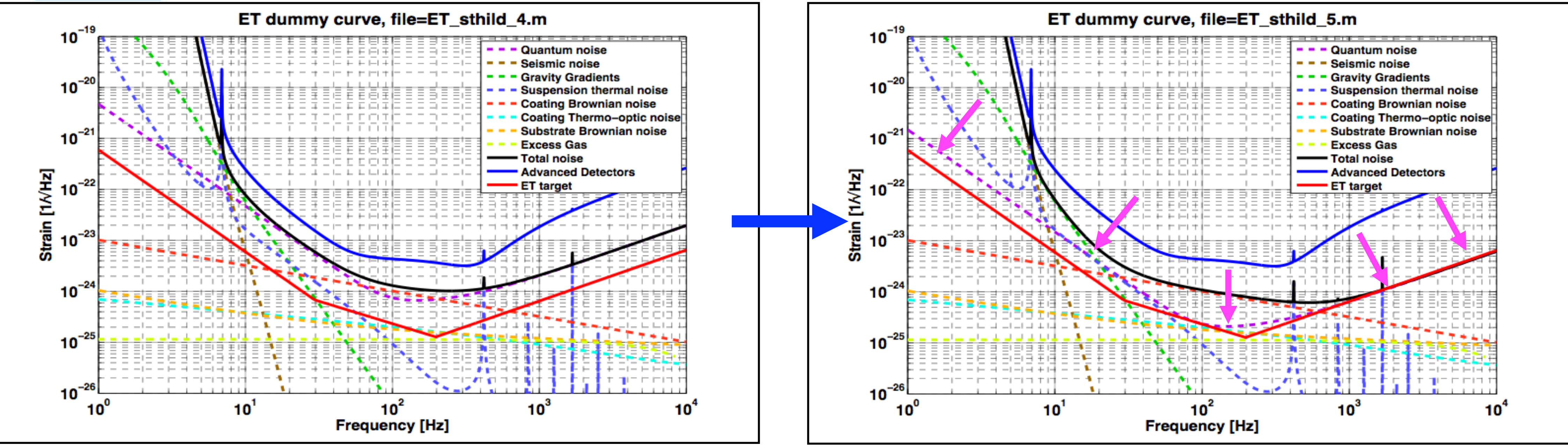
$$\Delta\hat{X}_1\Delta\hat{X}_2 \geq 1$$

- Quantum noise can be reduced by the injection of squeezed light states.
- Squeezing already successfully implemented in GEO600.

- To reduce photon shot noise and radiation pressure noise we require a frequency dependent squeezing angle.
- Use dispersion in reflection of filter cavities.



Step 4: Quantum noise suppression

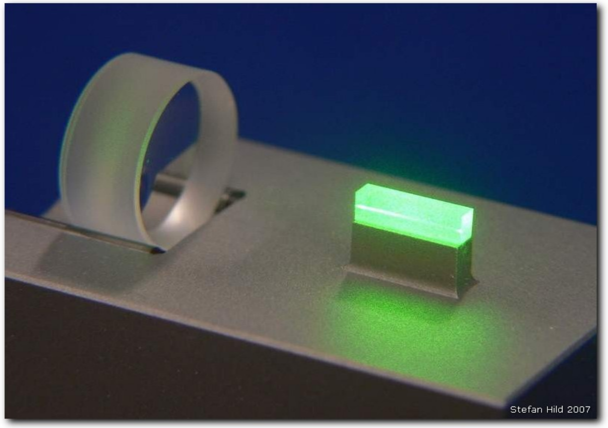


DRIVER: Shot noise at high frequencies

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



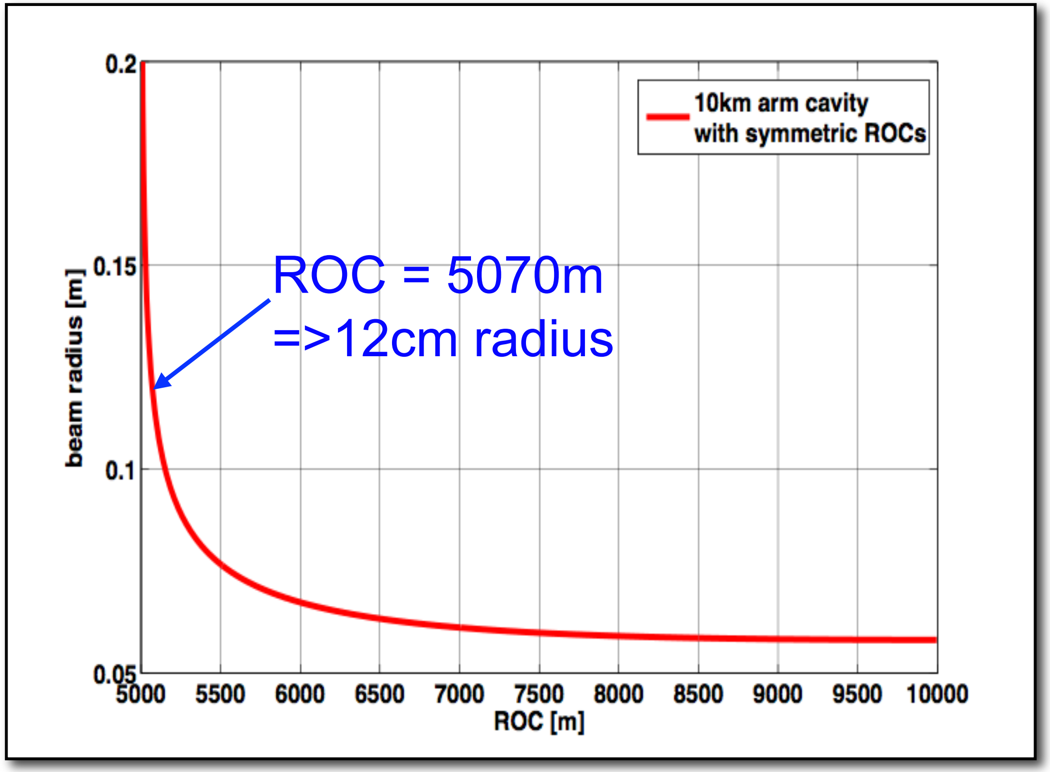
Increasing the beam size to reduce Coating Brownian noise

Increasing the beam size at the mirrors reduces the contribution of Coating Brownian.

Coating Brownian noise of one mirror:

$$S_x(f) = \frac{4k_\mathrm{B}T}{\pi^2 fY}\frac{d}{r_0^2}\left(\frac{Y'}{Y}\phi_{||} + \frac{Y}{Y'}\phi_\perp\right)$$

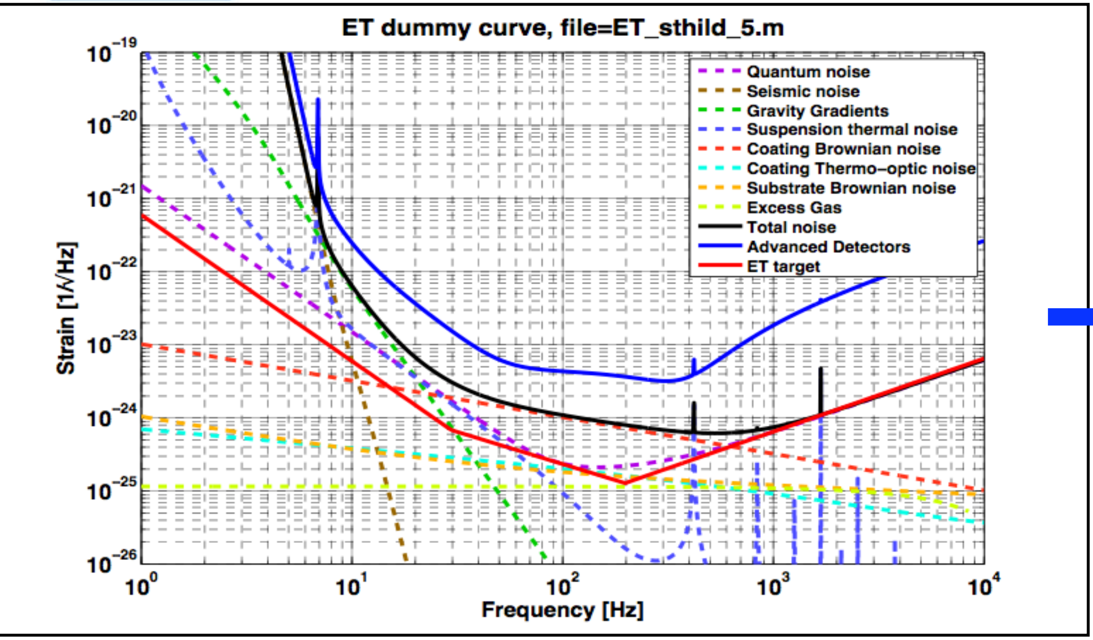
beam radius on mirror

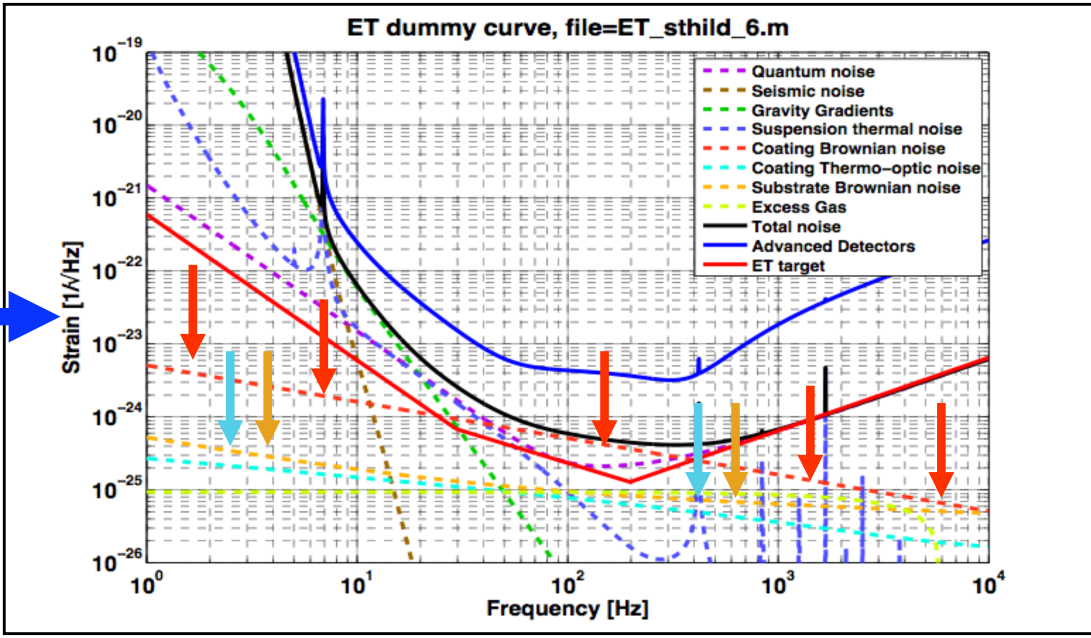


ROC = 5070m
=>12cm radius

Please note: a beam radius of 12cm requires mirrors of 60 to 70cm diameter

Step 5: Increasing the beam size





DRIVER: Coating Brownian noise

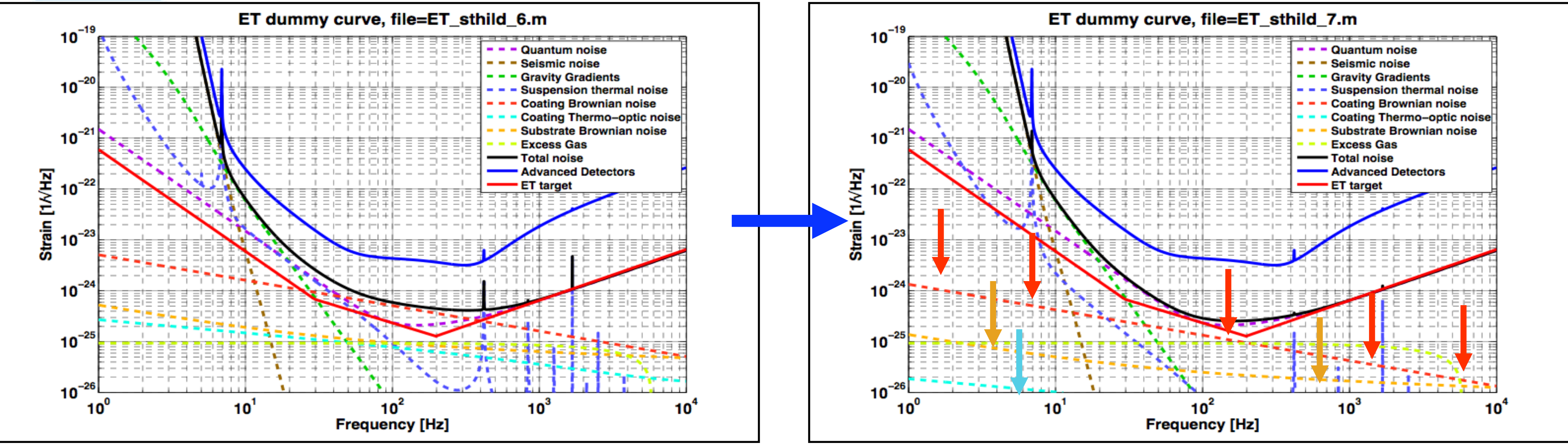
ACTION: Increase of beam radius from 6 to 12cm

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%)

Step 6: Cooling the test masses

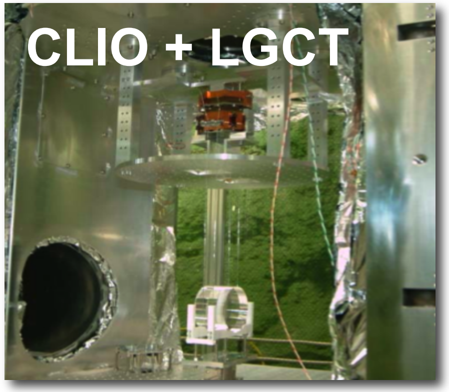


DRIVER: Coating Brownian noise

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

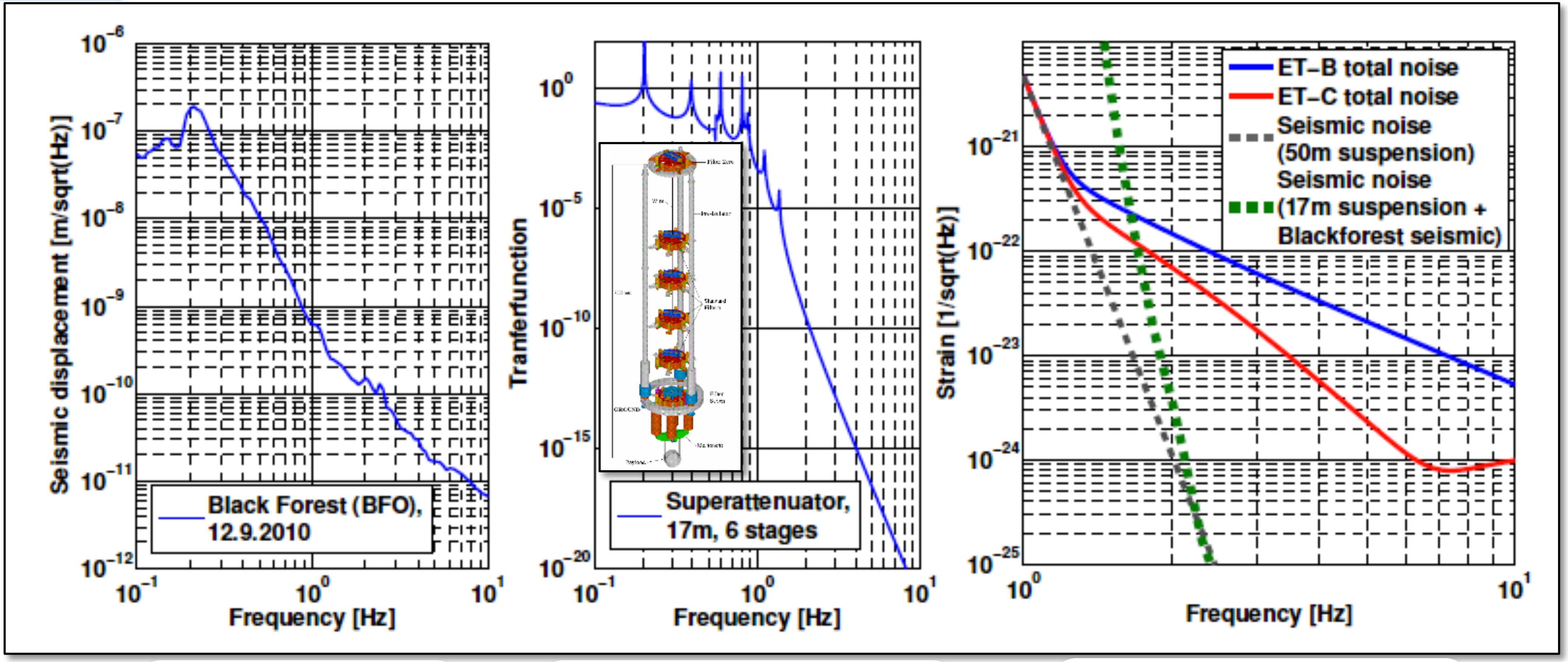
EFFECT: Decrease Brownian by ~ factor of 4

