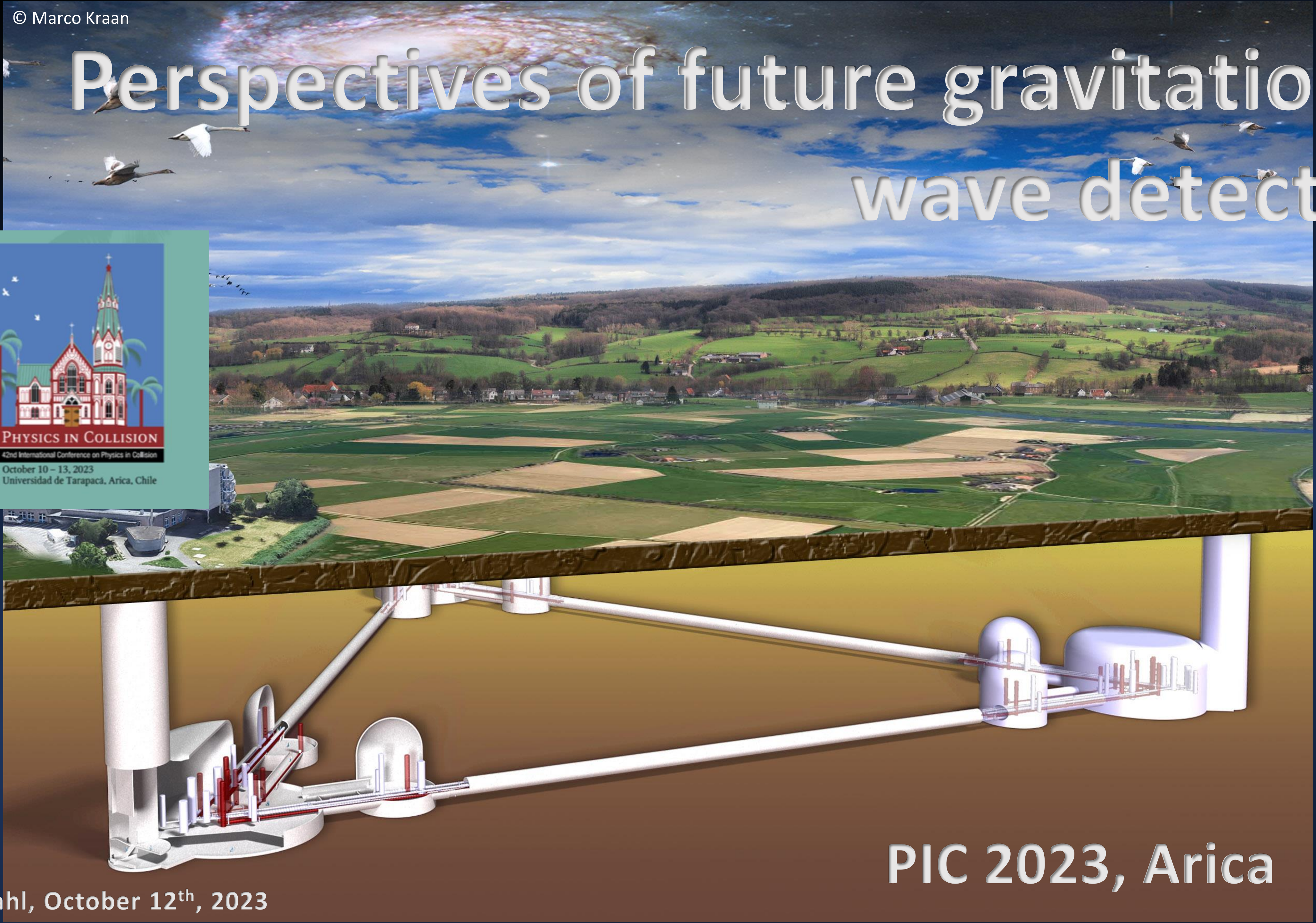
Perspectives of future gravitational wave detectors

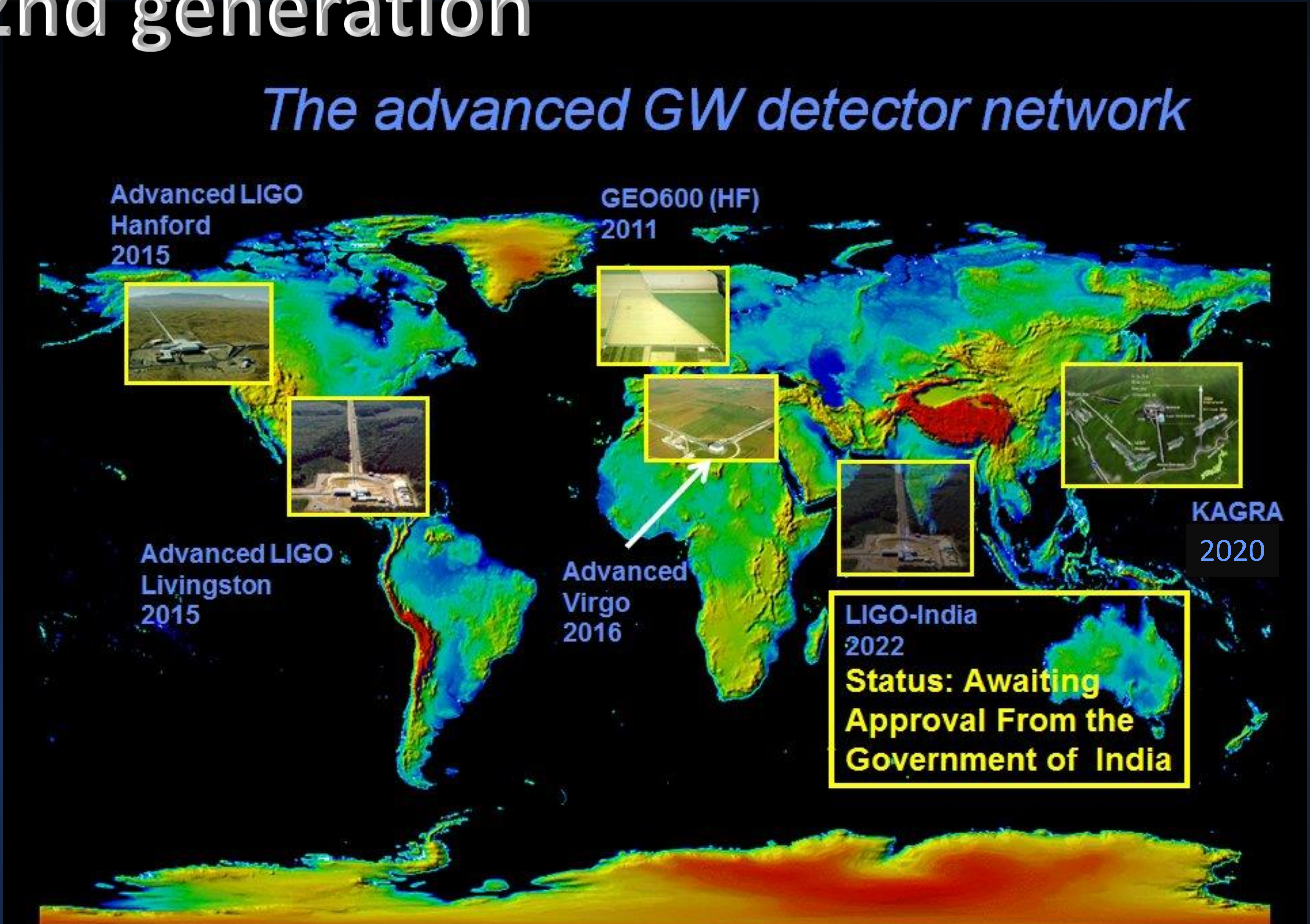


PIC2023
PHYSICS IN COLLISION
42nd International Conference on Physics in Collision
October 10 – 13, 2023
Universidad de Tarapacá, Arica, Chile

