1st Astrophysics in the New Era of MM Astronomy International Conference

Poços de Caldas, Brazil - December 4-8th 2023

The Sar-Grav laboratory for Einstein Telescope

Andre Contu

Domenico D'Urso

Davide Rozza

University of Cagliari, Sassari & INFN

Site characterization team

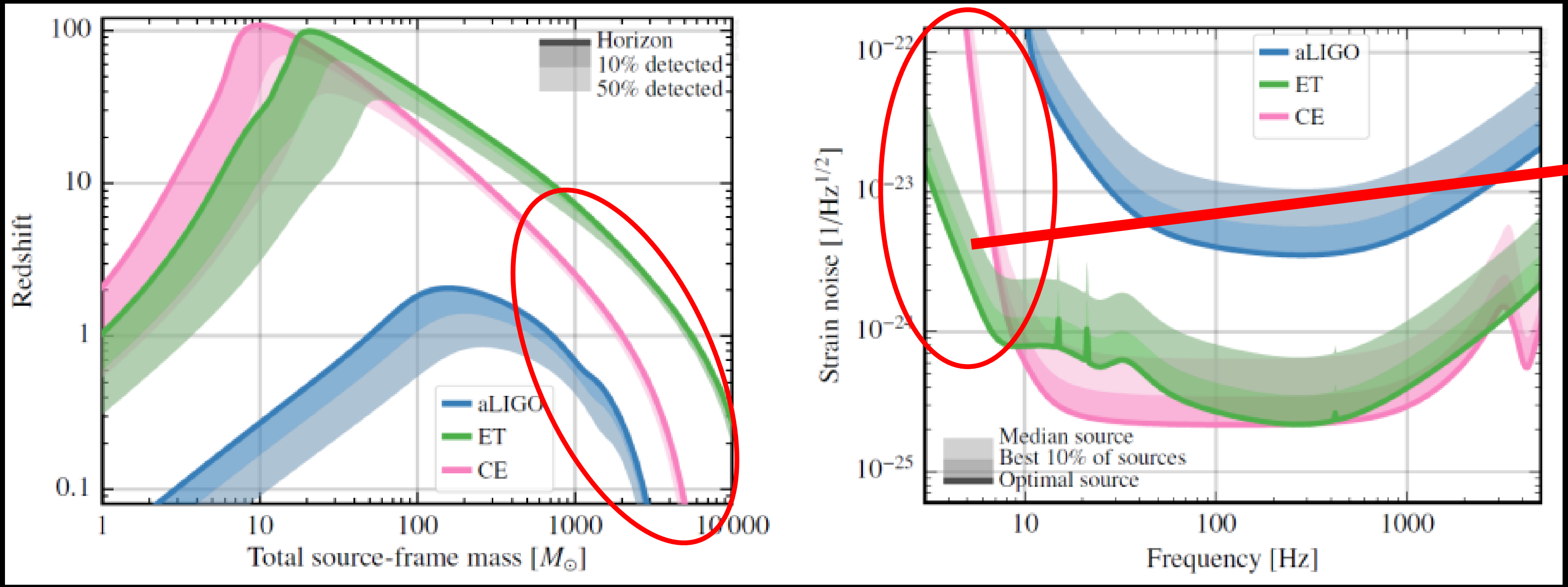
- 50 people from 8 INFN sections, 4 INGV sections and 6 Italian Universities directly involved in site activities and more people will joint the effort in the future
- Collaboration with Polish and Hungarian groups
  - Seismic studies
  - Infrasound monitoring
- Collaboration with German group
  - Seismic studies
- Collaboration with EU Region groups
  - Sharing of experience
  - Discussion on analysis tools and instrumentation
  - Data analysis comparison

Einstein Telescope science

See A. Contu talk

ET will be a new discovery machine: ET will explore almost the entire Universe listening the gravitational waves emitted by black hole, back to the dark ages after the Big Bang

ET will be a precision measurement observatory: ET will detect, with high SNR, hundreds of thousands coalescences of binary systems of Neutron Stars per year, revealing the most intimate structure of the nuclear matter in their nuclei



