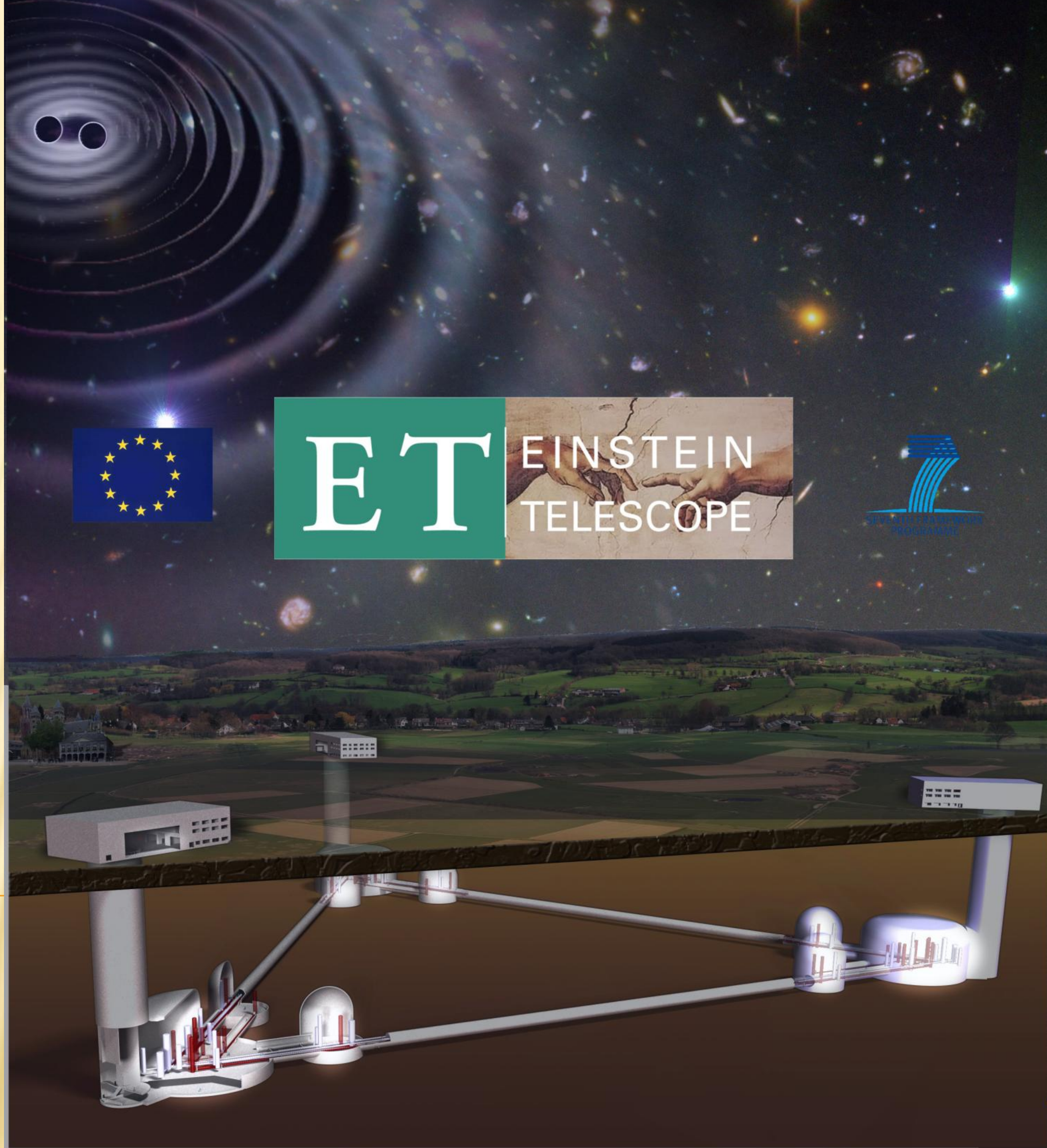
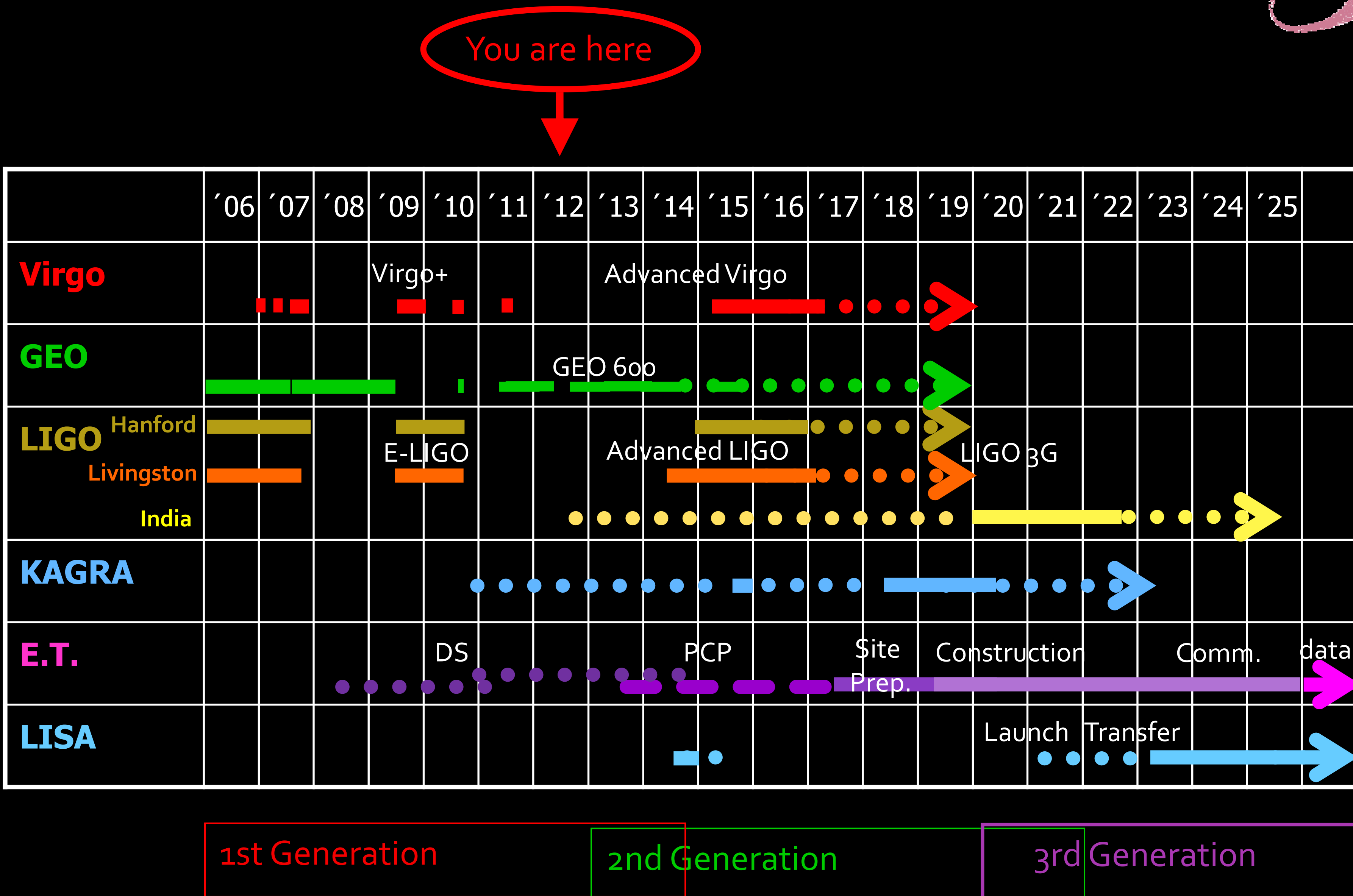
Harald Lück
AEI Hannover

RECENT R&D FOR ET



LIGO-G1200578-v1

GW Timelines



ET COMMUNITY

- Had large Science Team in DS phase
- Trying to bridge gap to Technical Design Phase
- Networking:
  - Through ASPERA common call (funding 2013)
  - Through ELITES

Most of R&D presented at this meeting is relevant for baseline or future ET

ELITES

ET- LCGT TELESCOPES EXCHANGE OF SCIENTISTS
FP7-PEOPLE-2011-IRSES

- Framework Programme 7 of the EU
- People Programme
- International Research Staff Exchange Scheme (IRSES)
- March 2012 – Feb. 2016

PARTICIPANTS

- EGO, Cascina
- University of Tokyo
- University la Sapienza, Roma
- Uni Sannio
- FSU, Jena
- MPG – AEI, Hannover
- Uni Glasgow
- University of the West of Scotland
- FOM, NIKHEF, Amsterdam

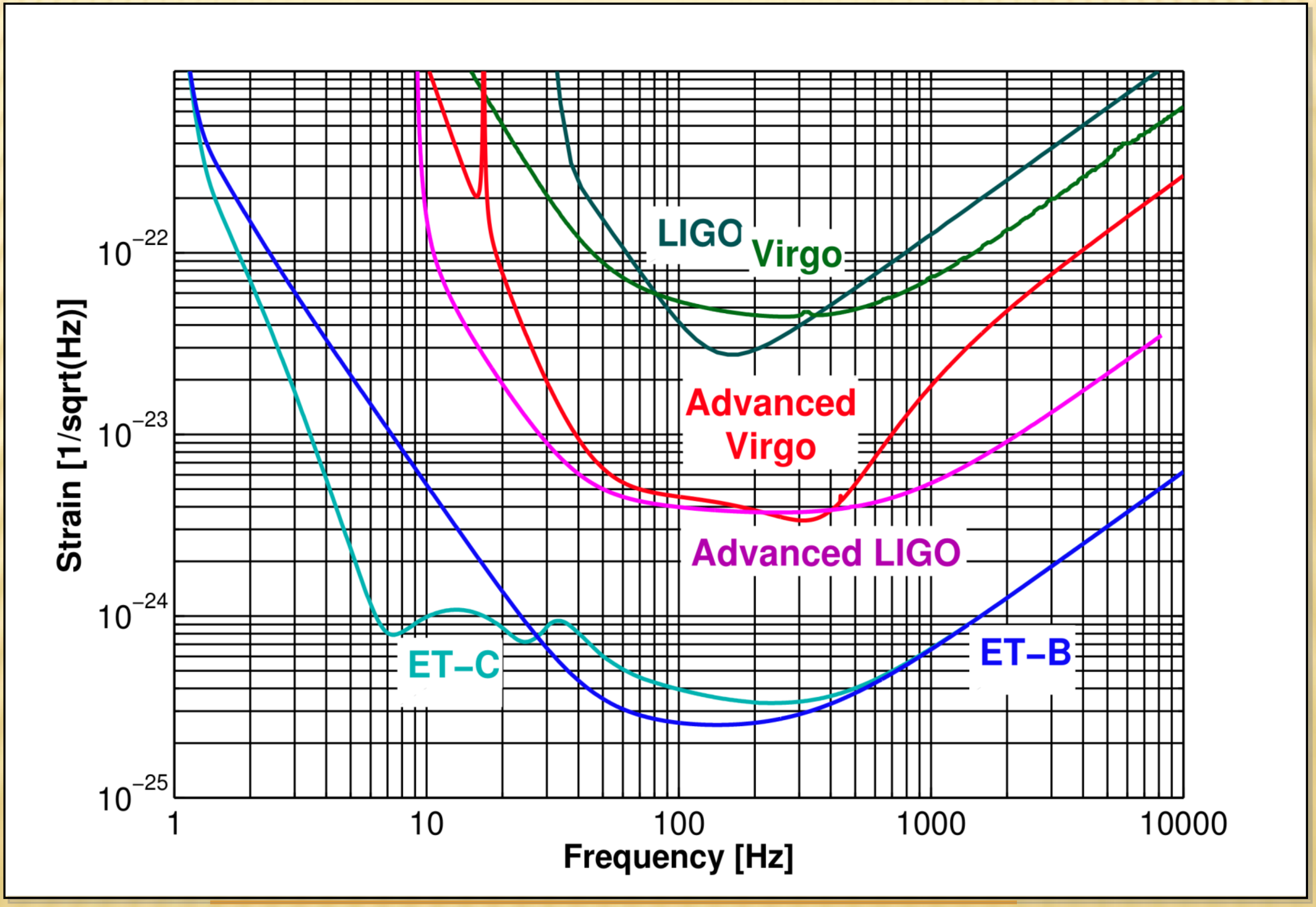
ELITES WORKING PACKAGES

- WP1
  - Cryogenics and suspensions (E. Majorana)
- WP2
  - Mirror thermal noise and cryogenics (R. Nawrodt)
- WP3
  - Large-scale cryogenic infrastructure for LCGT and ET (K. Somiya)