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



Kuroda 2008
LIGO-G080060

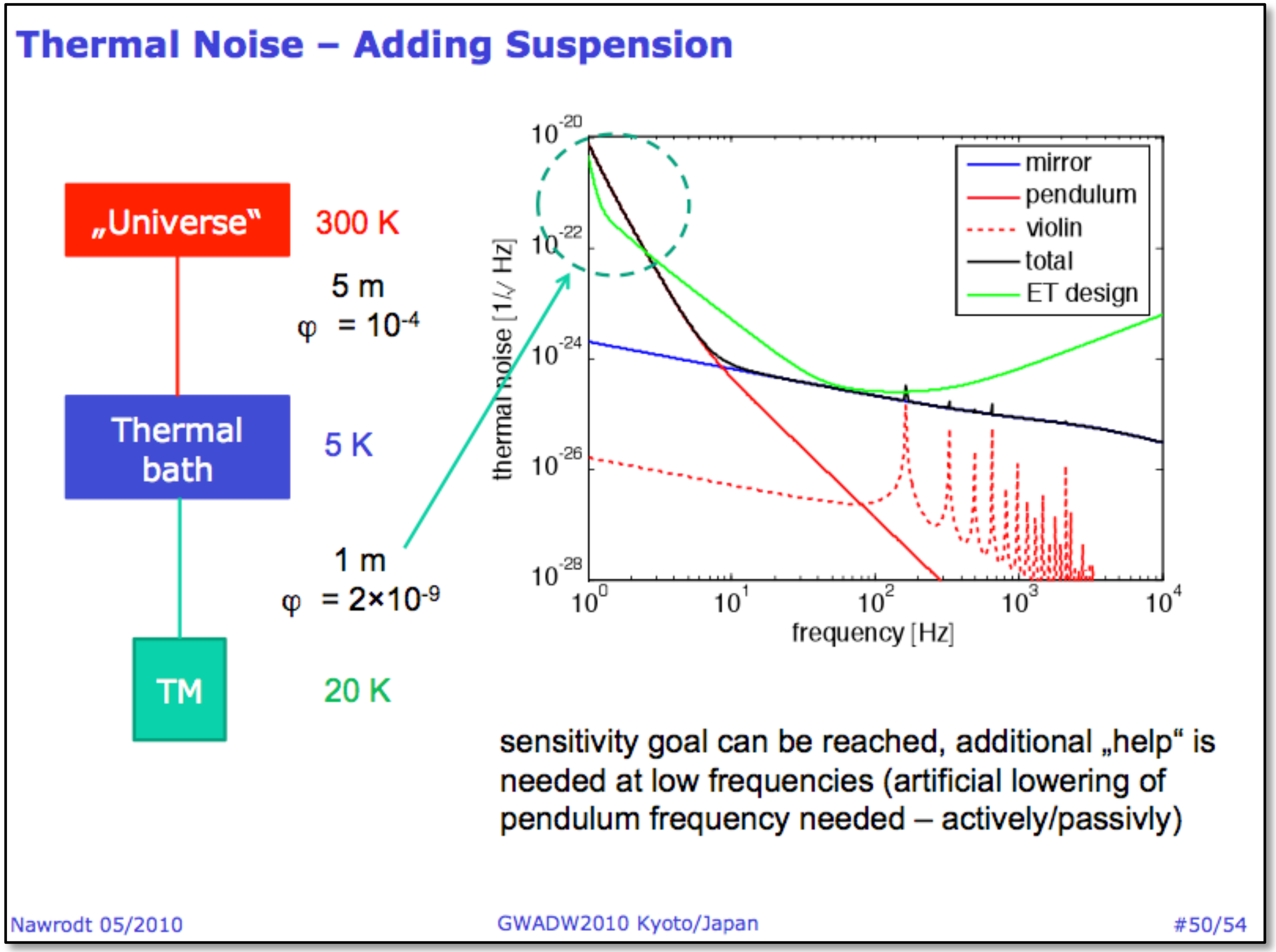
Seismic noise



Seismic excitation x **17m SA Transfer function** = **Seismic noise contribution**

Suspension Thermal noise

- Suspension thermal noise is probably the main driver for going to cryogenic temperatures.
- Actual level strongly depends design details of suspension.



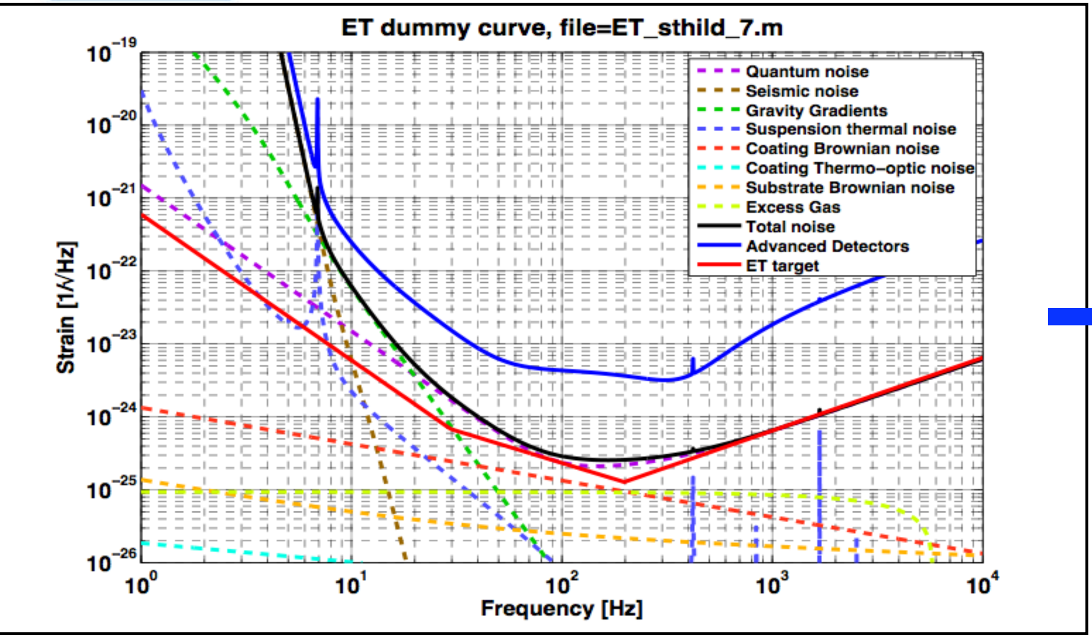
Thermal Noise – Adding Suspension

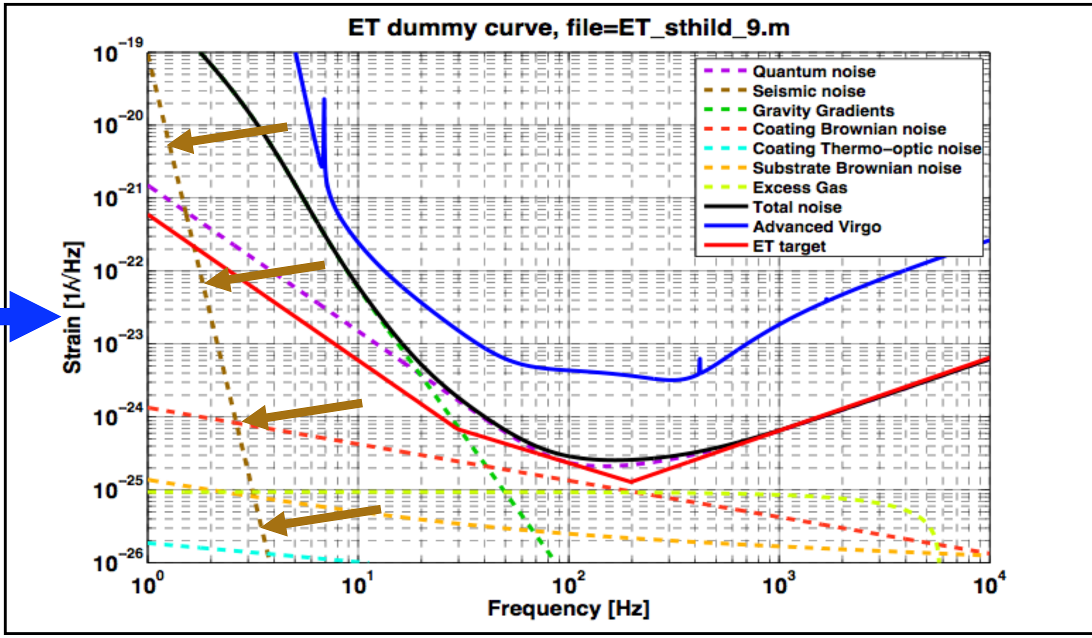
sensitivity goal can be reached, additional „help" is needed at low frequencies (artificial lowering of pendulum frequency needed – actively/passivly)

Nawrodt 05/2010 GWADW2010 Kyoto/Japan #50/54

R. Nawrodt: http://gw.icrr.u-tokyo.ac.jp/gwadw2010/program/2010_GWADW_Nawrodt_ETWP2.pptx

Step 7: Longer Suspensions





DRIVER: Seismic noise

ACTION: Build 50m tall 5 stage suspension (corner freq = 0.158 Hz)

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

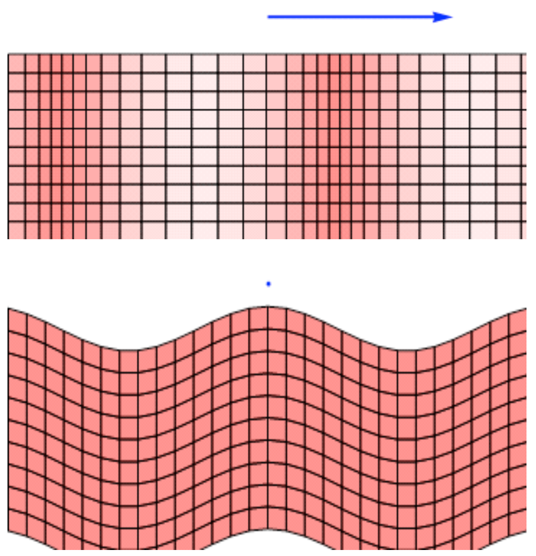
Same performance can be achived by a 17m high superattenuator S.Brachini: http://gw.icrr.u-tokyo.ac.jp/gwadw2010/program/2010_GWADW_Braccini.ppt

What is Gravity Gradient Noise

- Changes in the gravitational potential around a test mass.
- Causes 1: Humans, Lorries, Clouds etc
  - Hopefully not problematic because at frequency below detection band.
- Causes 2: Seismic driven changes
  - Density waves, shaking of cave walls etc
- Can be approximated by:

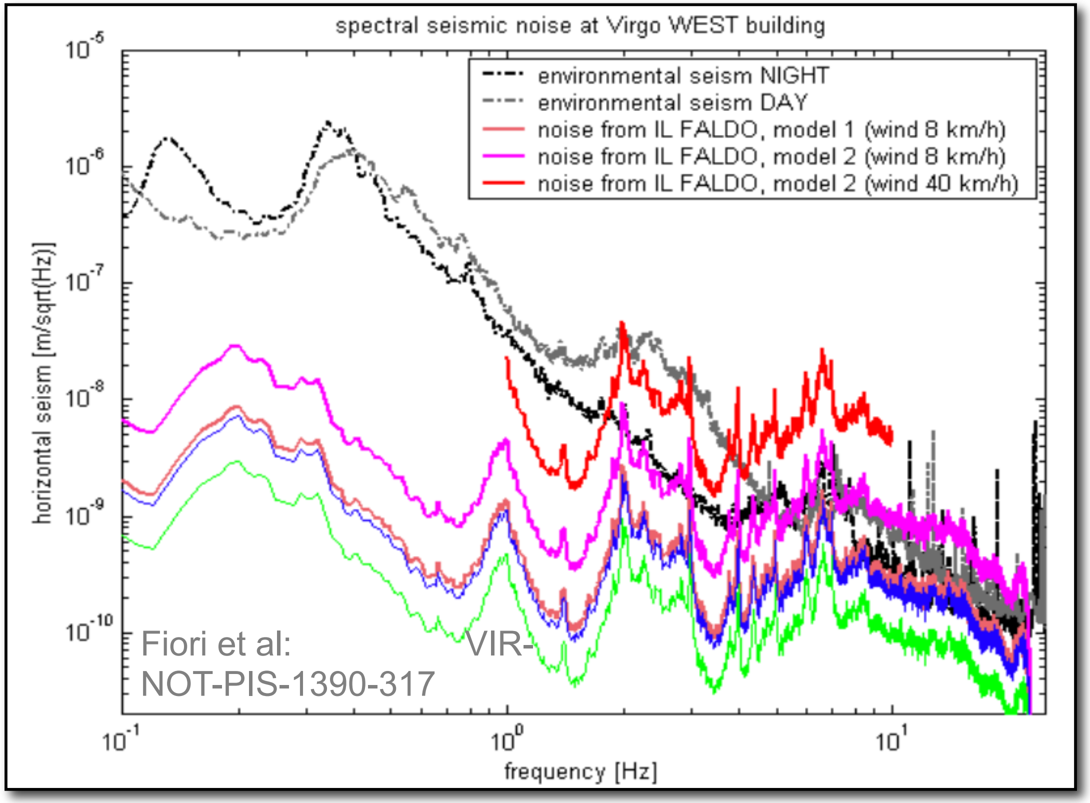
Testmass Noise = Seismic Excitation x Coupling Transfer function

- Coupling Transfer function given by law of gravity. Not much we can do!
- Seismic Excitation can be reduced by finding a quiet site !



Images: G.Cella

Tackling Gravity Gradient noise: going underground



Fiori et al: VIR-NOT-PIS-1390-317

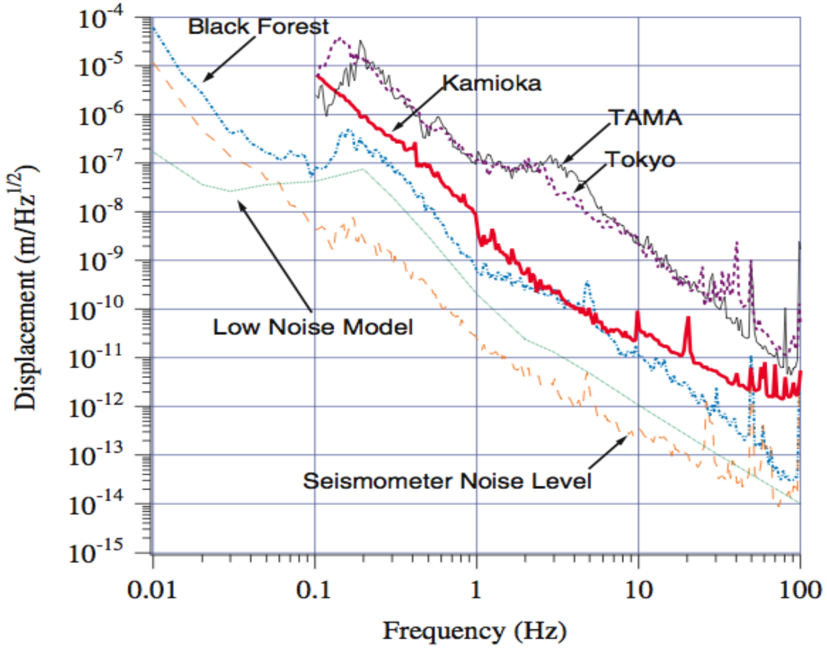


Figure 7. Low seismic noise environment at the Kamioka site. Displacement noises at Kamioka, TAMA site, Tokyo, Black Forest Geophysical Observatory (Germany) and a low noise model (a hybrid spectrum of quiet sites in the world) are described.

Ohasi et al: Class. Quantum Grav. **20** (2003) S599-607

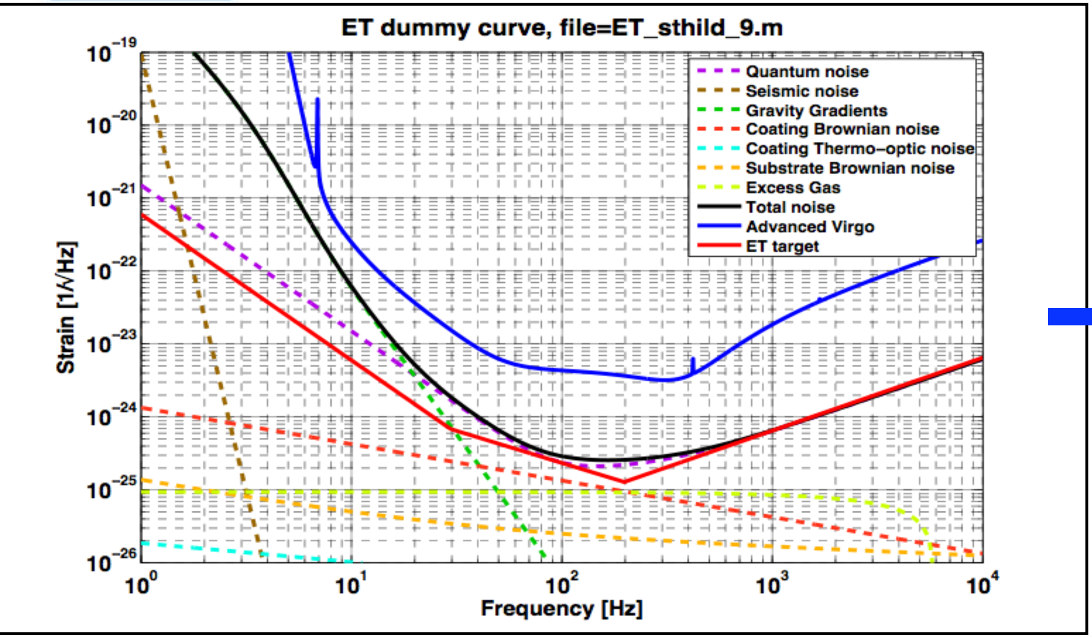
Surface (Cascina)

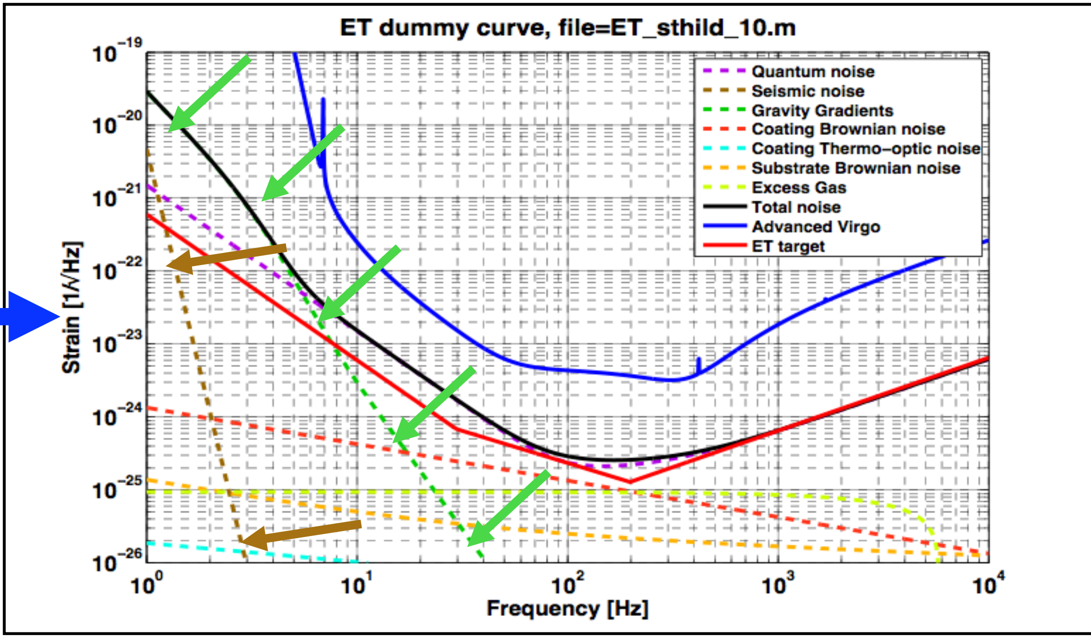
about $1 \cdot 10^{-7}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$