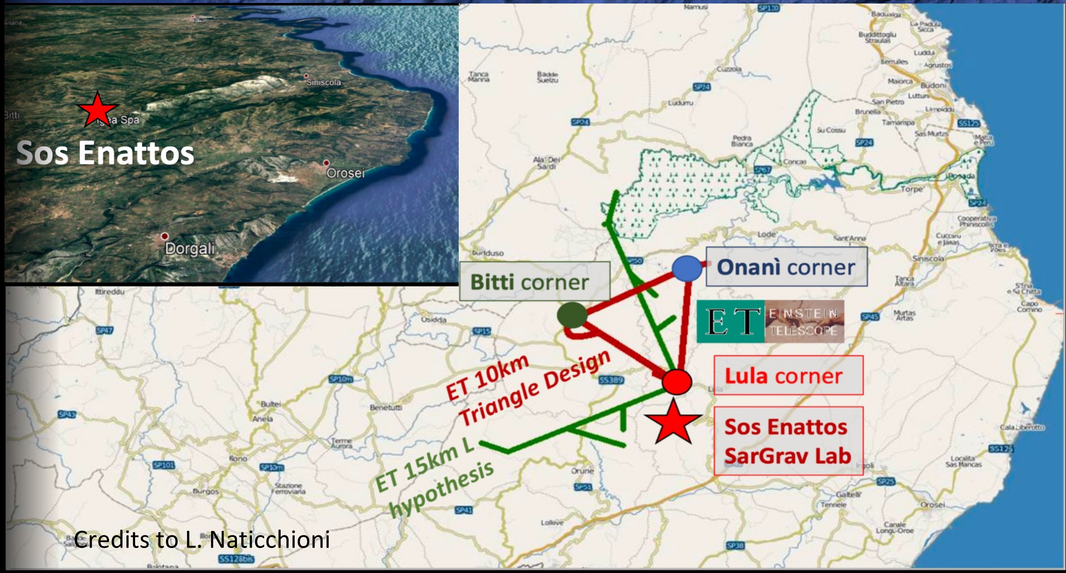
Below 10 Hz the main noise source are due to seismic noise and Newtonian noise

We need to find a place characterized by a low environmental noise

The **Sos Enattos site** (close to Lula, in Sardinia, Italy) **is candidate to host Einstein Telescope (ET).**

(Sos Enattos: former mine with underground access guaranteed through tunnels and shaft)

In the area of the mine, the **SARGRAV laboratory,** a seed of ET, aims to host underground experiments, cryogenic payloads, low frequency and cryogenic sensor development that need low seismic and anthropogenic noise



SAR-GRAV surface


Credits to D. Rozza

A large area of $\sim$900 m^2 on surface is available for experiments: 3 tons crane, experimental areas, optical lab, fiber network link (1 Gbps).


Credits to D. Rozza


Credits to A. Allocca


Credits to D. Rozza

Future facilities: 20 tons crane, clean room, data storing and management system.

SAR-GRAV underground

Several underground stations are available for site monitoring at different depths (-86 m, -111 m, -160 m).

Credits to D. Rozza


Credits to D. Rozza


Credits to A. Cardini


Credits to D. Rozza

Why Sos Enattos?

LOW SEISMIC NOISE

the Sardinia microplate is not involved in present-day geodynamic of the Mediterranean domain. No significant earthquakes.

LOW ANTHROPOGENIC NOISE

noise related to human activities is very low since the inner NE Sardinia region is one of the less populated area in Europe.