EINSTEIN TELESCOPE

ELITES MEETING HERE @ GWADW

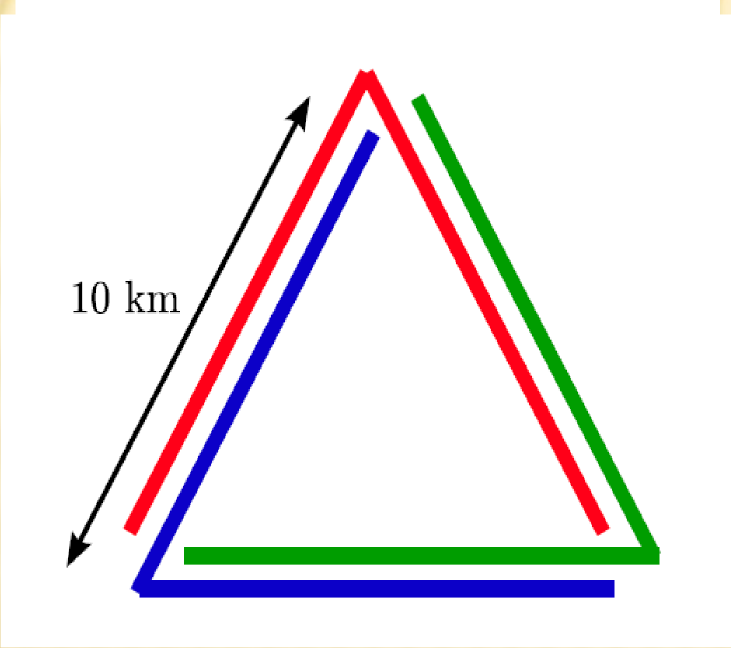
THE GOAL

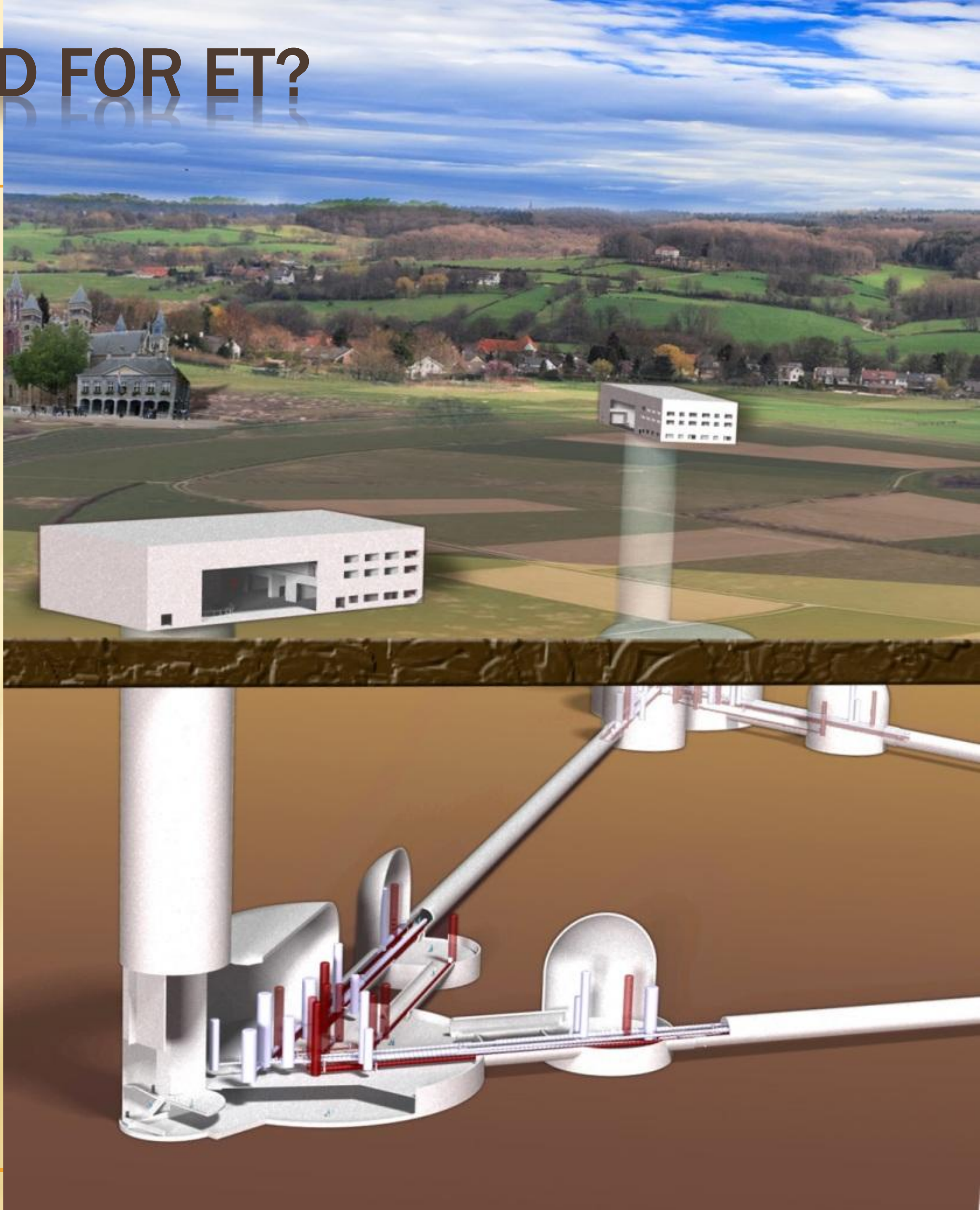


LIGO
Virgo
Advanced
Virgo
Advanced LIGO
ET–C
ET–B
10^{-22}
10^{-23}
10^{-24}
10^{-25}
Strain [1/sqrt(Hz)]
1
10
100
1000
10000
Frequency [Hz]

WHAT DO WE NEED FOR ET? BASIC ET FACTS

- long lasting (decades) infrastructure
- 10km Δ (<displ. Noise)
- 100-200m underground
- „conservative“ design
- Subsequent upgrades to novel techniques





WHAT DO WE NEED FOR ET? BASIC ET FACTS

- long lasting (decades) infrastructure
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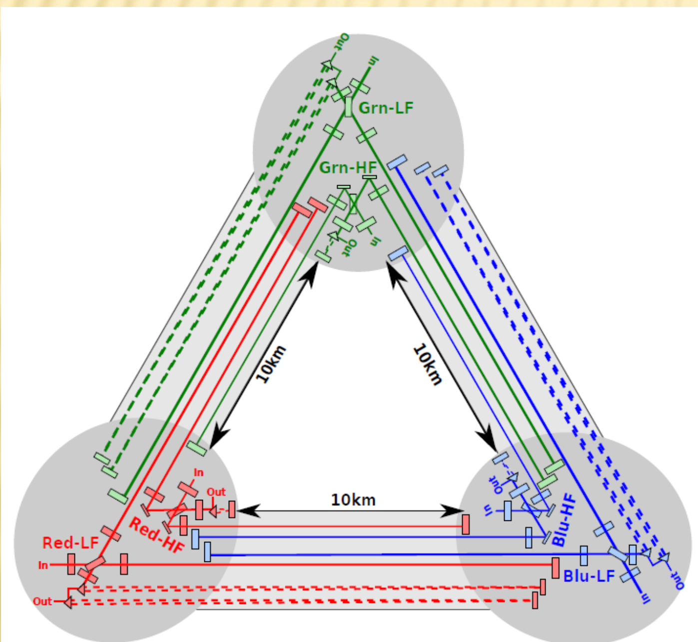
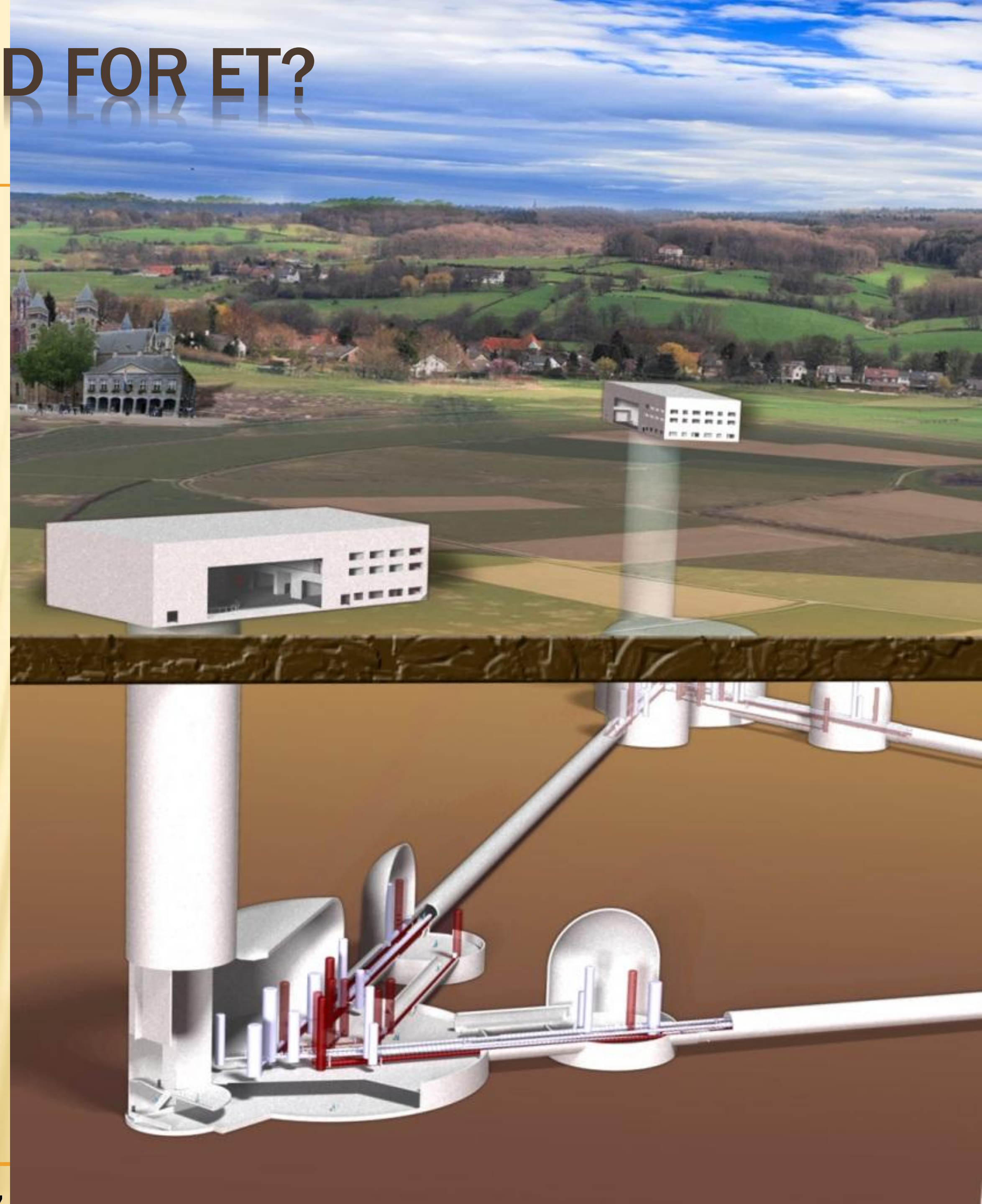