Underground (Kamioka)

about $5 \cdot 10^{-9}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$

Step 8: Going underground





DRIVER: Gravity gradient noise

ACTION: Go from the surface to underground location

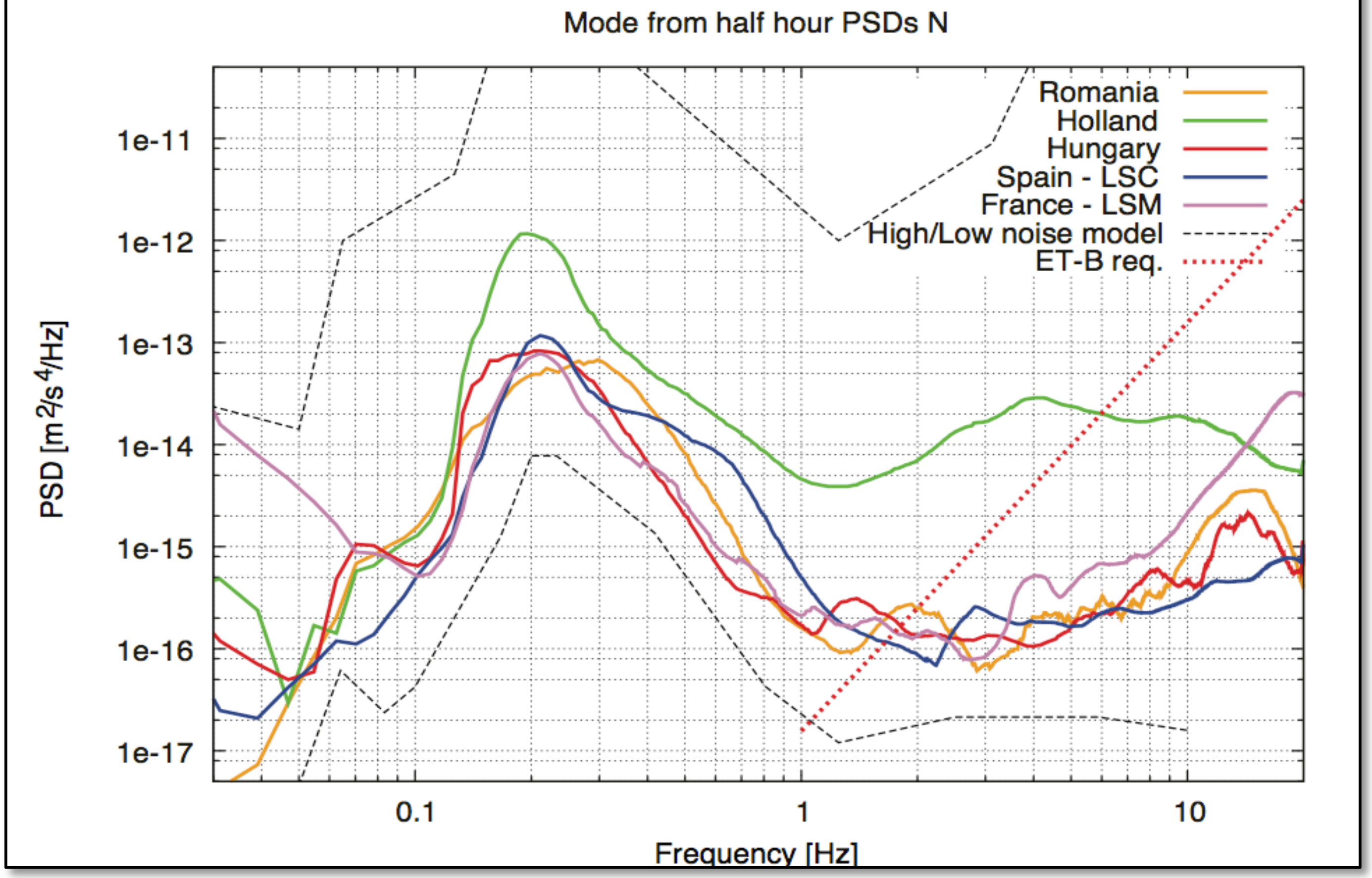
EFFECT: Decrease gravity gradients by a factor 20

SIDE EFFECTS: Decrease in seismic noise by a factor 20

Seismic measurements

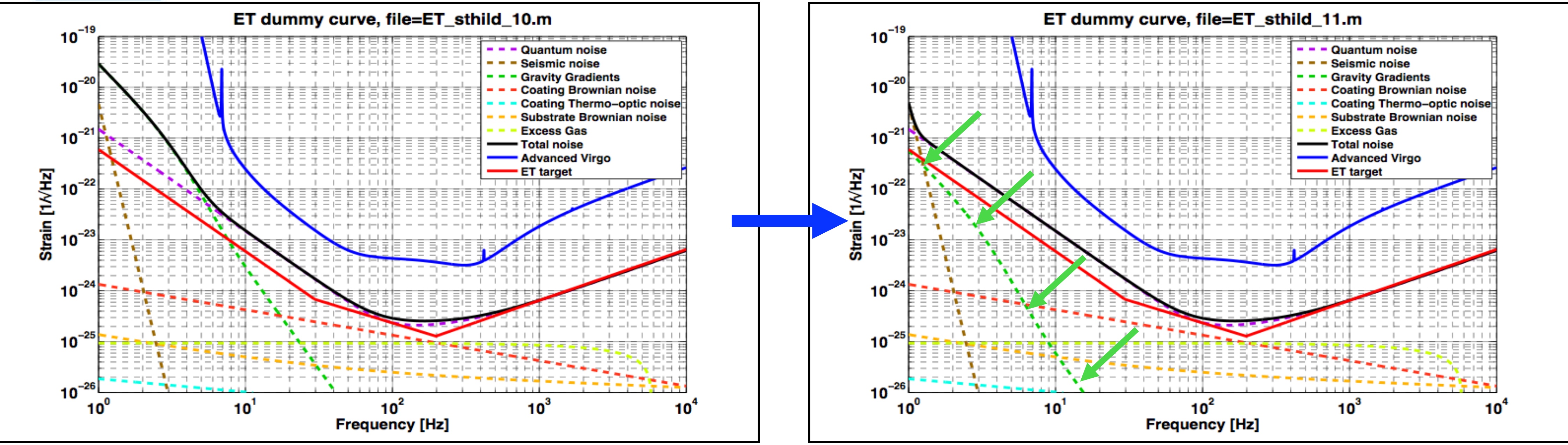
- Seismic measurement campaign showed that there are several underground sites which have a seismic level even below Kamioka.
- Gravity gradient noise compitabile with 3rd generation sensitivity for frequencies above 2Hz.

Locations in Hungary, France and Spain have shown to be within ET-B requirements > 2 Hz



M.Baker: http://gw.icrr.u-tokyo.ac.jp/gwadw2010/program/2010_GWADW_Beker.pdf

Step 9: Gravity gradient suppression

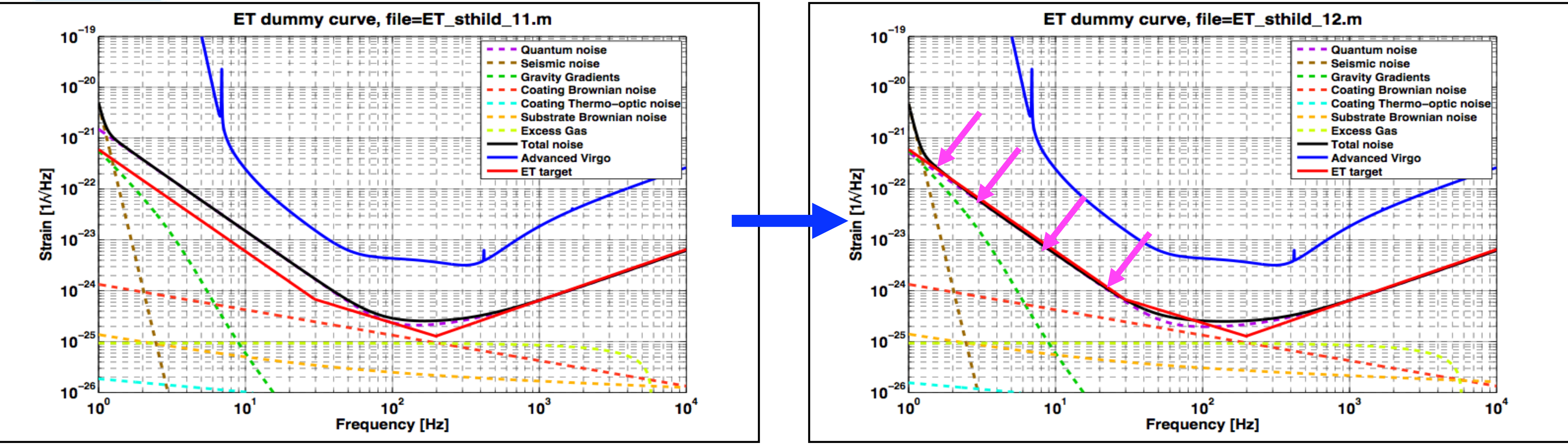


DRIVER: Gravity gradient noise

ACTION: Very quite underground site + active subtraction of the gravity gradients below a few Hz

EFFECT: Decrease gravity gradient noise by a factor 50.

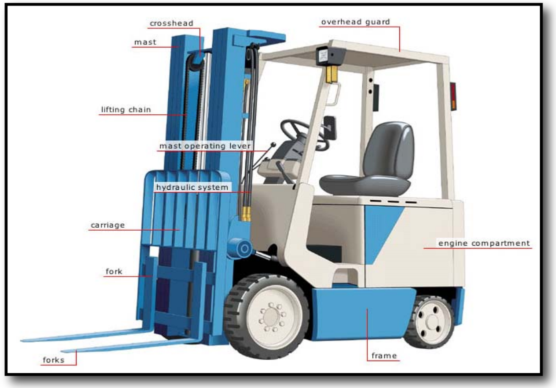
Step 10: Heavier mirrors

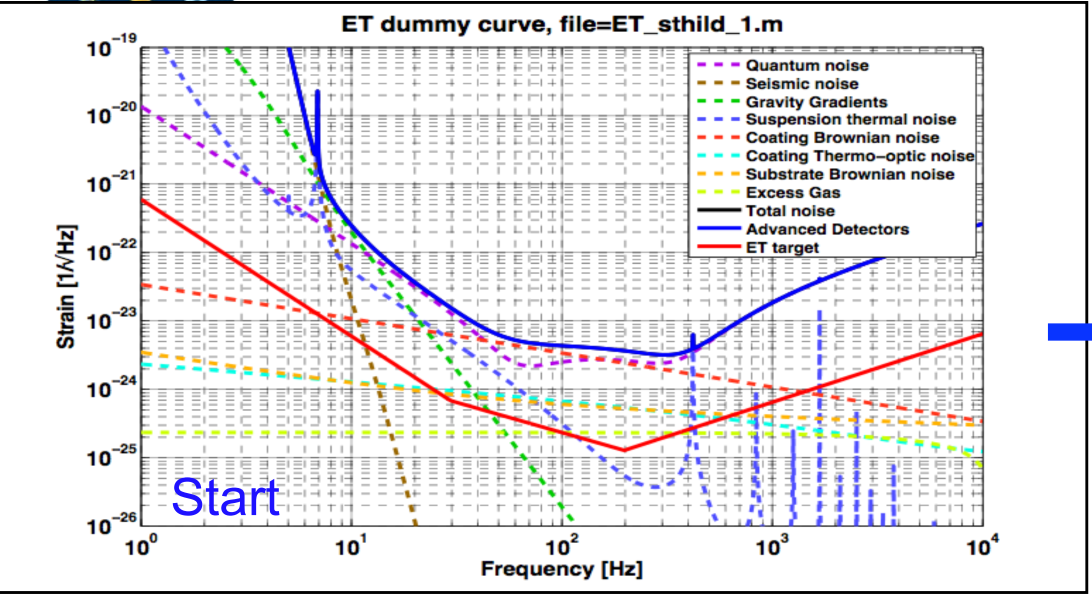


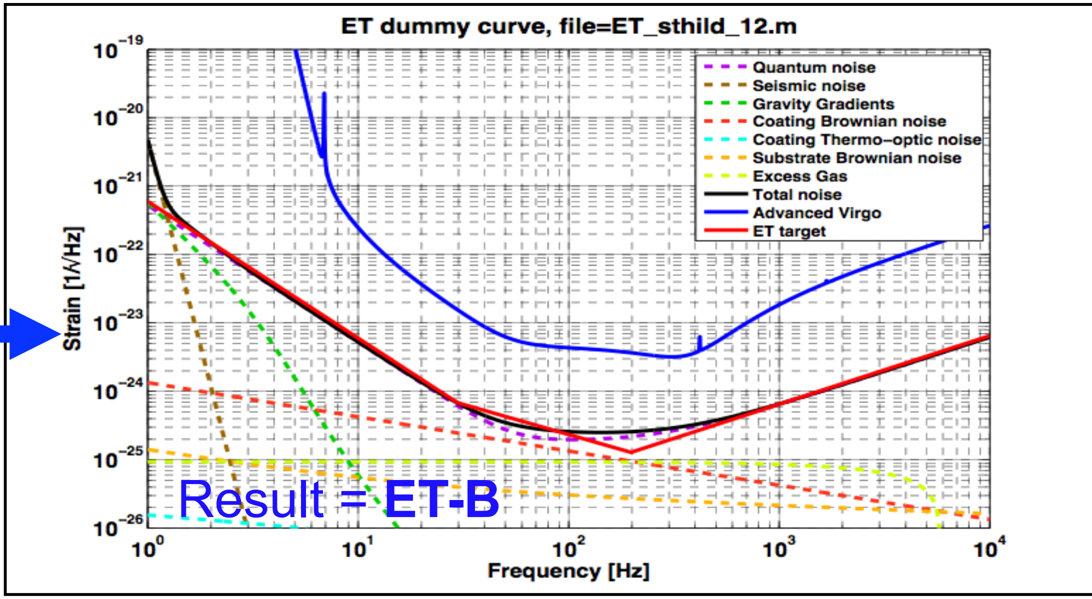
DRIVER: Quantum noise at low frequencies

ACTION: Increase test mass weight from 42 kg to 120 kg (or even 200 kg)

EFFECT: Decrease of radiation pressure noise





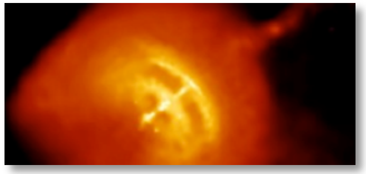


	advanced detector	potential ET design
Arm length	3 km	10 km
SR-phase	detuned (0.15)	tuned (0.0)
SR transmittance	11 %	10 %
Input power (after IMC)	125 W	500 W
Arm power	0.75 MW	3 MW
Quantum noise suppression	none	10 dB
Beam radius	6 cm	12 cm
Temperature	290 K	20 K
Suspension	Superattenuator	5 stages of each 10 m length
Seismic	$1 \cdot 10^{-7}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$ (Cascina)	$5 \cdot 10^{-9}\,\mathrm{m}/f^2$ for $f > 1\,\mathrm{Hz}$ (Kamioka)
Gravity gradient reduction	none	factor 50 required
Mirror masses	42 kg	120 kg
BNS range	150 Mpc	2650 Mpc
BBH range	800 Mpc	17700 Mpc

S.Hild et al: arXiv:0810.0604

Overview of this presentation

- ET – the start of Gravitational Wave Astronomy

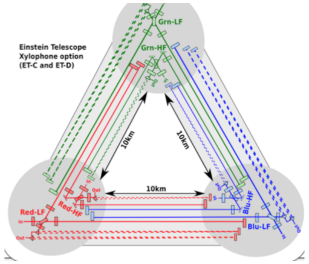


- Where is the transition from 2nd to 3rd Generation?

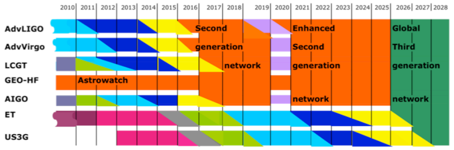
2G → 2.5G → 3G

- The Brute Force approach to achieve the 3rd Generation target sensitivity.