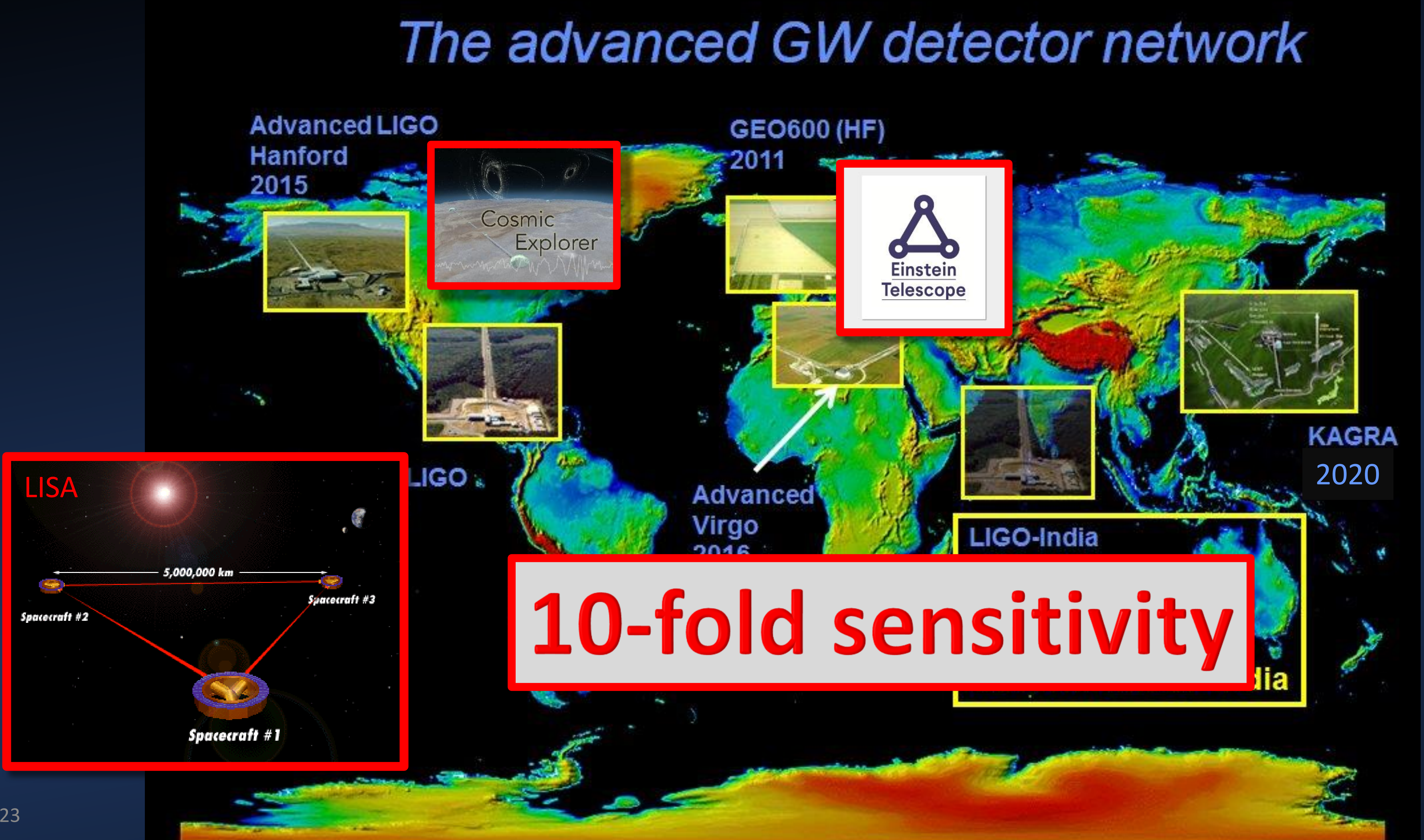
PIC 2023, Arica

Achim Stahl, October 12th, 2023

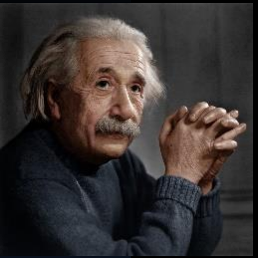
The 2nd generation

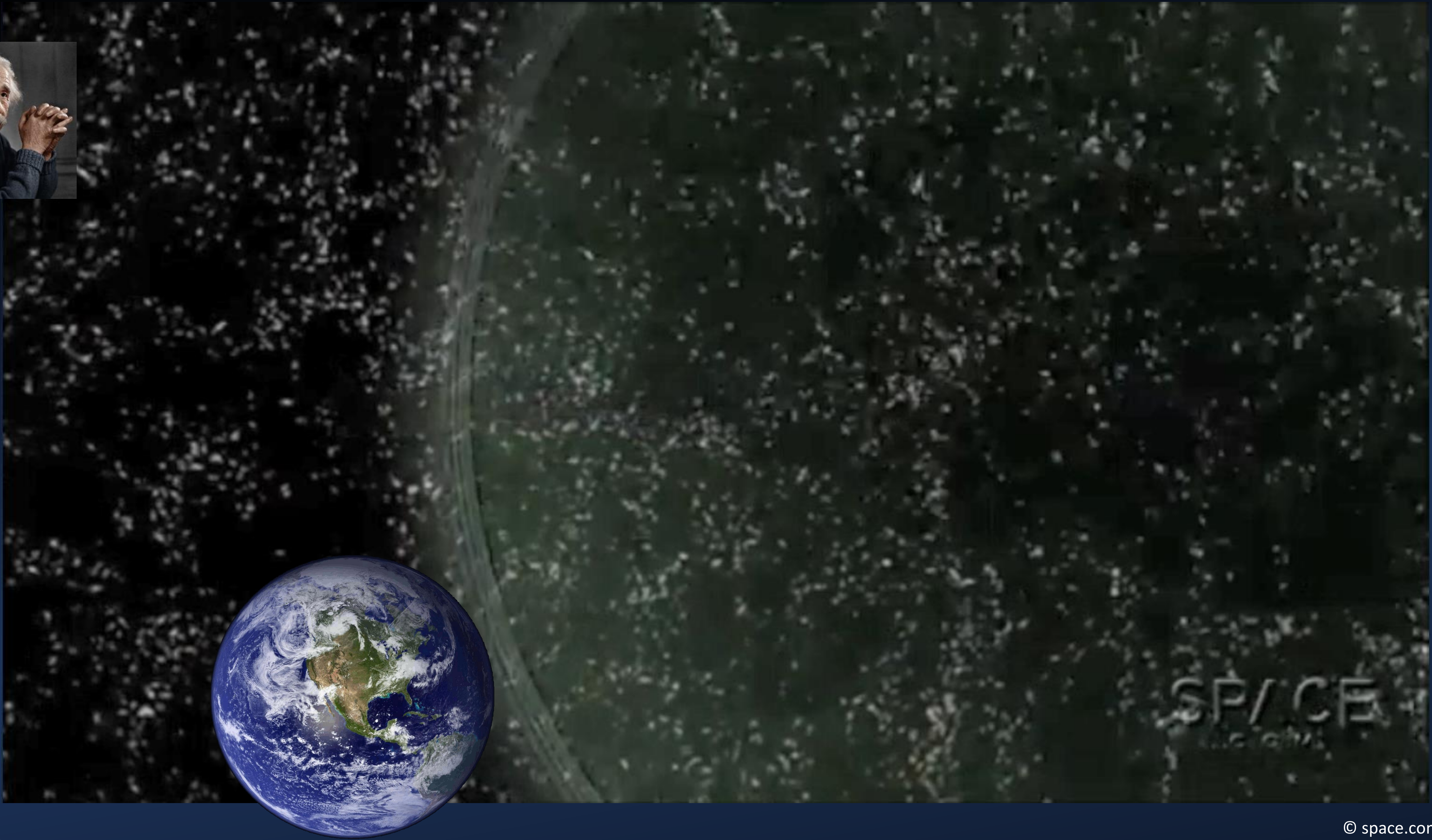


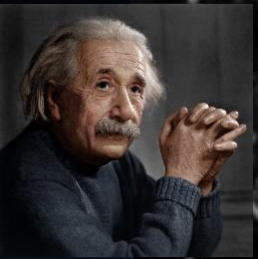
The 3rd Generation



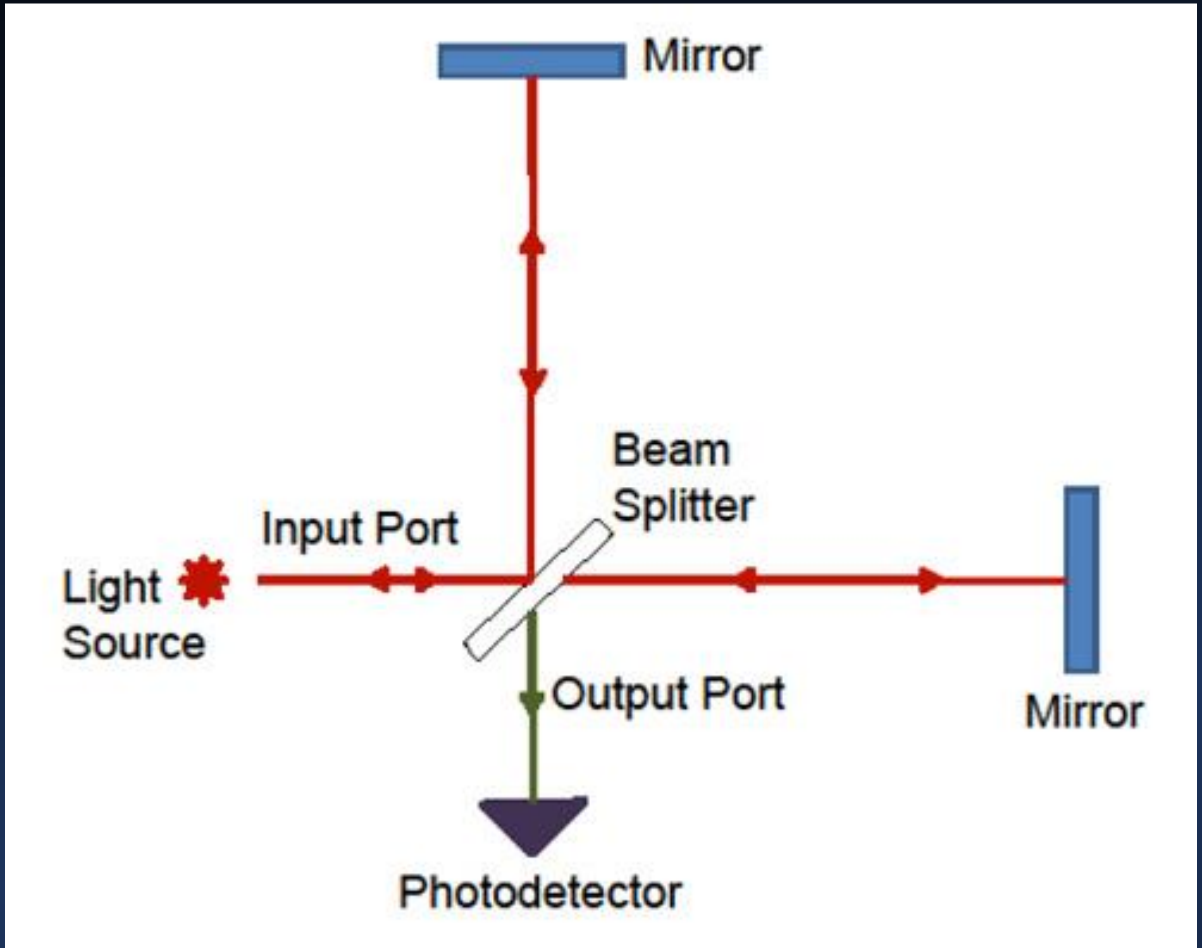
10-fold sensitivity







Michelson-Interferometer



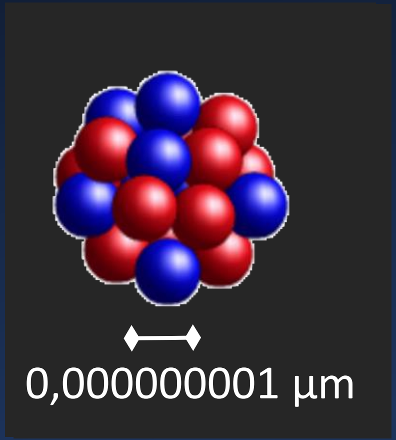
Sensitivity: 0,0000000000004 µm

Wave length: 1 µm

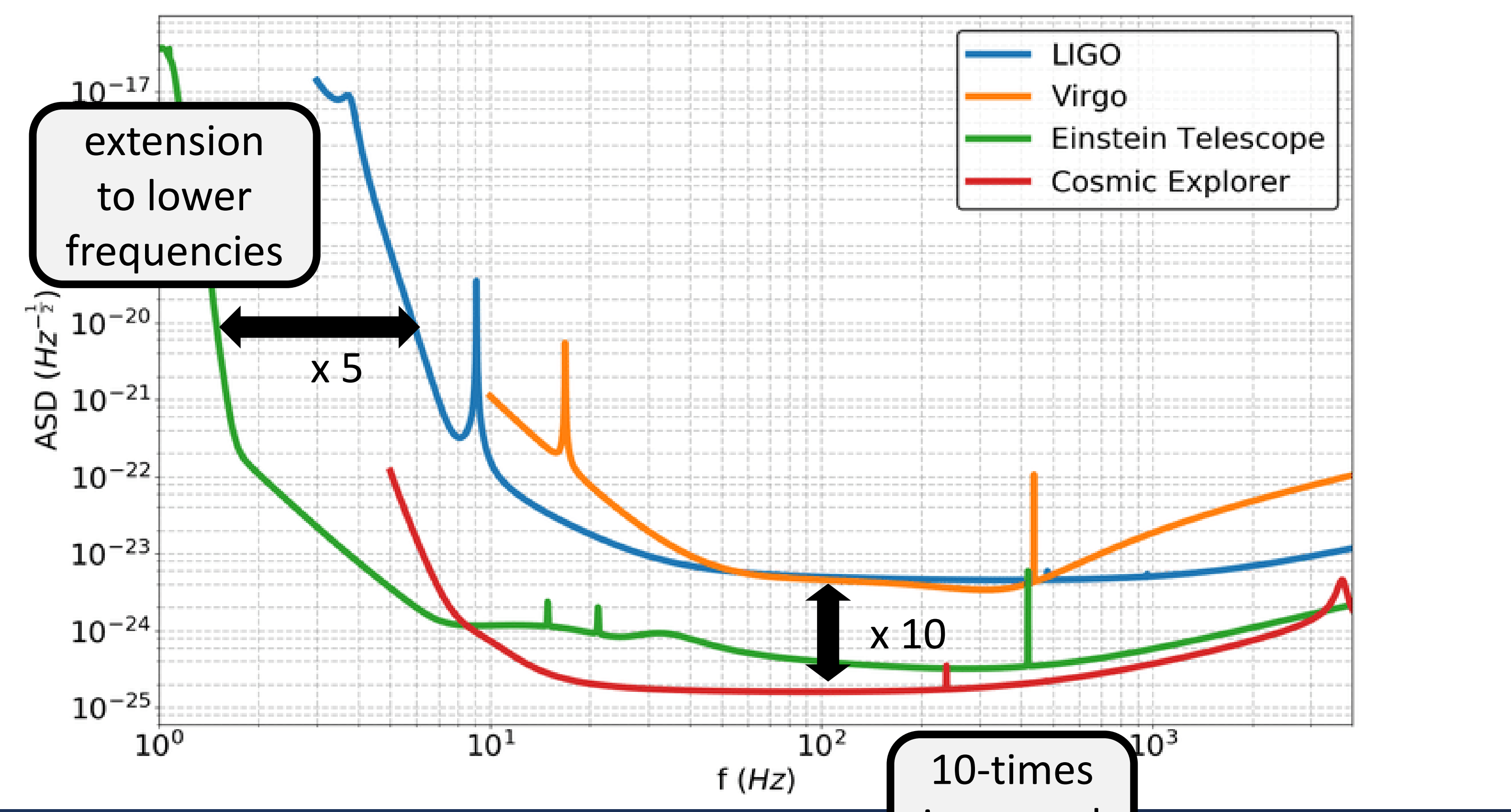
Atom: 0,0001 µm

Nucleus: 0,00000001 µm

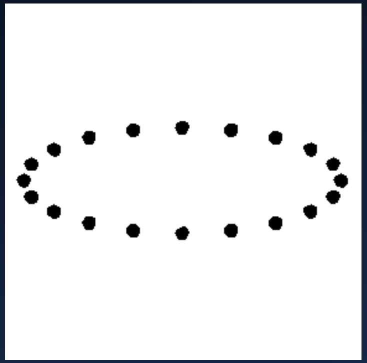
Proton: 0,000000001 µm



Goals of the next Generation



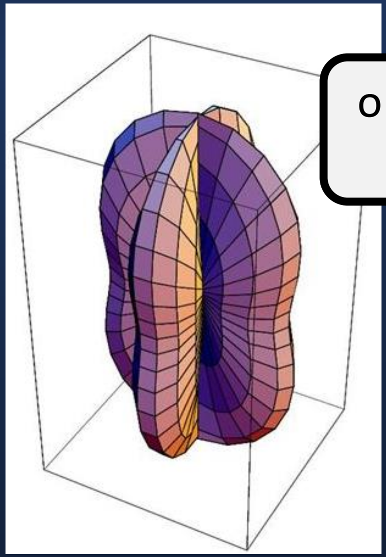
10-times increased sensitivity



+ polarization

x polarization

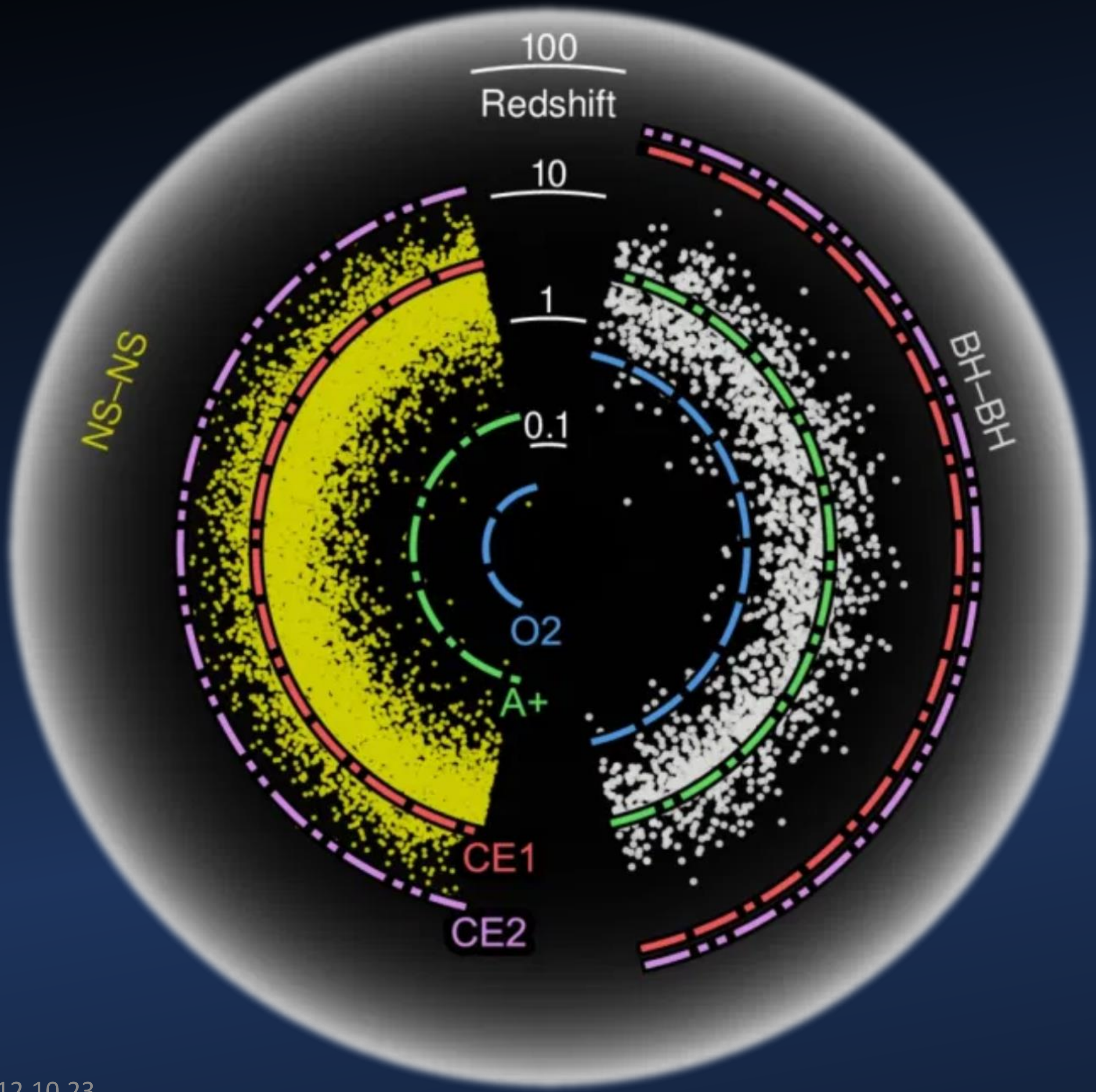
Access to polarization



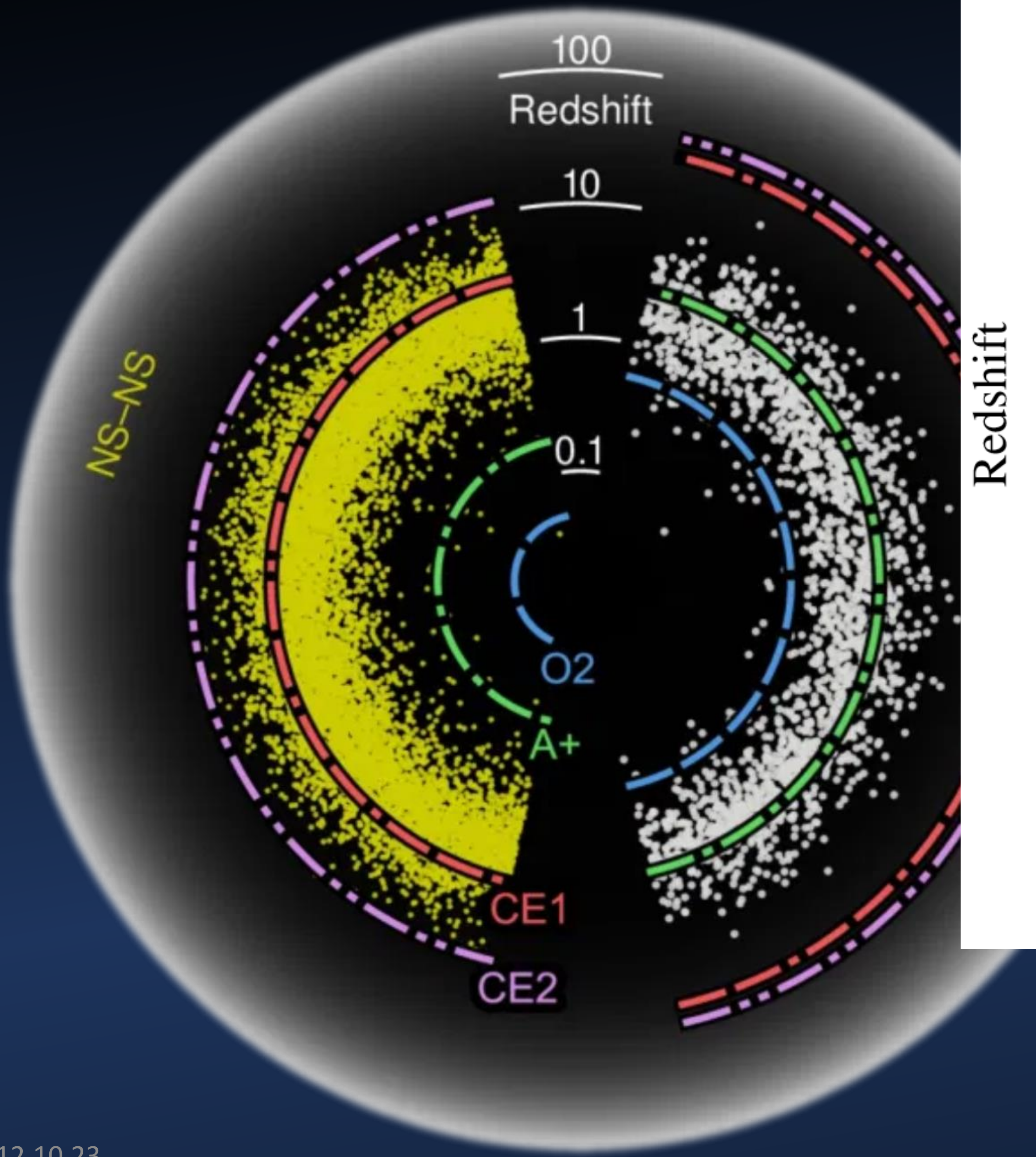