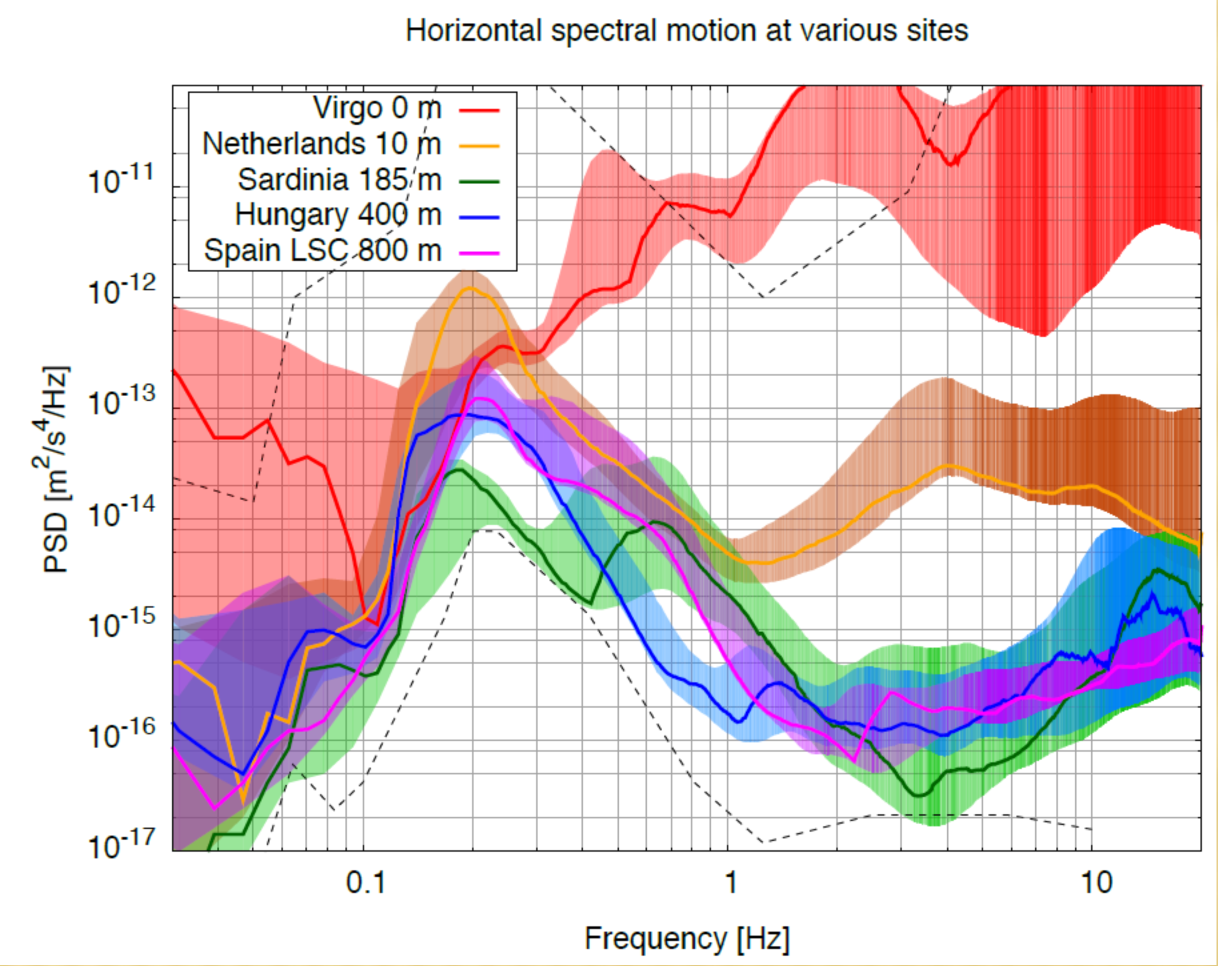
WE NEED A GOOD LOCATION

- Snapshots of seismic motion

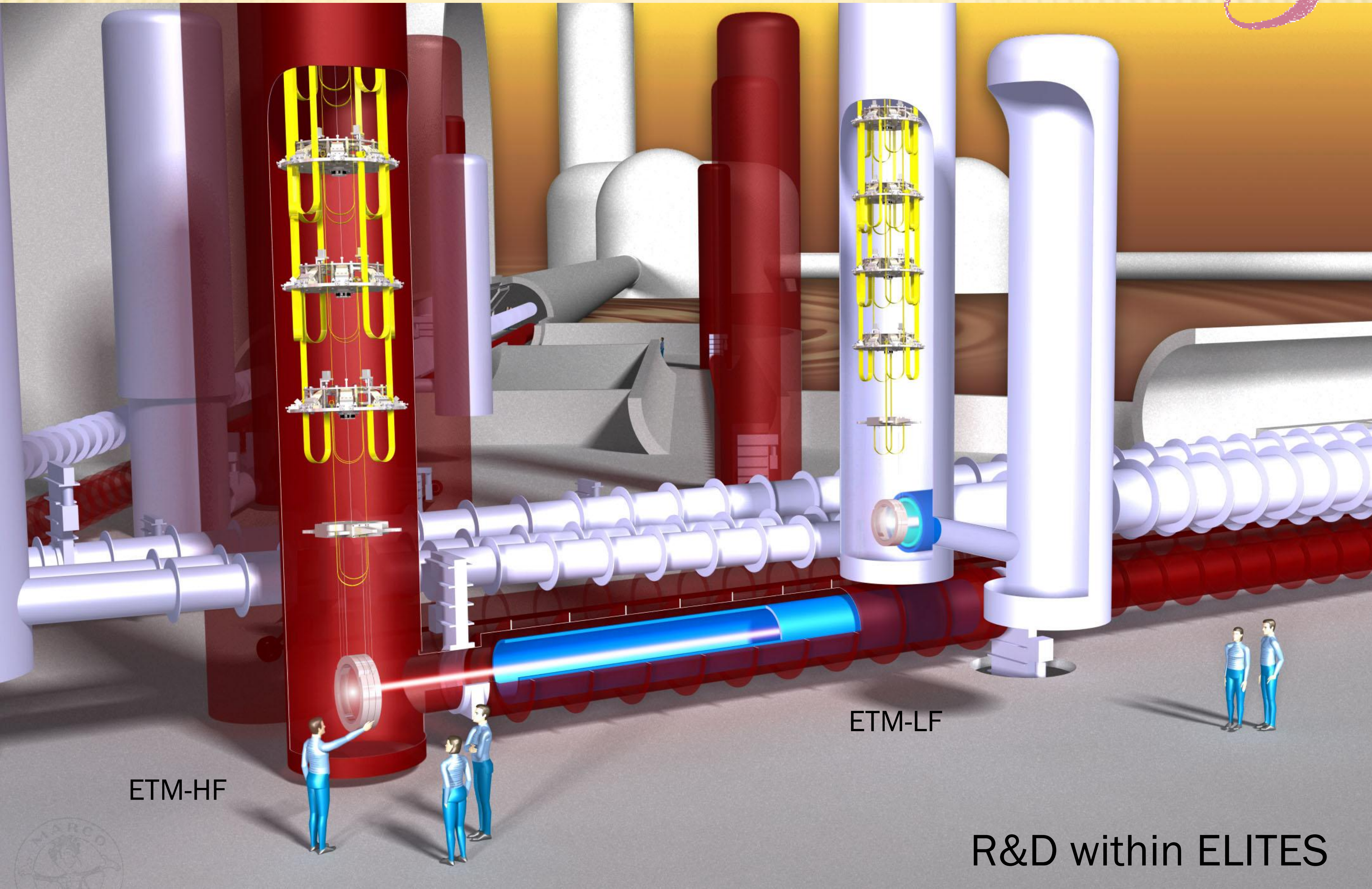
One-week spectral variation results of four European sites in comparison to Virgo

We need to include seasonal variations

No news yet. To be picked up soon by NIKHEF.