- The ET baseline design

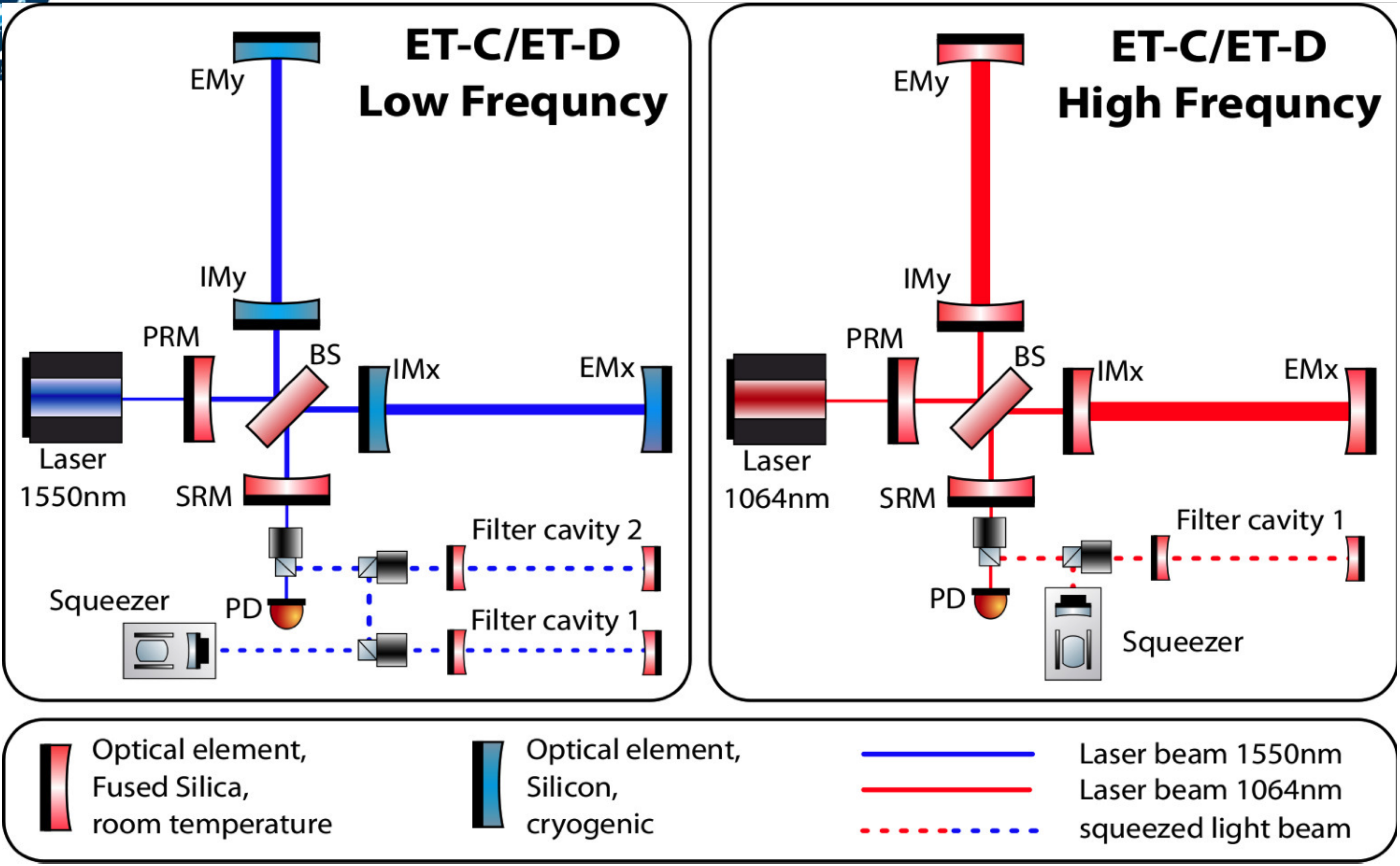


- Time line towards the Einstein Telescope



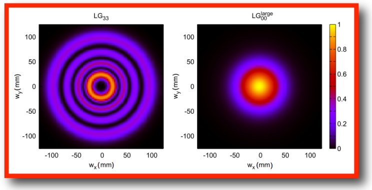
Motivation for Xylophone observatories

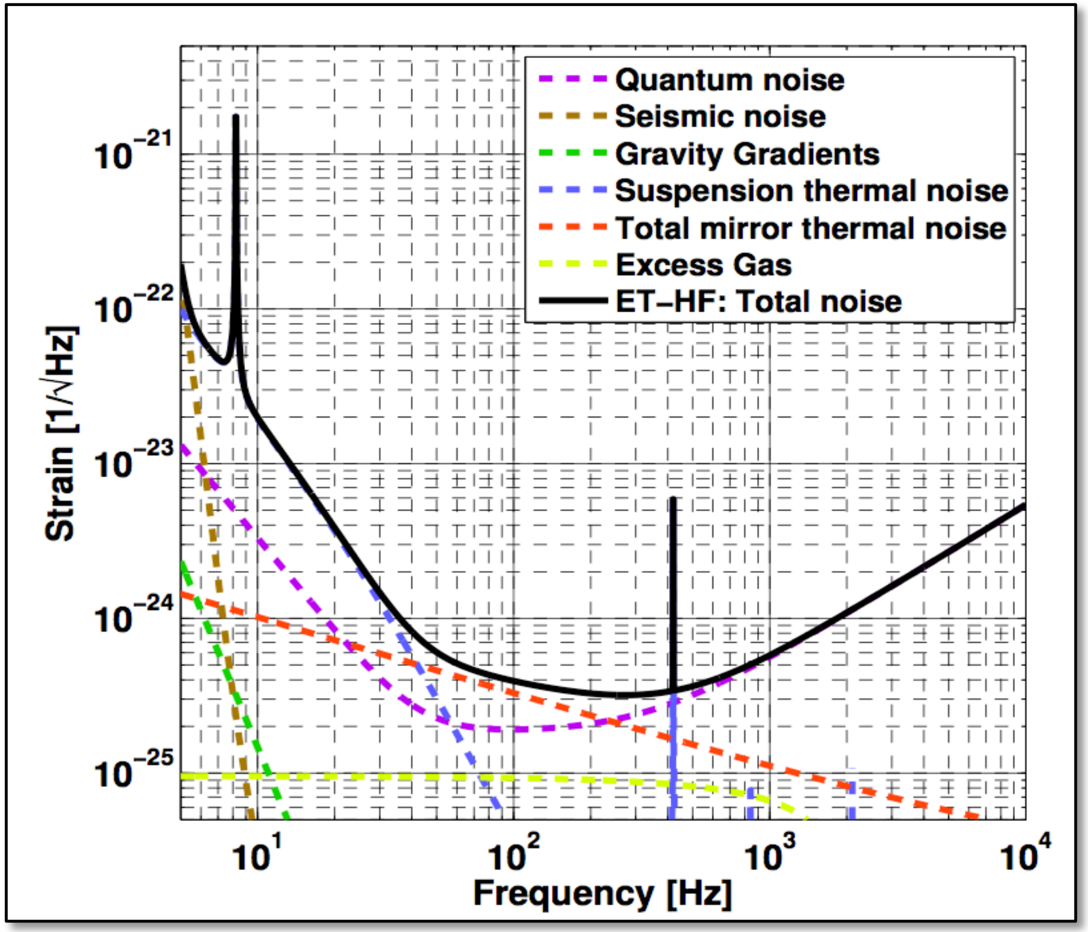
- Due to residual absorption in substrates and coatings high optical power (3MW) and cryogenic test masses (20K) don't go easily together.
- IDEA: Split the detection band into 2 or 3 instruments, each dedicated for a certain frequency range. All 'xylophone' interferometer together give the full sensitivity.
- Example of a 2-tone xylophone:
  - Low frequency: low power and cryogenic
  - High frequency: high power and room temperature


ET-C/ET-D
Low Frequncy
EMy
IMy
PRM
BS
IMx
EMx
Laser
1550nm
SRM
Filter cavity 2
Filter cavity 1
Squeezer
PD
ET-C/ET-D
High Frequncy
EMy
IMy
PRM
BS
IMx
EMx
Laser
1064nm
SRM
Filter cavity 1
PD
Squeezer
Optical element,
Fused Silica,
room temperature
Optical element,
Silicon,
cryogenic
Laser beam 1550nm
Laser beam 1064nm
squeezed light beam

High Frequency Detector

- **Quantum noise:** 3MW, tuned Signal-Recyling, 10dB Squeezing, 200kg mirrors.
- **Suspension Thermal and Seismic:** Superattenuator at surface location.
- **Gravity gradient:** No Subtraction
- **Thermal noise:** 290K, 12cm beam radius, fused Silica, LG33 (reduction factor of 1.6 compared to TEM00).

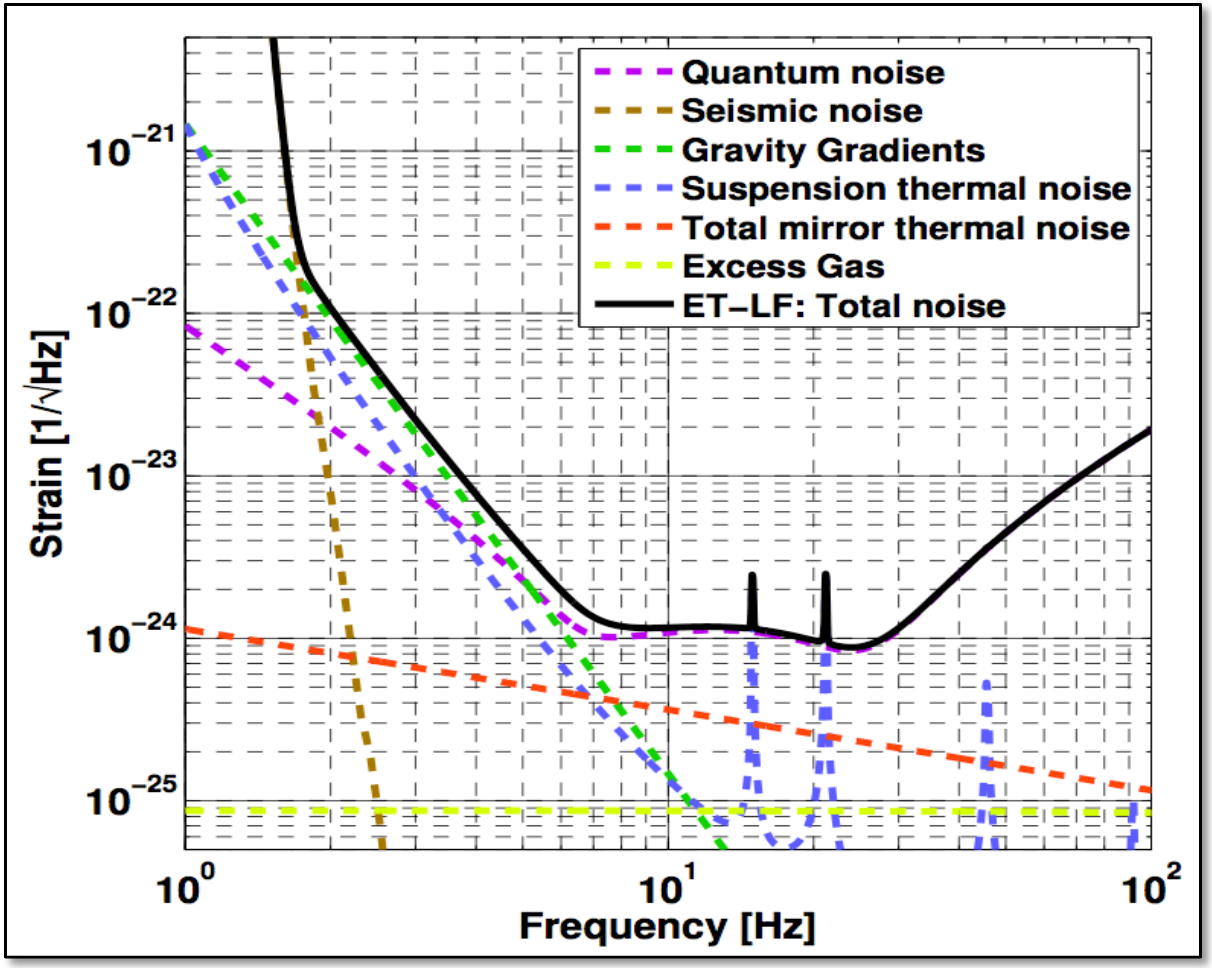




Coating Brownian reduction factors (compared to 2G): 3.3 (arm length), 2 (beam size) and 1.6 (LG33) = 10.5

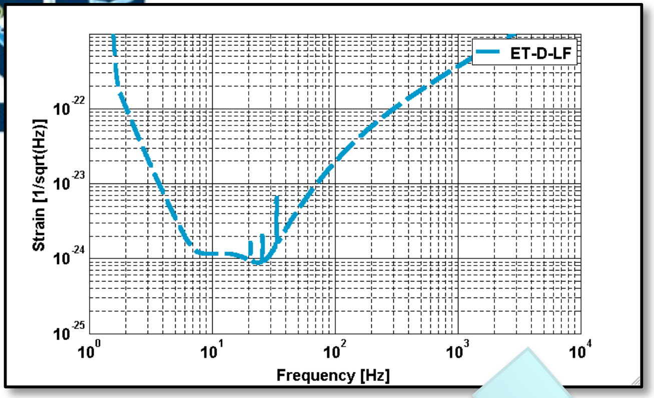
Low Frequency Detector

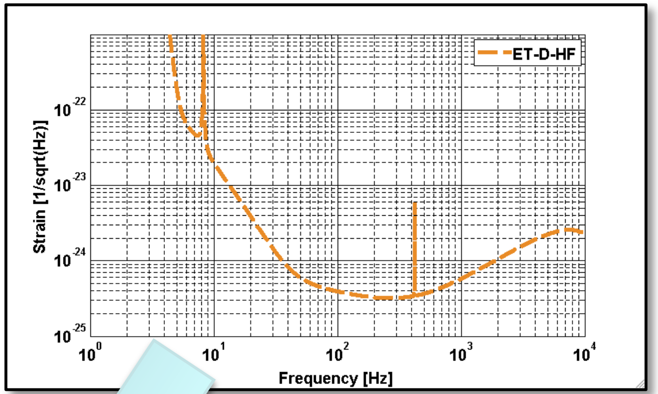
- **Quantum noise:** 18kW, detuned Signal-Recyling, 10 dB frequency dependent Squeezing, 211kg mirrors.
- **Seismic:** 5x10m suspensions, underground.
- **Gravity gradient:** Underground, factor 50 subtraction
- **Thermal noise:** 10K, Silicon, 12cm beam radius, TEM00.
- **Suspension Thermal:** not included. :(



As mirror TN is no longer limiting, one can relax the assumptions on the material parameters and the beam size…