omnidirectional sensitivity

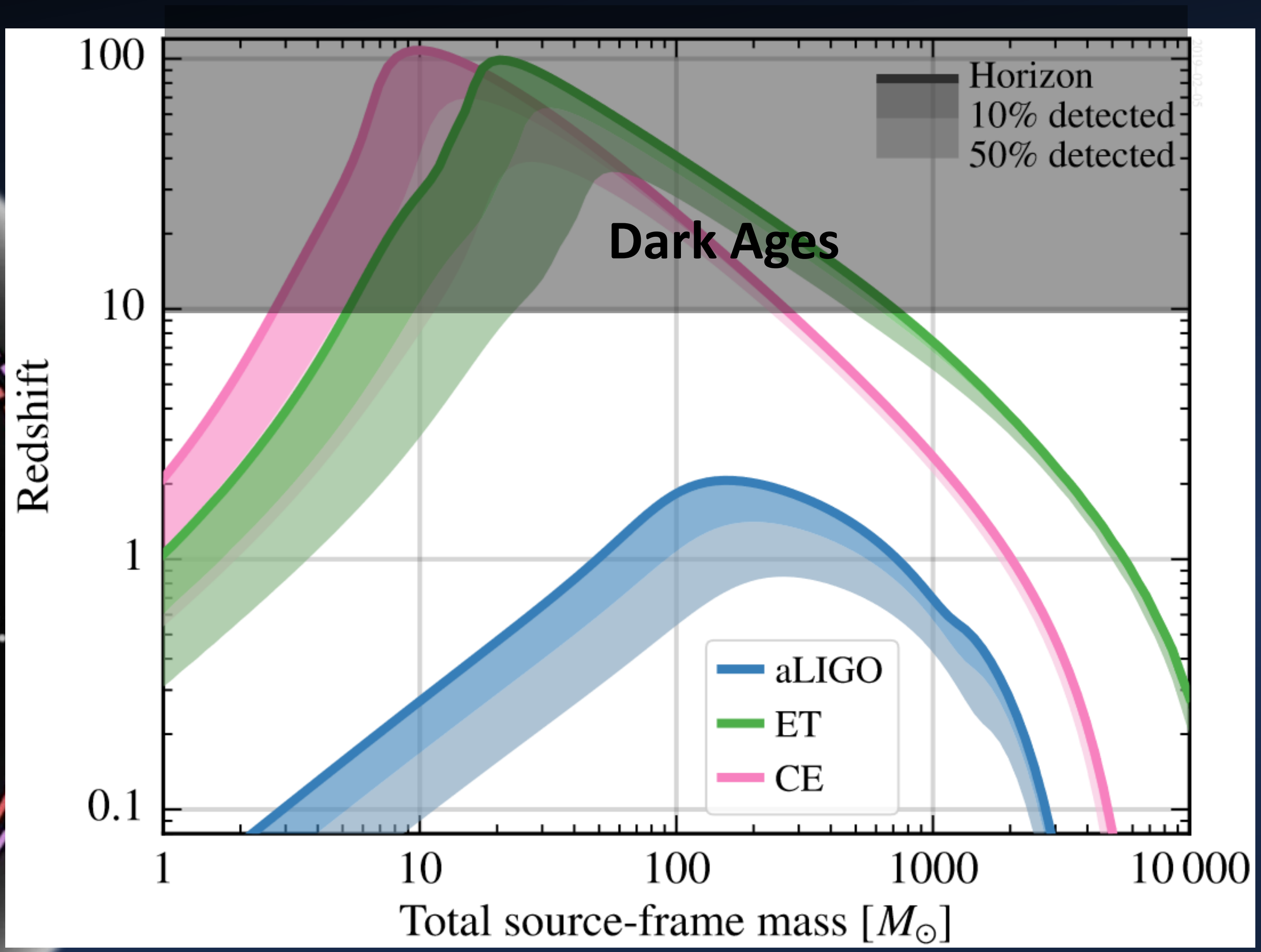
LIGO
antenna pattern
x polarization

Scientific Reach

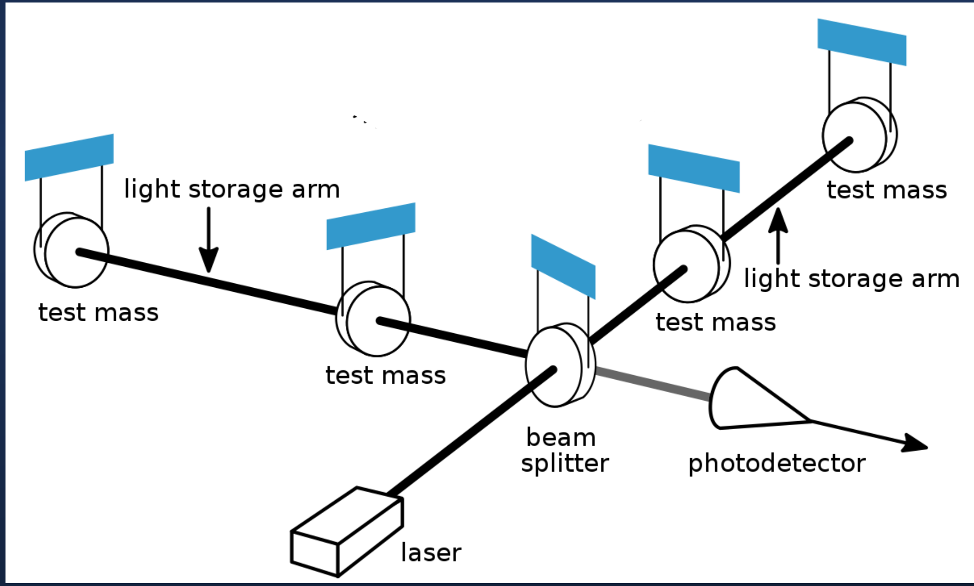


Scientific Reach

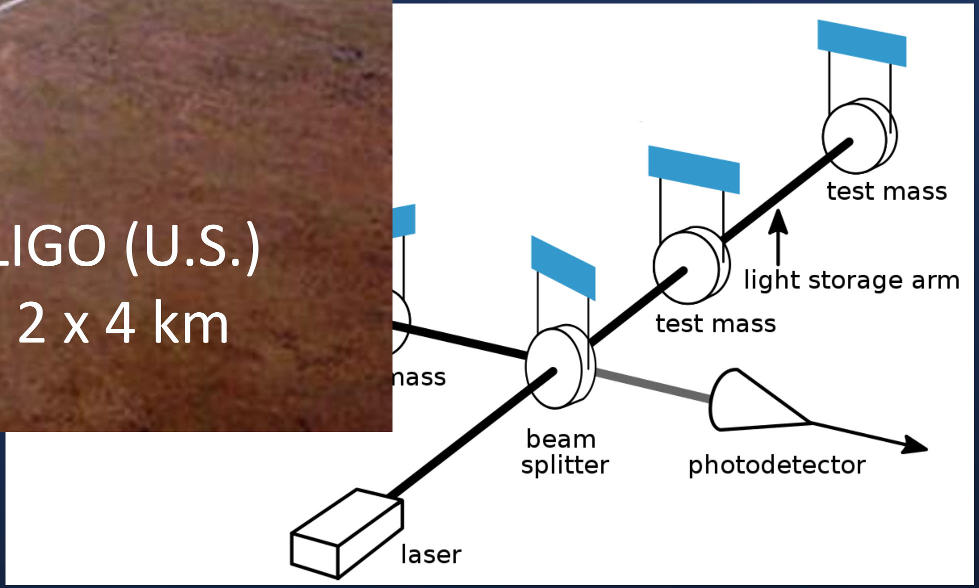




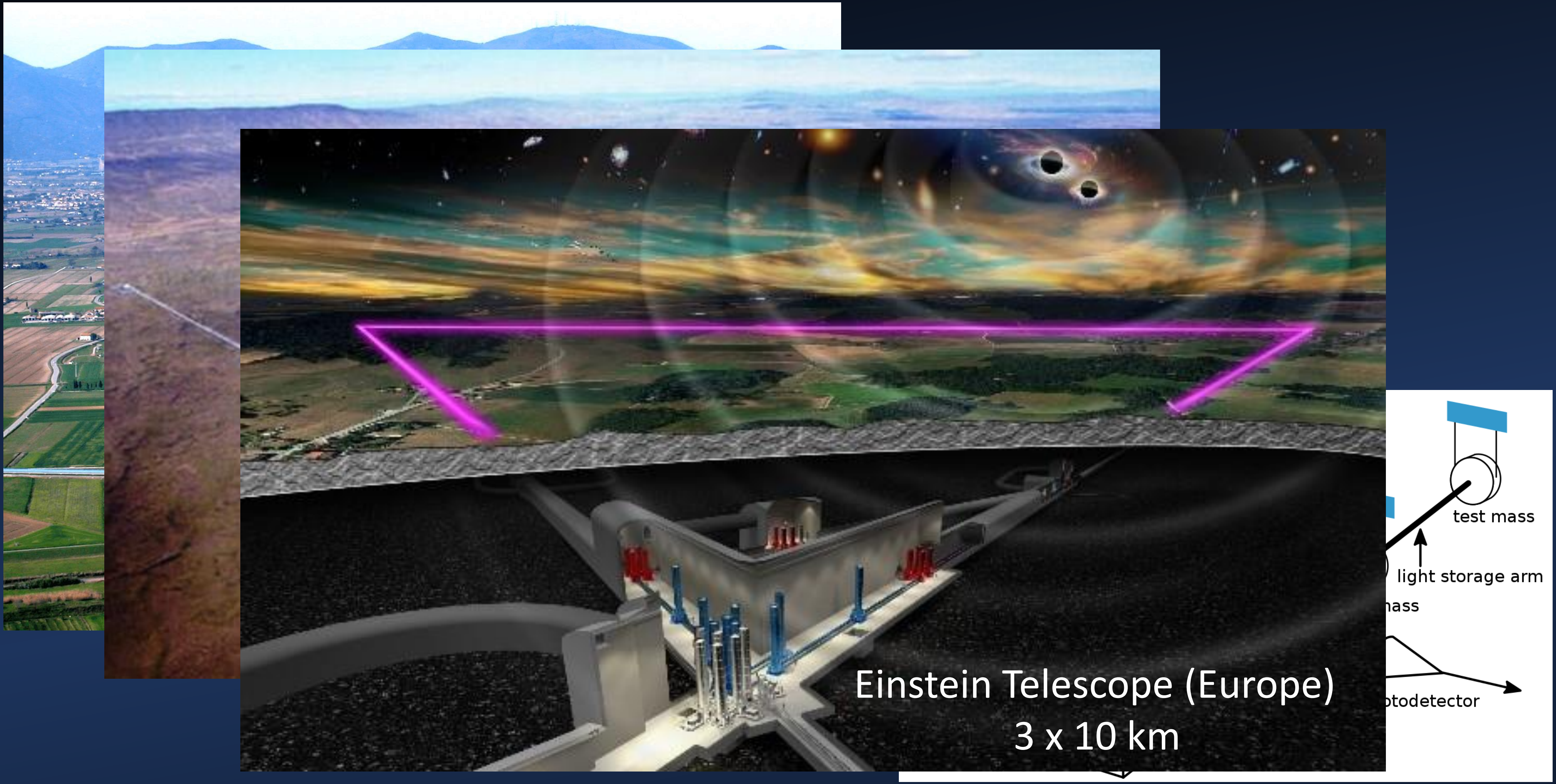
Increased Signal



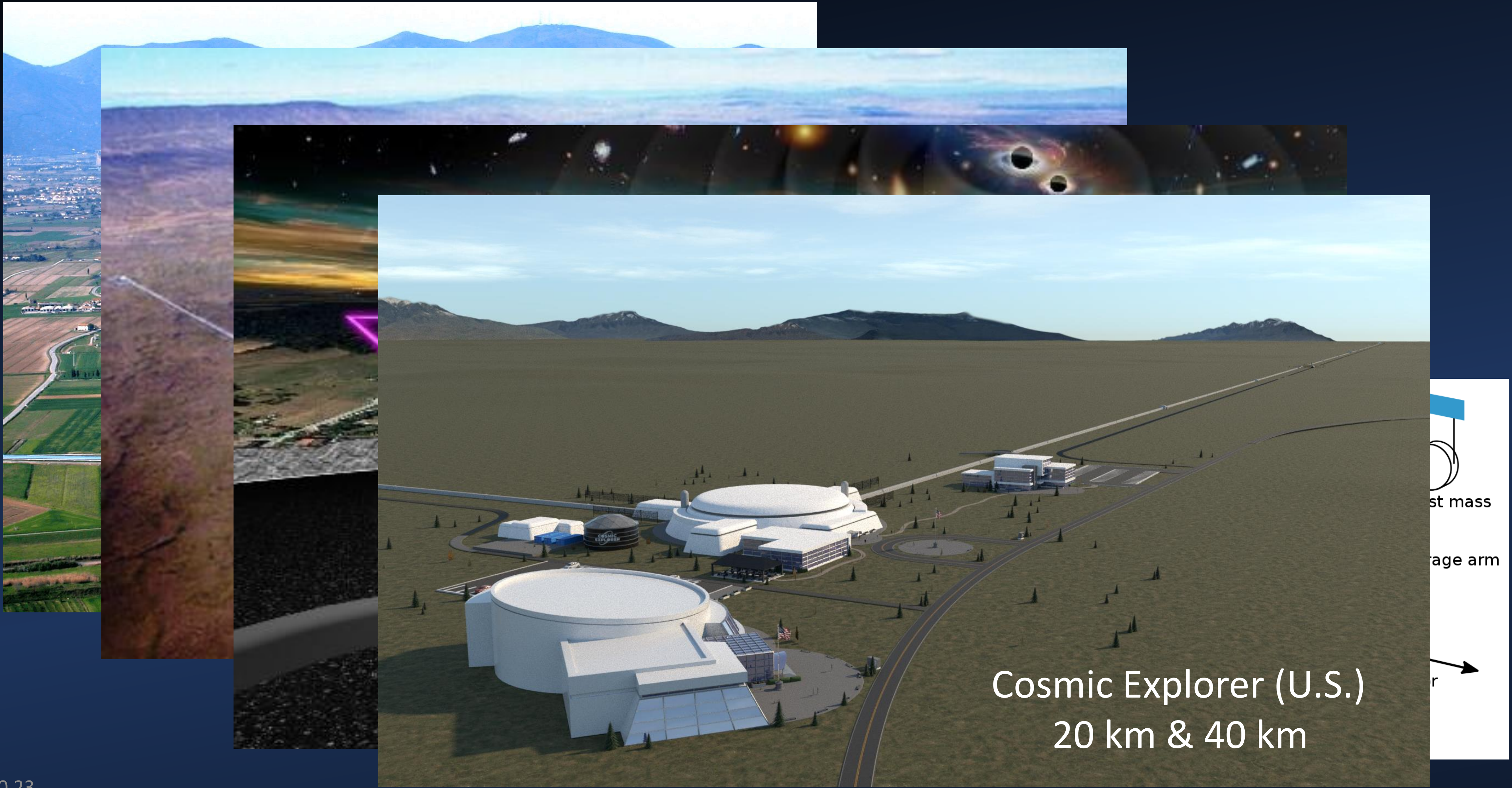
Increased Signal



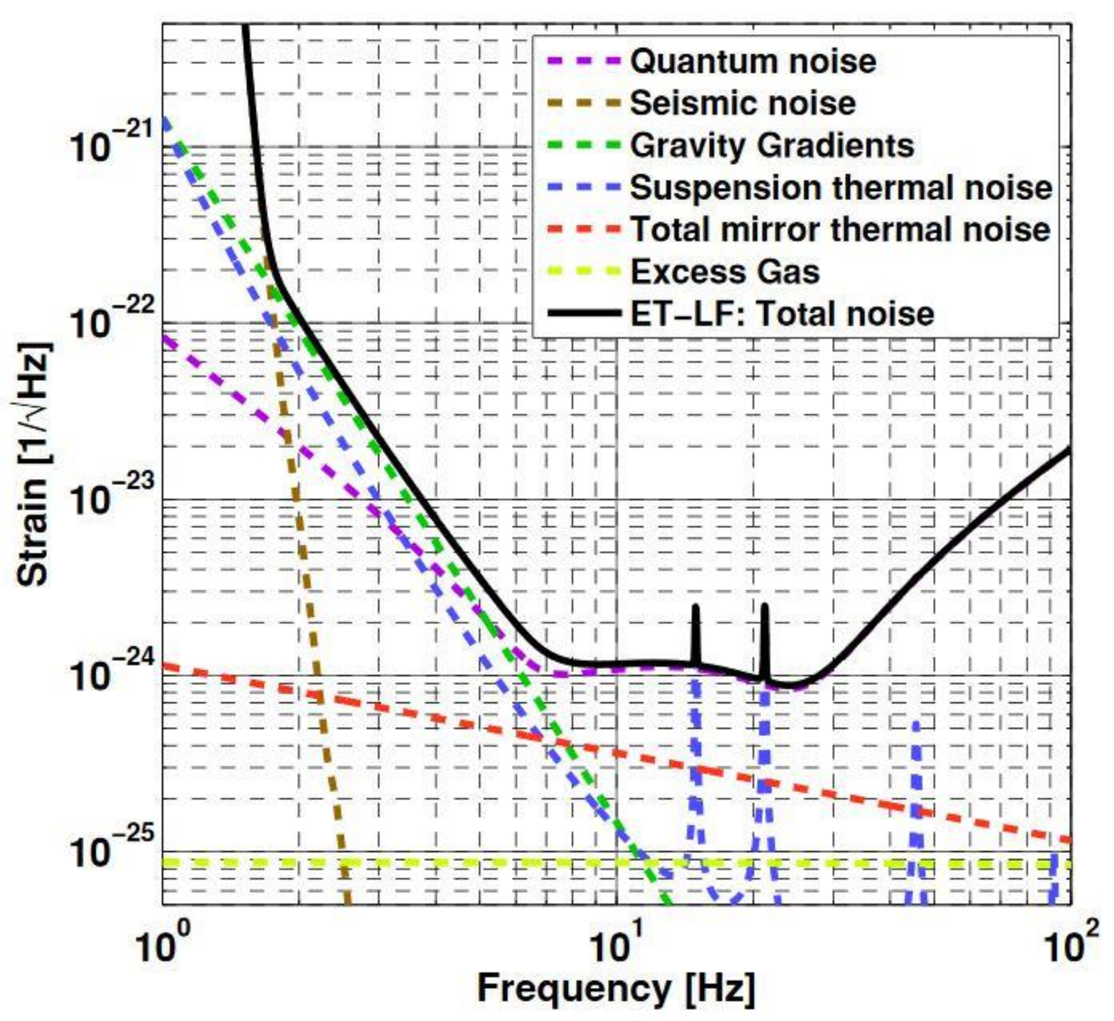
Increased Signal

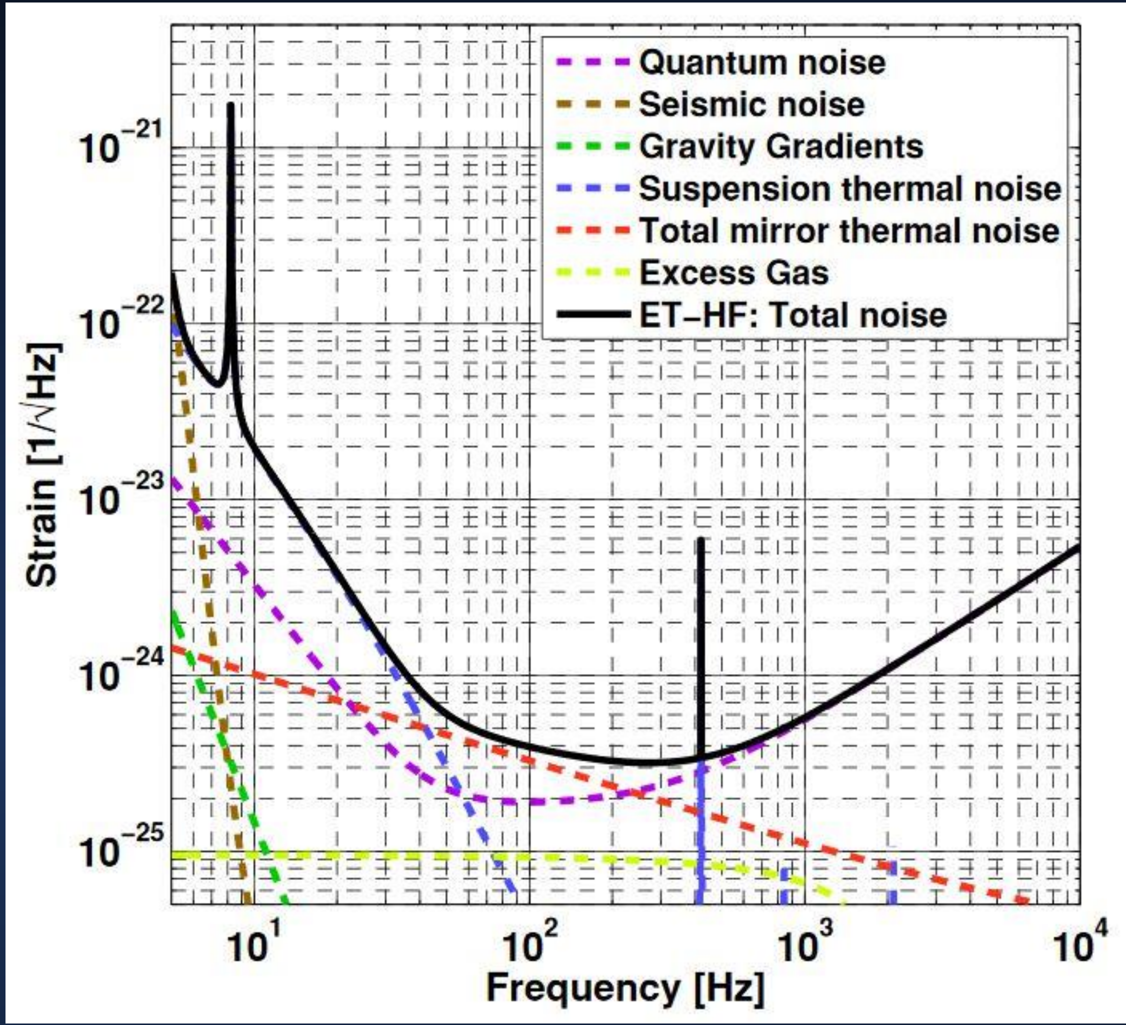


Increased Signal

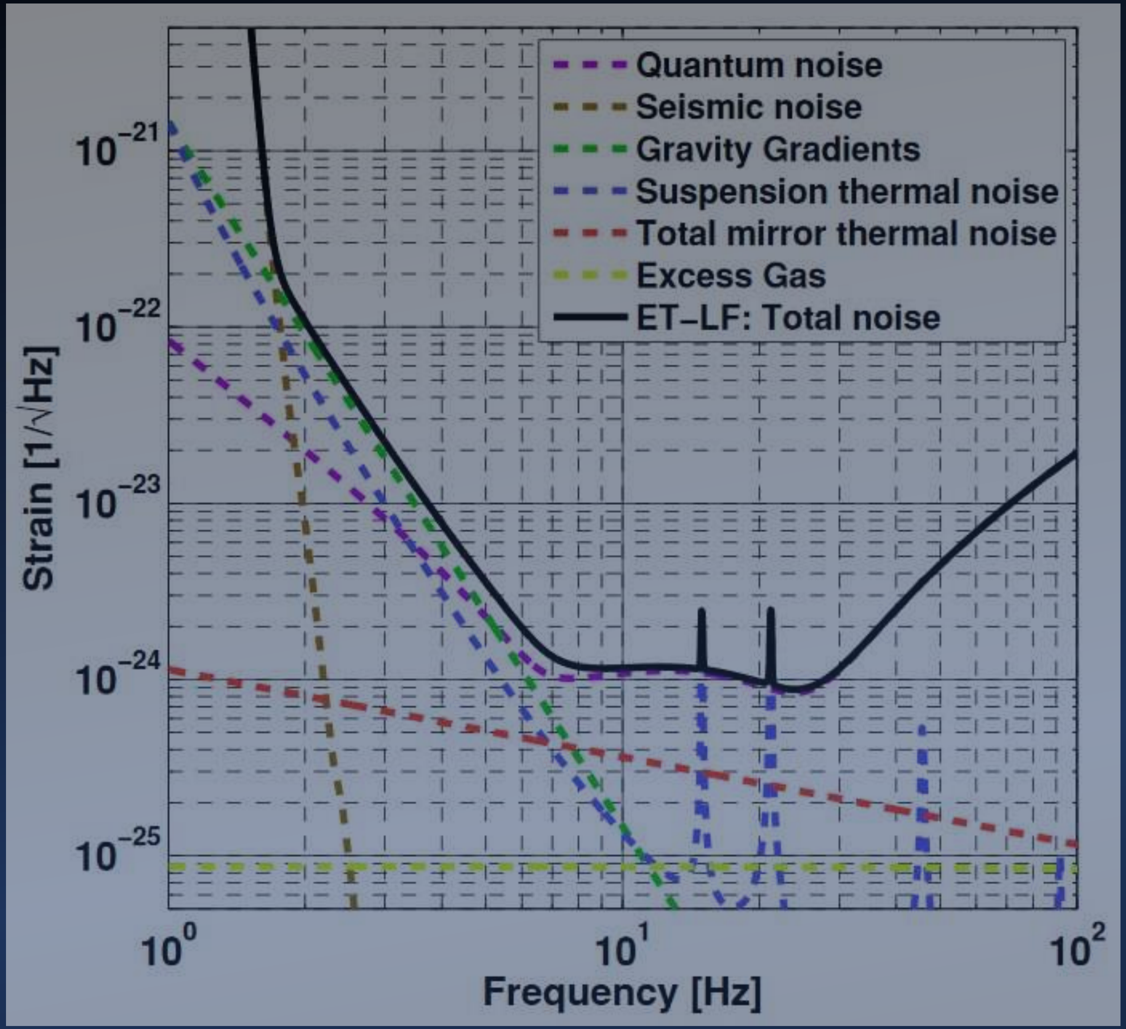


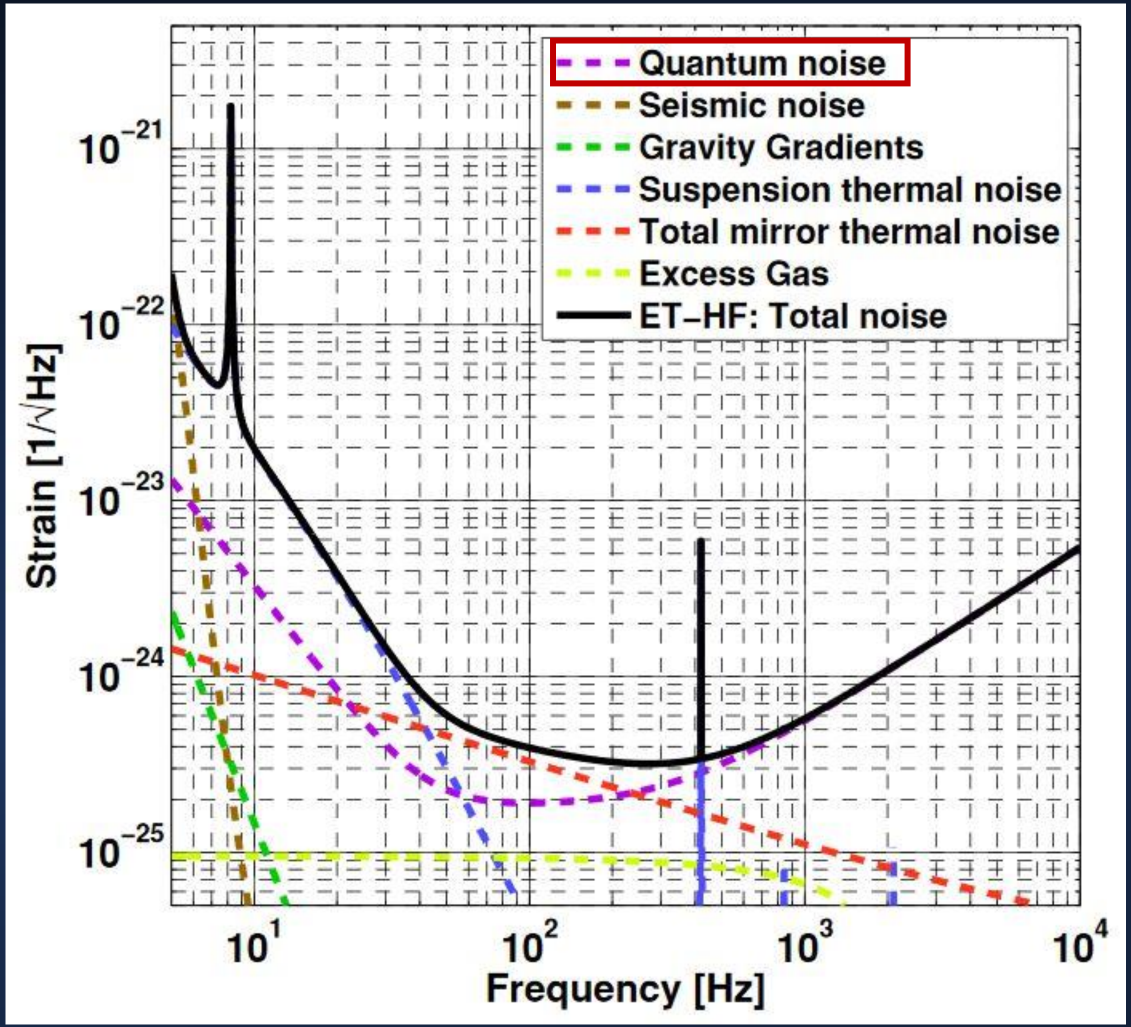
Understanding the noise





Understanding the noise



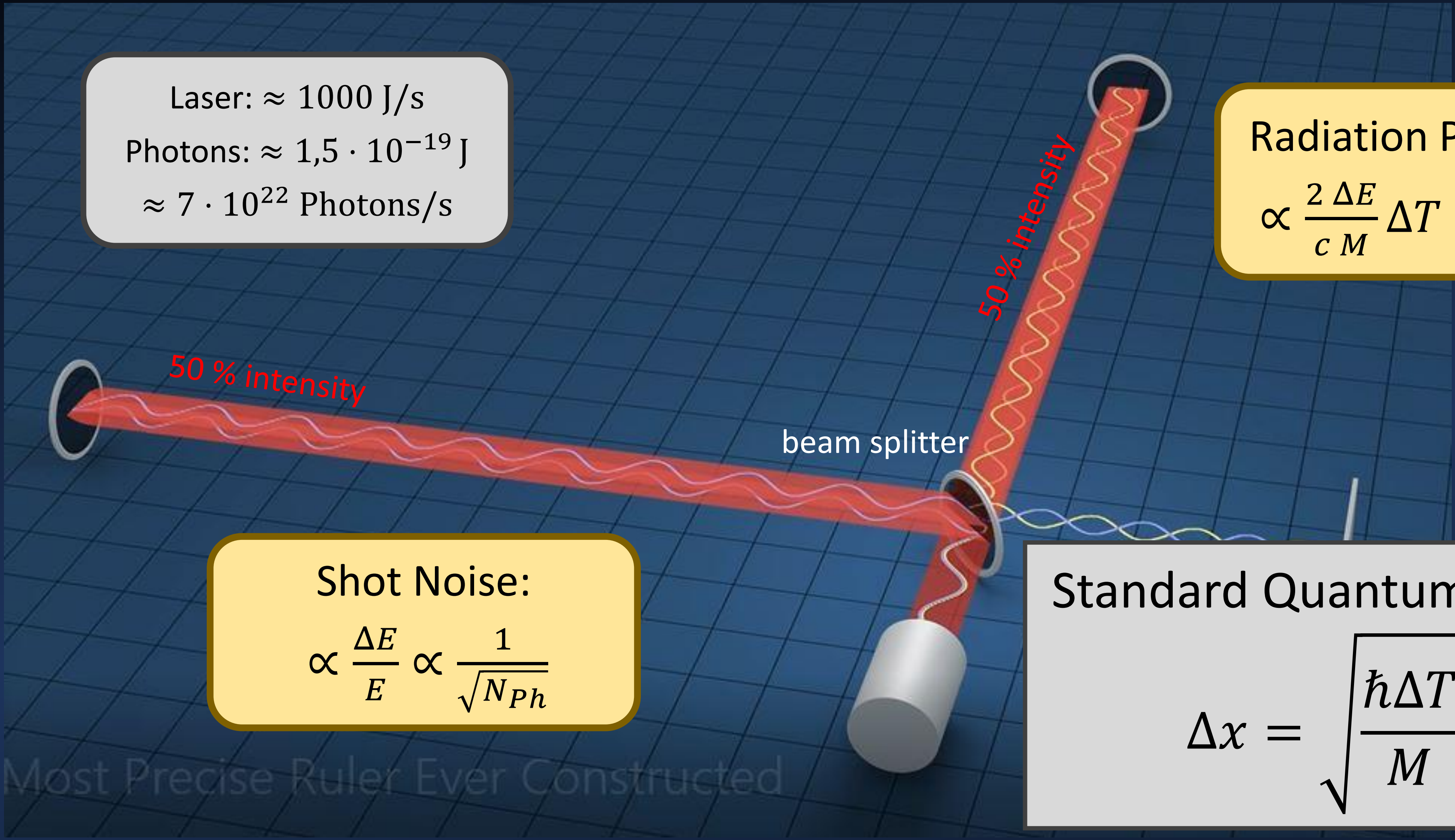


Quantum Noise

Laser: $\approx 1000\ \mathrm{J/s}$

Photons: $\approx 1{,}5 \cdot 10^{-19}\ \mathrm{J}$

$\approx 7 \cdot 10^{22}$ Photons/s



Radiation Pressure:

$$\propto \frac{2\,\Delta E}{c\,M}\Delta T \propto \sqrt{N_{Ph}}$$

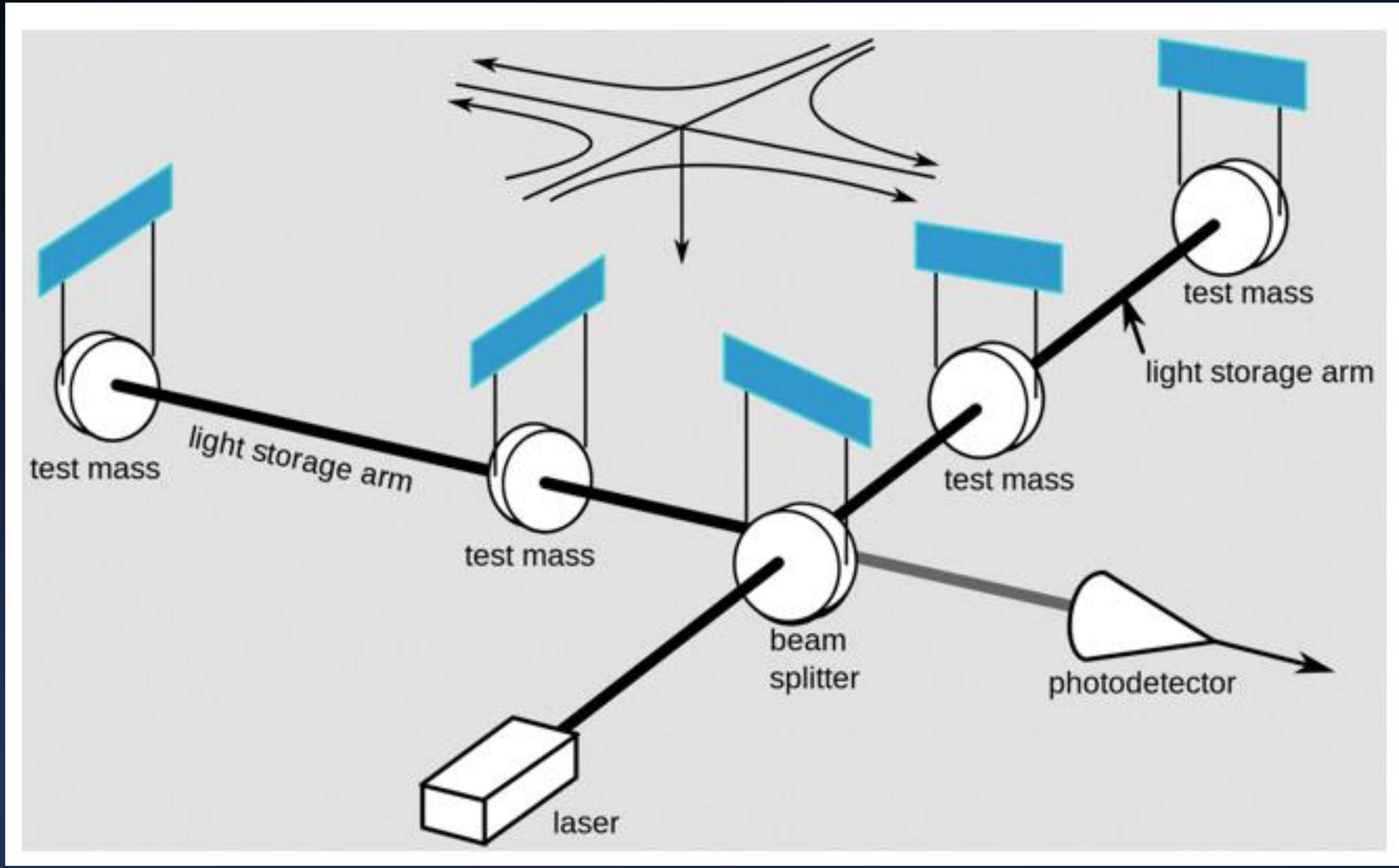
Shot Noise:

$$\propto \frac{\Delta E}{E} \propto \frac{1}{\sqrt{N_{Ph}}}$$

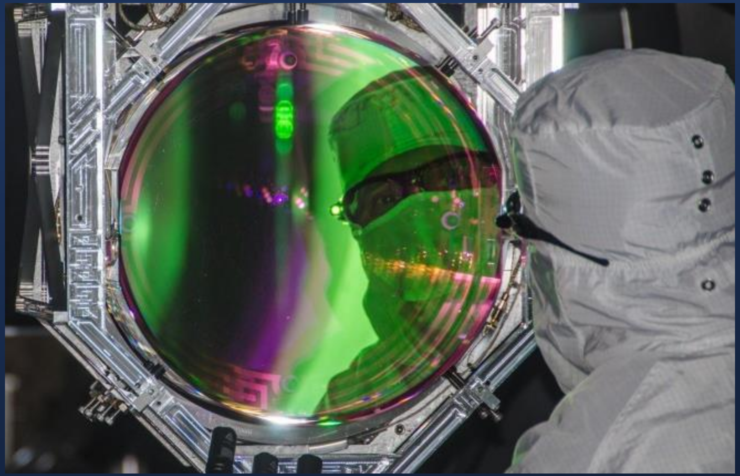
Standard Quantum Limit

$$\Delta x = \sqrt{\frac{\hbar \Delta T}{M}}$$

GW-Interferometer

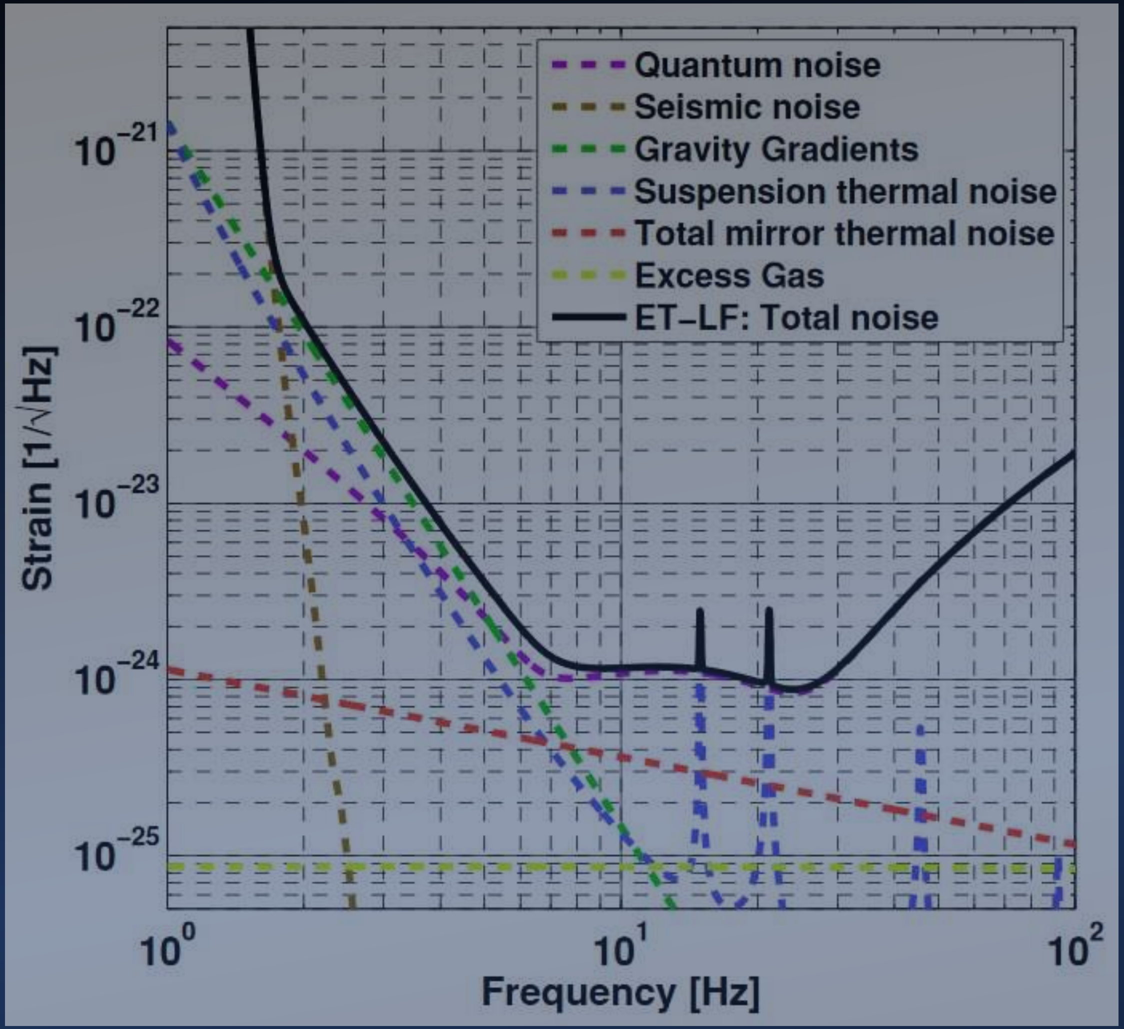


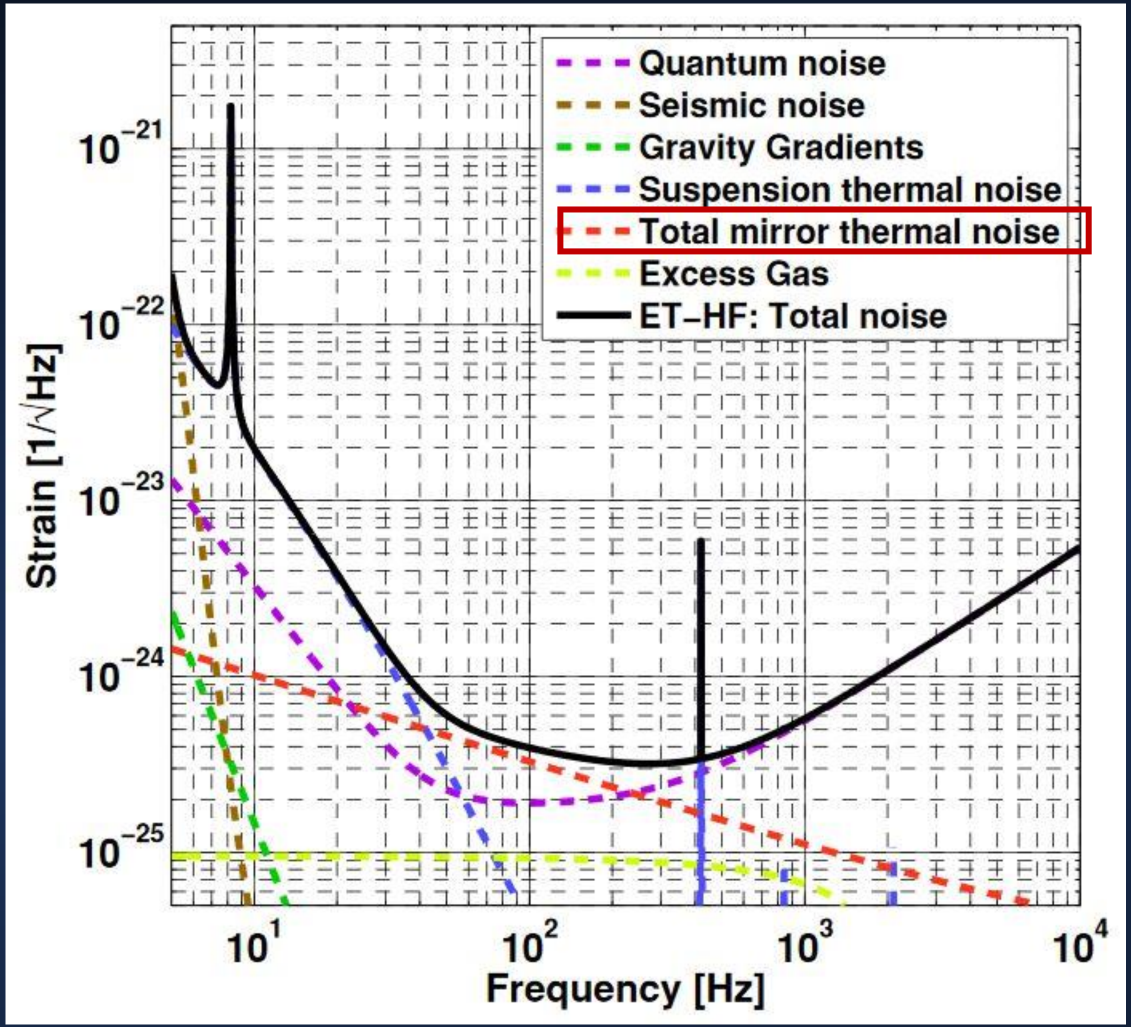
ET-HF: mirrors
Fused silica
Ø 62 cm / 200 kg
3 MW laser power



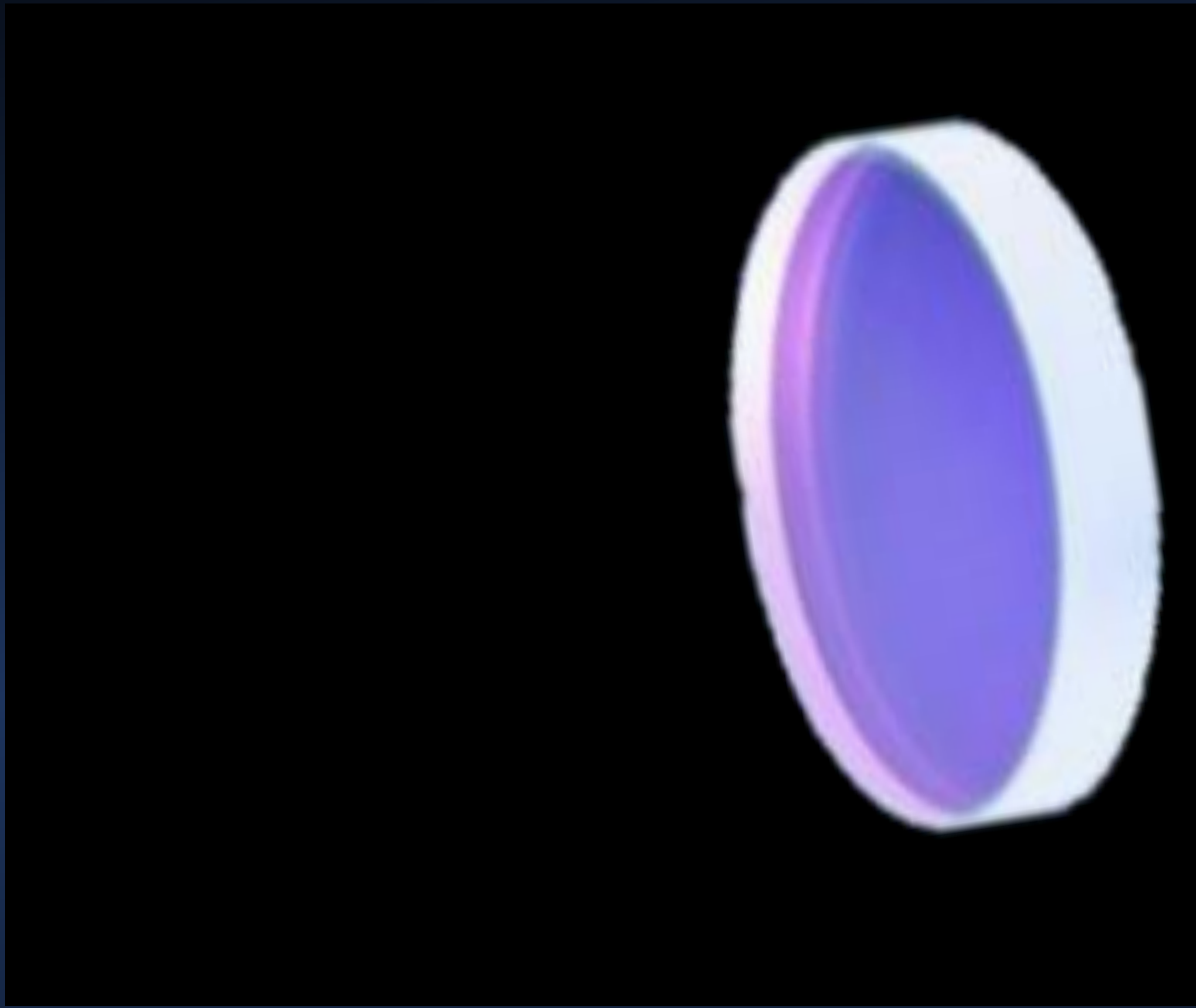
LIGO mirror

Understanding the noise

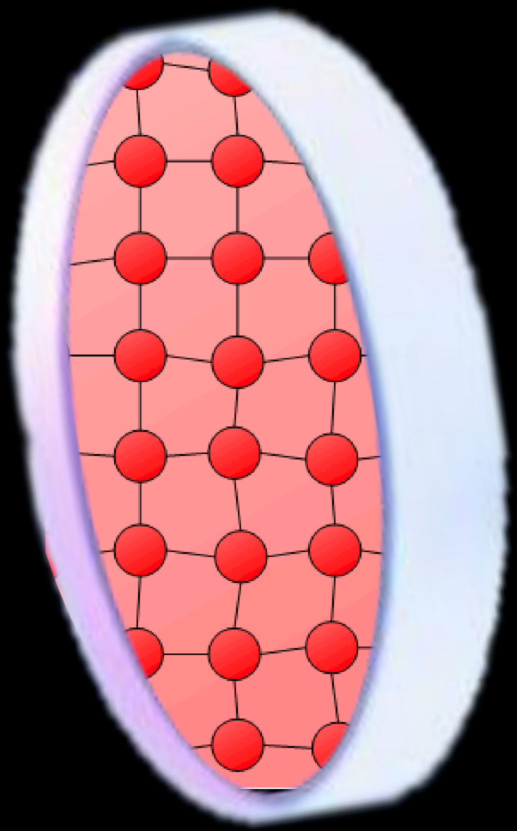




Thermal Noise



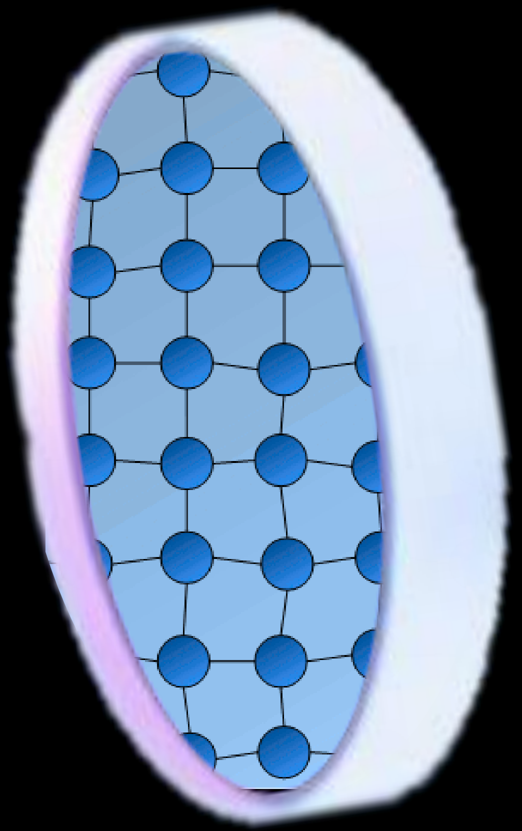
Thermal Noise



Brownian motion cause the reflective layers to move

Thermal Noise

cool the mirror to 10 K

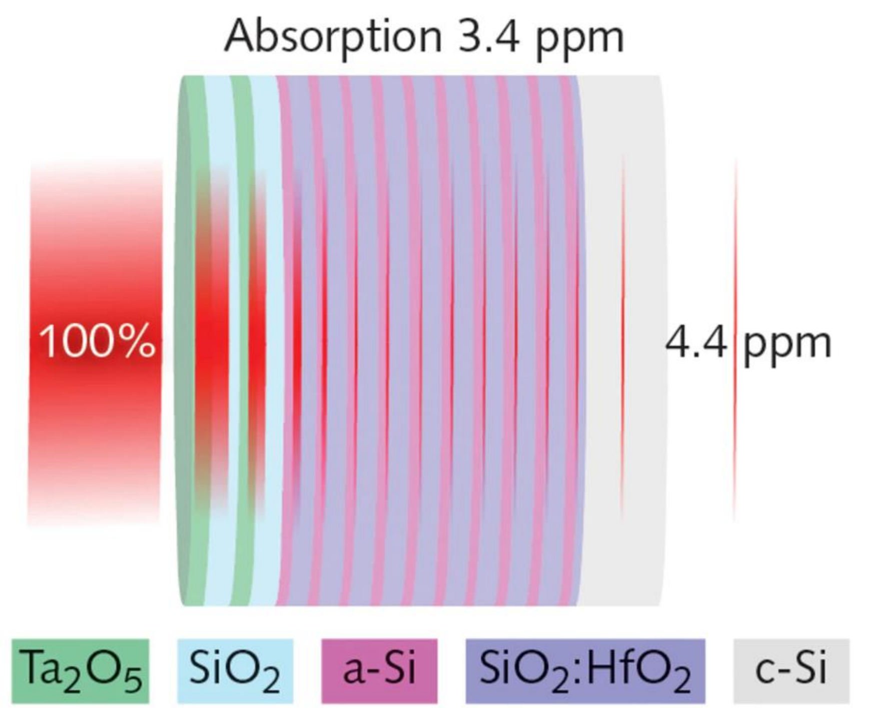


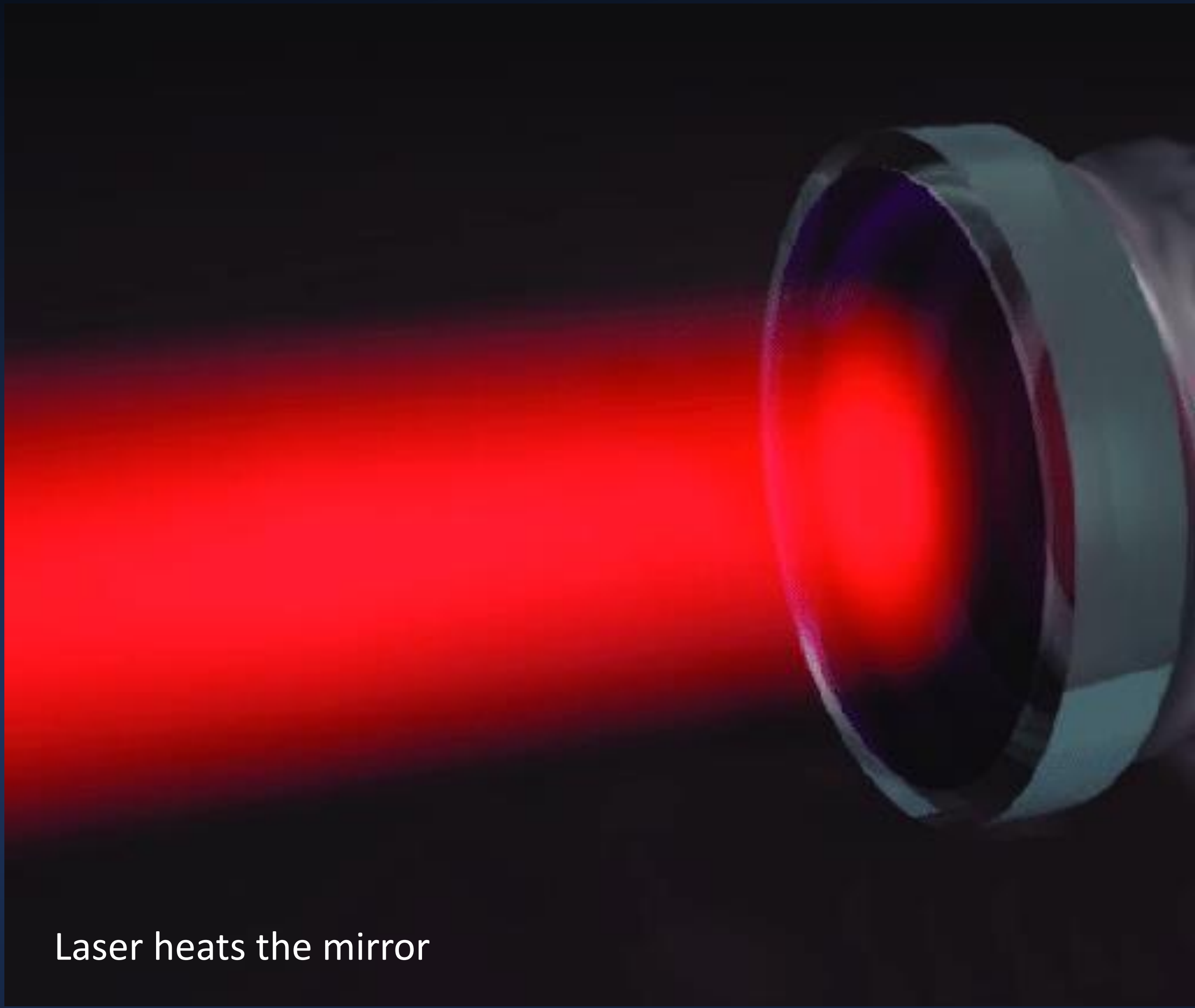
Brownian motion cause the reflective layers to move