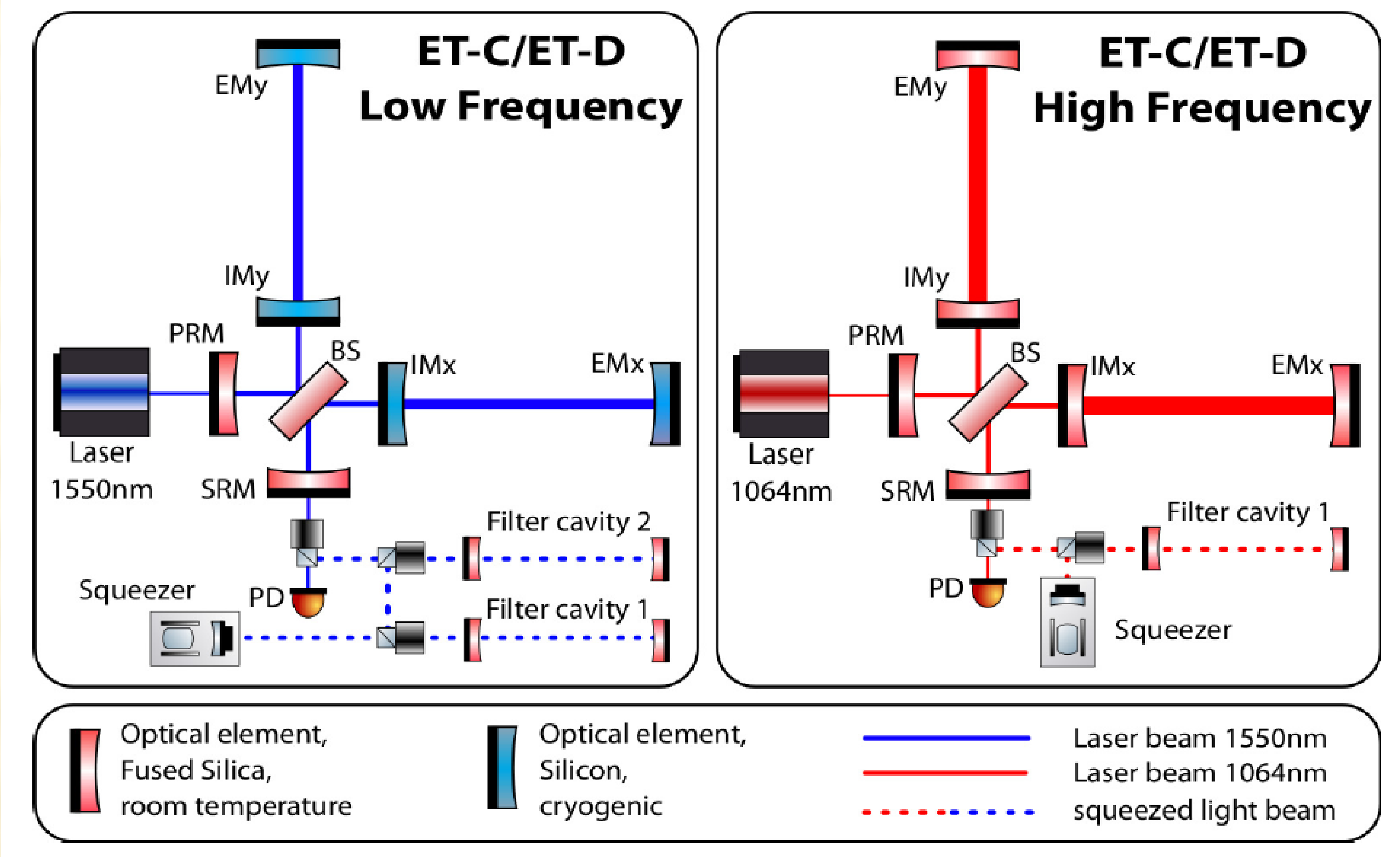


SUSPENSIONS

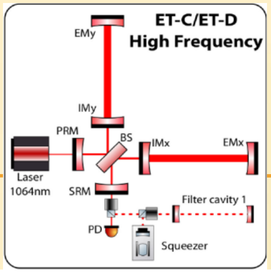


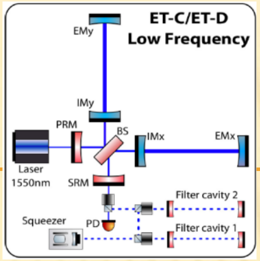
R&D within ELITES

XYLOPHONE STRATEGY



ET PARAMETER

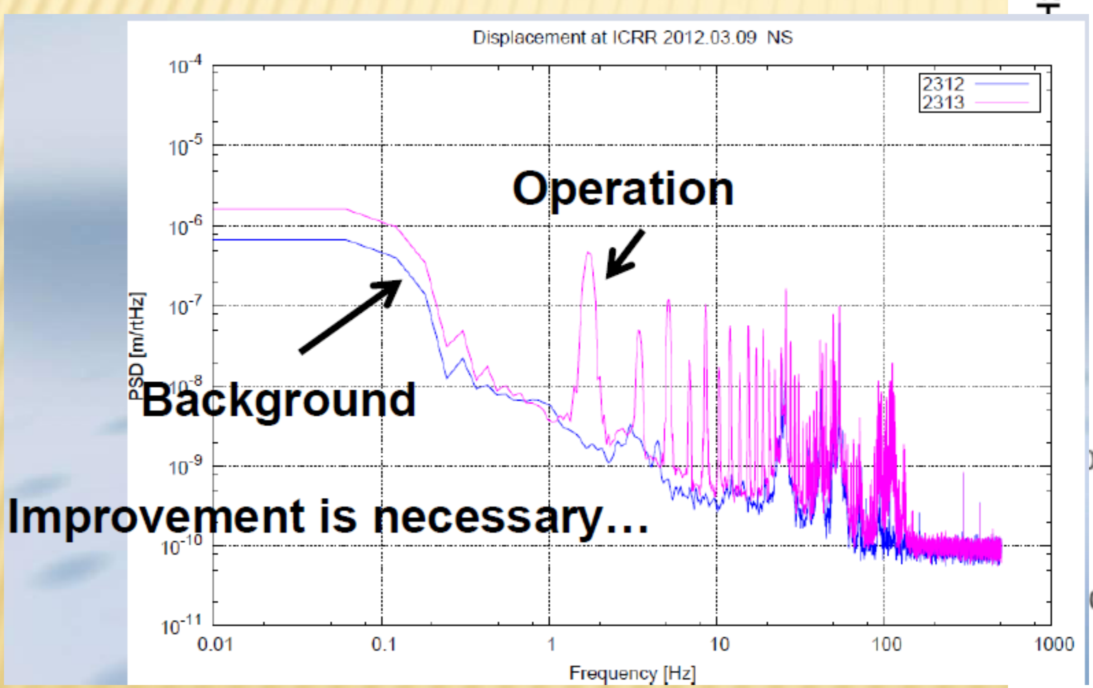




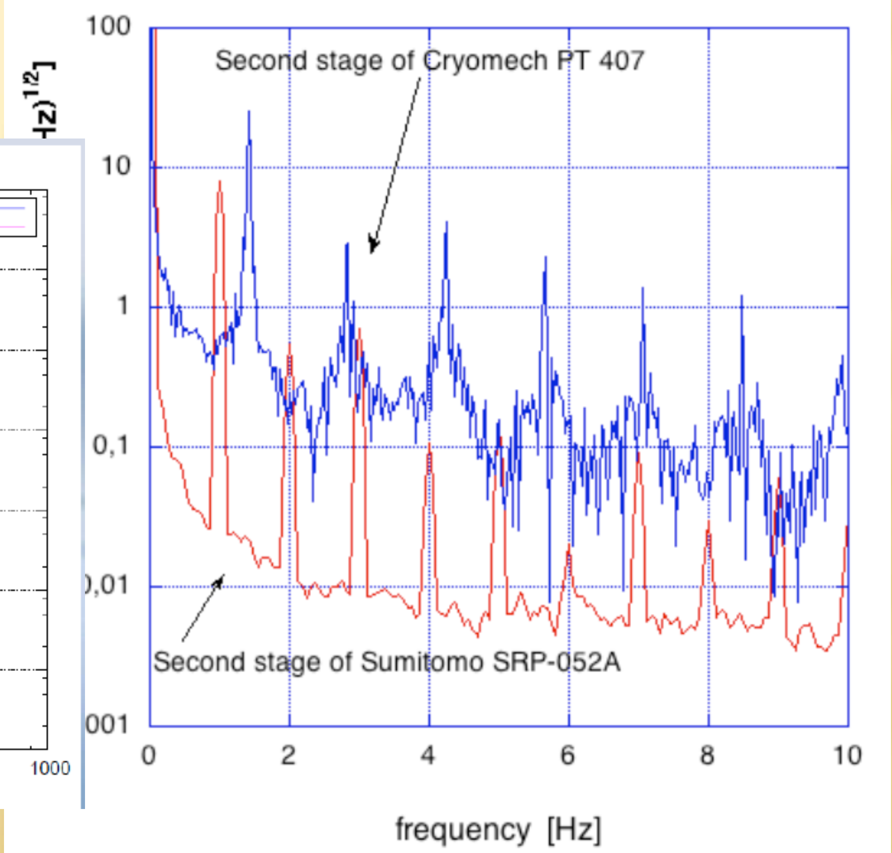
Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ T
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	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
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

WE NEED TO KEEP THE ENVIRONMENT & THE TEST MASSES QUIET

- Pulse tube coolers pulse
  →ELITES



Kazuhiro Yamamoto, this meeting



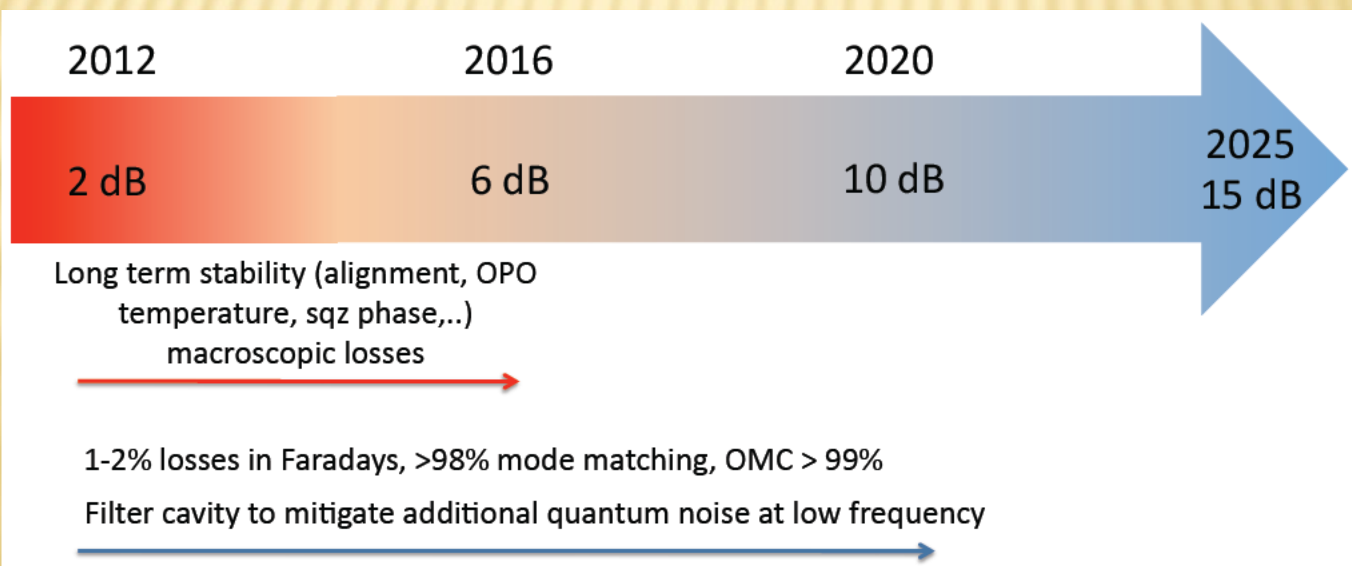
ET DS

LASER

- 1064 nm need 500W@IMC for ET HF
  - aLIGO laser 200W
  - >150 W fibre amplifier
- 1550 nm ok for ET LF
  - 50W TEM00 fibre laser
- Currently AEI laser team focusses on aLIGO laser