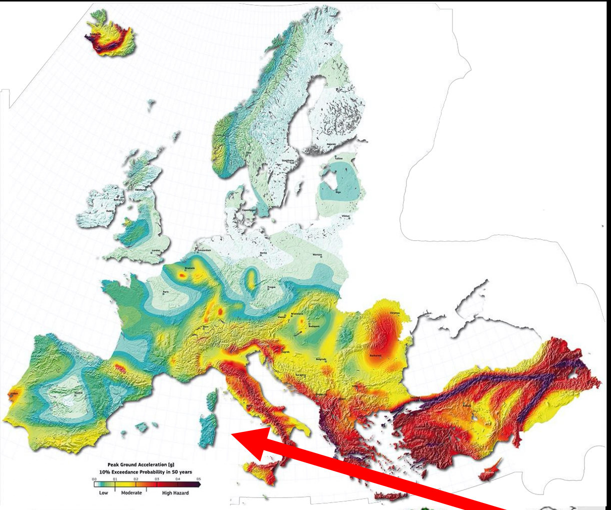
SITE CHARACTERIZATION

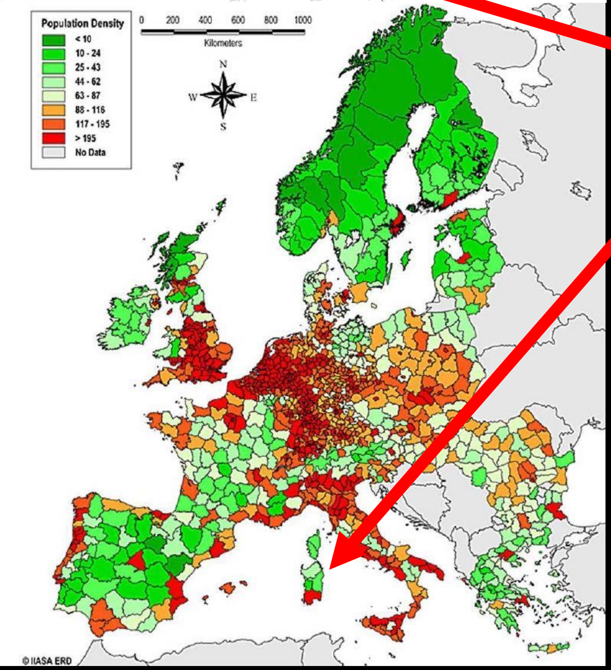
environmental noise monitored with different kind of sensors both on surface and underground.

SUPPORT AVAILABLE

in terms of logistics and manpower, mechanics and masonry services for both surface and underground work.