Thermal Noise

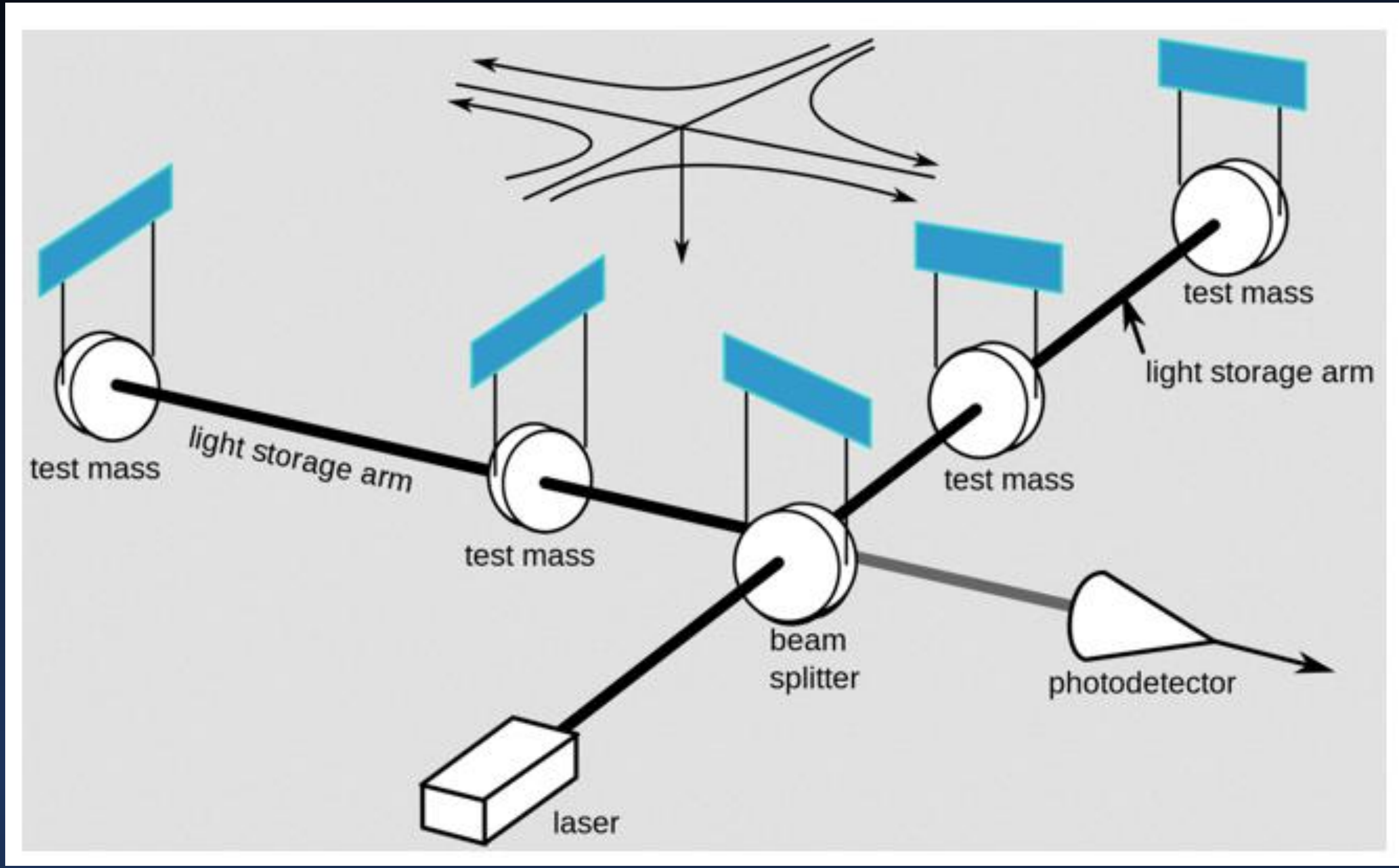
cool the mirror to 10 K

improve reflectivity – reduce absorption

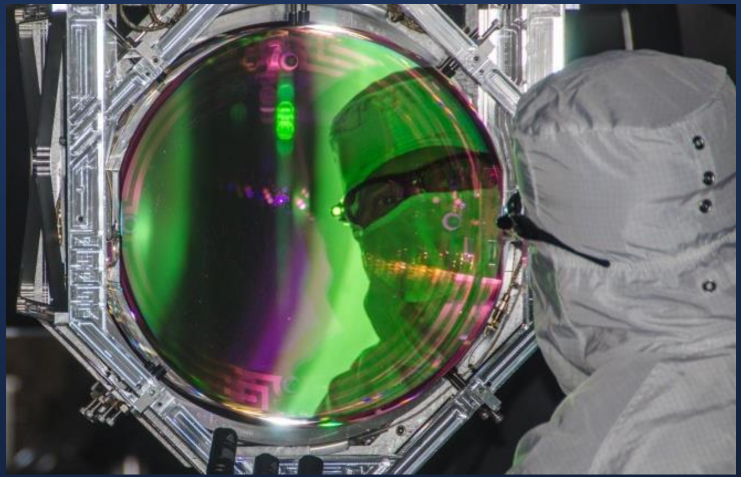




GW-Interferometer



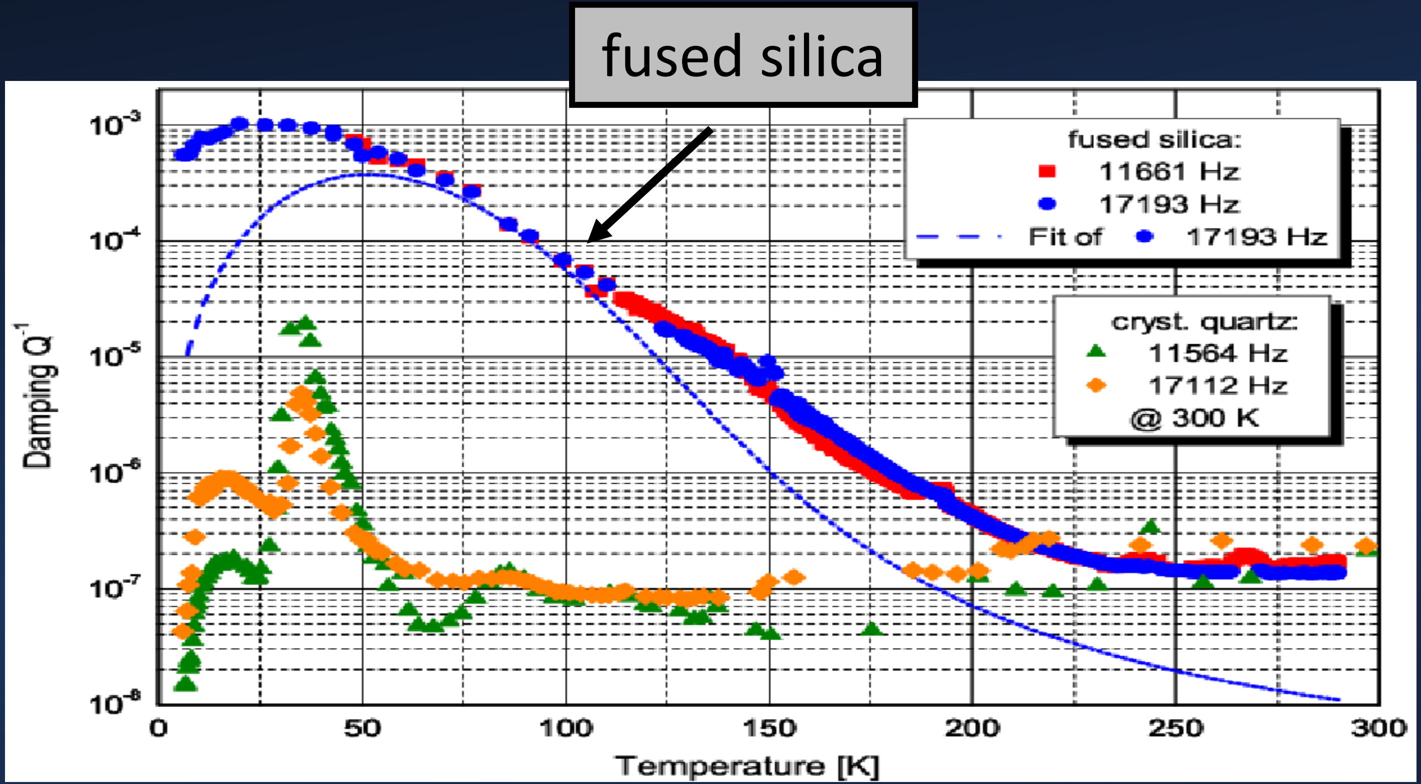
ET-LF: mirrors
Silicon
Ø 40 … 60 cm / 200 kg
18 kW laser power
Temperature 10 … 20 K

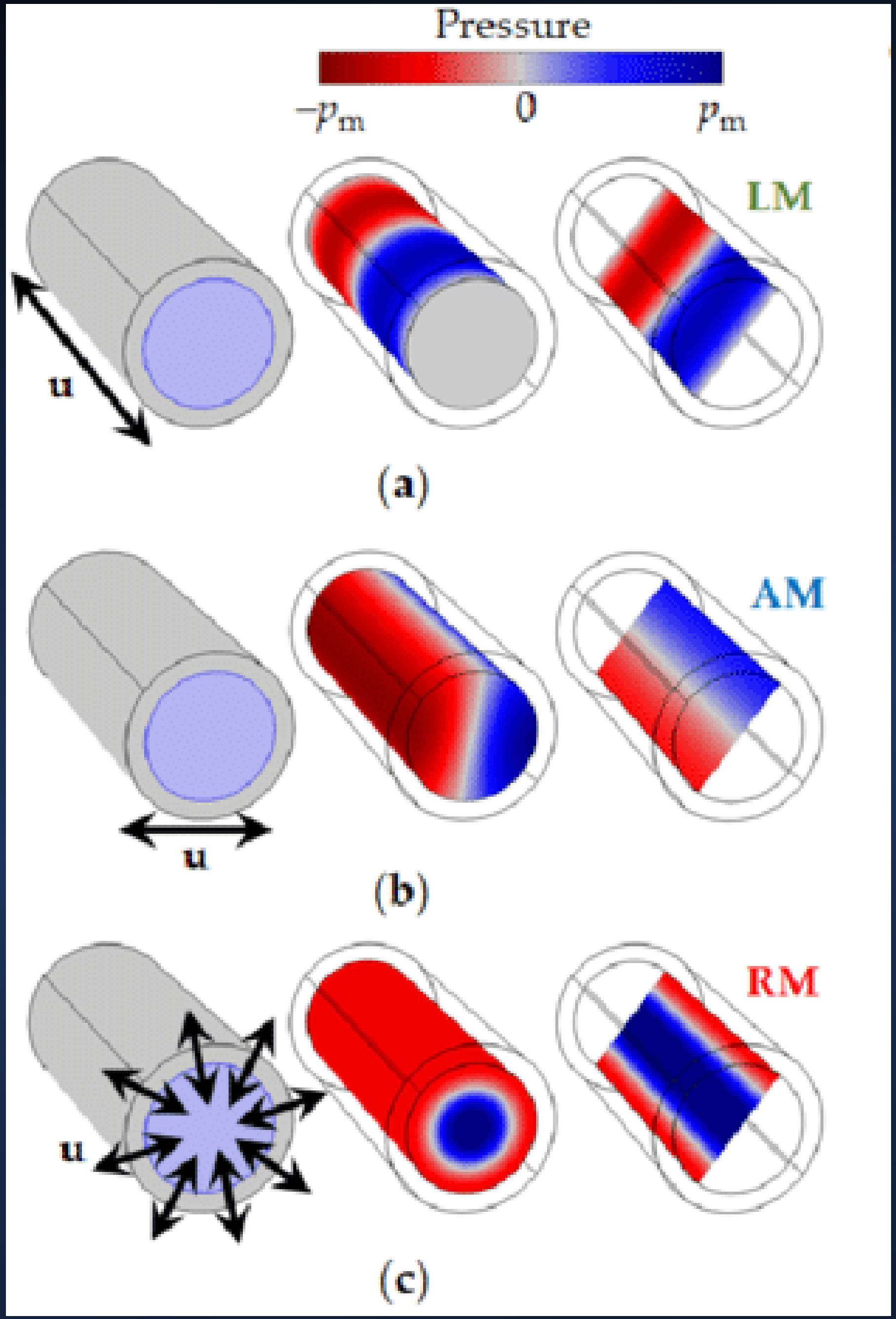


LIGO mirror

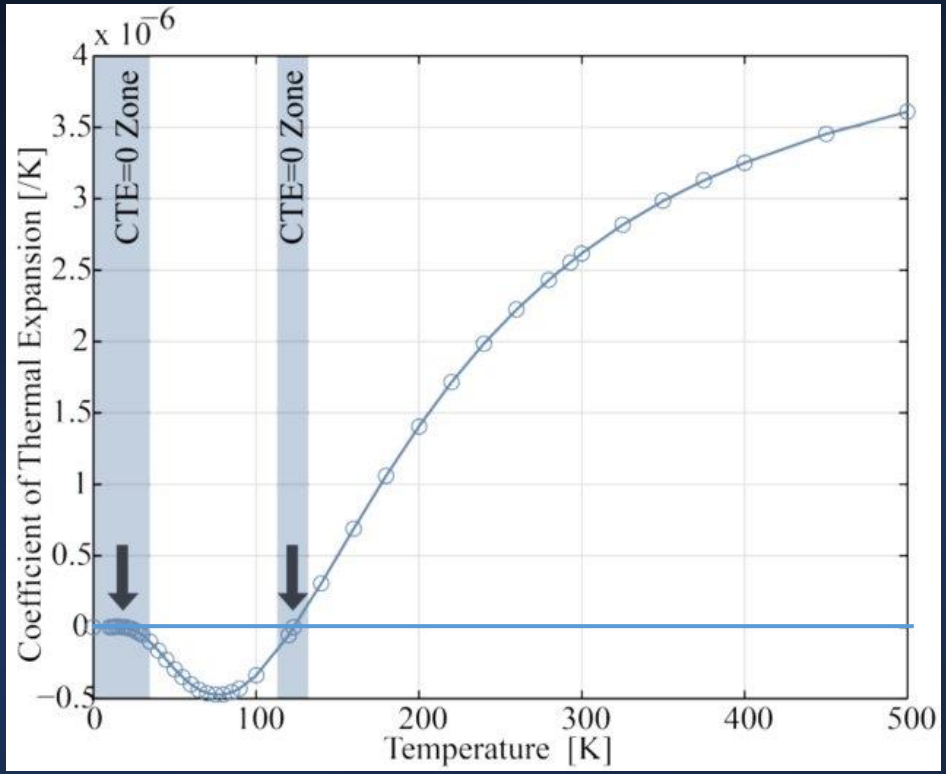
Collective Modes

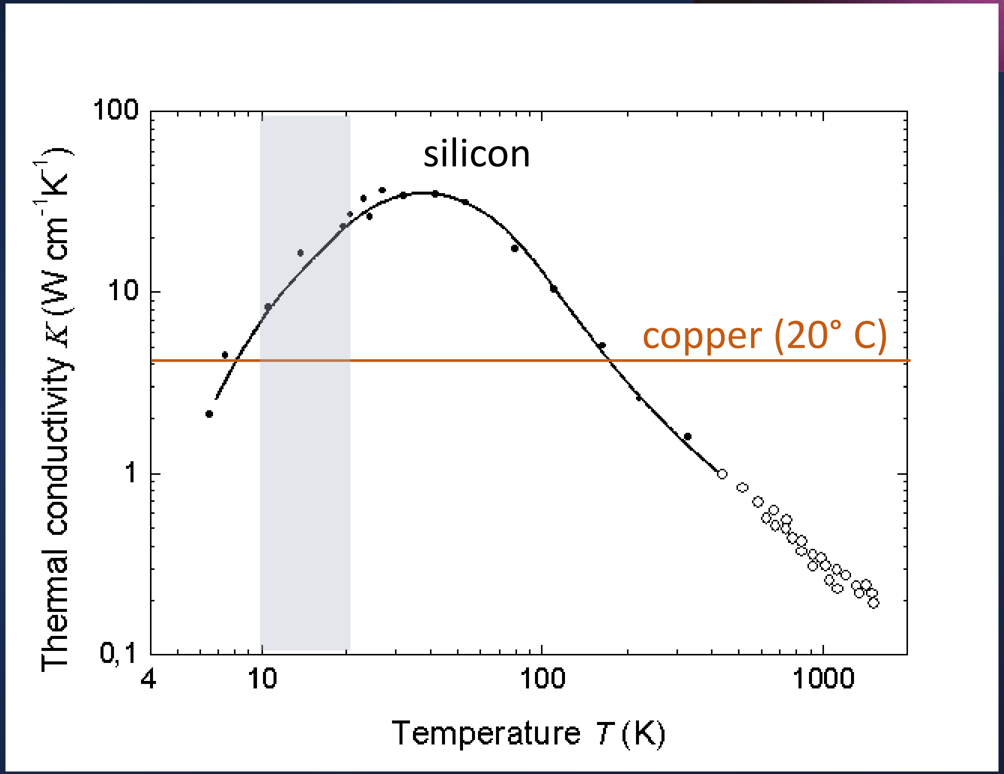
Low mechanical loss (high Q-value)
→ low coupling of collective modes
to thermal bath