SQUEEZING

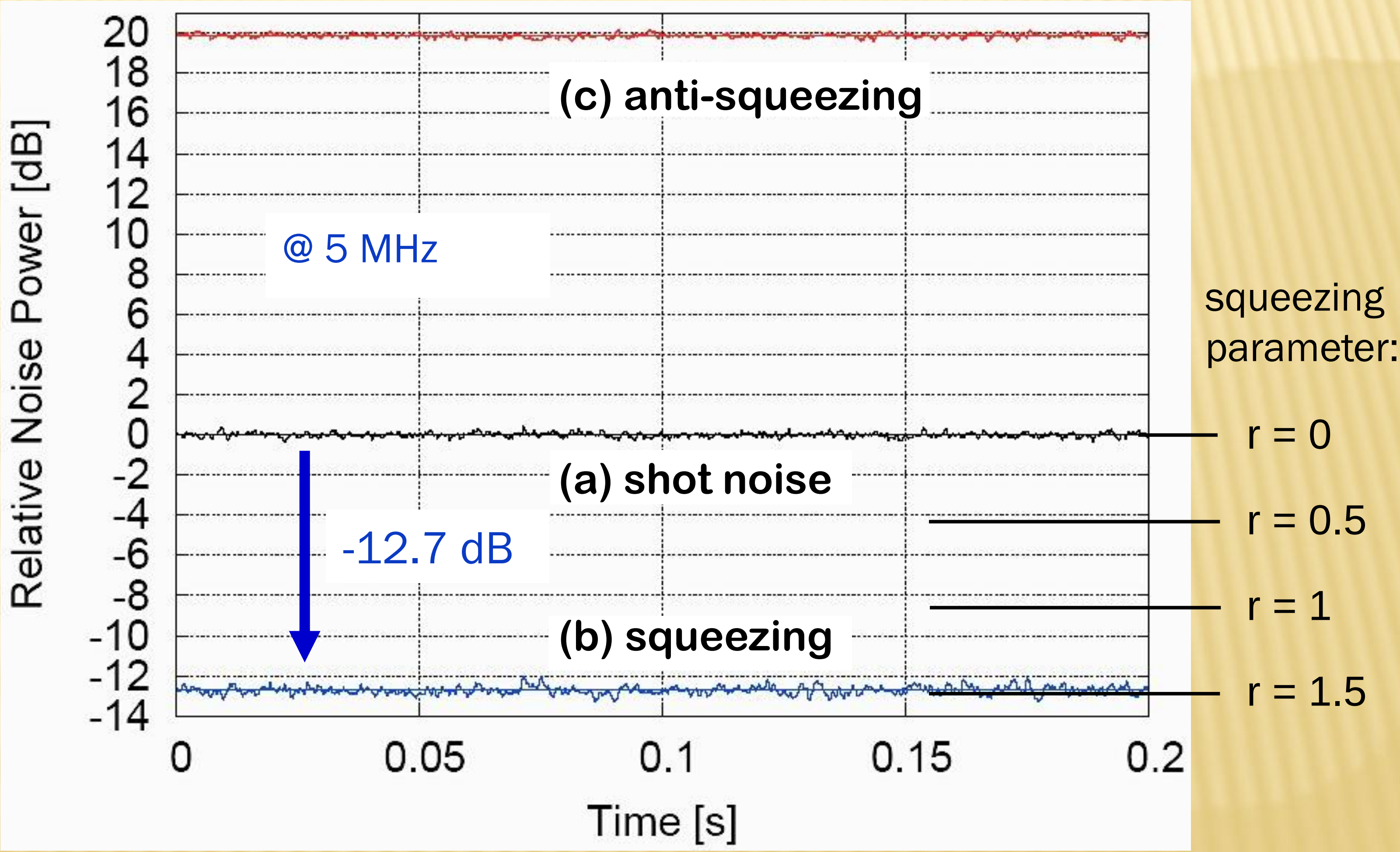
- We have got ~13dB (@5MHz)
- We need more
  ET goal: effective 10dB squeezing
- e.g. 15dB squeezing & 7% total losses
- A matter of optical losses; very challenging



Lisa Barsotti
LIGO- G1200571

12.7 DB @1064 NM / TIME SERIES

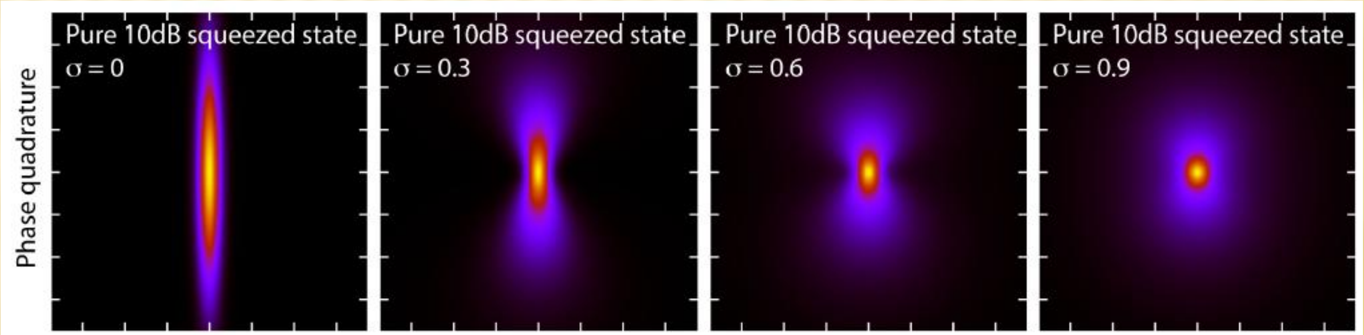
Slide from Roman Schnabel this workshop



[T. Eberle *et al.*, PRL **104**, 251102 (2010)]

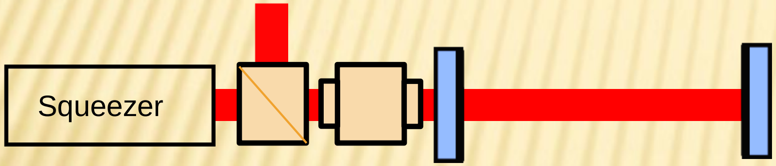
FILTER CAVITIES

- What is the optimal length?
  - Costs vs. Optical performance
  - What are realistic optical losses
- Control of filter cavities
  - Robust control
  - Low phase noise

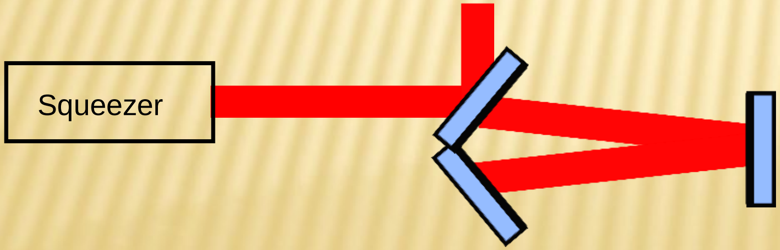


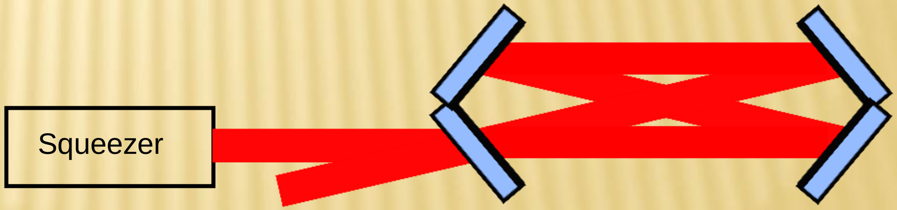
FILTER CAVITIES

- Allowable loss budget given by squeezing goal
- Optical arrangement (linear, triangular, bow-tie)

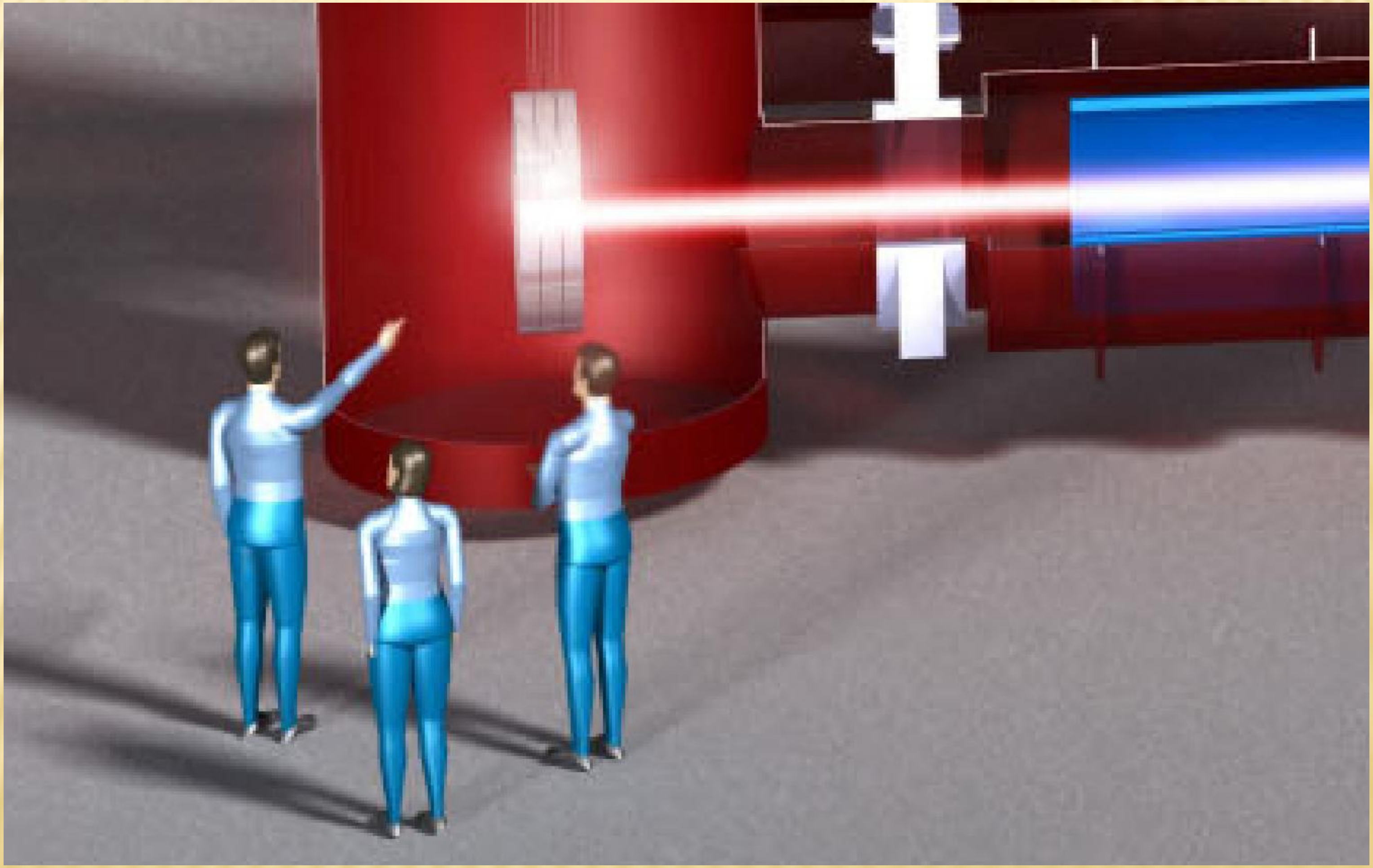


Determined by max. mirror size?





