Seismic Isolation Systems for next-generation Gravitational Wave Detectors

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Gravitational Wave Astronomy is revolutionizing our understanding of the Universe, opening **a new frontier in the exploration of cosmic phenomena**. Third-generation ground-based gravitational wave interferometers will play a crucial role: **the Einstein Telescope (ET)**, expected to be built in Europe in 2030's, will be an order of magnitude more sensitive than current interferometers like Advanced Virgo, LIGO and KAGRA.

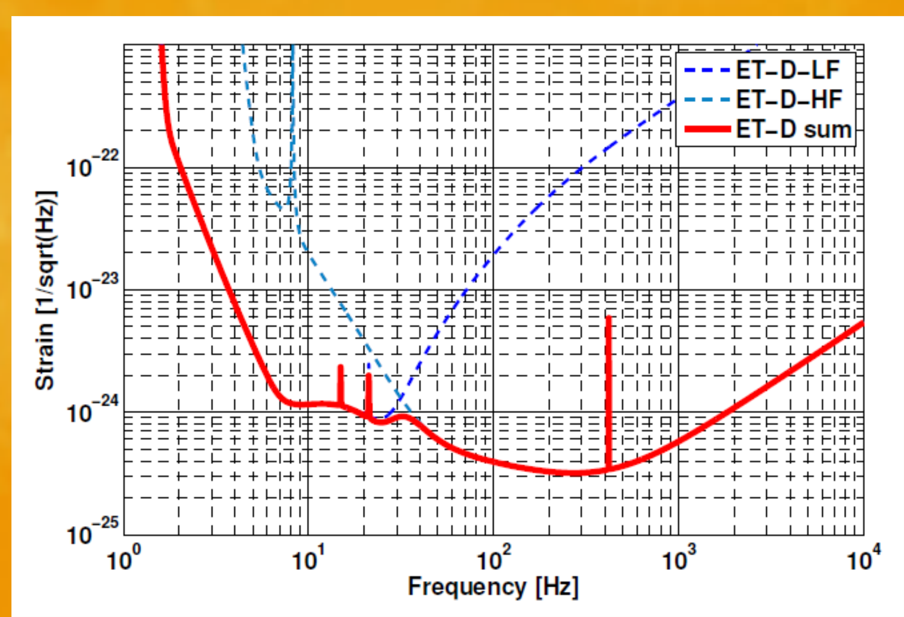
Low-frequency sensitivity will allow the detection of binary compact coalescences up to high redshift, improve the capability to study intermediate-mass black holes and enhance early alerts of binary neutron star coalescences.

As we strive for **increasing detection capabilities in a frequency range extending down to 3 Hz**, mitigating **low-frequency noise** sources becomes crucial. Superattenuators are precision mechanical devices designed to isolate gravitational wave detectors from seismic and thermal disturbances, relying on **passive and active noise mitigation**. Designing **new-generation seismic attenuation systems** is crucial to achieve desired sensitivity at low frequencies. The optimization of prototypes of passive seismic isolation for the Einstein Telescope also passes through **decreasing the size**, thus significantly reducing the amount of underground civil works needed.