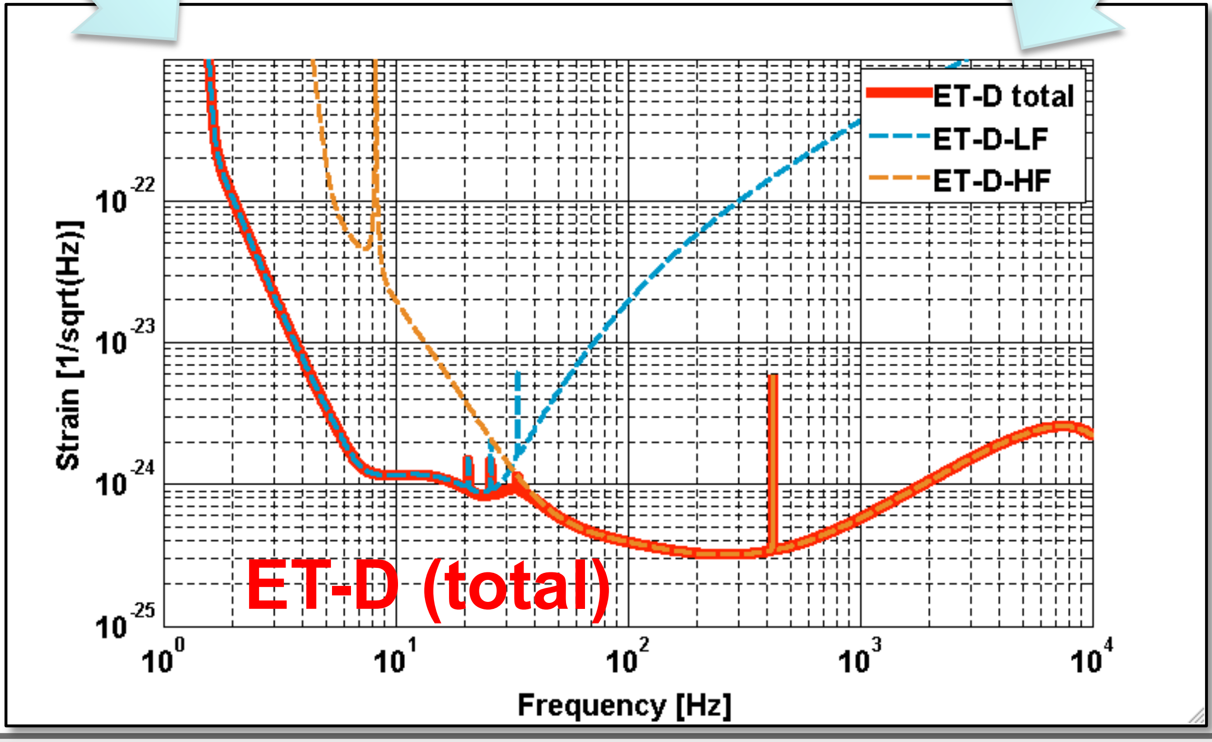
Combining the two interferometers





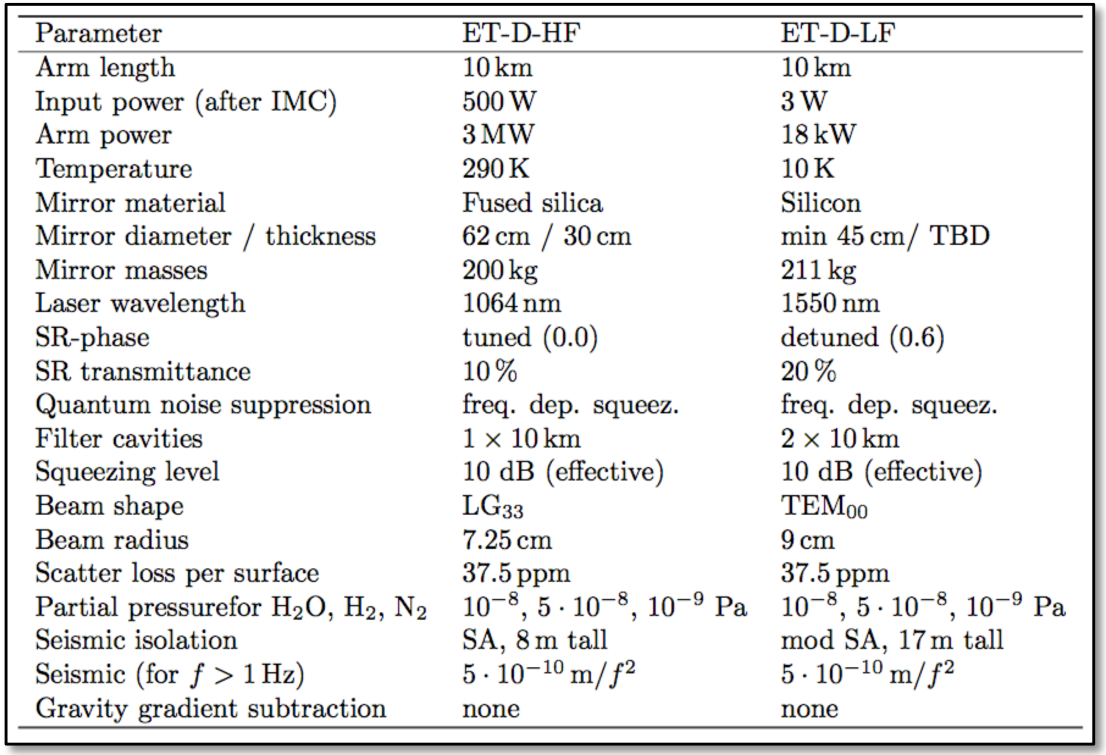
ET-D-LF

ET-D-HF

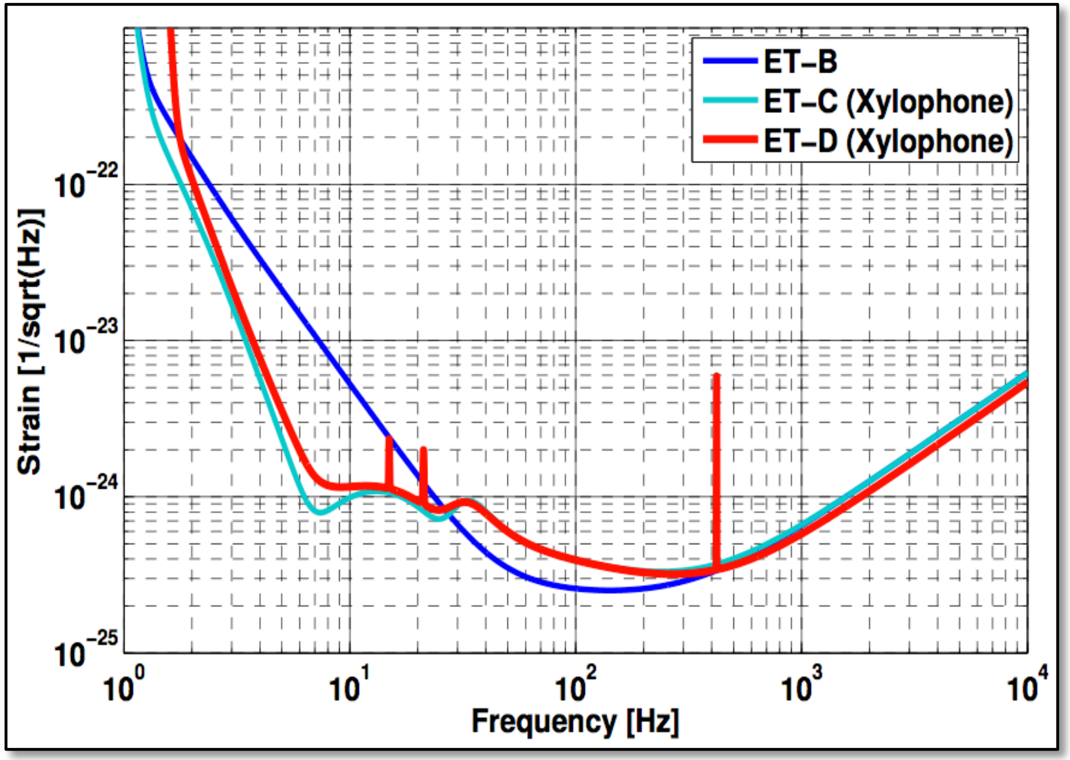


ET-D (total)

ET-Xylophone: ET-D



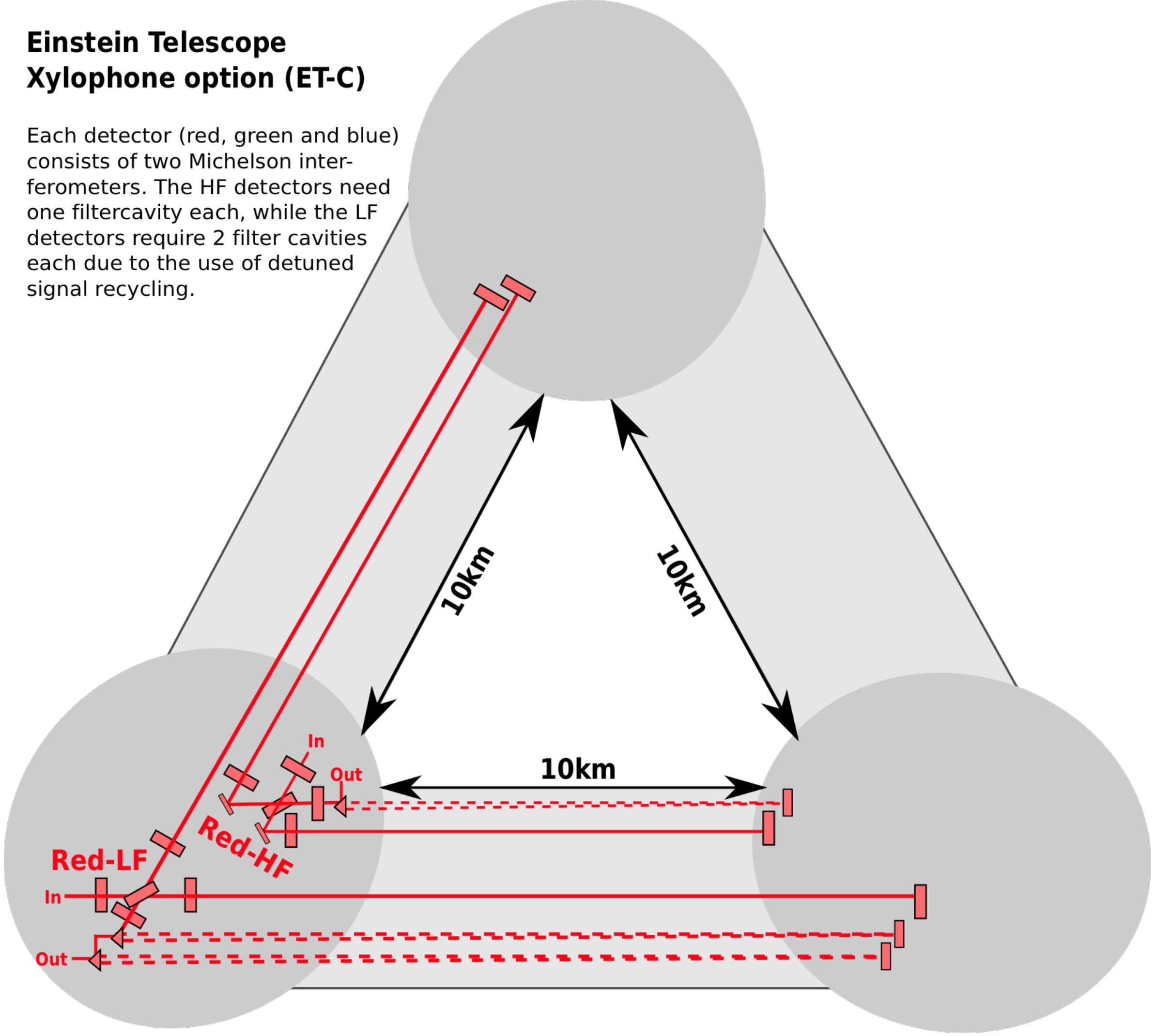
Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	Fused silica	Silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ TBD
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	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}, $5 \cdot 10^{-8}$, 10^{-9} Pa	10^{-8}, $5 \cdot 10^{-8}$, 10^{-9} Pa
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	none



- Data from ET-LF and ET-HF can be coherently or incoherently be added, depending on the requirements of the analysis.
- For more details please see S.Hild et al: ‘A Xylophone Configuration for a third Generation Gravitational Wave Detector’, CQG 2010, 27, 015003 and S.Hild et al: ‘Sensitivity Studies for Third-Generation Gravitational Wave Observatories’, arXiv:1012.0908v1 [gr-qc].

How to build an Observatory?

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

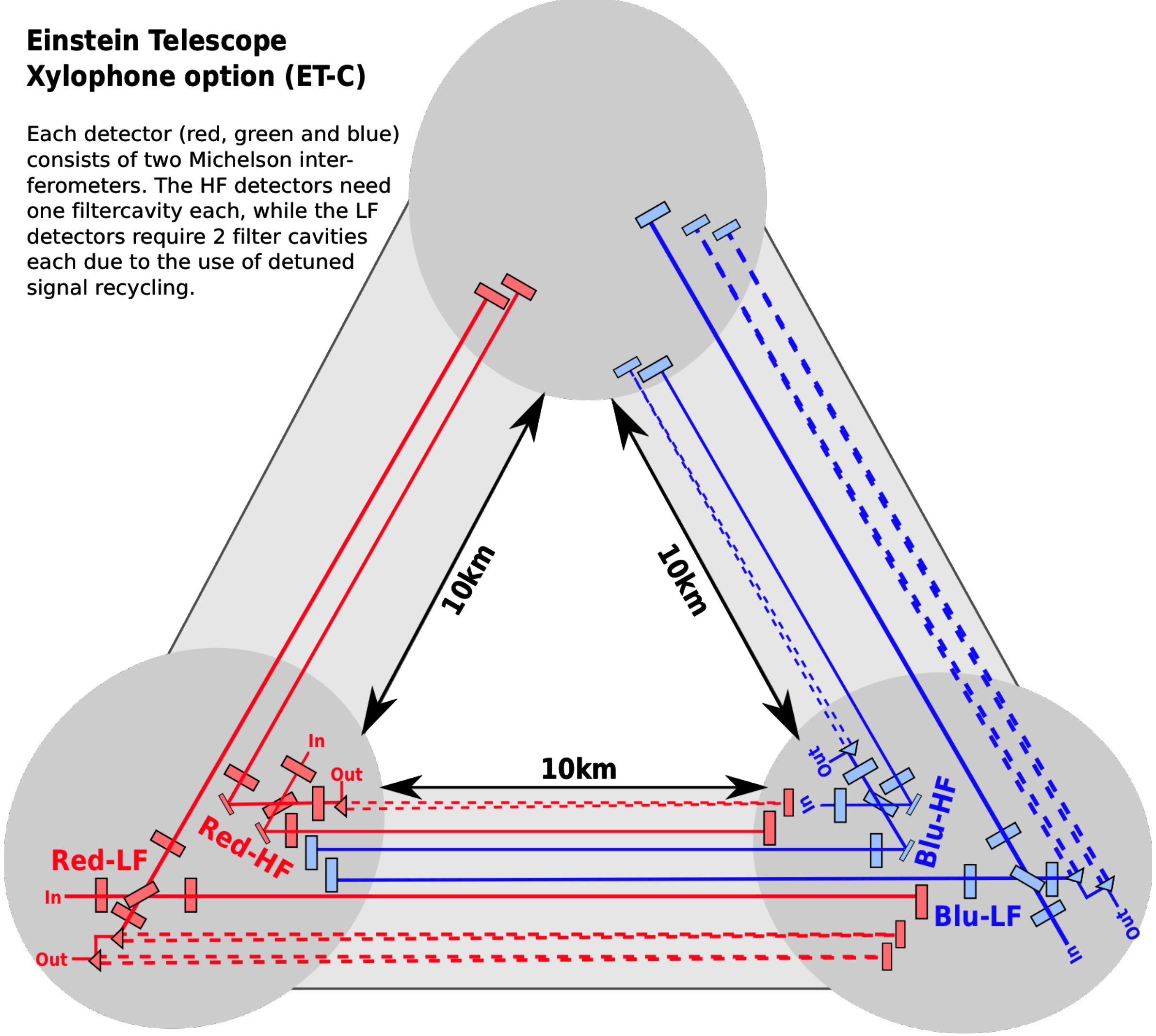


Einstein Telescope
Xylophone option (ET-C)

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filtercavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.

How to build an Observatory?

- For efficiency reasons build a triangle.
- Start with a single xylophone detector.
- Add second Xylophone detector to fully resolve polarisation.

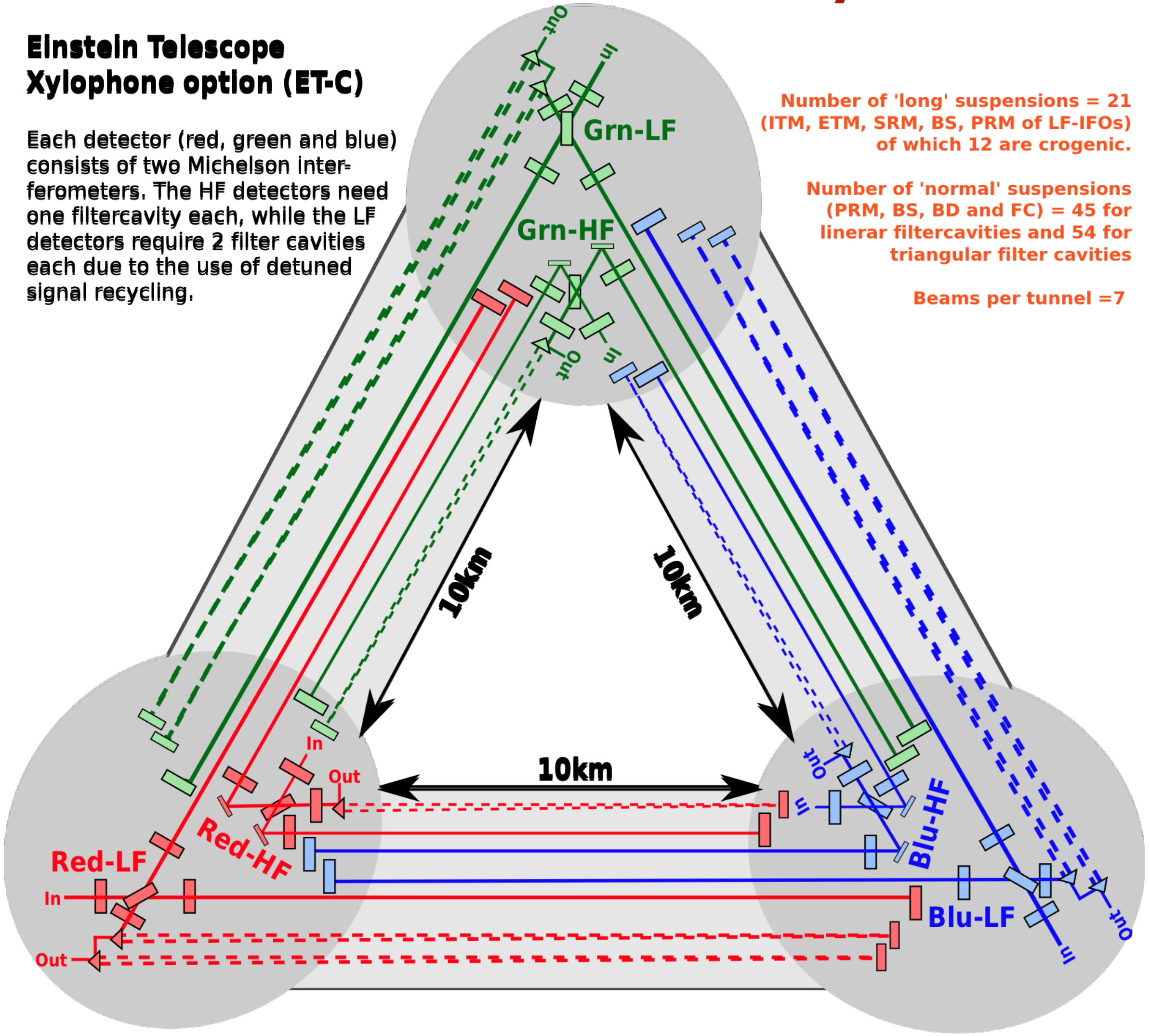


**Einstein Telescope
Xylophone option (ET-C)**

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filtercavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.

How to build an Observatory?

- 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.



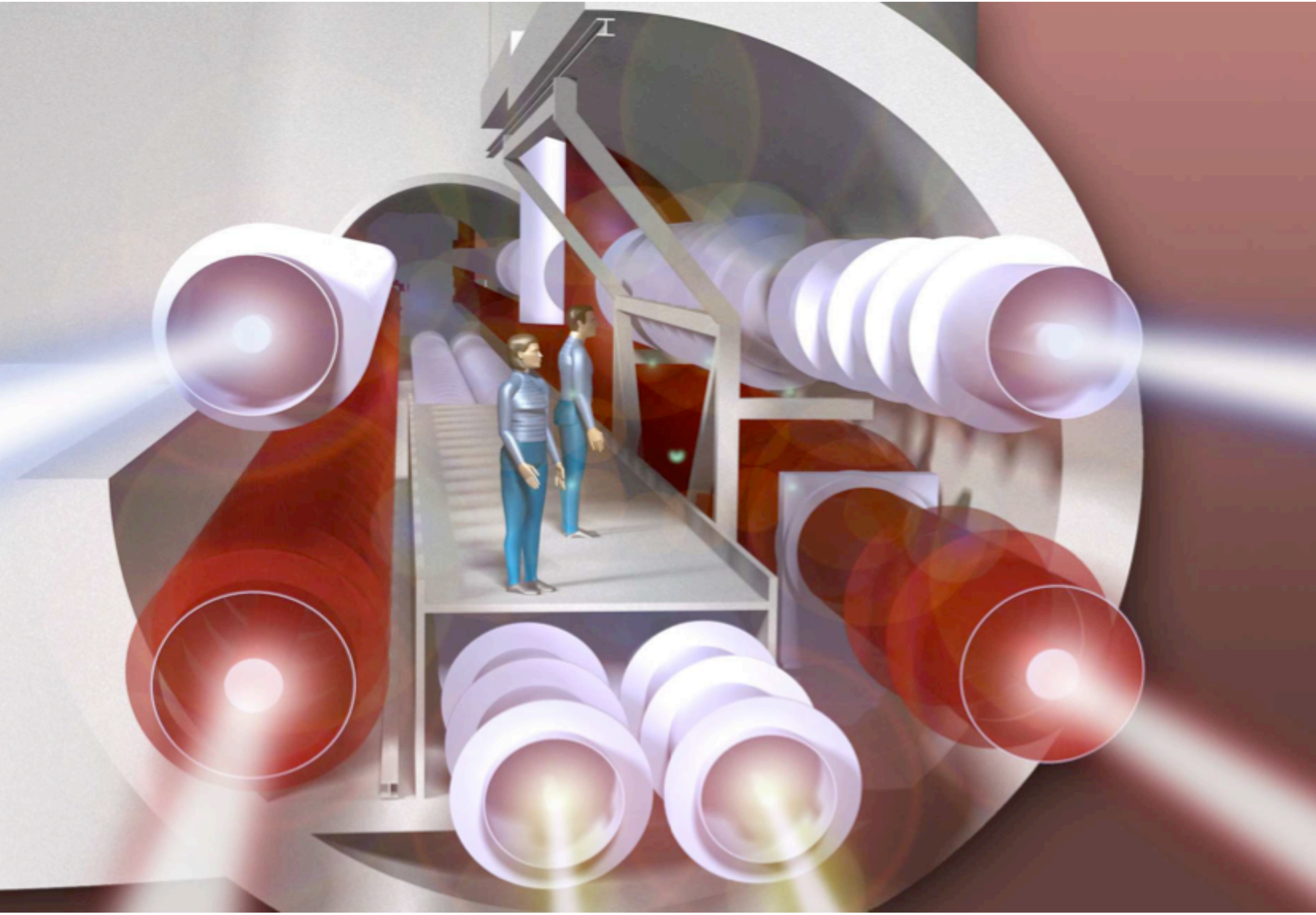
Einstein Telescope Xylophone option (ET-C)

Each detector (red, green and blue) consists of two Michelson interferometers. The HF detectors need one filtercavity each, while the LF detectors require 2 filter cavities each due to the use of detuned signal recycling.