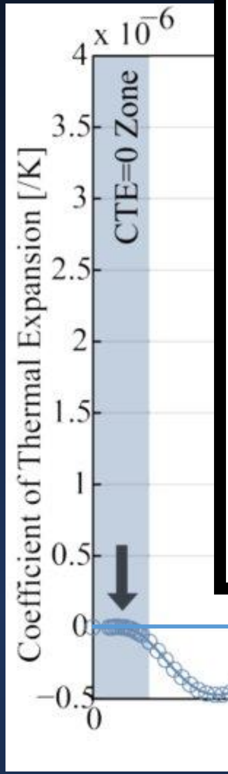


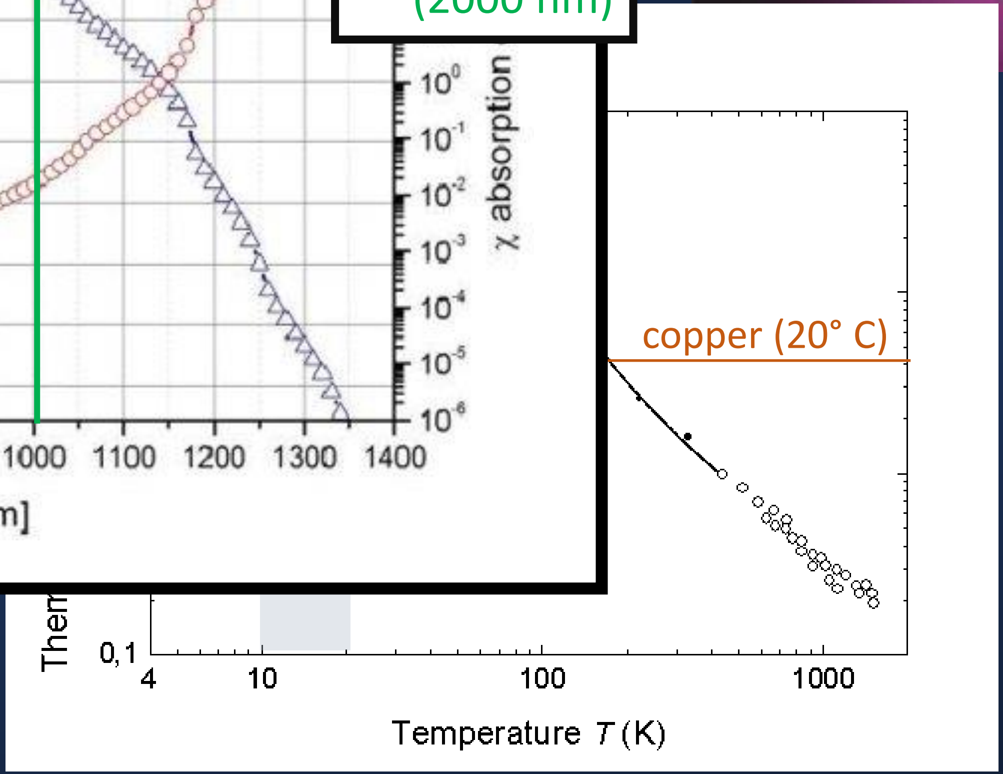
Silicon Mirrors

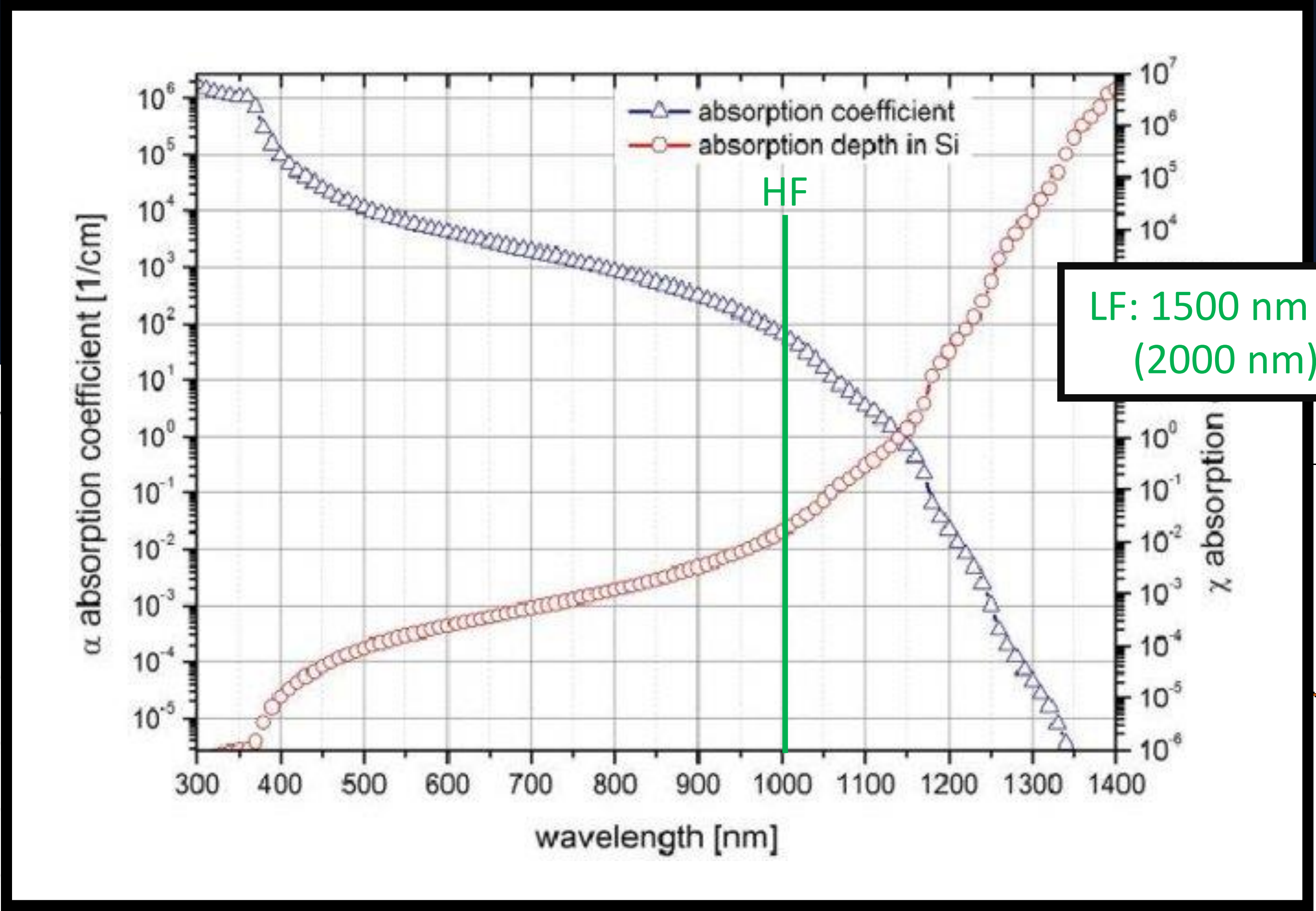




Silicon Mirrors

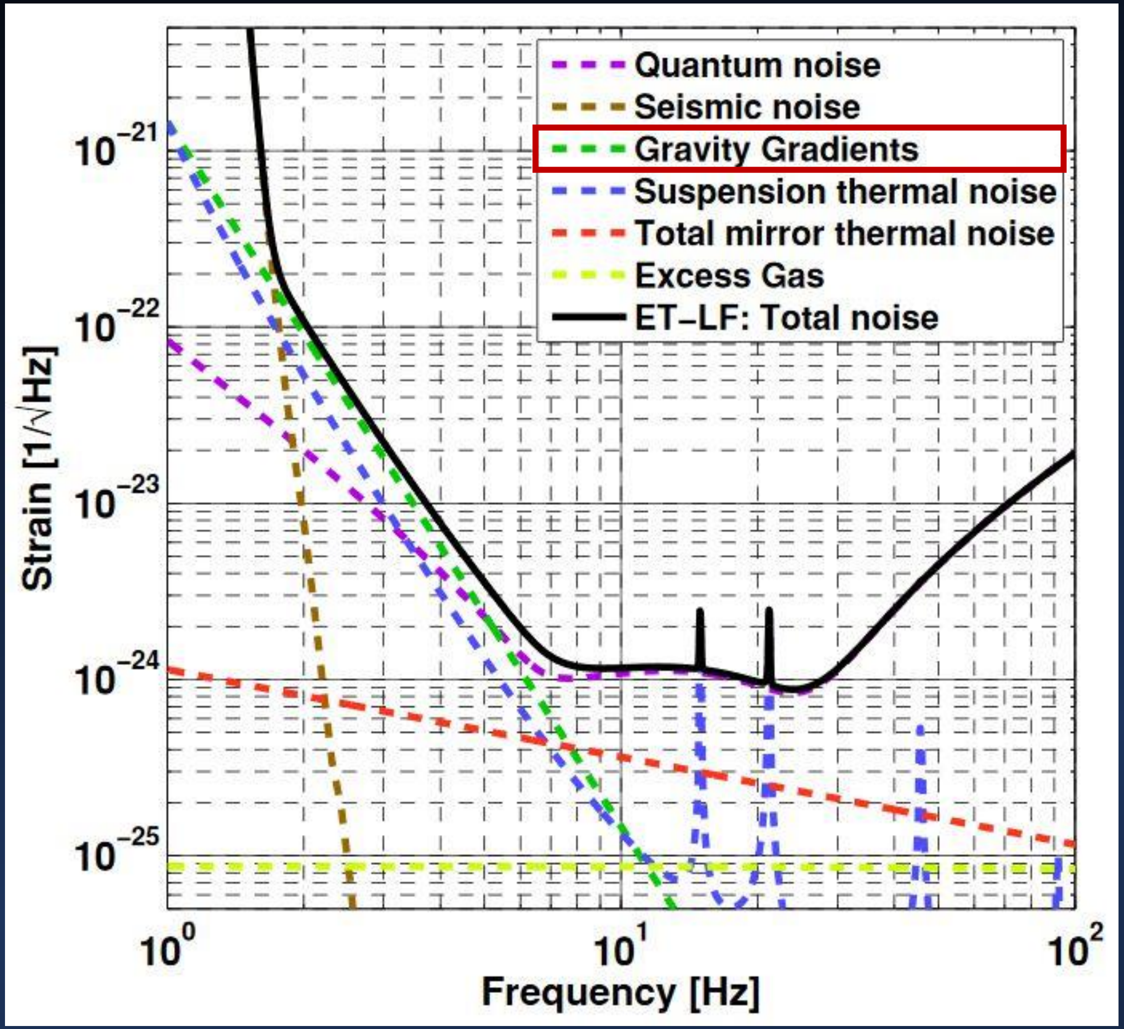


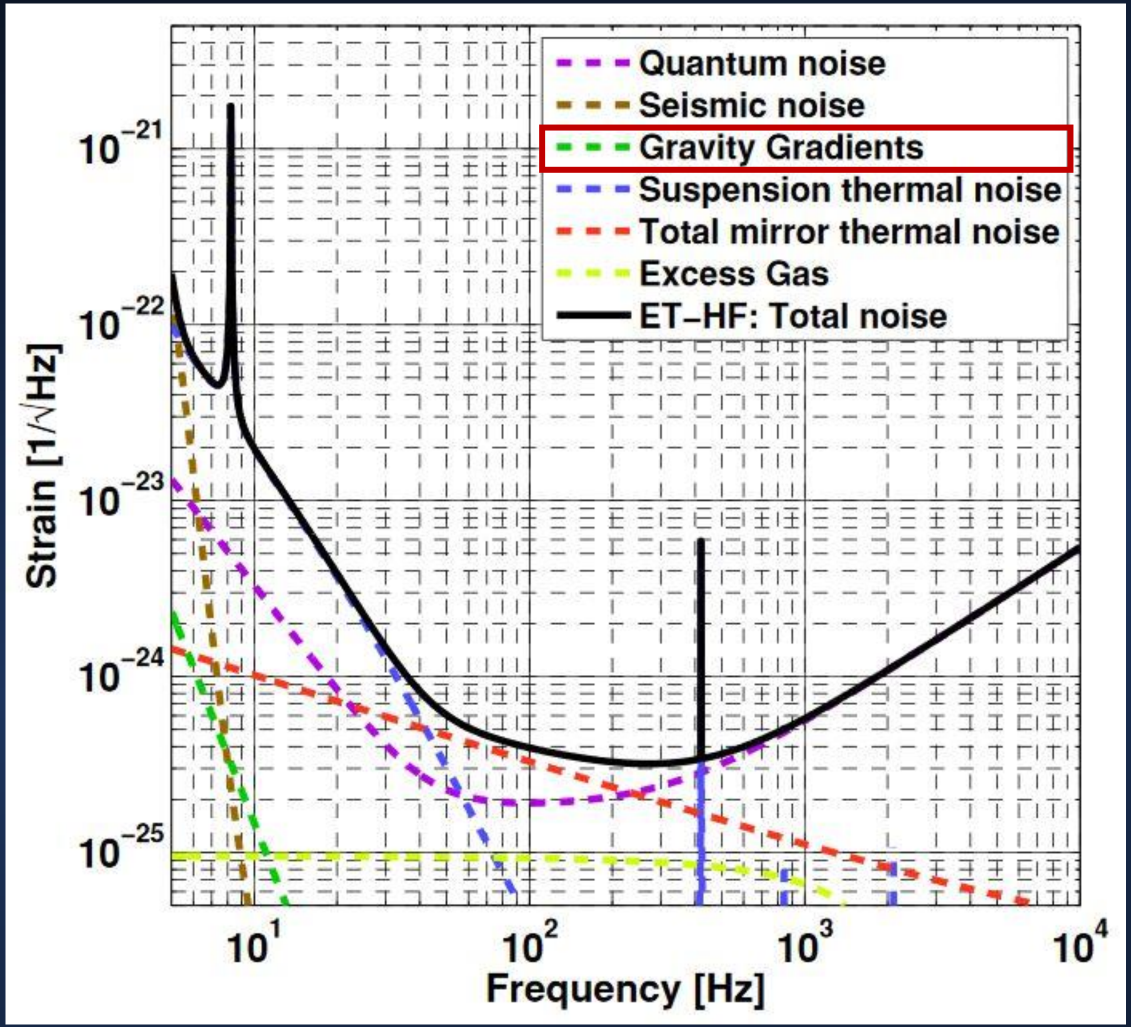




LF: 1500 nm
(2000 nm)

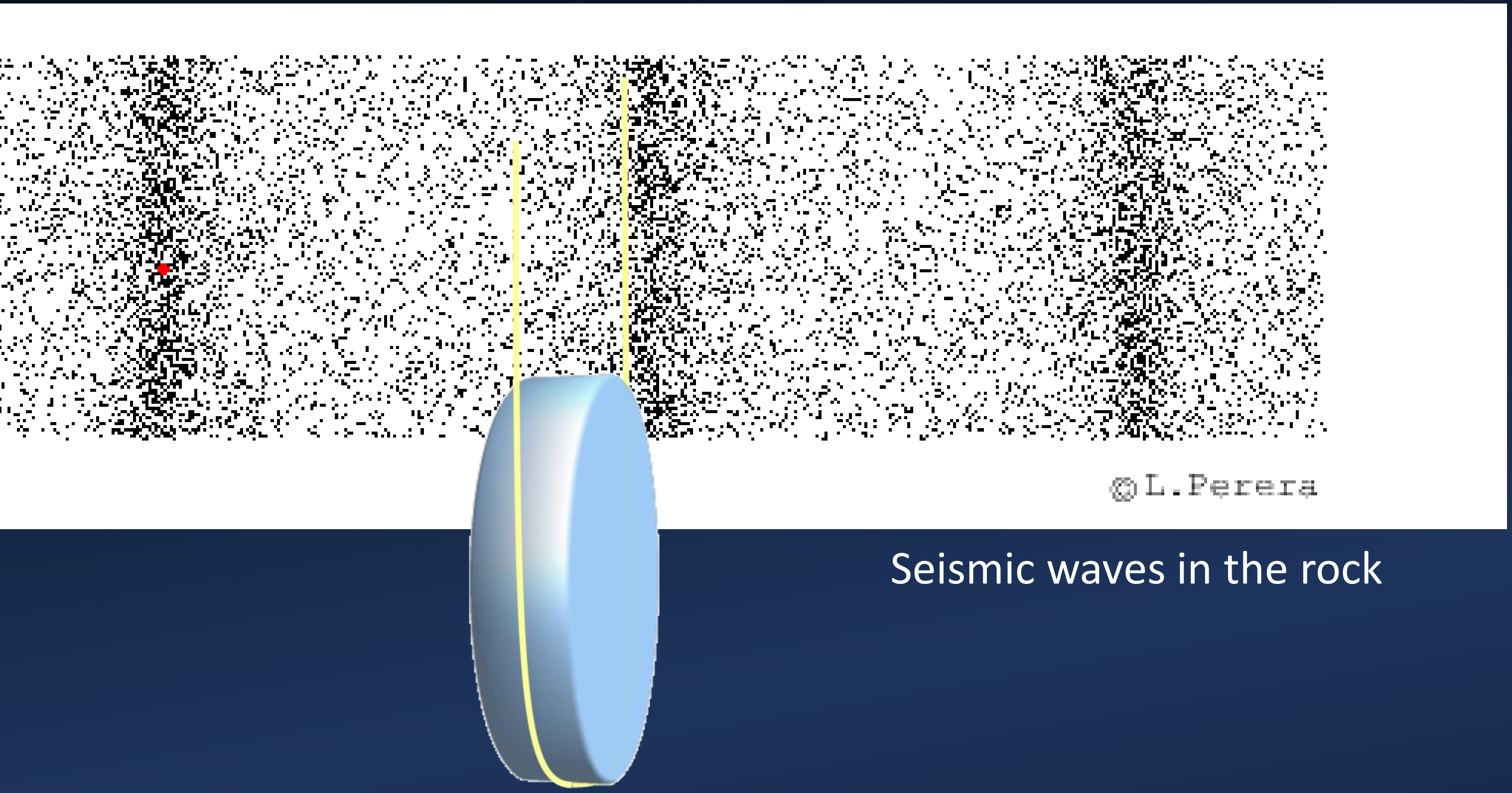
Understanding the noise





Newtonian noise / Gravity Gradient Noise

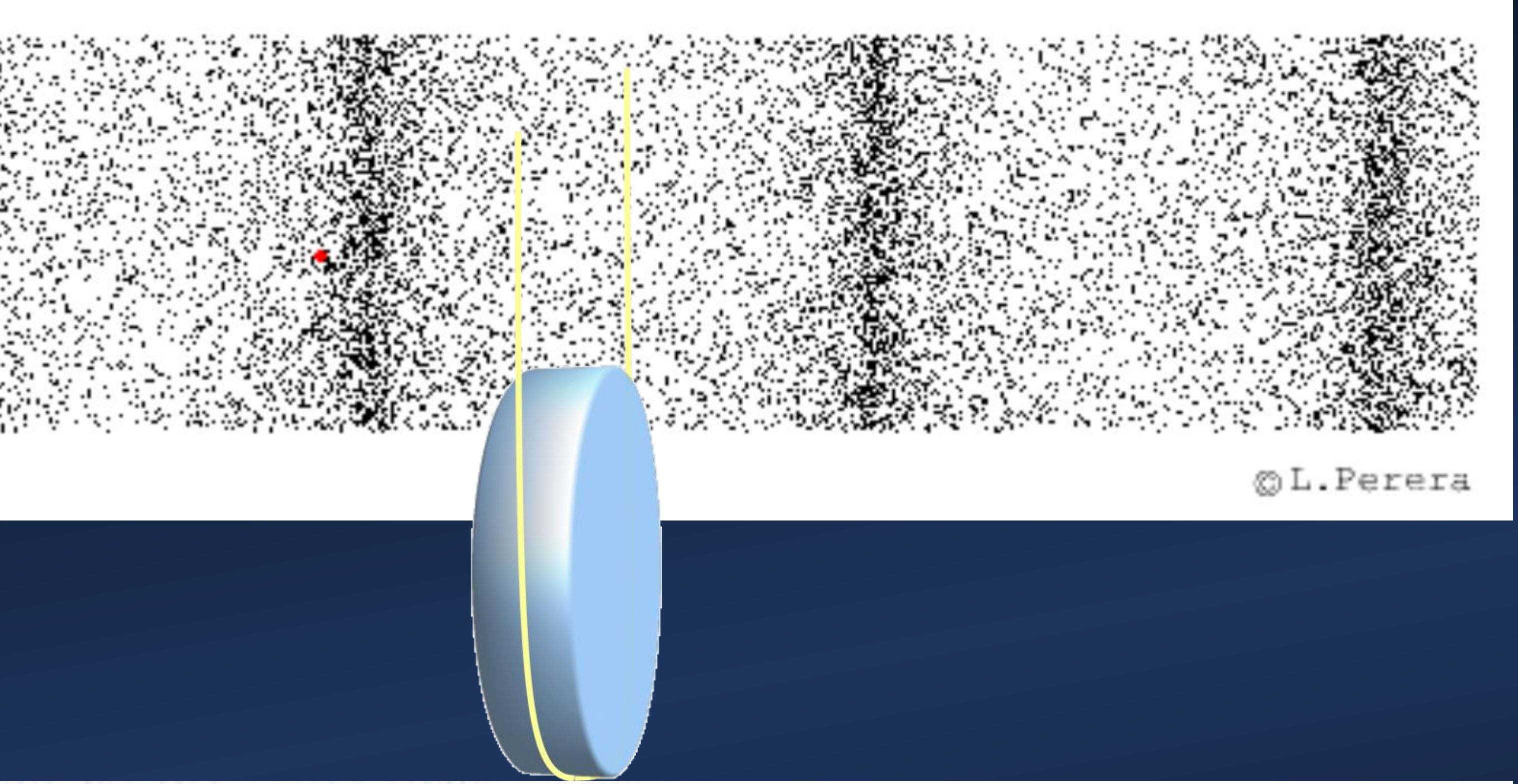
Attraction by moving objects cannot be shielded



Seismic waves in the rock

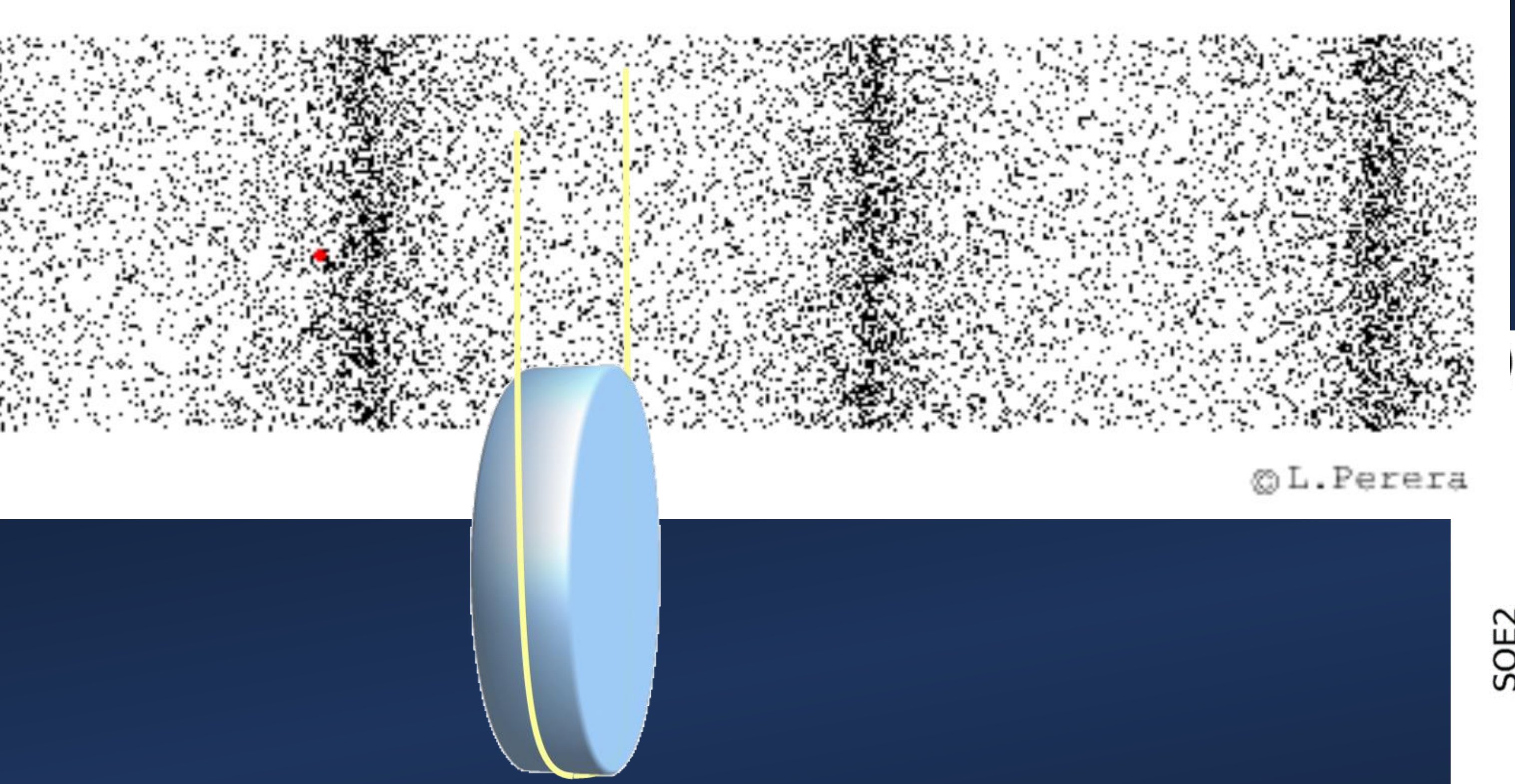
Newtonian noise

Attraction by moving objects cannot be shielded



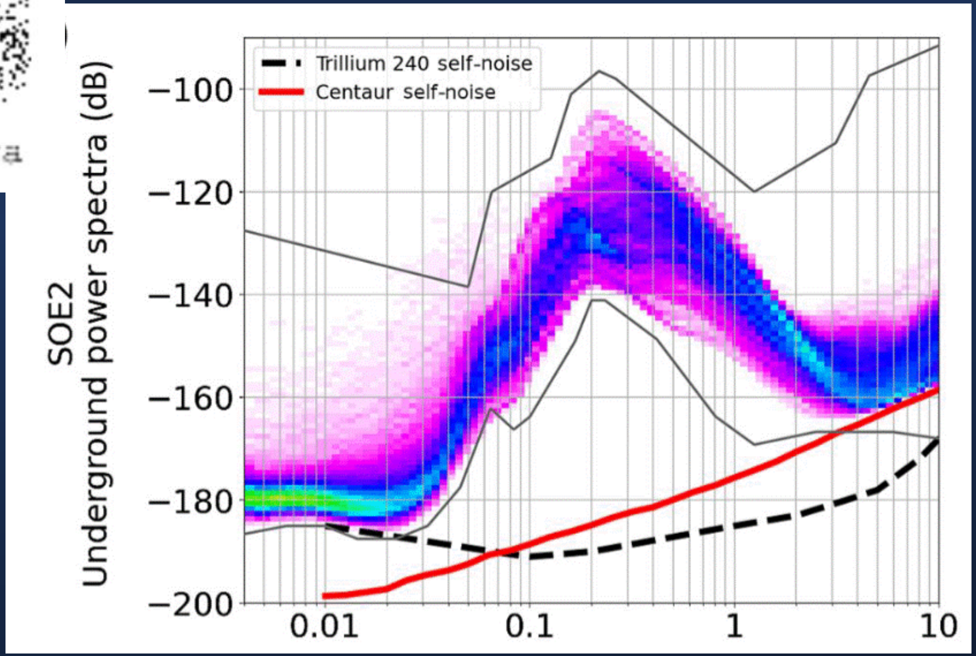
Newtonian noise

Attraction by moving objects cannot be shielded



Find a quiet location !