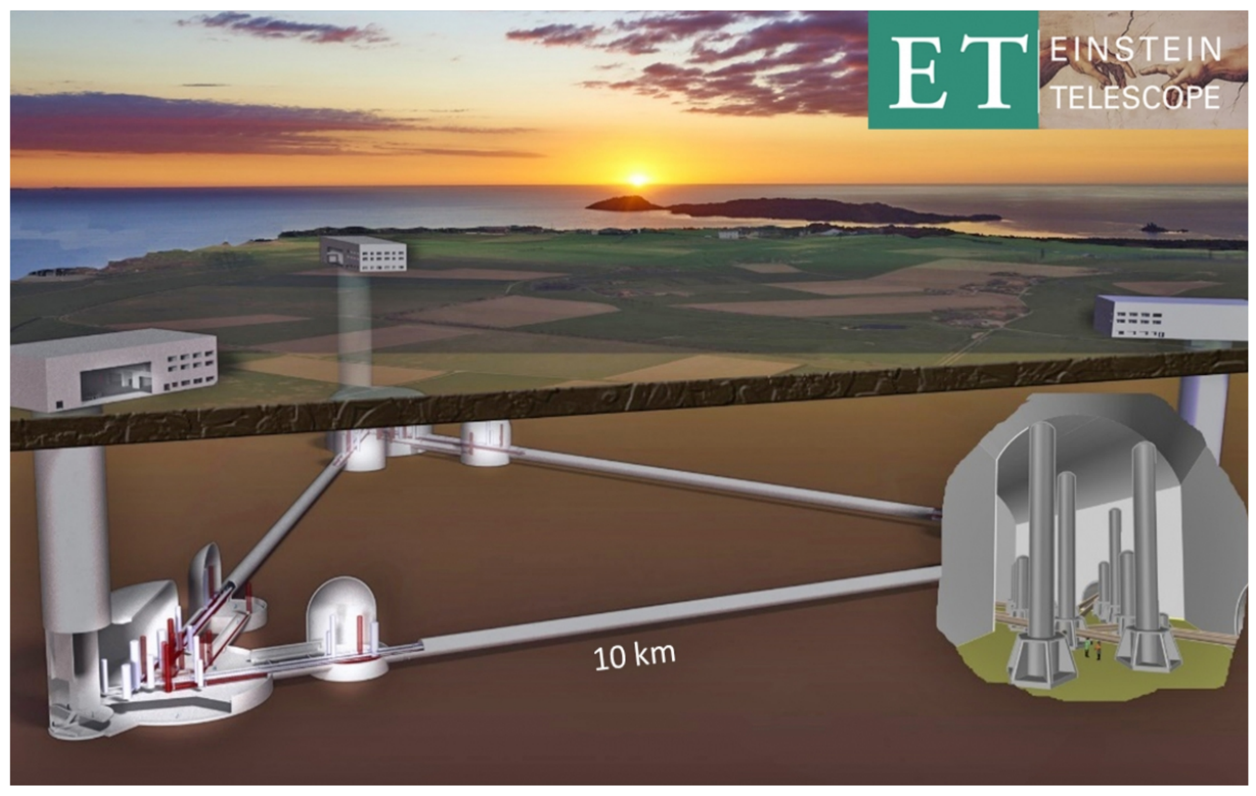
The Einstein Telescope and the 3G ground-based interferometers

Third-generation ground-based interferometers will open a new windows on the Universe

- Einstein Telescope [1] and Cosmic Explorer [2] will be 10x more sensitive with respect to Advanced Virgo and LIGO
- Could be operative in the mid 2030's
- Extend the sensitivity band down to 3 Hz
- Capable of detecting high-z black holes, opening Gravitational Wave physics to cosmological distance
- Discovery potential in astrophysics, cosmology and fundamental physics [3]



Sensitivity of the Einstein Telescope [3]

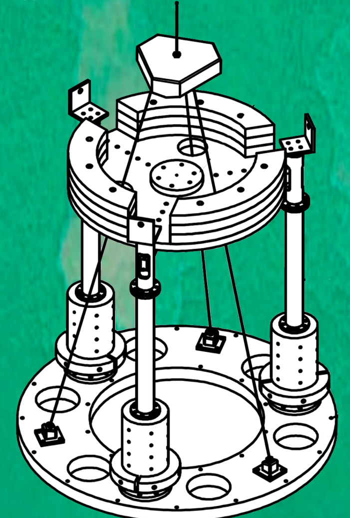


An artistic view of the Einstein Telescope

Pendulum-Inverted Pendulum

Black Holes for ET in SArdinia (BHETSA) is a 3-year PRIN project aimed at designing an efficient suspension system for the Einstein Telescope

- Goal: suspension system for ET at frequencies above 2 Hz with height of about 10 m (similar to Virgo superattenuator)
- Improve over the 17-m high current suspensions for ET, reducing civil engineering works and costs
- Upgrade of standard mechanical filter and inverted pendulum pre-isolator
- Suitable for 50 years planned for ET