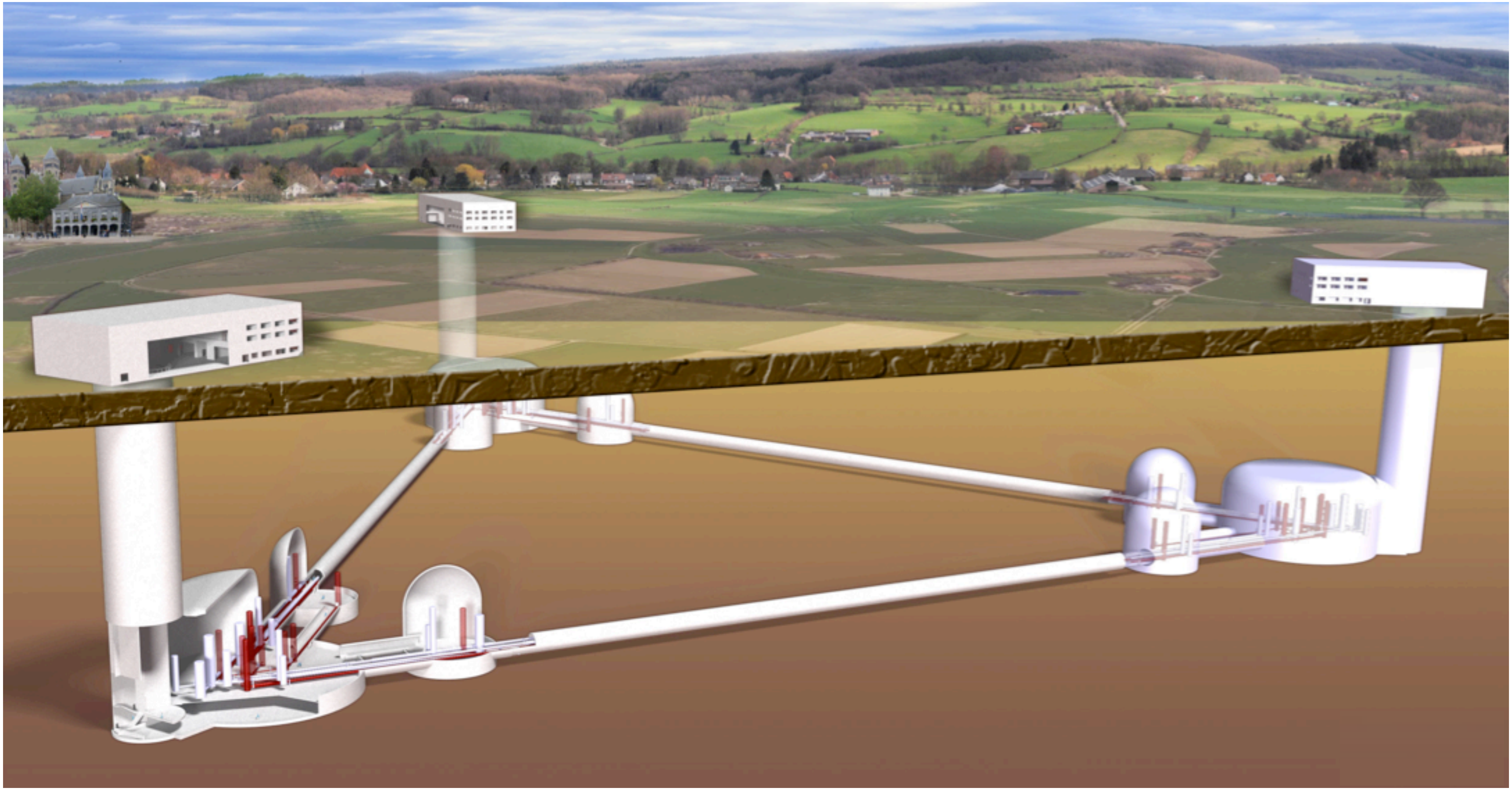
Number of 'long' suspensions = 21 (ITM, ETM, SRM, BS, PRM of LF-IFOs) of which 12 are crogenic.

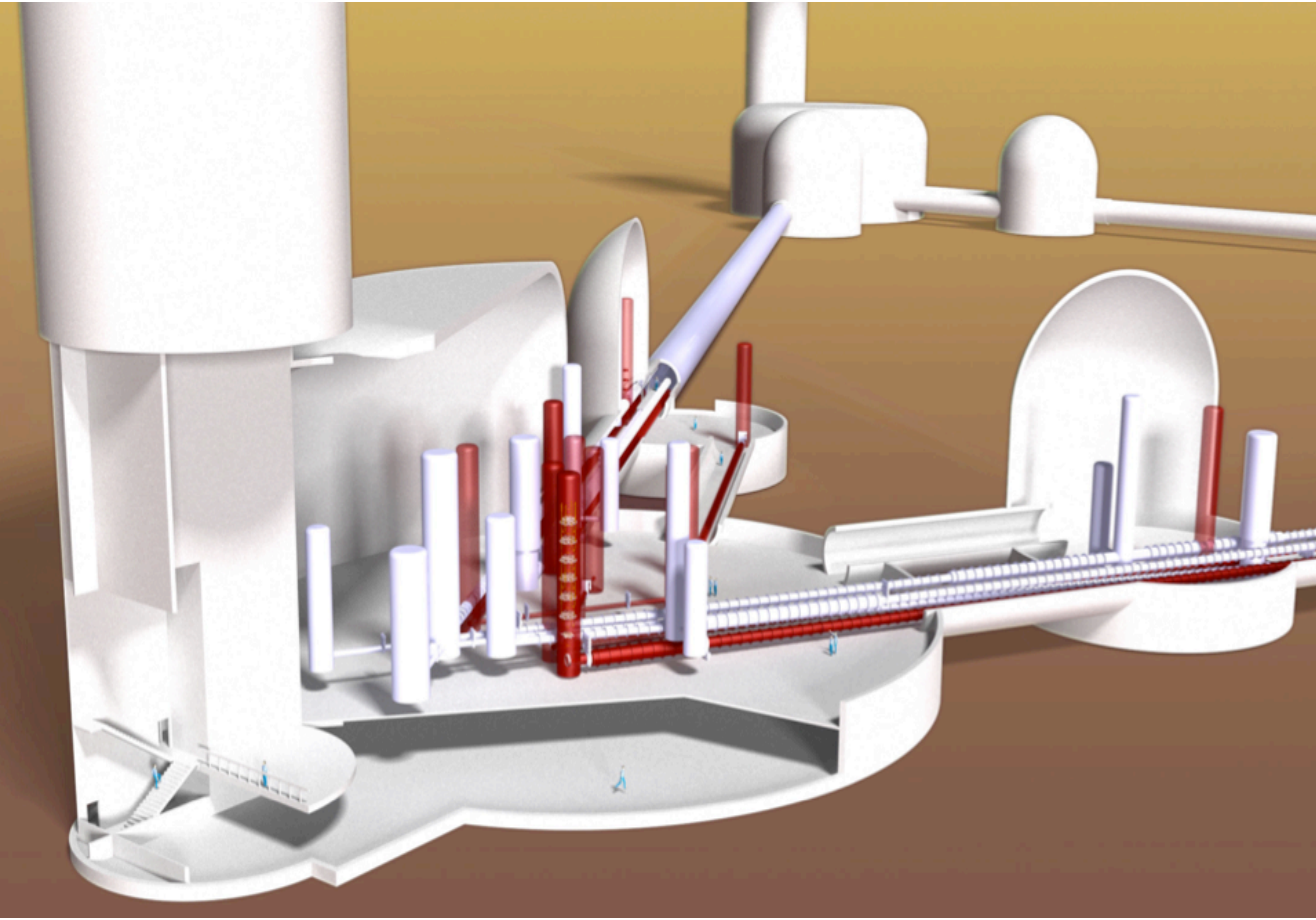
Number of 'normal' suspensions (PRM, BS, BD and FC) = 45 for linerar filtercavities and 54 for triangular filter cavities

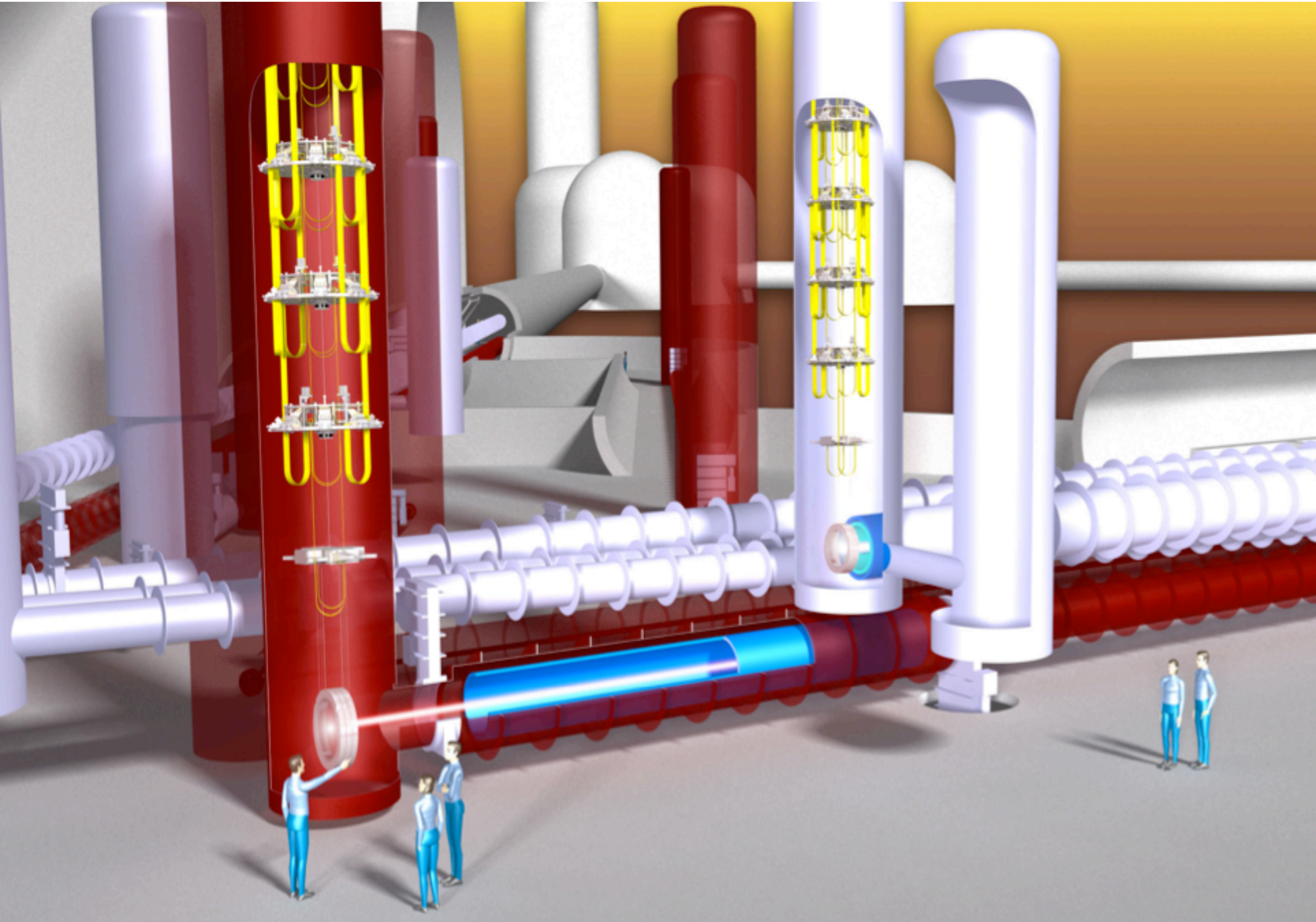
Beams per tunnel =7



Artist’s View of ET

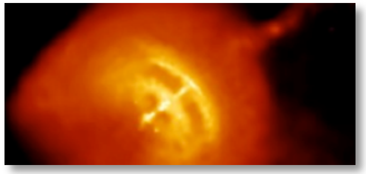






Overview of this presentation

- ET – the start of Gravitational Wave Astronomy



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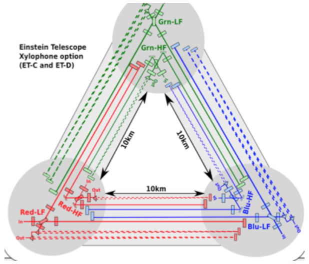
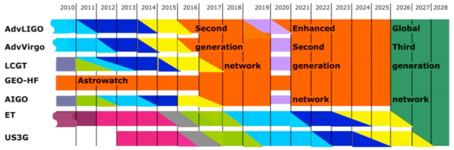
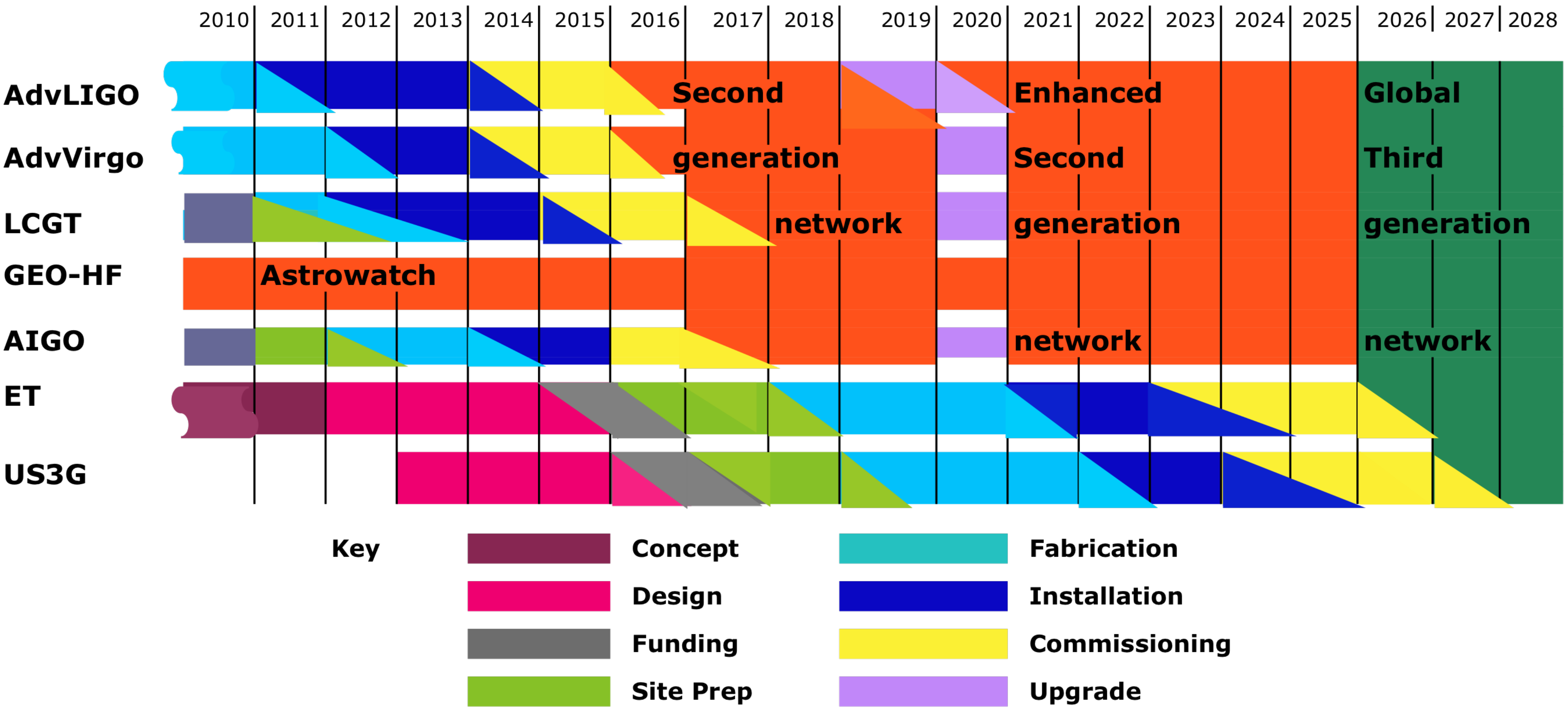