MIRRORS

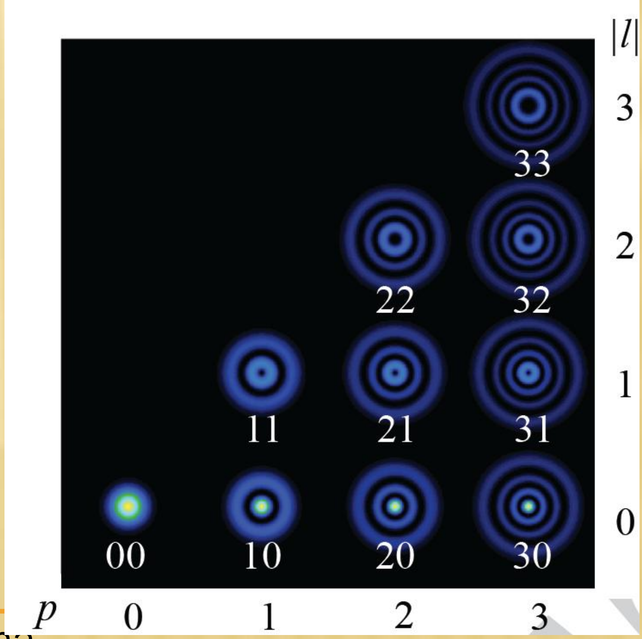


MIRRORS (SURFACE + COATING)

- We need large optics (62cm SiO_2 / 45cm Si)
  - Metrology (machines, self deformation)
  - Polishing (IBF, CC)
  - Large coatings
- We need extremely low optical losses
  - HR absorption fine; but AR absorption, annealing dependent; needs more R&D
  - Surface figure specifications
    - 1D spectra → Zernike polynomials represent needs better

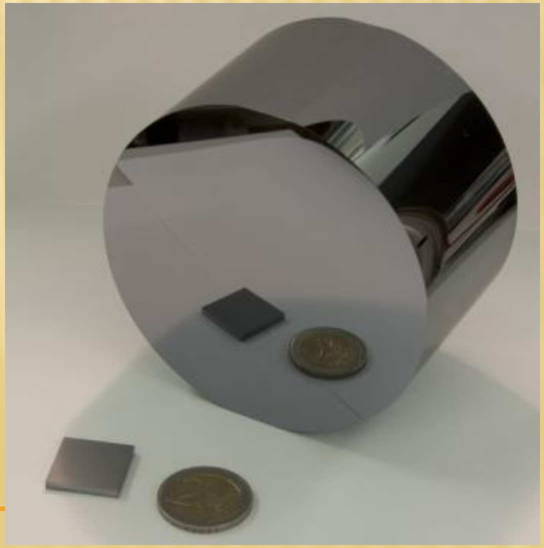
OTHER BEAM GEOMETRIES

- LG33 modes
  - Foreseen for ET HF to cut down Thermal noise
  - Generation √
  - Increases demands on mirror surface figure specs
  - The problem of degeneracy
  - Control issues
  - Alignment requirements



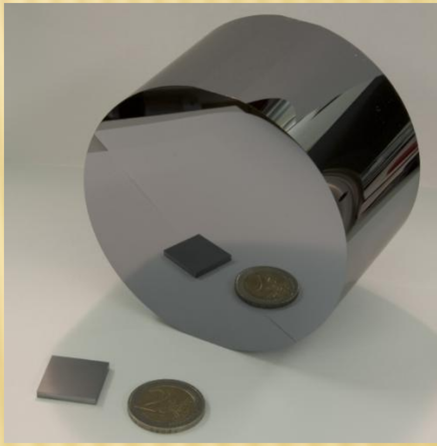
SUBSTRATE MATERIAL

- Silicon is baseline material for ET LF
- Alternatives ?
  - Sapphire: loss peak at low temperatures; optical losses ~10^2x fused silica
  - GaAs: @ cryo T mechanical dissipation induced by illumination with visible light
    200mm ∅ max.



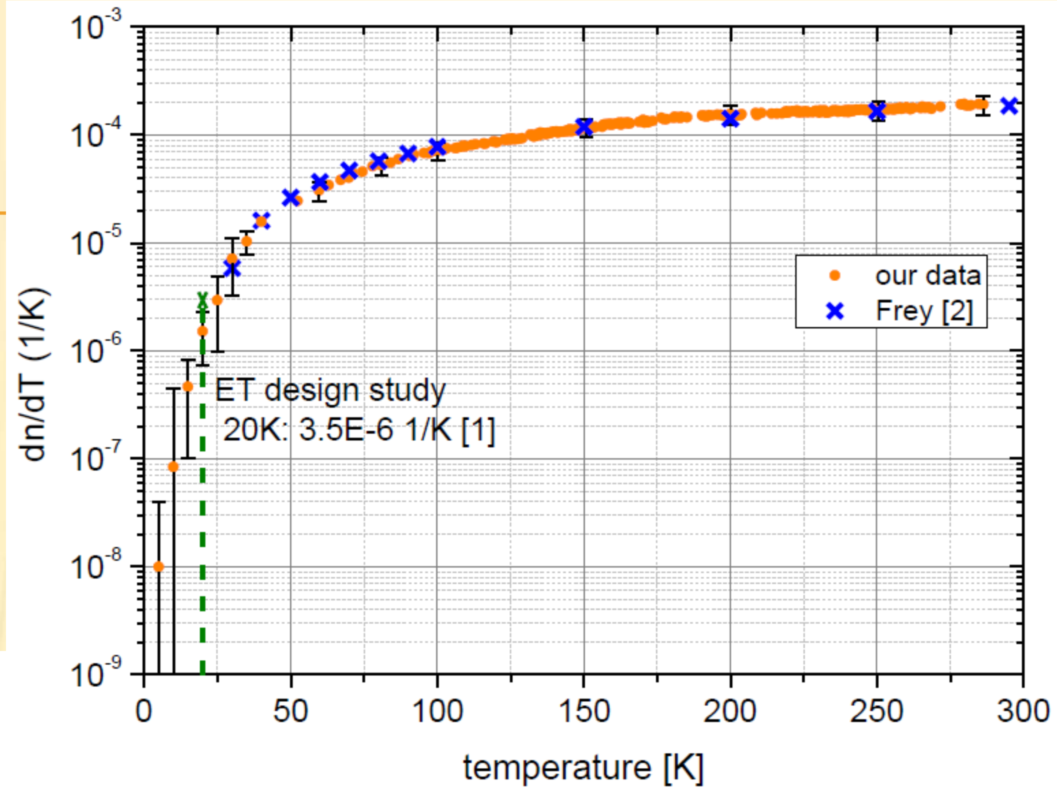
WE NEED TO KNOW MORE ABOUT SILICON @ 10 – 20K

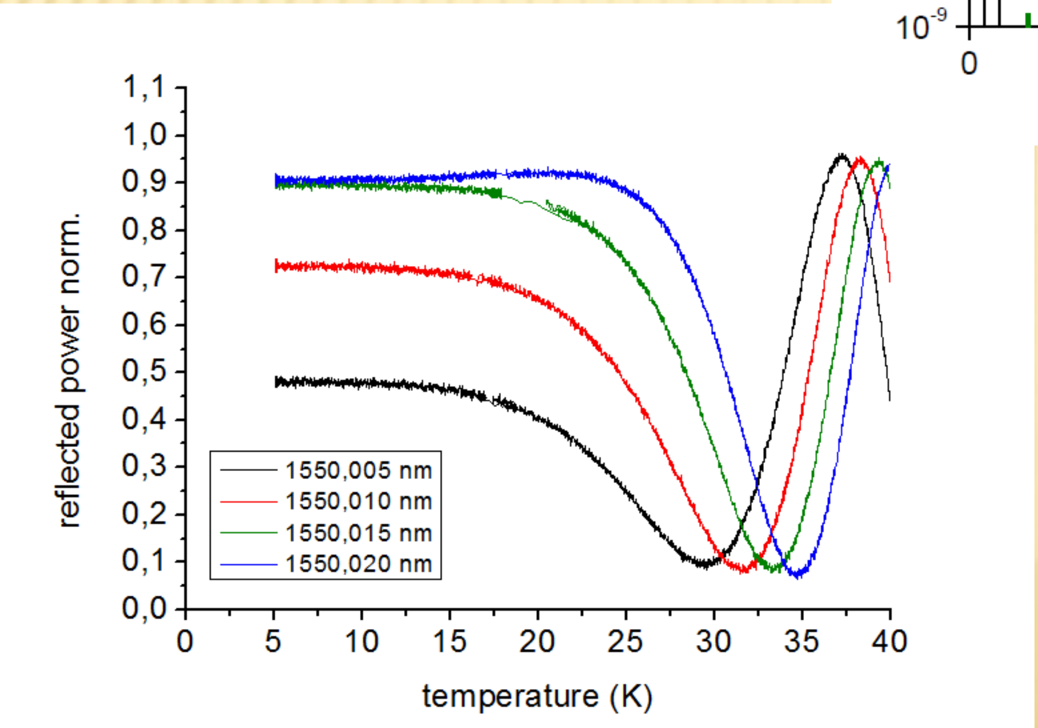
- Optical absorption of Silicon @ 1550nm (Jena, Hannover, Stanford, LMA?)
  - Poor @ 300K (free carriers)
  - TBD @ 10K
- Mechanical dissipation of bulk Silicon
- Thermal and mechanical properties of suspension elements (fibres, bond areas, etc.)
- Coatings for Silicon optics (that work @ 10K)