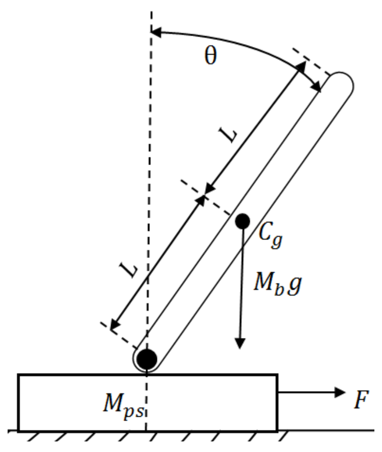
Simulation key ideas:

- Prototype under development and test in Pisa
- fine tuning of mechanical components
- computation of transfer function
- Octopyus Python simulator under development
- Study and optimize performance of prototype
- Based on impedance metric approach (developed by P.Ruggi@EGO)
- Easy and flexible for user

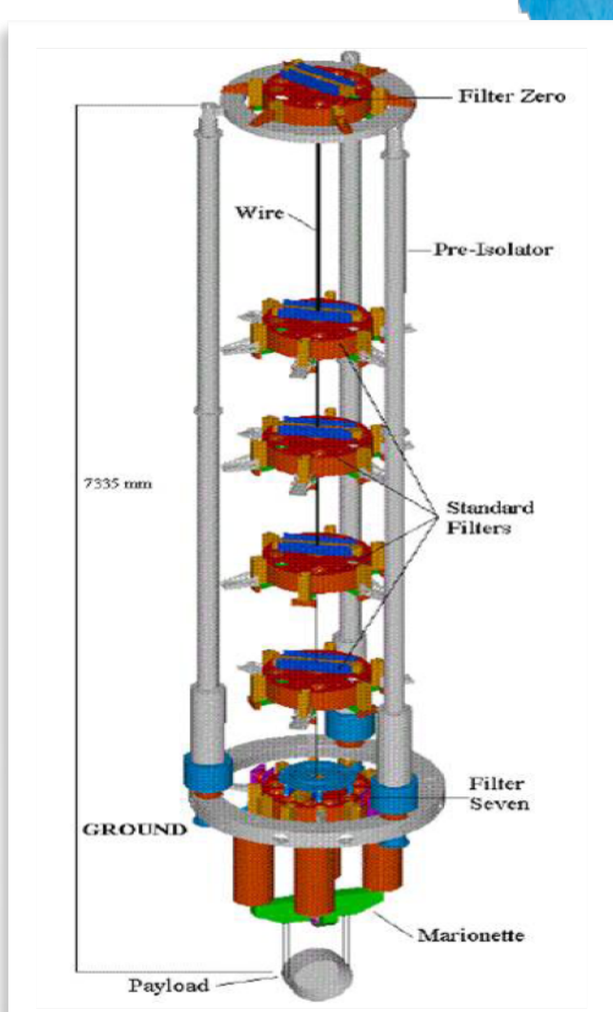
The inverted pendulum

consists of a rigid structure with a mass on top, pivoted at its base. It acts as a first-stage low-frequency pre-attenuation stage.

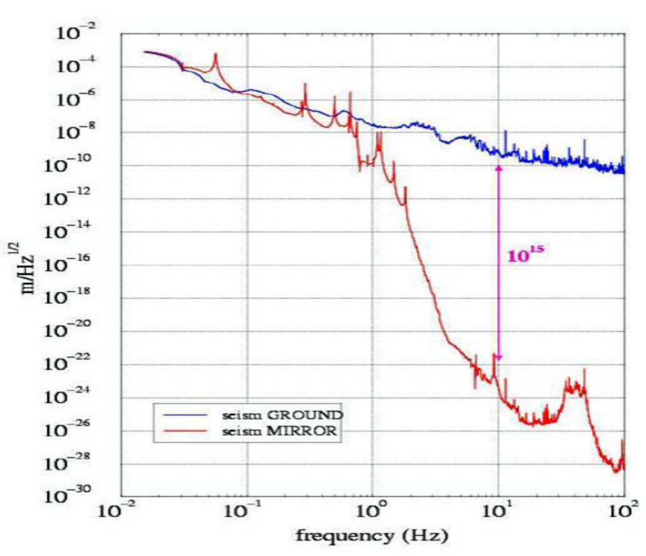
Higher attenuation power requires more filter stages and active control systems.