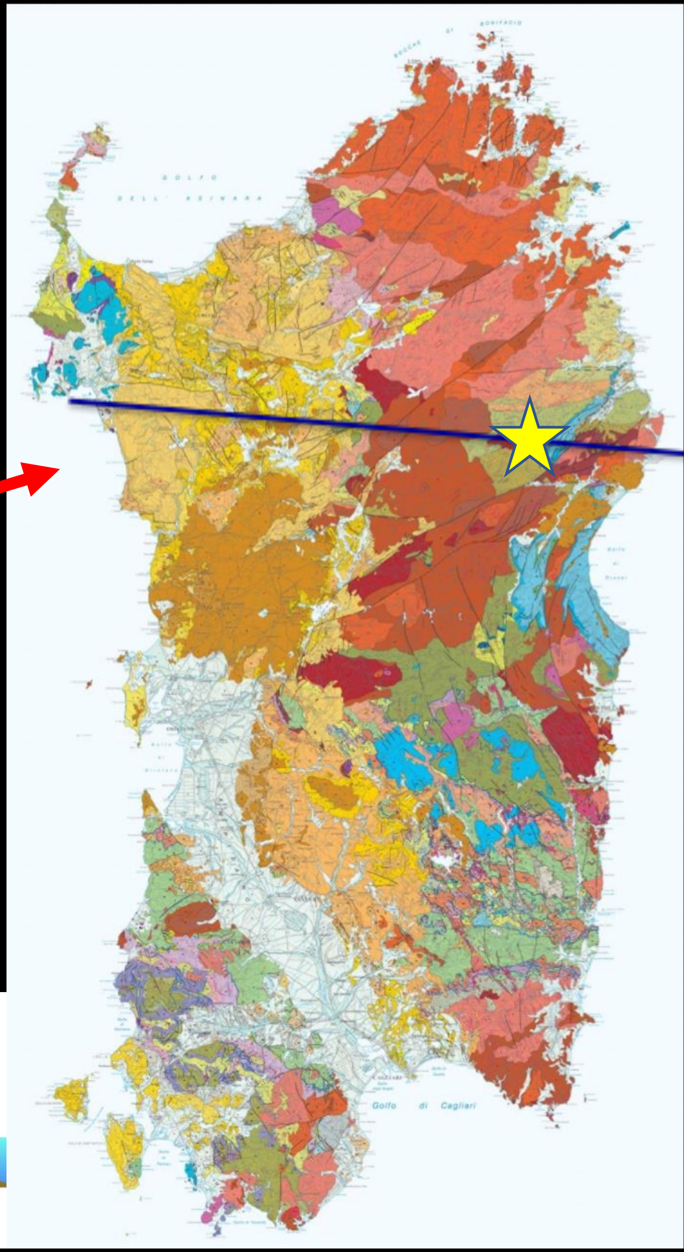
Sardinia environment

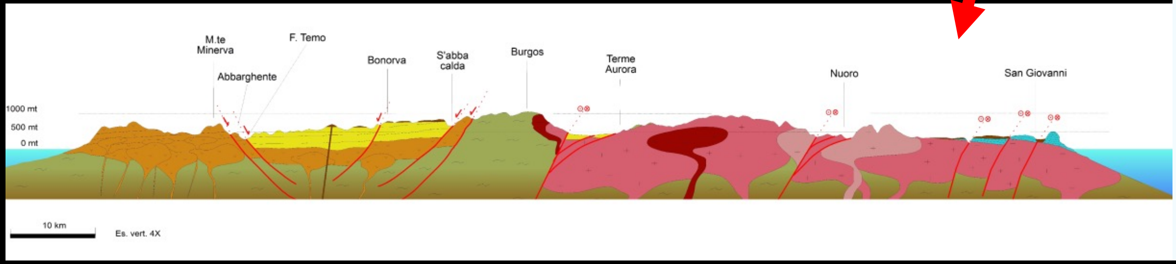




The ET Italian candidate site is located in the stable Variscan basement of Sardinia.

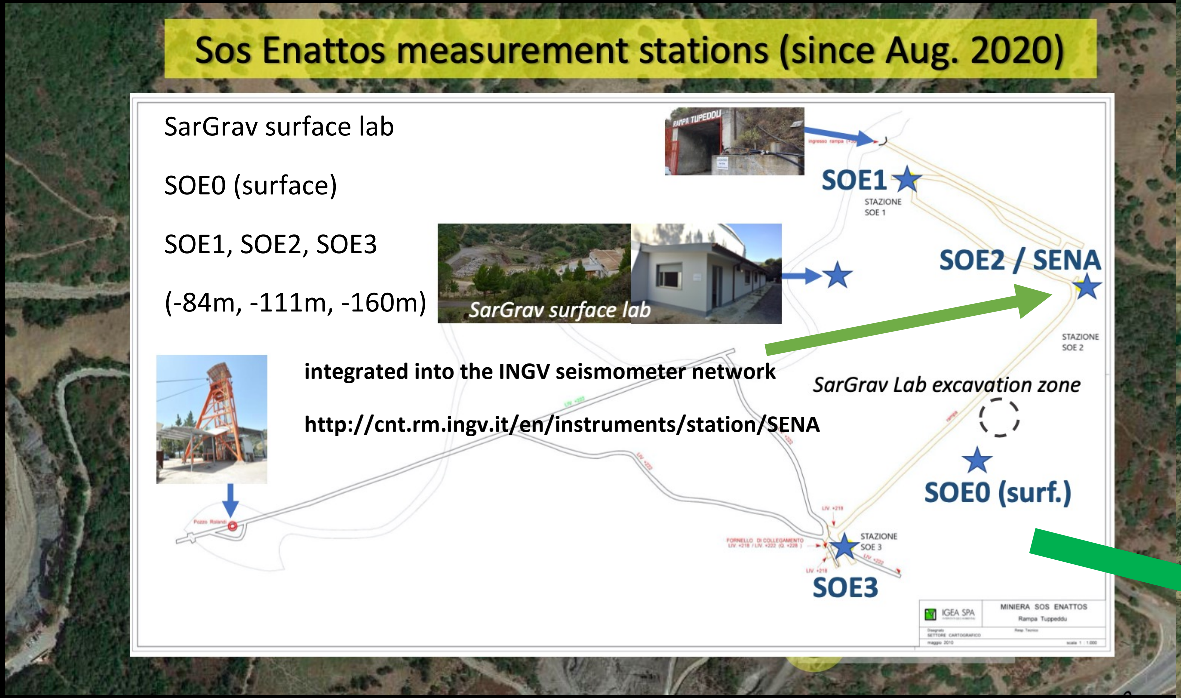
- Geodynamic quietness
- Low Anthropogenic noise
- Low E.M. noise