SILICON dn/dT

FSU Jena



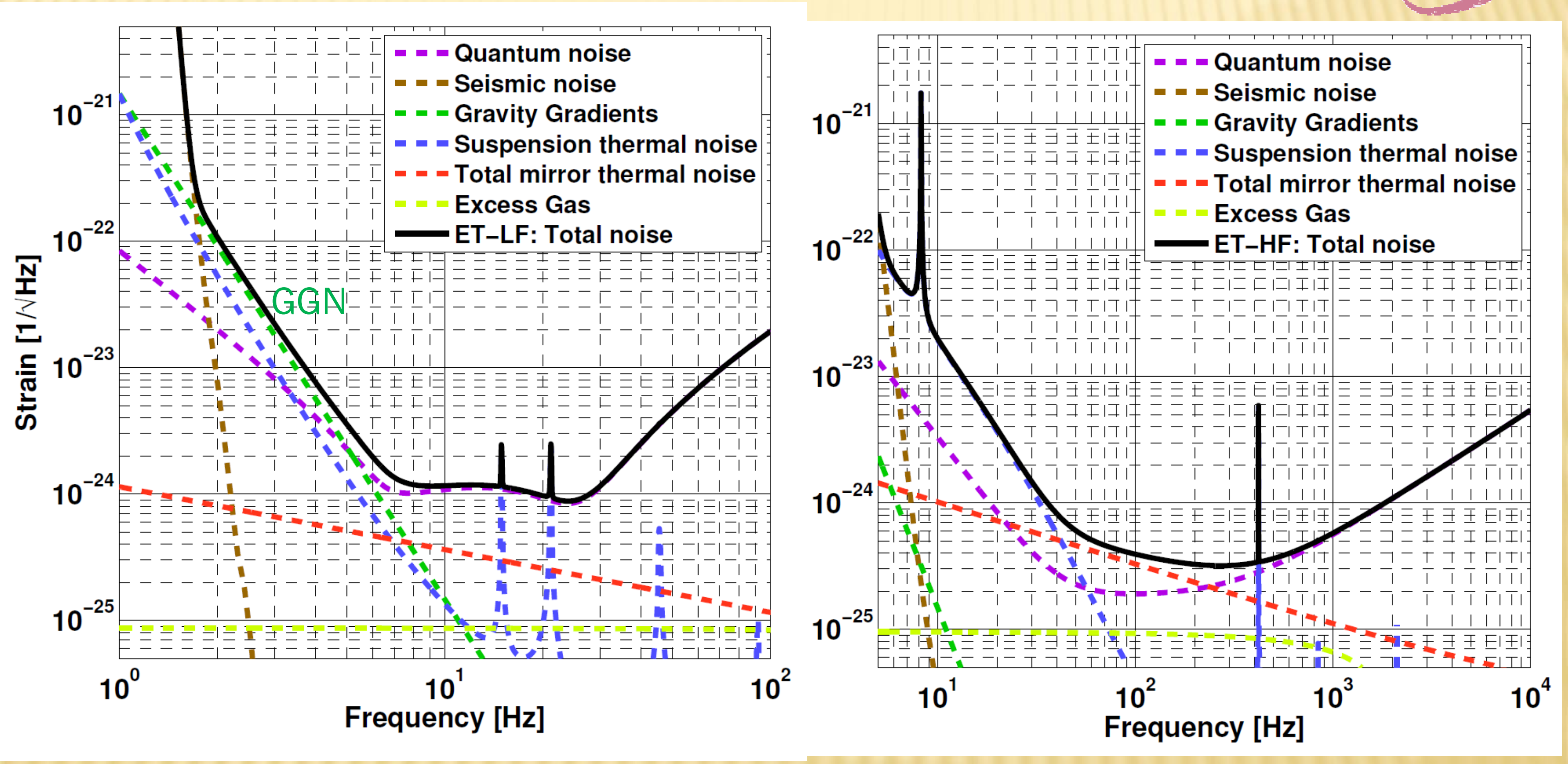


COATINGS

- A „playground for dissipation haters“
  - Default: SiO_2/Ta_5O_2 doped, annealed, optimized,...
  - Alternatives
    - crystalline AlGaAs
    - Amorphous SiO_2/SiO
    - GaP/AlGaP
    - Monolithic waveguide gratings

    } Not good enough yet
  - If we can find good low loss coatings we may initially get away with TEM00 beams → eases mirror manufacturing & operation
  - R&D together with KAGRA → ELITES

NOISE BUDGET



GGN & SUBTRACTION

- Subtraction not foreseen for baseline ET but would benefit the sensitivity
- Finding well suited sites:
  - Low seismic; long term measurements
  - Homogeneous soil/rock environment
- Investigate GGN aspects of infrastructure design
- Subtraction schemes and efficiency
  - Controversial results require clarification

„QND READOUTS“ / SPEEDMETER

- Not included in ET baseline
- Promise good low frequency performance
  - No mature design (control schemes, noise transfer etc.)
  - Lacking experimental experience
- R&D needed to find out practical difficulties
- Principles should work

WHICH ARE THE OPTIMAL PARAMETERS?

- **Temperature, mirror mass, Signal Recycling configuration, SUS fibre length, optical power…**
- So far these were only optimised individually, disregarding many inderdependencies.
- Optimisation of complete sus+cryo+mirrors including all material parameters to obtain optimal parameters
- … Spin-off from LIGO-3G „red team“ work.

DA R&D : The first ET Mock Data Challenge

Slide from Sathya

- What was the data?
  - Gaussian background noise with ET-B sensitivity curve
    - Data from 3 detectors, ET1, ET2, ET3, located at the same site as Virgo
  - A cosmological population of binary neutron stars
  - A year's worth of data
- What was the challenge?
  - How good are current detection pipelines in disentangling overlapping signals and can we reach theoretical detection efficiency?
  - Does a cosmological population create a confusion background and if so at what level?
    - Can we detect the confusion background and learn about the underlying pop?
- What did we do?
  - Estimation of PSD using the null stream
  - Recovery of BNS background from residuals
  - Search for BNS using iHOPE pipeline
  - Search for stochastic background

WHAT DID WE FIND?

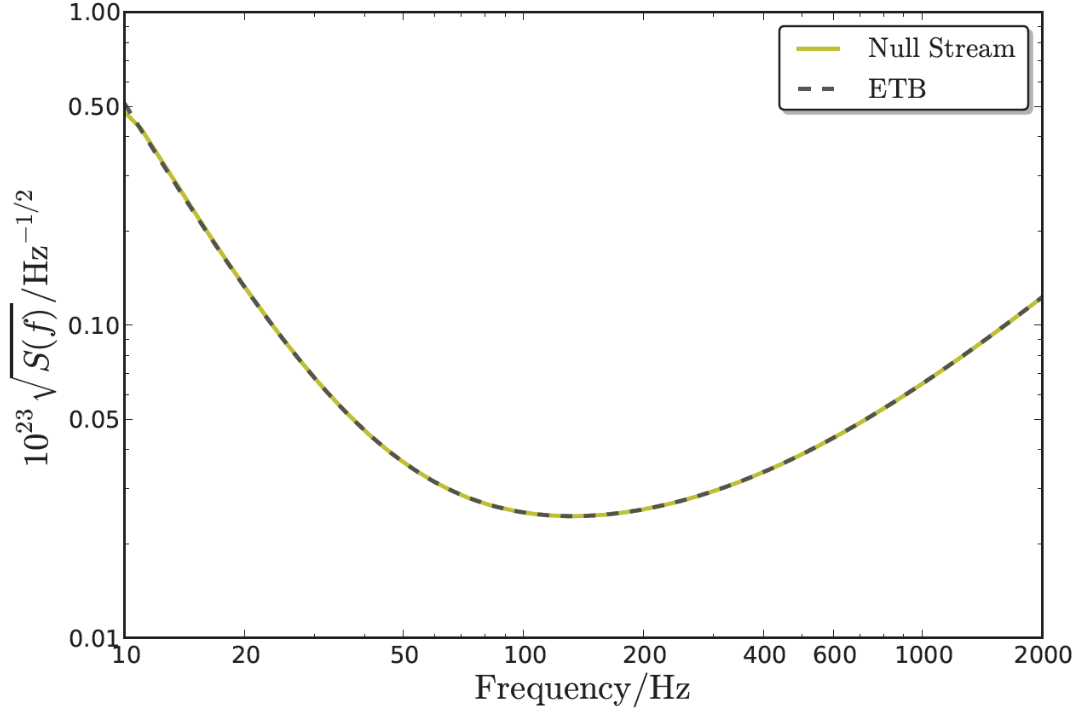
Slide from Sathya

- Null stream is a very powerful data stream in ET

$$\mathbf{d}^1 = \frac{1}{2}(\mathbf{e}_1 \otimes \mathbf{e}_1 - \mathbf{e}_2 \otimes \mathbf{e}_2),$$
$$\mathbf{d}^2 = \frac{1}{2}(\mathbf{e}_2 \otimes \mathbf{e}_2 - \mathbf{e}_3 \otimes \mathbf{e}_3),$$
$$\mathbf{d}^3 = \frac{1}{2}(\mathbf{e}_3 \otimes \mathbf{e}_3 - \mathbf{e}_1 \otimes \mathbf{e}_1),$$

$$x^A(t) \equiv n^A(t) + d^A_{ij} h^{ij}(t),$$

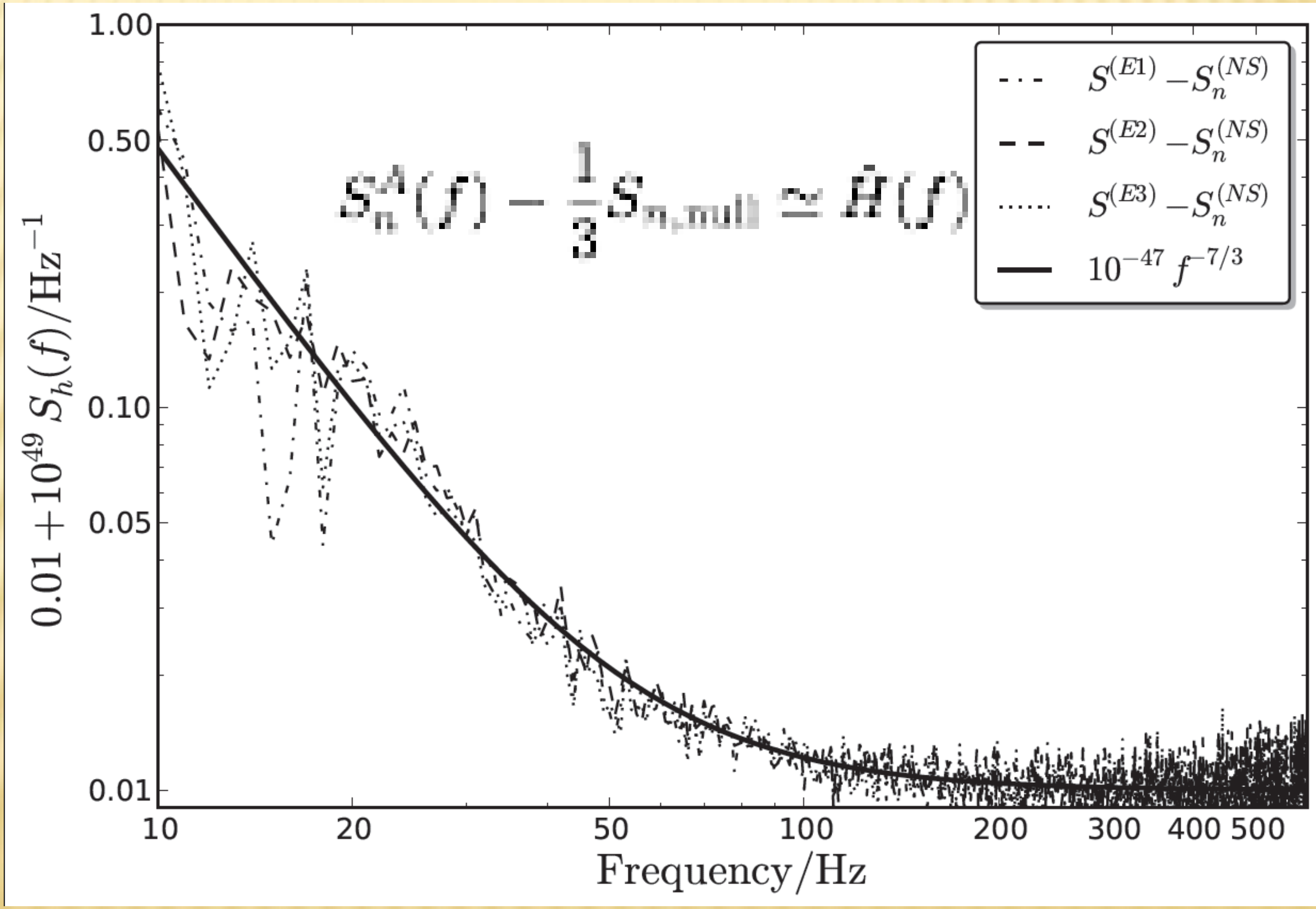
$$x_{\rm null}(t) \equiv \sum_{A=1}^{3} x^A(t) = \sum_{A=1}^{3} n^A(t) + \sum_{I=1}^{3} d^A_{ij} h^{ij}(t) = \sum_{A=1}^{3} n^A(t)$$