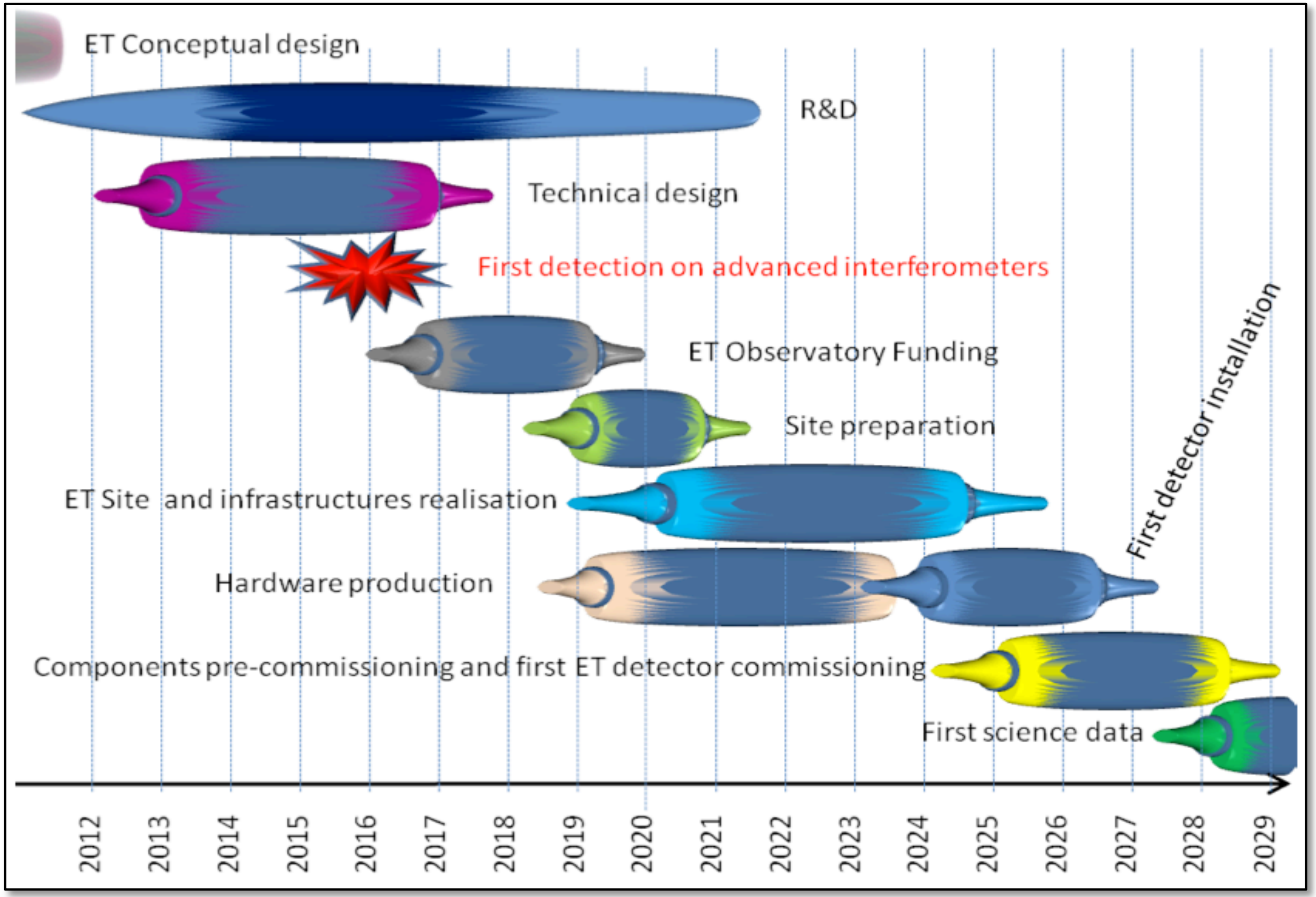
- Time line towards the Einstein Telescope



Time Lines (from GWIC Roadmap)



ET Timeline


ET Conceptual design
R&D
Technical design
First detection on advanced interferometers
ET Observatory Funding
Site preparation
ET Site and infrastructures realisation
Hardware production
First detector installation
Components pre-commissioning and first ET detector commissioning
First science data
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029

ET Conceptual Design

- Conceptual design study is the main deliverable.
- Public presentation of the design study will take place on 20th of May in Pisa, Italy.

Einstein Telescope design study presentation

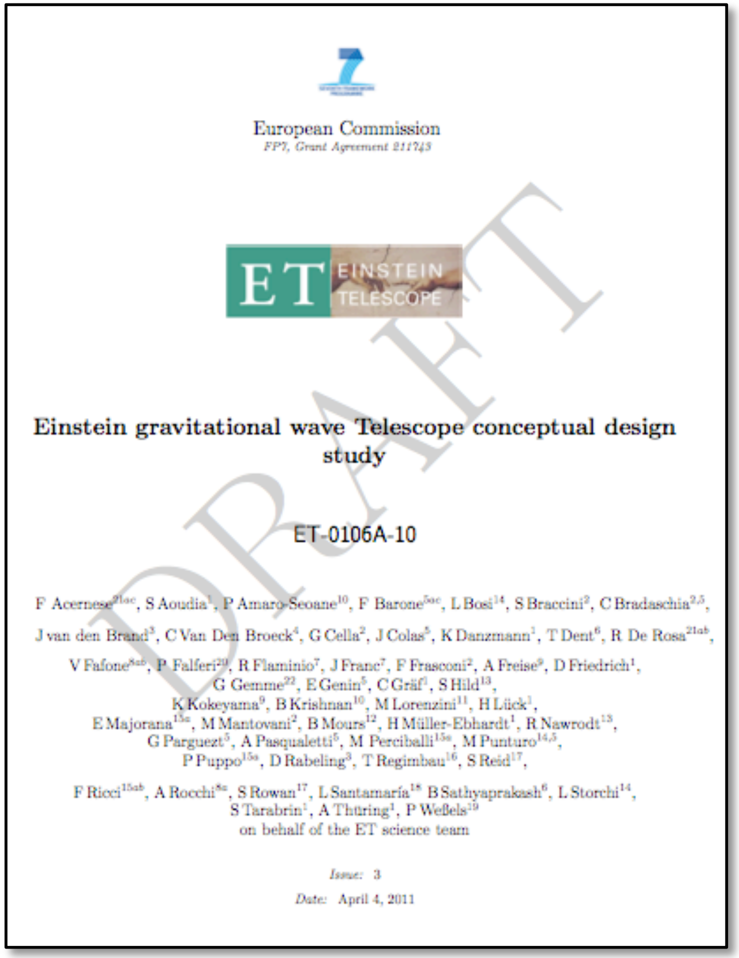
at the European Gravitational Observatory

May, 20th 2011

Cascina (PI) - Italy

Agenda

11:00 Welcome talk
European Gravitational Observatory
Gravitational wave search in Europe and in the World
The Virgo experiment
Visit of the site
13:00 *Lunch*
14:30 Einstein Telescope design study
European Research Infrastructures perspectives
16:00 Conclusion



European Commission
FP7, Grant Agreement 211743

Einstein gravitational wave Telescope conceptual design study

ET-0106A-10

F Acernese[21ac], S Aoudia[1], P Amaro-Seoane[10], F Barone[5ac], L Bosi[14], S Braccini[2], C Bradaschia[2,5],
J van den Brand[3], C Van Den Broeck[4], G Cella[2], J Colas[5], K Danzmann[1], T Dent[6], R De Rosa[21ab],
V Fafone[8ab], P Falferi[20], R Flaminio[7], J Franc[7], F Frasconi[2], A Freise[9], D Friedrich[1],
G Gemme[22], E Genin[5], C Gräf[1], S Hild[13],
K Kokeyama[9], B Krishnan[10], M Lorenzini[11], H Lück[1],
E Majorana[15a], M Mantovani[2], B Mours[12], H Müller-Ebhardt[1], R Nawrodt[13],
G Parguezt[5], A Pasqualetti[5], M Perciballi[15a], M Punturo[14,5],
P Puppo[15a], D Rabeling[3], T Regimbau[16], S Reid[17],
F Ricci[15ab], A Rocchi[8a], S Rowan[17], L Santamaría[18] B Sathyaprakash[6], L Storchi[14],
S Tarabrin[1], A Thüring[1], P Weßels[19]
on behalf of the ET science team

Issue: 3

Date: April 4, 2011

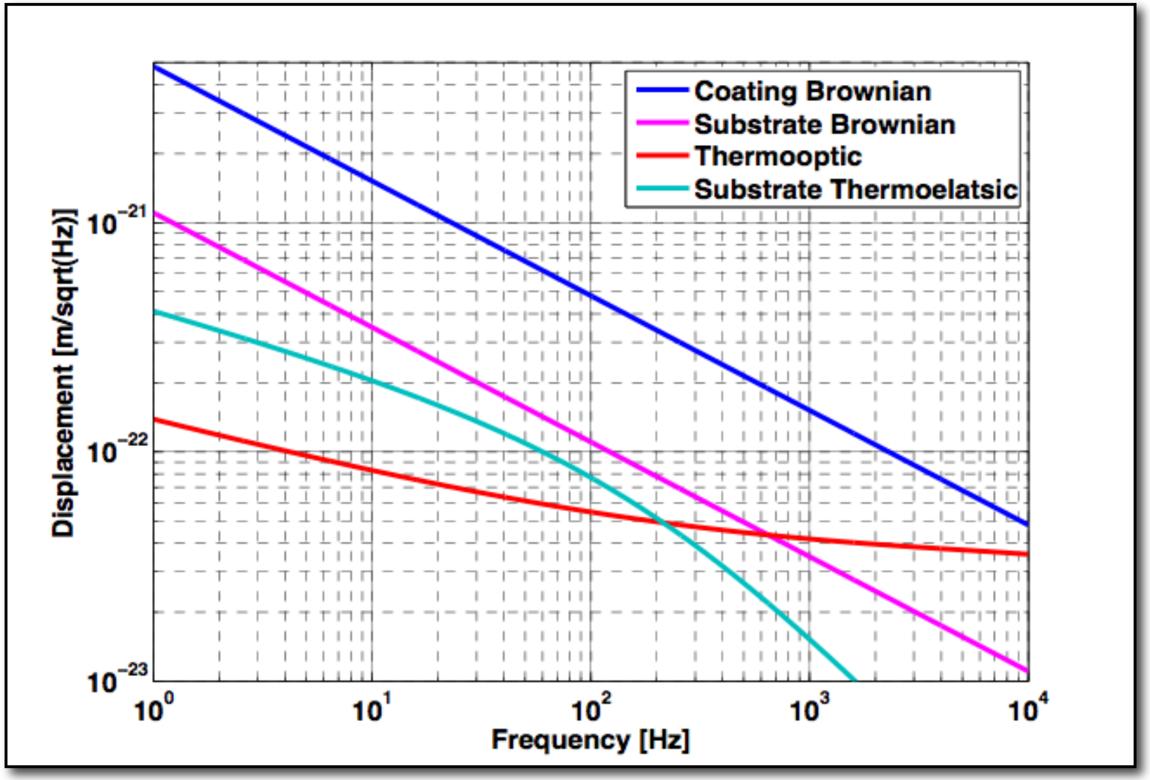
Summary

- 2nd generation GW detectors will make the first direct detection of gravitational waves. With ET will provide us with frequent high-SNR events and therefore mark the start of gravitational wave astronomy.
- ET can provide lots of exciting science in the fields of astrophysics, fundamental physics and cosmology.
- We identified the best technologies for reaching the very demanding sensitivity target of ET and are about to complete the conceptual design.
- Build up a very strong Science Team working on ET.
- Next steps include:
  - Side identification (long term seismic measurements and discussions with national funding agencies).
  - Lots of R+D (e.g. materials, interferometry, lasers, cryogenics) to support the transition from the conceptual to the technical design stage.

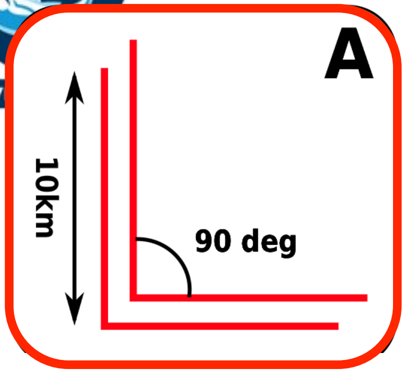
EXTRA SLIDES

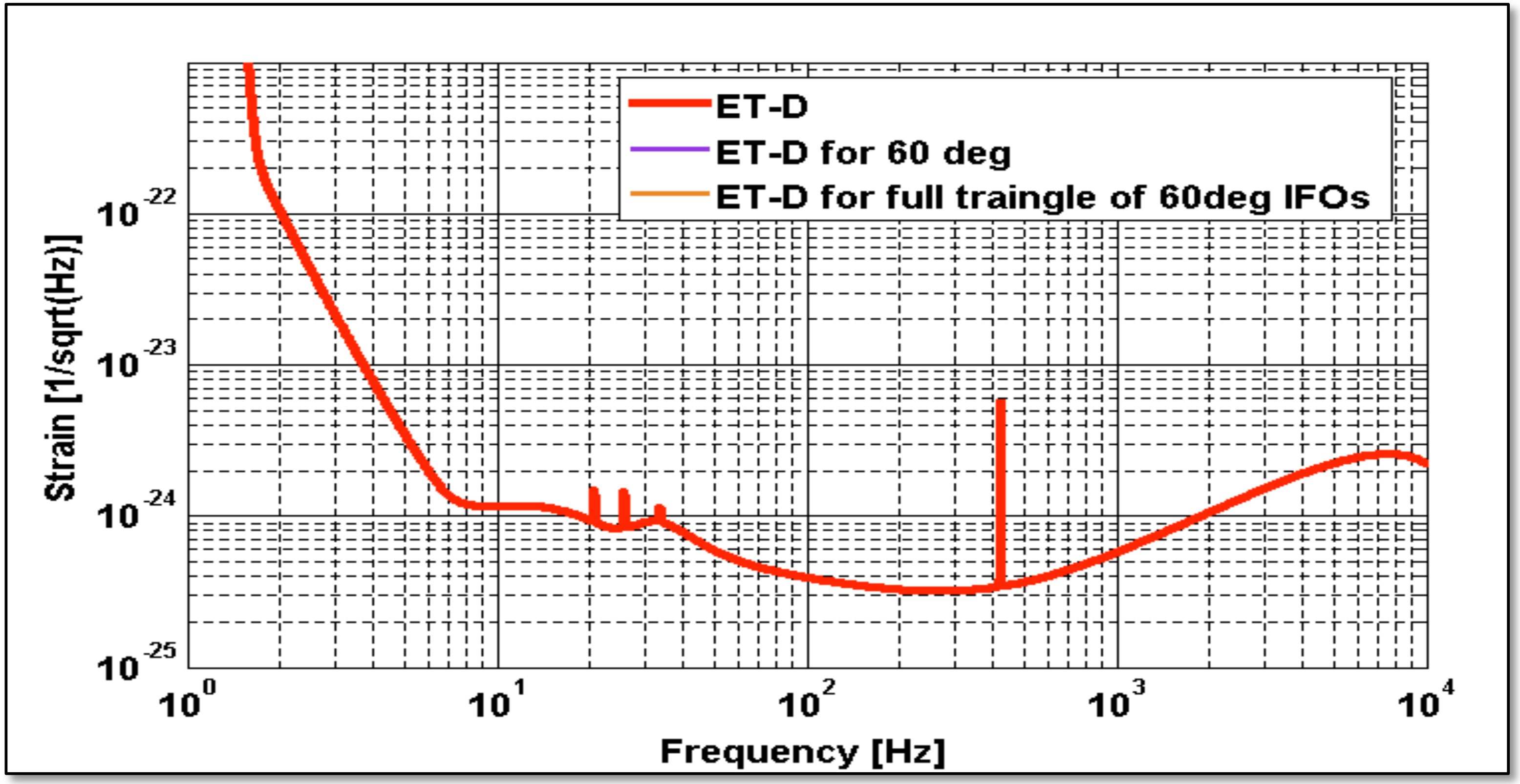
LF-Detector: Cryogenic Test masses

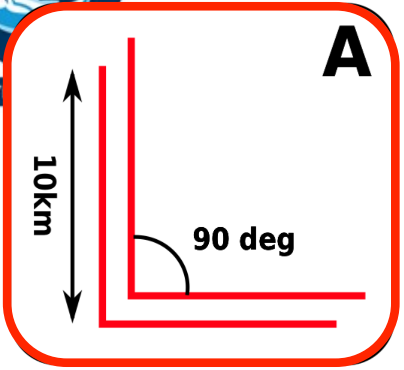
- Thermal noise of a single cryogenic end test mass.
- Assumptions:
  - Silicon at 10K
  - Youngs Modulus = 164GP
  - Coating material similar to what is currently available for fused silica at 290K (loss angles of 5e-5 and 2e-4 for low and high refractive materials)

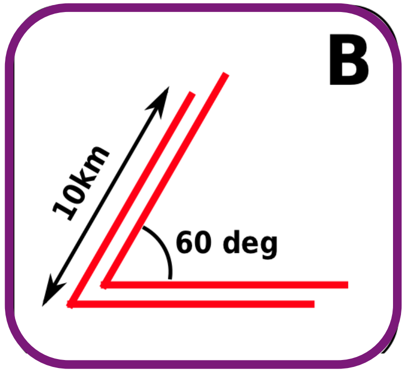


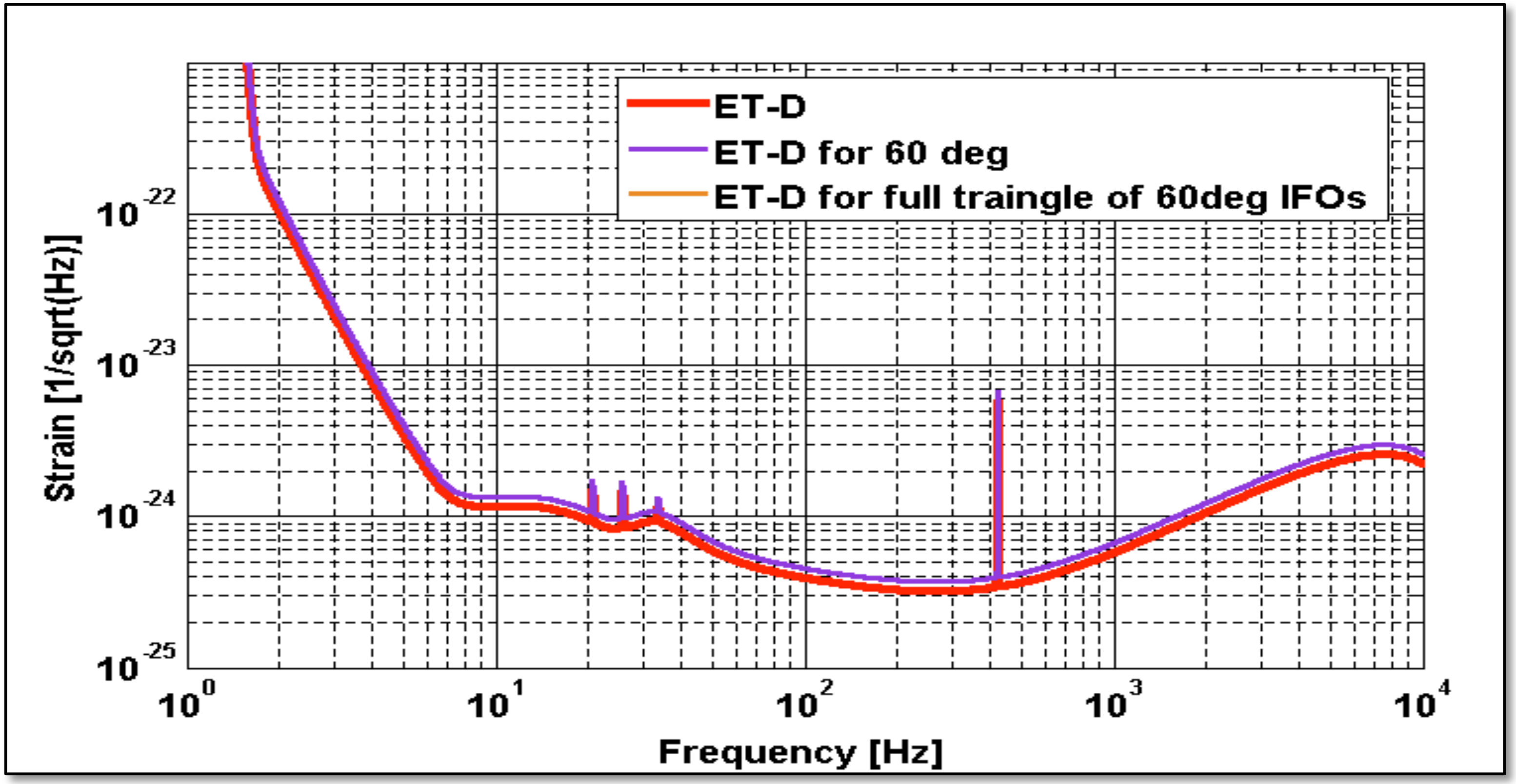
How to get from here to total mirror TN in ET?
- Sum over the 4 different noise types.
- Go from displacement to strain (divide by 10000).
- Uncorrelated sum of 2 end mirrors and 2 input mirrors