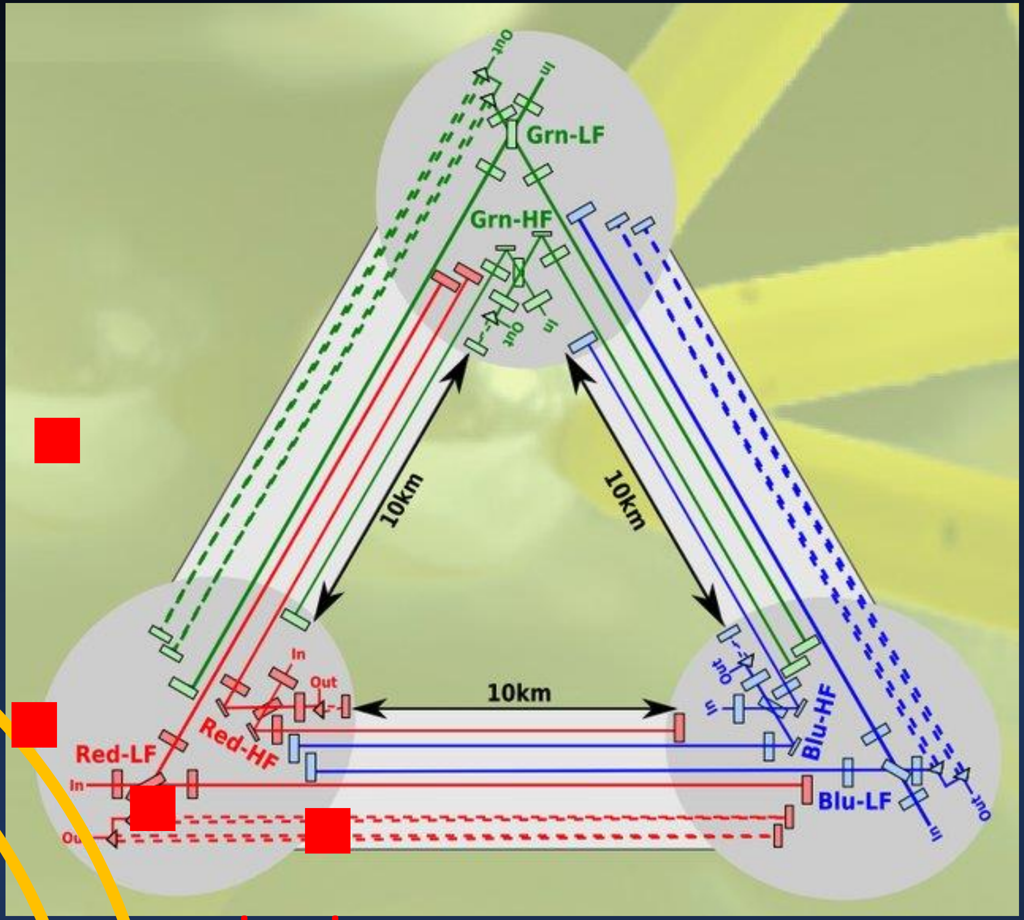
Los Enatos Sardenia

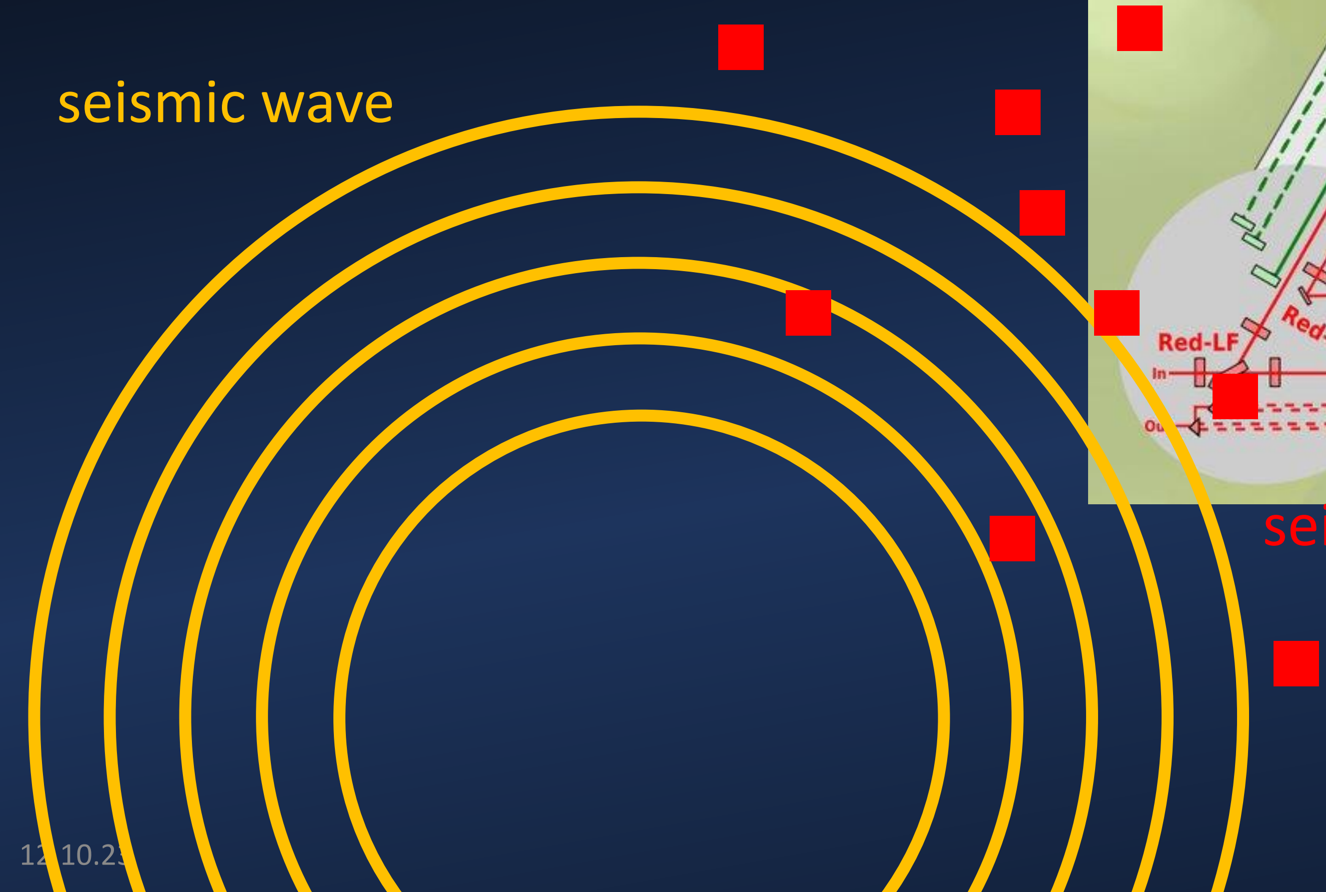


frequency [Hz]

Newtonian noise

Active Noise Mitigation





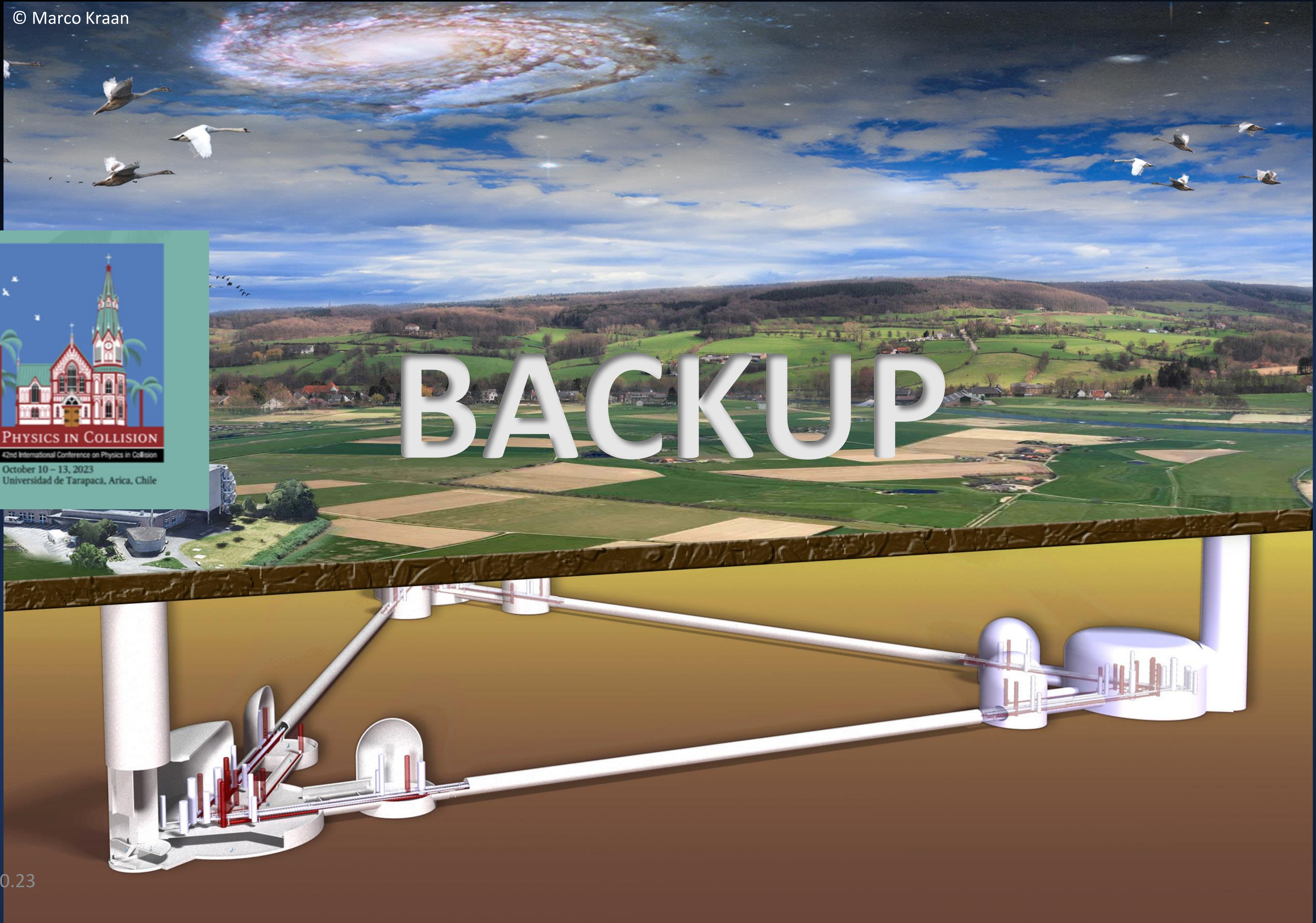
- wave field reconstruction
- active compensation
- test at DZA underground lab

Einstein Telescope

Conclusion

- The next generation of Telescopes will open new horizons in GW astronomy.
- Higher, omnidirectiononal sensitivity, lower frequencies, access to polarization.
- Interesting technological challenges.

Approval soon ?



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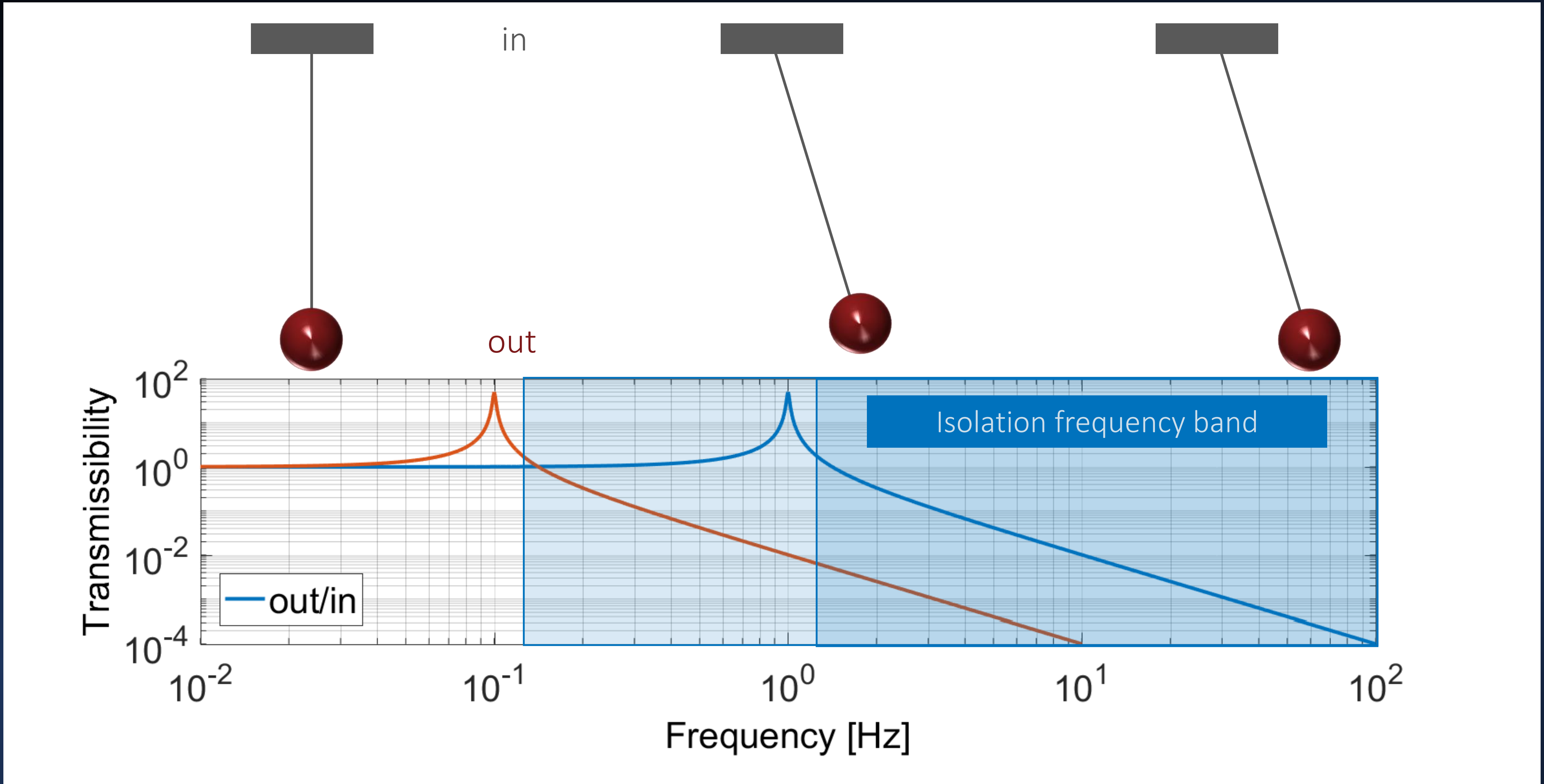
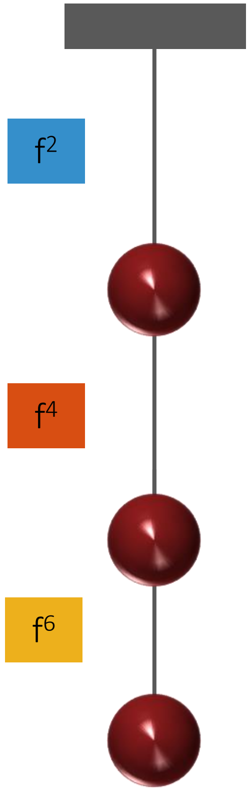
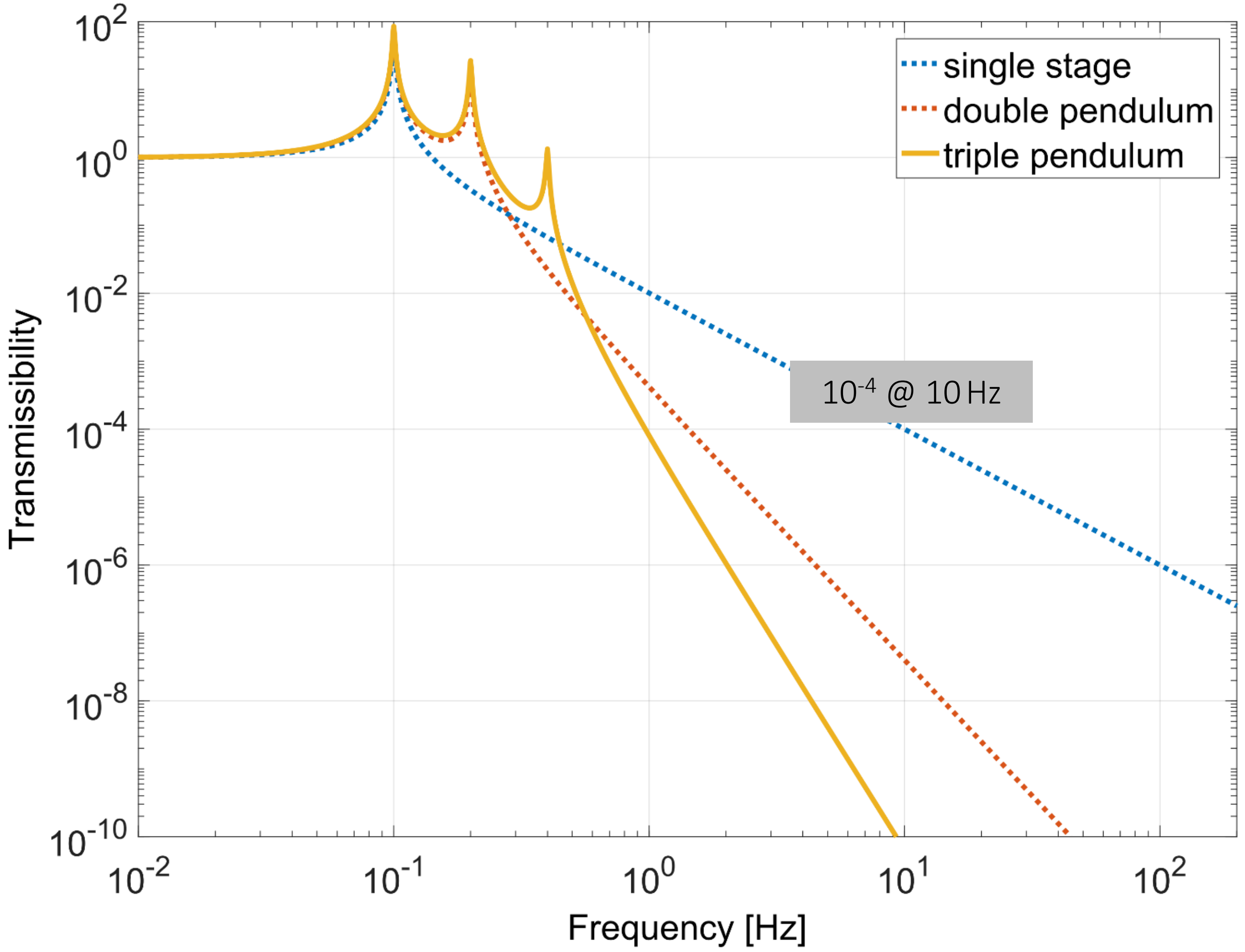
BACKUP