Slide from Sathya

RESIDUALS

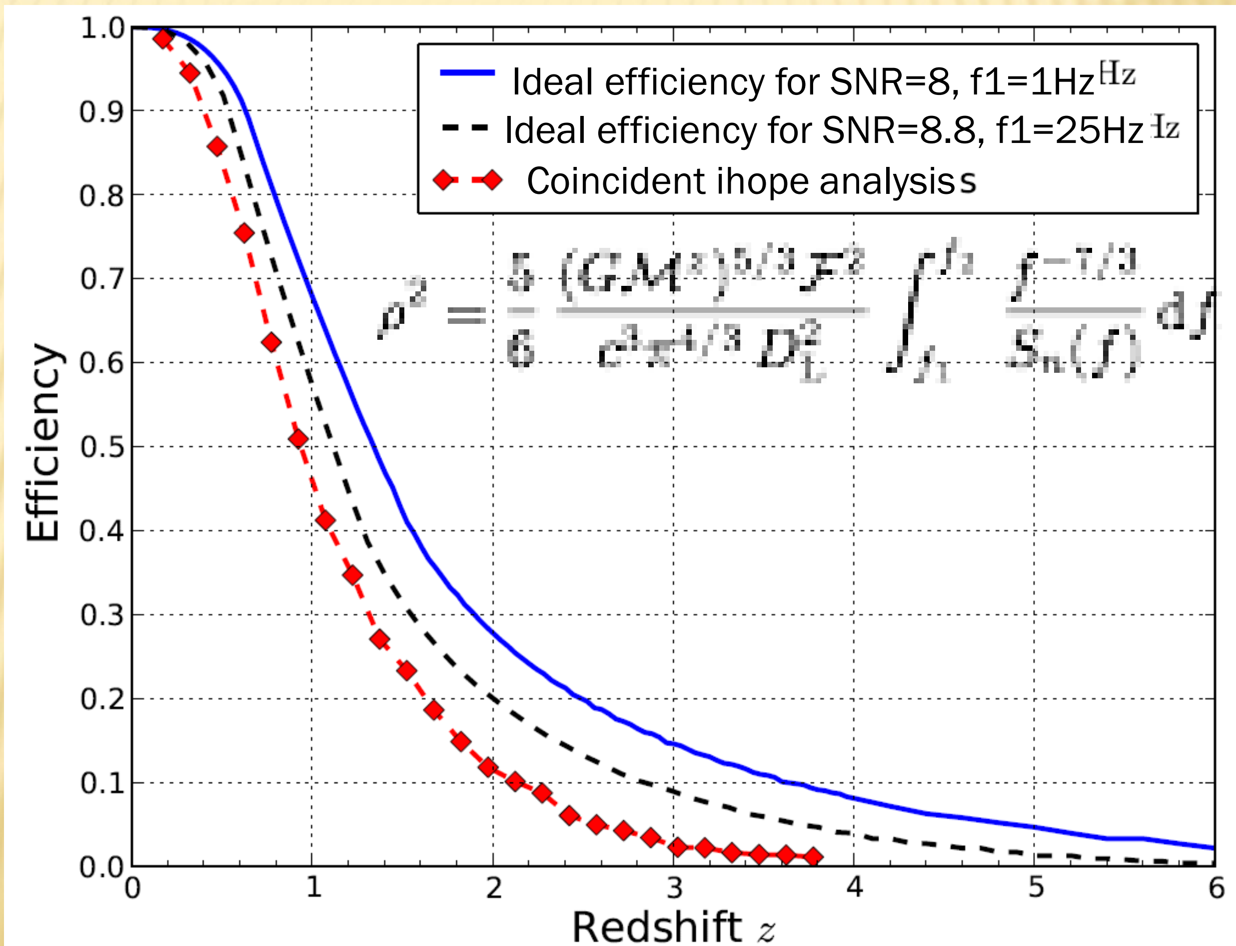
- All quantities have been scaled by 10^{49} and a constant value of 0.01 added



Slide from Sathya

DETECTION EFFICIENCY FOR BNS

$$\epsilon(D_L) = \frac{1}{8\pi}\int_0^{\pi}\int_0^{\pi}\int_0^{2\pi} \Pi(\rho/\rho_T - 1)\,\sin\theta\,\sin\iota\,d\theta\,d\iota\,d\psi$$

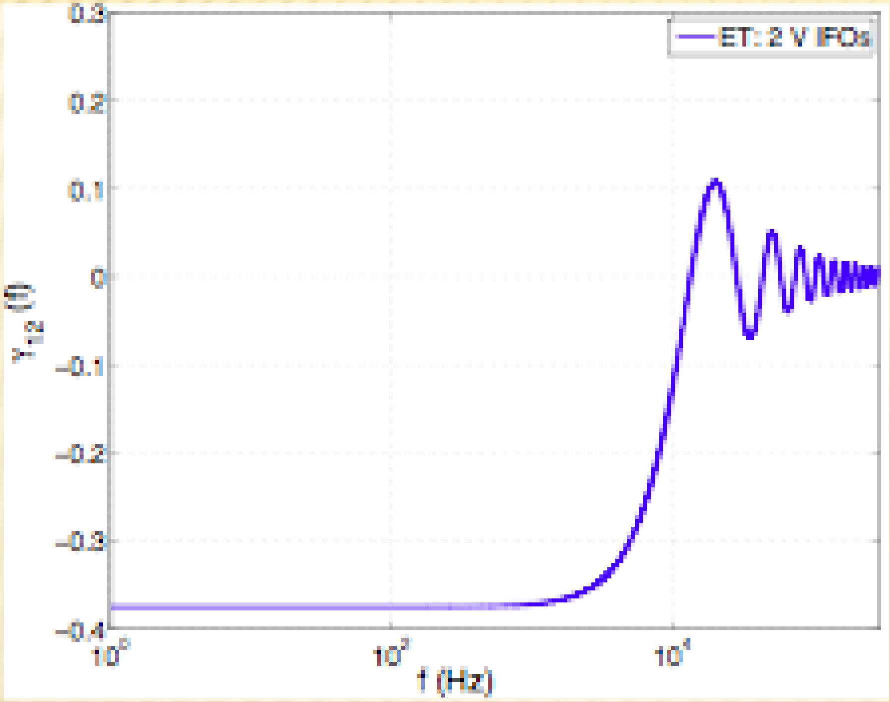


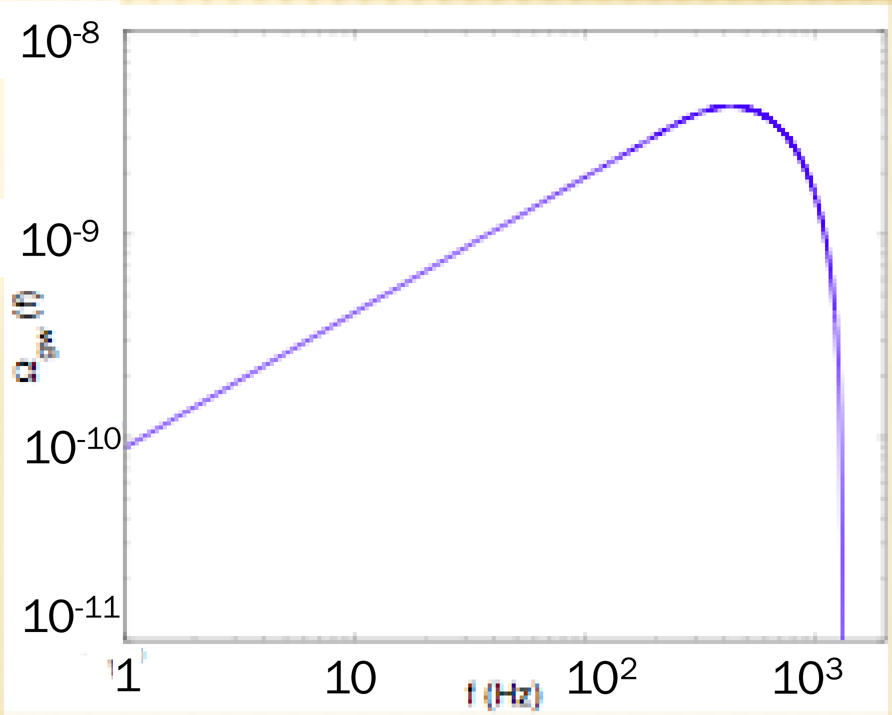
$$\rho^2 = \frac{5}{6}\,\frac{(G\mathcal{M}^z)^{5/3}\mathcal{F}^2}{c^3\pi^{4/3}D_L^2}\int_{f_1}^{f_2}\frac{f^{-7/3}}{S_n(f)}\,df$$

SEARCH FOR STOCHASTIC BACKGROUND

- Used LV Cross correlation code to search for a stochastic background in the three detectors

For each of the pairs E1-E2, E2-E3 and E1-E3, we found a point estimate of 1.02×10^{-9} with error $\sigma_\Omega = 2.6 \times 10^{-11}$ at 100 Hz.





ET R&D LIST

- Silicon absorption @ 10 -20 K
- Silicon suspensions
- Better coatings for 20K (Si) & 300K (SiO_2)
- Optimisation of filter cavities
- Long term seismic measurements for site candidates
- High power laser
- LG Modes
- Mirror specifications (1D → Zernike)
- „Noiseless“ cooling
- Speedmeter
-

ET R&D LIST

- Funding R&D
- Silicon absorption @ 10 -20 K
- Silicon suspensions
- Better coatings for 20K (Si) & 300K (SiO_2)
- Optimisation of filter cavities
- Long term seismic measurements for site candidates
- High power laser
- LG Modes
- Mirror specifications (1D → Zernike)
- „Noiseless“ cooling
- Speedmeter

WP1 - CRYOGENICS AND SUSPENSIONS

- Measurement of the performance of designed cryogenic suspension system in a practical interferometer from the point of seismic and vibration isolation
- Design and test of auxiliary attenuation system for thermal link

WP2 MIRROR THERMAL NOISE AND CRYOGENICS

- Investigation of the mechanical loss in both silicon and sapphire bulk materials.
- Performance of suitable optical coatings on sapphire substrates for the development of the mirrors for LCGT and to share the complimentary expertise contained within the LCGT and ET groups (e.g. Japanese expertise in studying low temperature properties of sapphire, European expertise in studying low temperature coatings).
- Assessment of the properties and suitability of silicate bonding for bonding sapphire, and comparison with the properties of bonded silicon, to develop techniques for constructing sapphire suspensions for use in LCGT and as a possible alternate suspension material for use in ET.
- Characterisation of the thermal and mechanical properties of suspension elements (fibres, bond areas, etc.)

WP3

- Specifying noise sources arising from cooling system quantitatively and qualitatively
- Optimum design of radiation shield
- Prevention of possible contamination of clean surface of mirrors