A
10km
90 deg

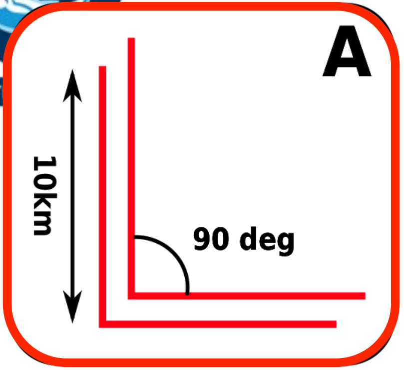

ET-D
ET-D for 60 deg
ET-D for full traingle of 60deg IFOs
Strain [1/sqrt(Hz)]
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
Frequency [Hz]

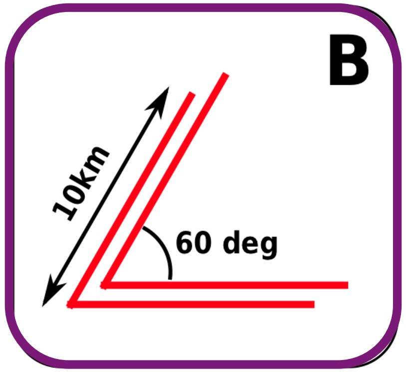


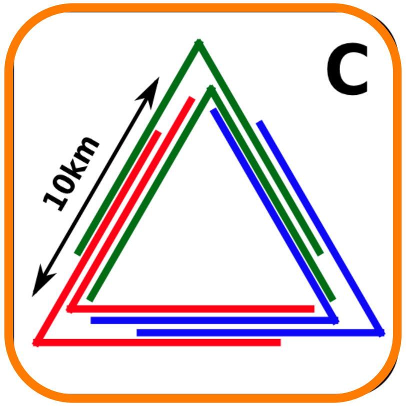


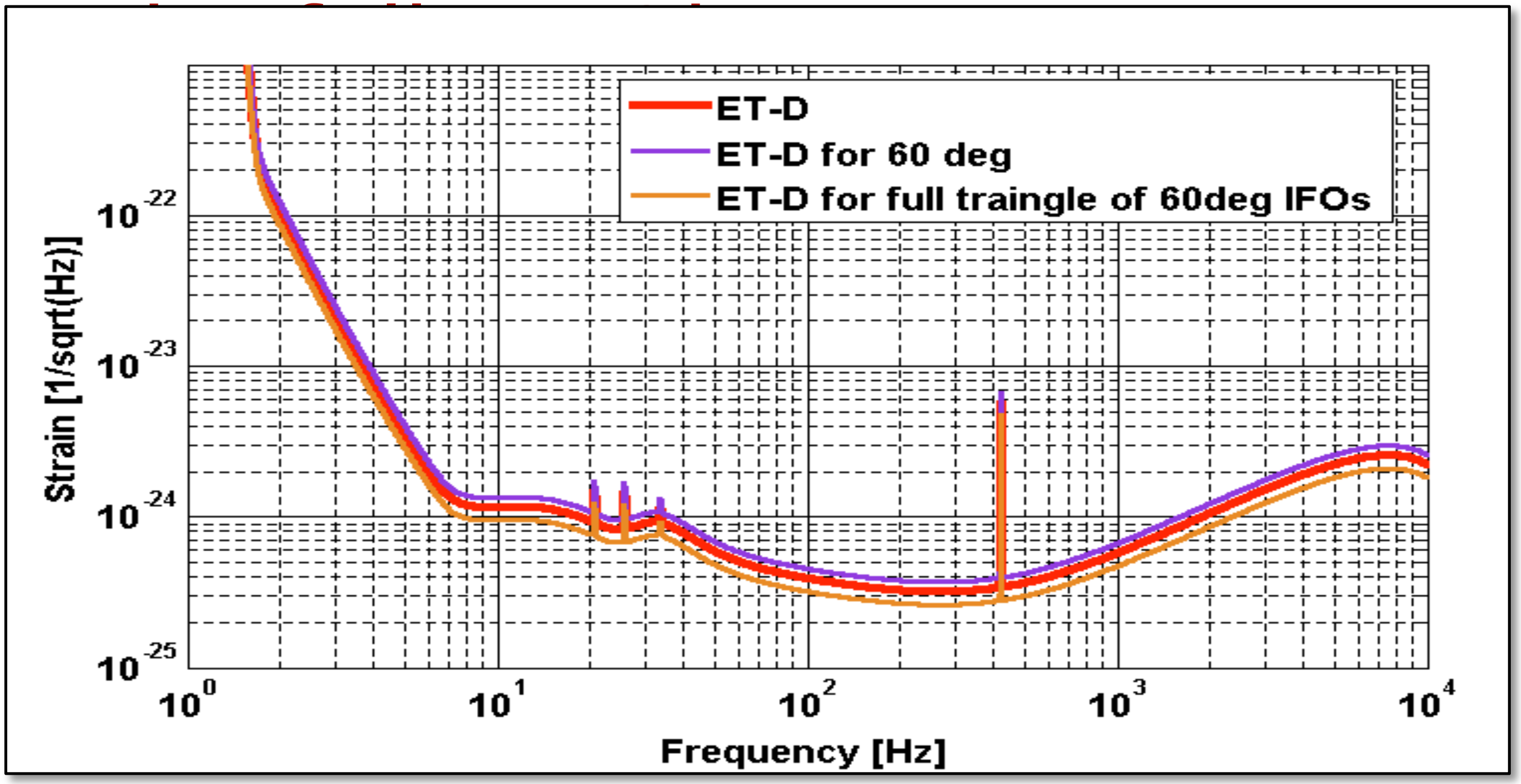


$$h(f)_{60} = \frac{1}{\sin(60^{\circ})} \times h(f)_{90} = 1.155 \times h(f)_{90},$$





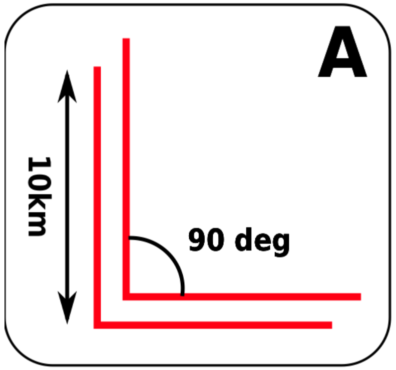


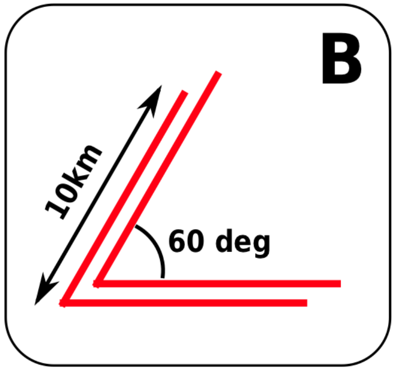


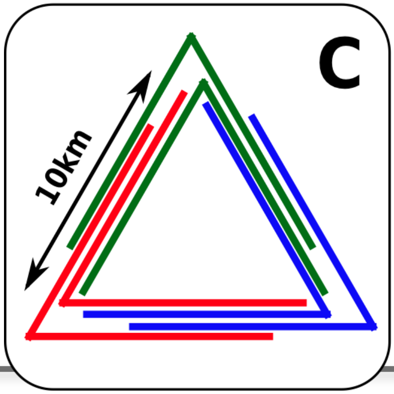
$$h(f)_{60} = \frac{1}{\sin(60^\circ)} \times h(f)_{90} = 1.155 \times h(f)_{90},$$

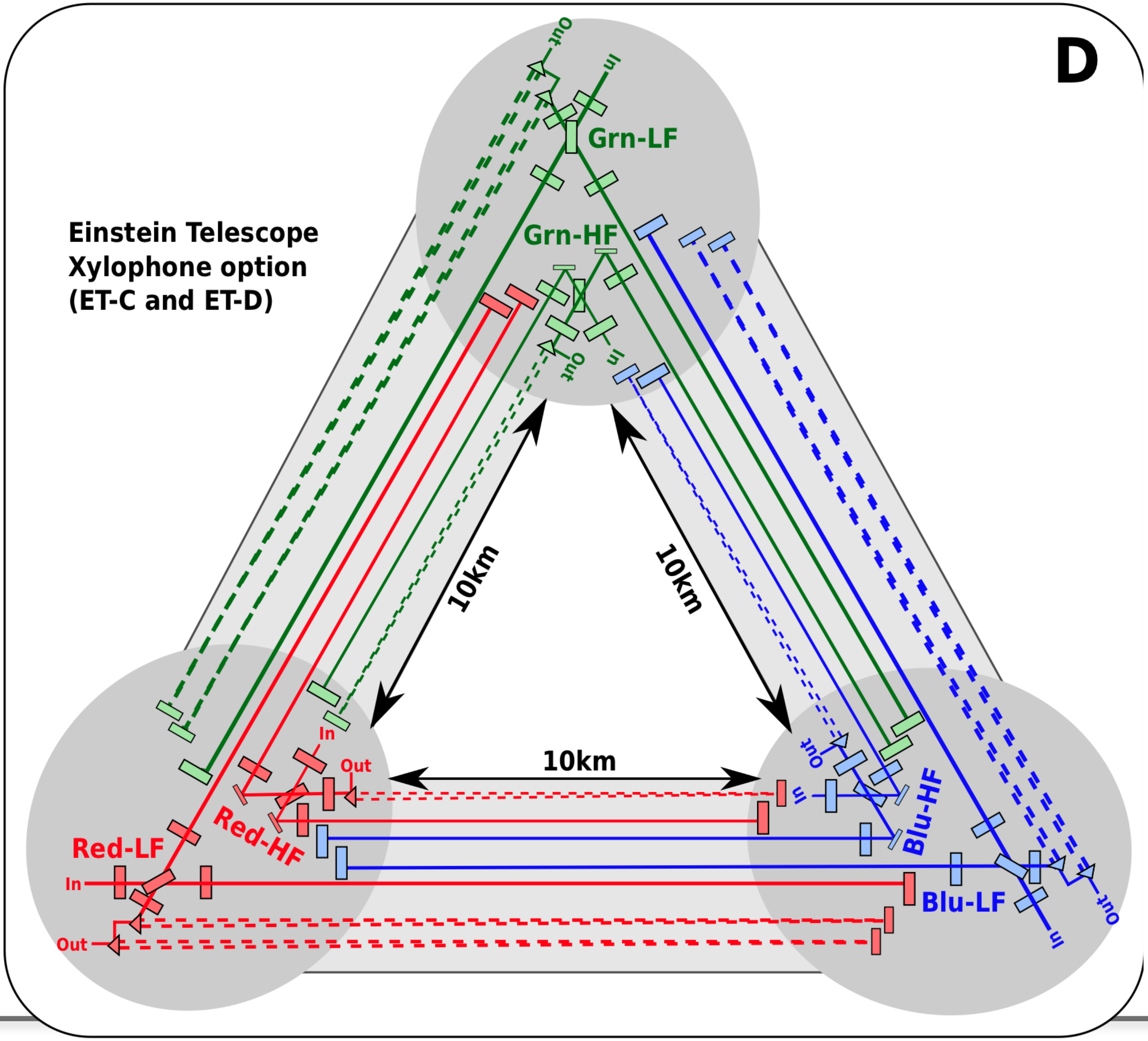
$$h(f)_{\Delta} = \frac{1}{\sqrt{(\sin(60^\circ))^2 + (\sin(60^\circ))^2}} \times h(f)_{90} = 0.816 \times h(f)_{90},$$

The full ET Observatory



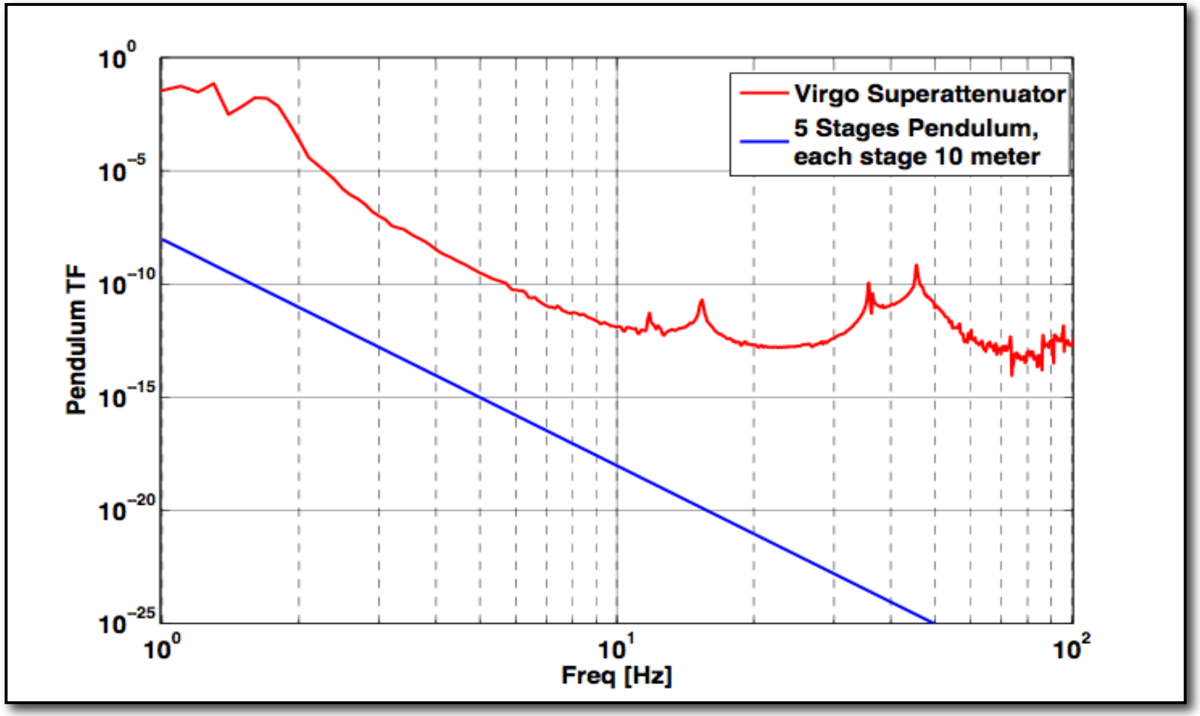




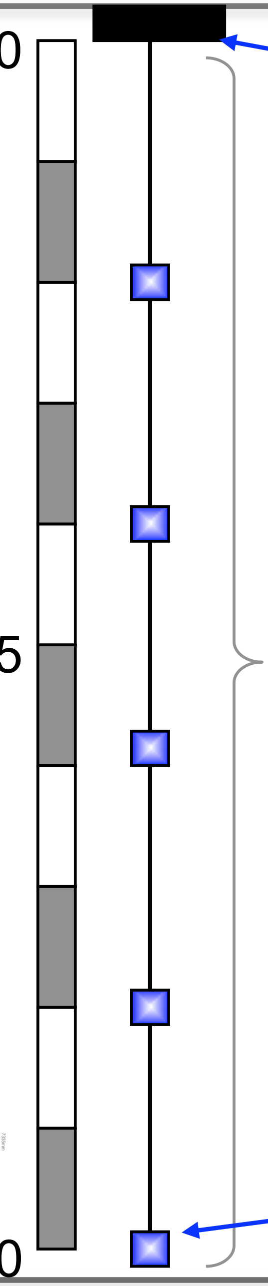


Einstein Telescope
Xylophone option
(ET-C and ET-D)

Seismic Isolation / Suspension



SA-data: G.Ballardin et al, Rev. Sci. Instrum., Vol.72, No.9 (2001)



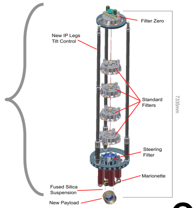
Suspension point

5 Stages of each 10 m height

corner freq = 0.158Hz

Main test mass

Virgo Superattenuator (height ~ 8 meter)



Is there any chance to substract the gravity gradient noise?

- Theoretically = YES.
- If it is possible to determine the seismic ‘all around’ the test masses and the corresponding coupling transfer functions to a certain accuracy it should be possible to subtract gravity gradient noise from h(t).
- This would require a big 3D array of seismometers, very homogenous rock, etc
- Has never been done … work in progress (and probably our only chance to get to the ET target sensitivity below about 2-3Hz).