Seismic Isolation

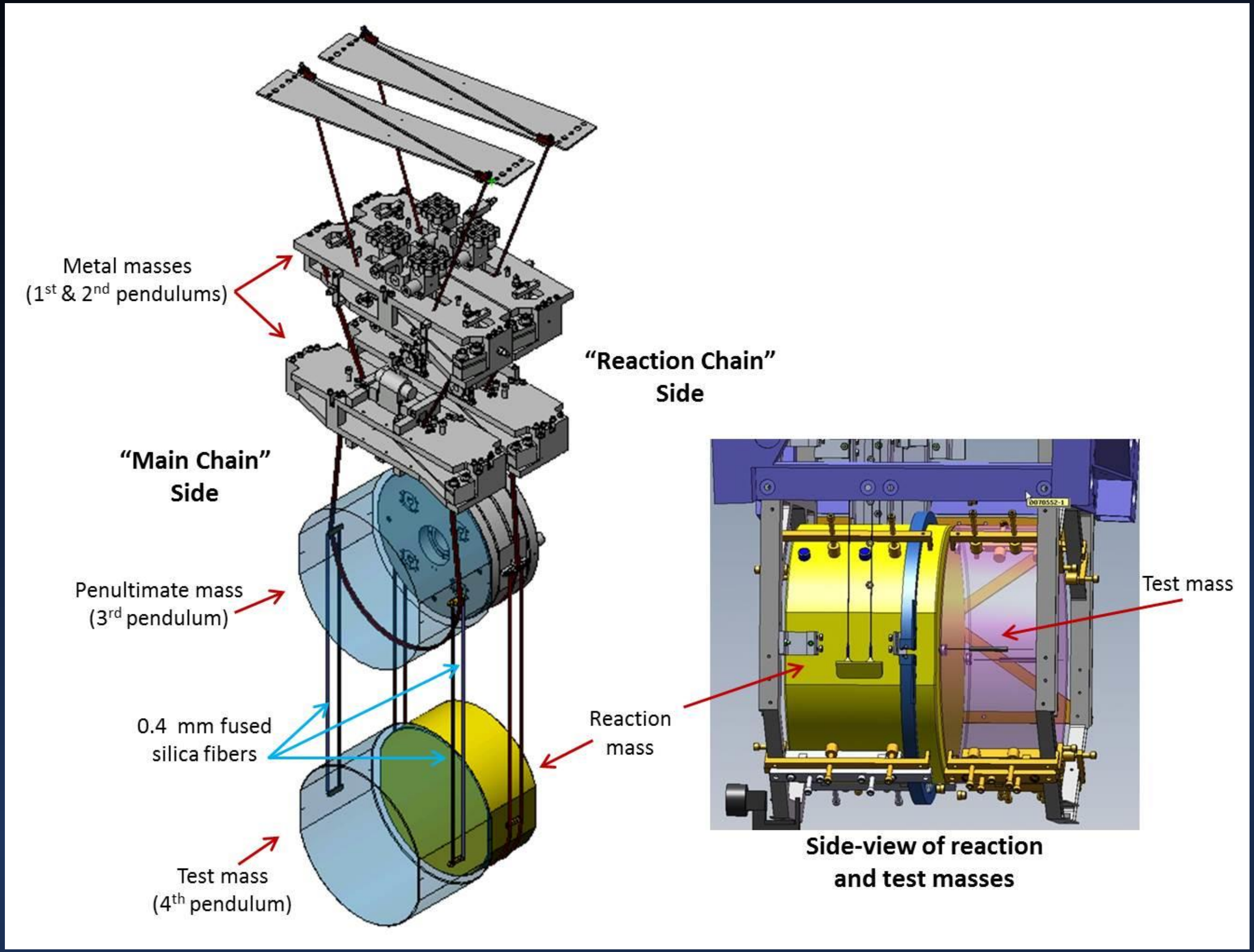


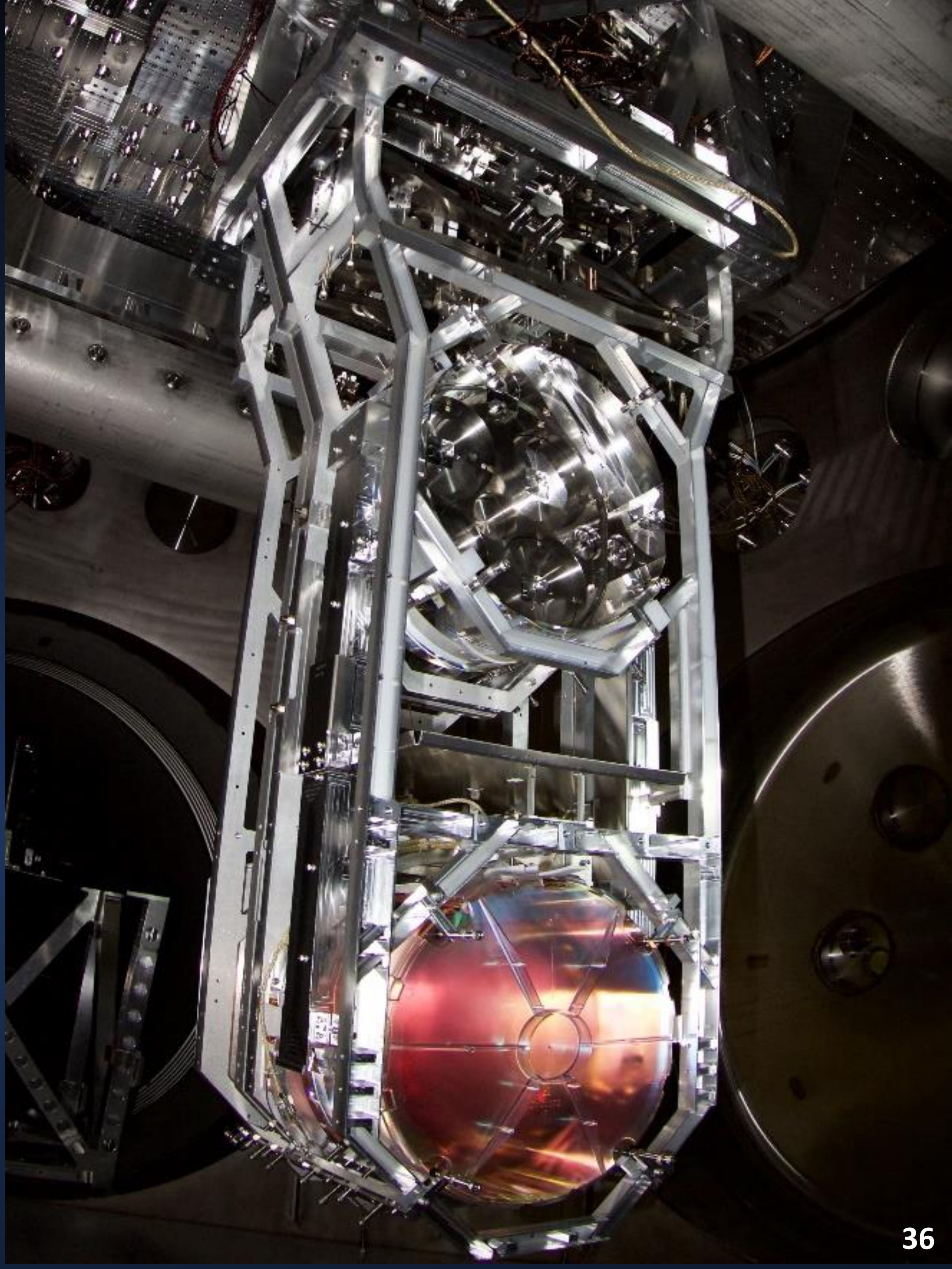
Seismic Isolation



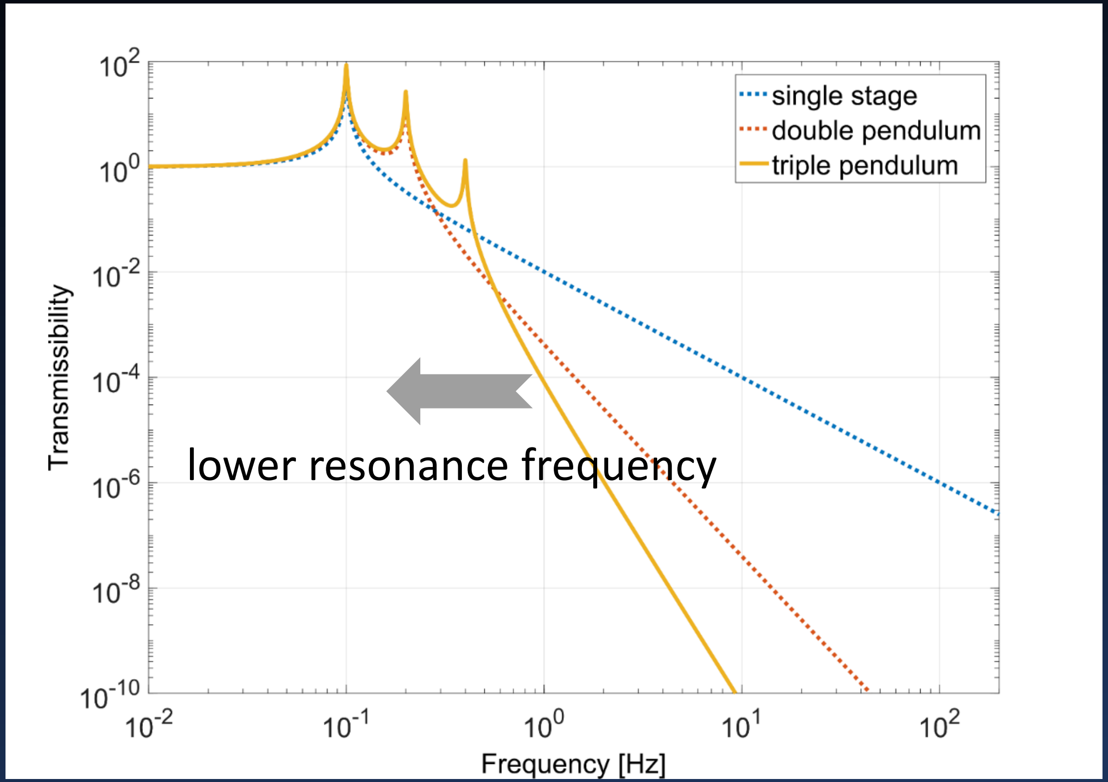


Seismic Isolation





Seismic Isolation



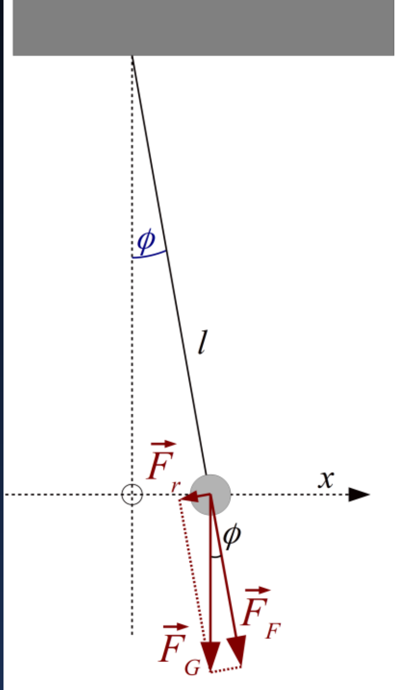
resonance frequency: $\omega_0 = \sqrt{g/l}$

mathematical pendulum

$$m \frac{d^2x(t)}{dt^2} = -k\, x(t)$$

$$\Rightarrow \omega_0 = \sqrt{k/m}$$

make k small! (here $\mathrm{k} = mg/l$)



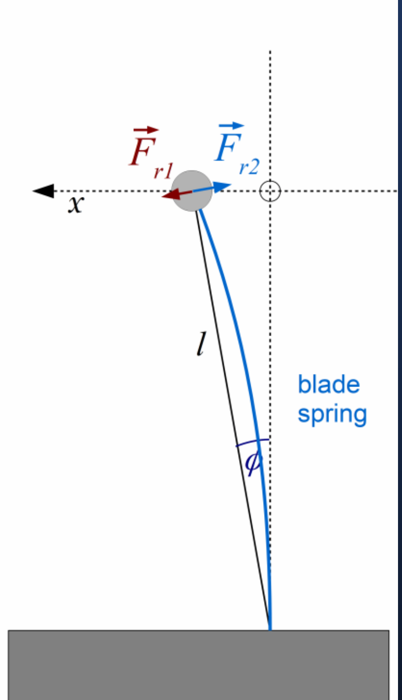
inverted pendulum

$$m \frac{d^2x(t)}{dt^2} = +k\, x(t)$$

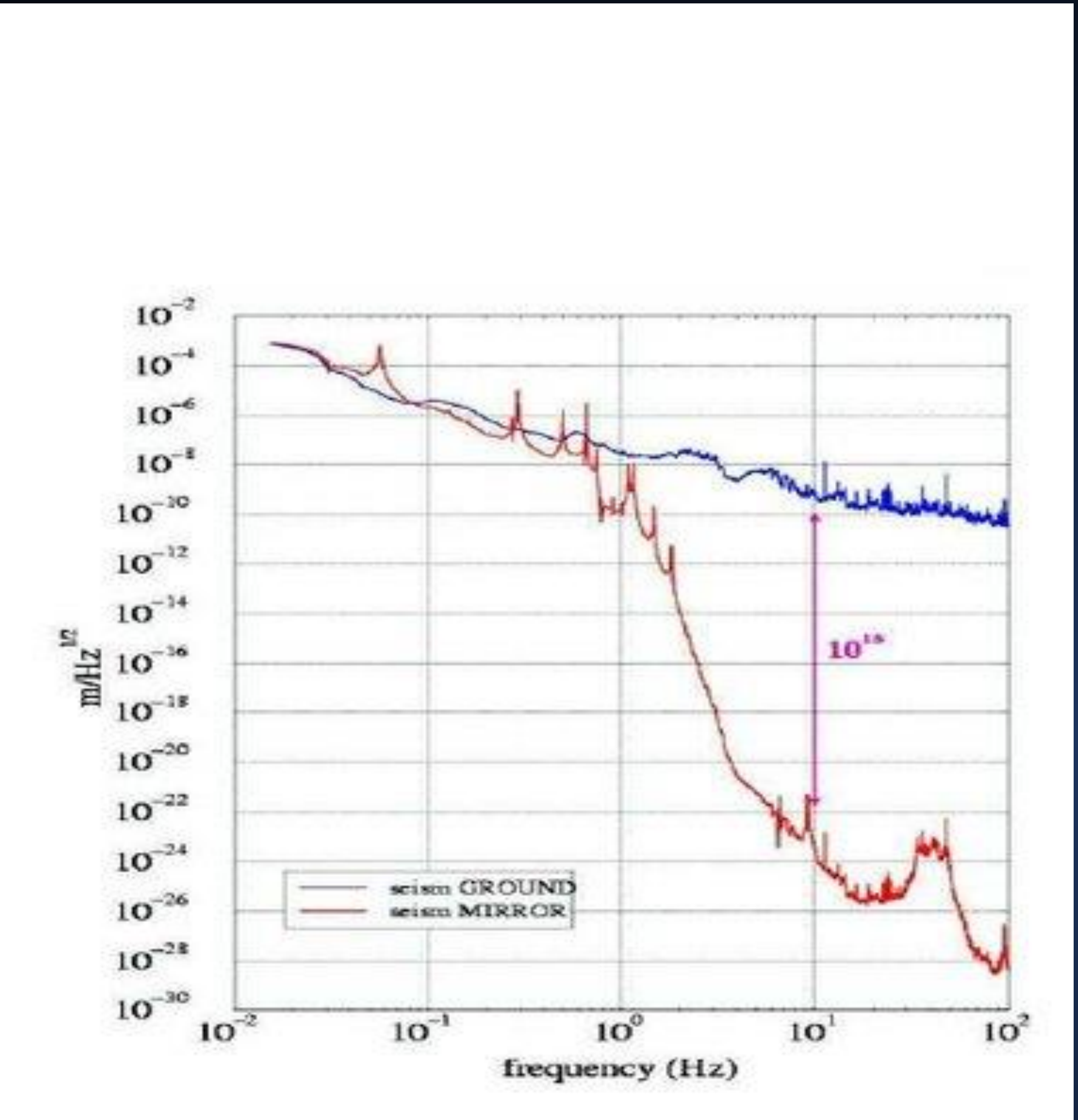
add a blade spring

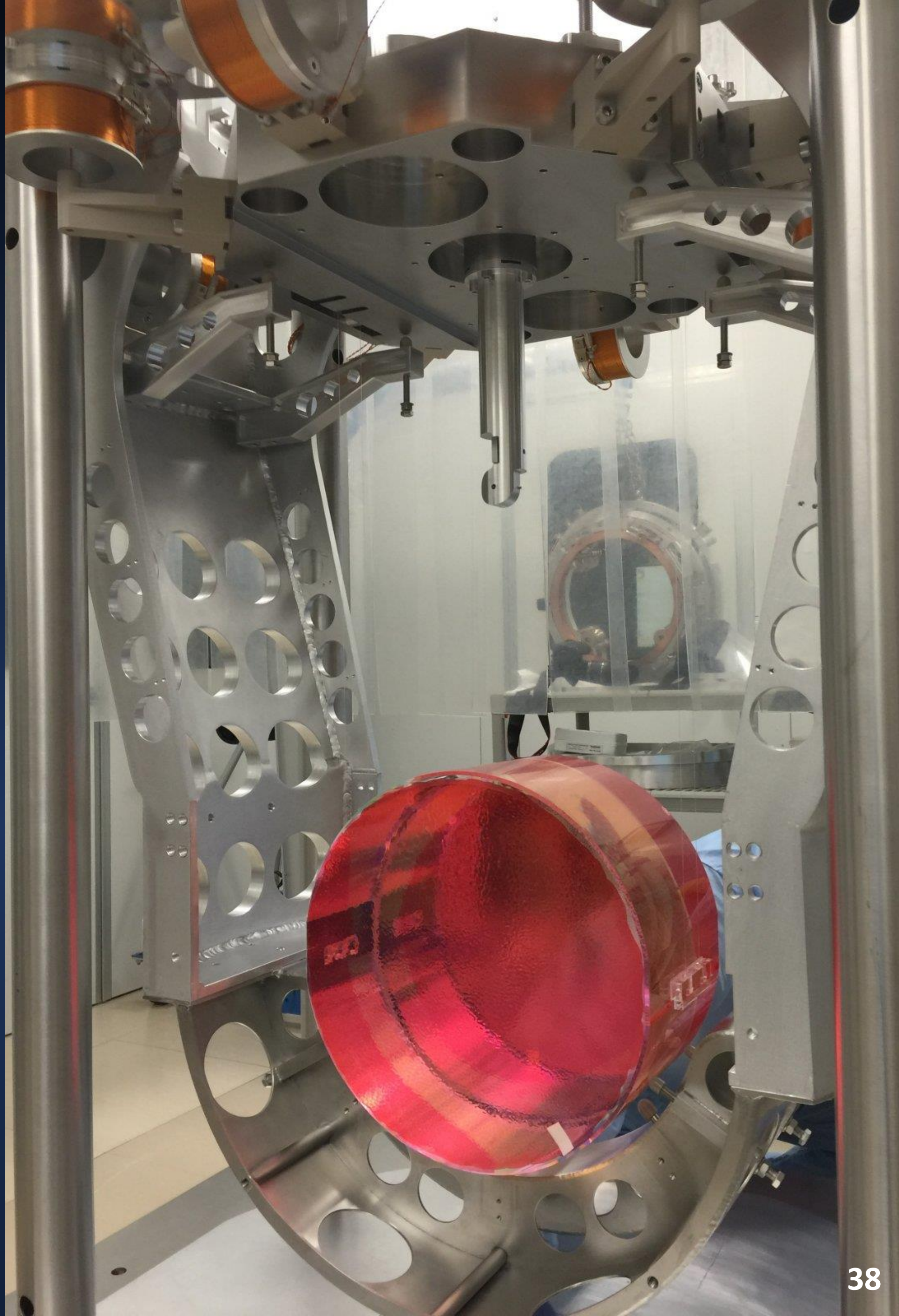
$$m \frac{d^2x(t)}{dt^2} = \underbrace{(k_1 - k_2)}\, x(t)$$

make small!



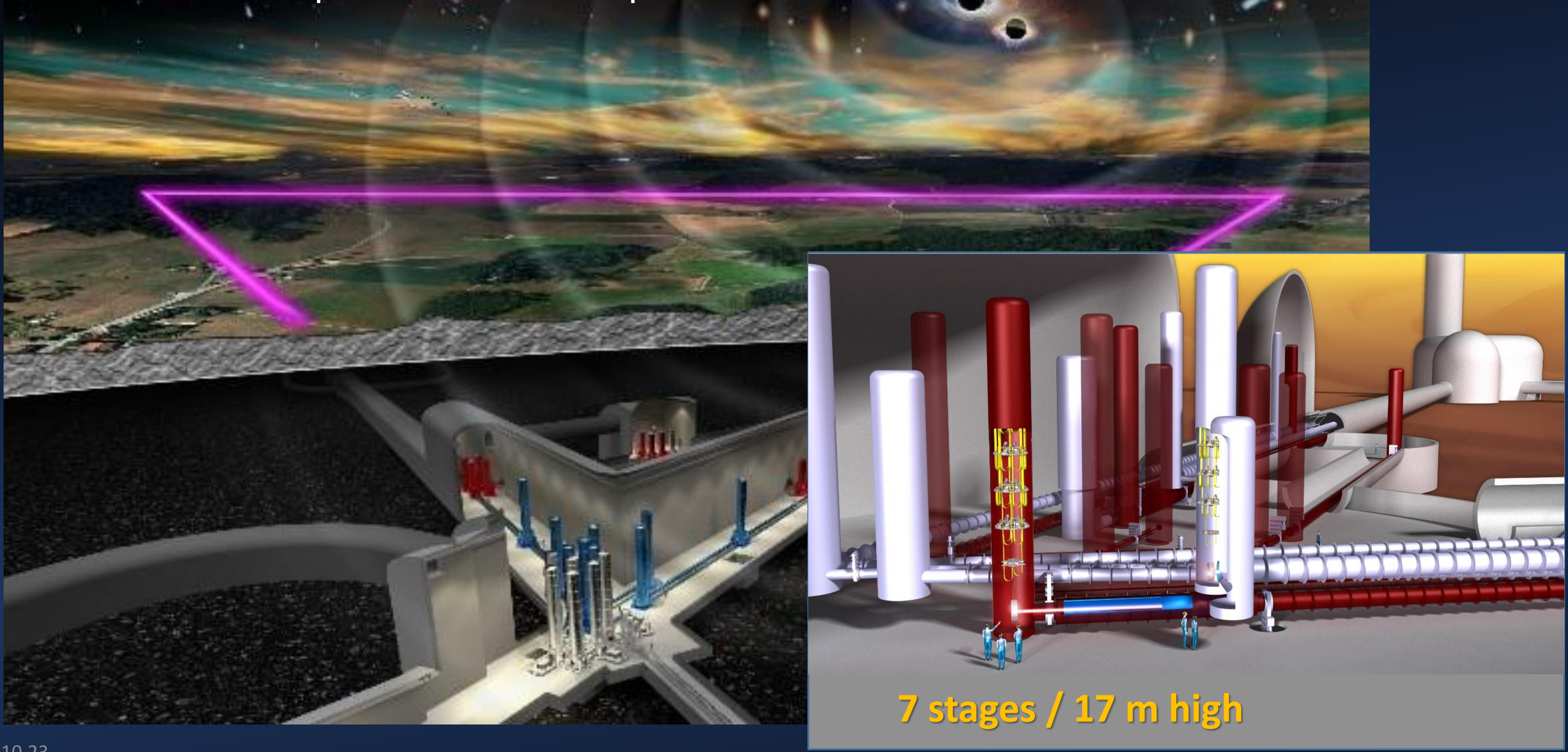
VIRGO Superattenuator





ET seismisc isolators

follow the concept of the VIRGO superattenuator



Seismic Isolation: Geometric Anti-Spring Filters