The Virgo Superattenuator is a multi-stage attenuation system providing seismic isolation across a broad frequency range, with both passive and active damping. The total length is about 10 m.



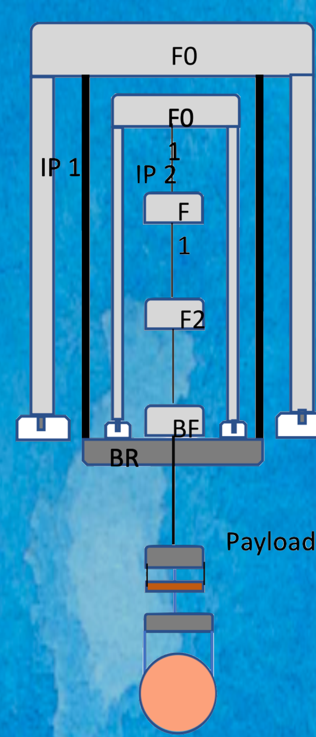
Attenuation capability reaches 15 orders of magnitude at 10 Hz [4].

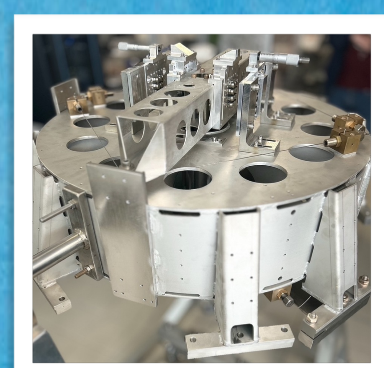


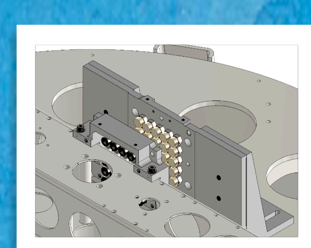
Nested Inverted Pendulum

New Generation Super Attenuator (NGSA) is a 3-year INFN project aimed at keeping the length of the ET Superattenuator below 10 m

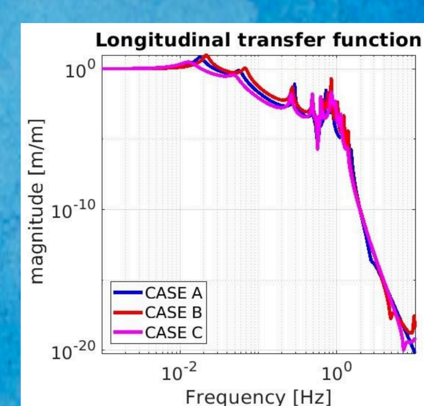
- Based on a two-stage Nested Inverted Pendulum (NIP)
- Advantages for the horizontal pre-isolation stages
- Vertical attenuation: redesign of Mechanical Filter with improved Magnetic Anti-Springs (MAS)

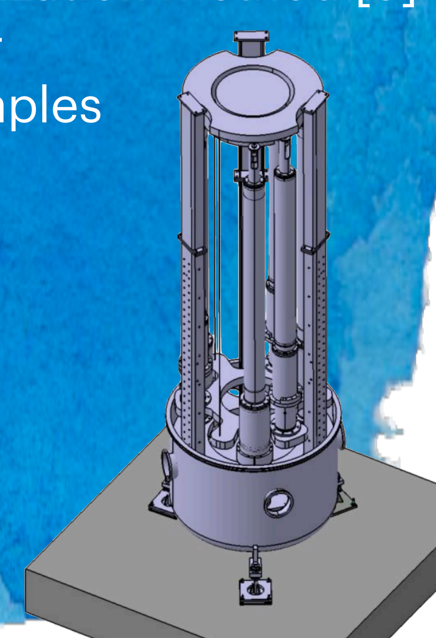






- Simulation based on impedance matrix approach + mass optimization method [5]
- A 1:2 prototype is under construction at INFN Naples





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[4] T. Accadia et al., "Status of the Virgo Project", Classical and Quantum Gravity 28, 11 (2011)
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