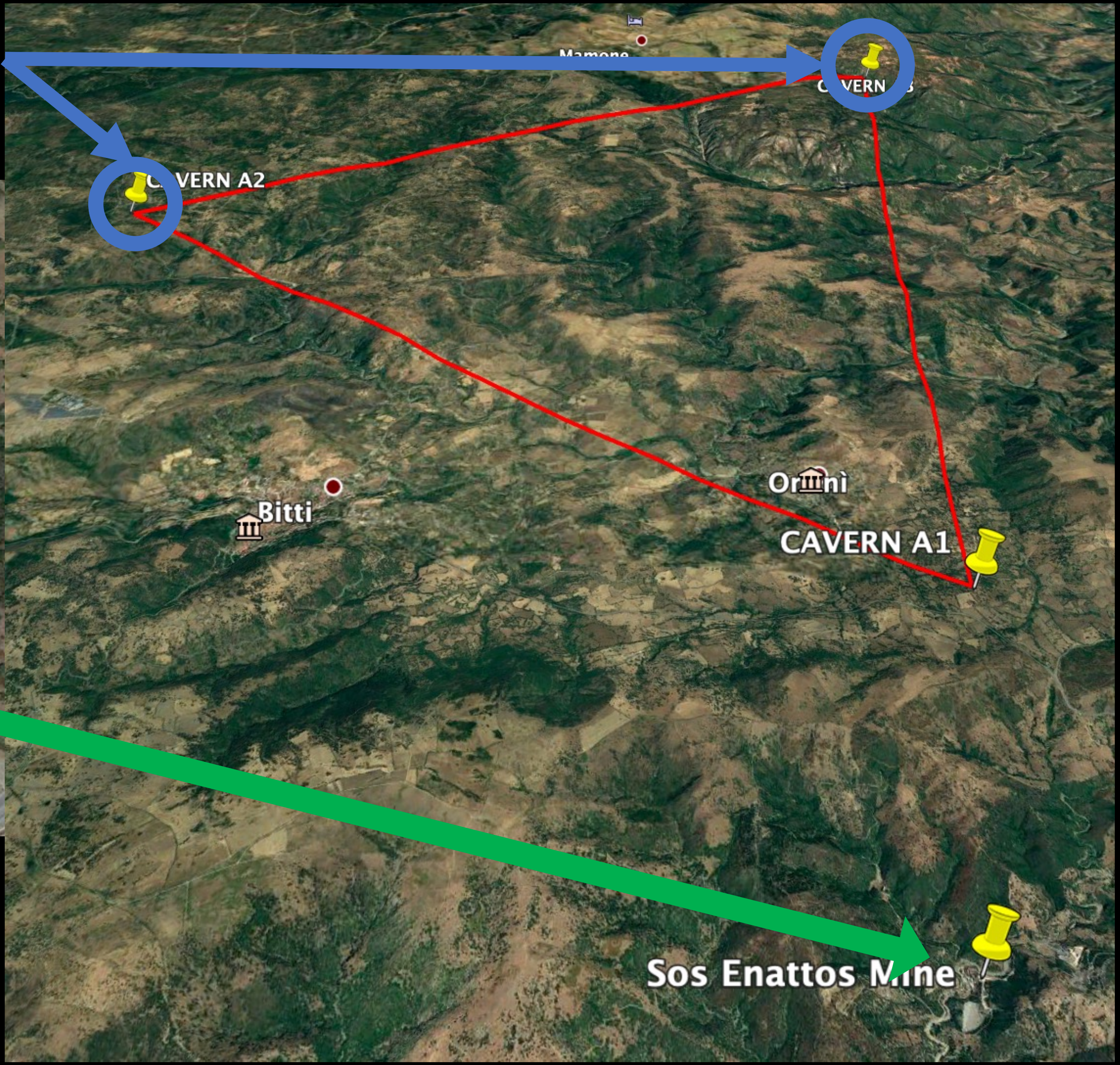




Measurement in Sardinia

Characterization of the Bitti and Onanì corners:
Surface and underground seismic and environmental measurements

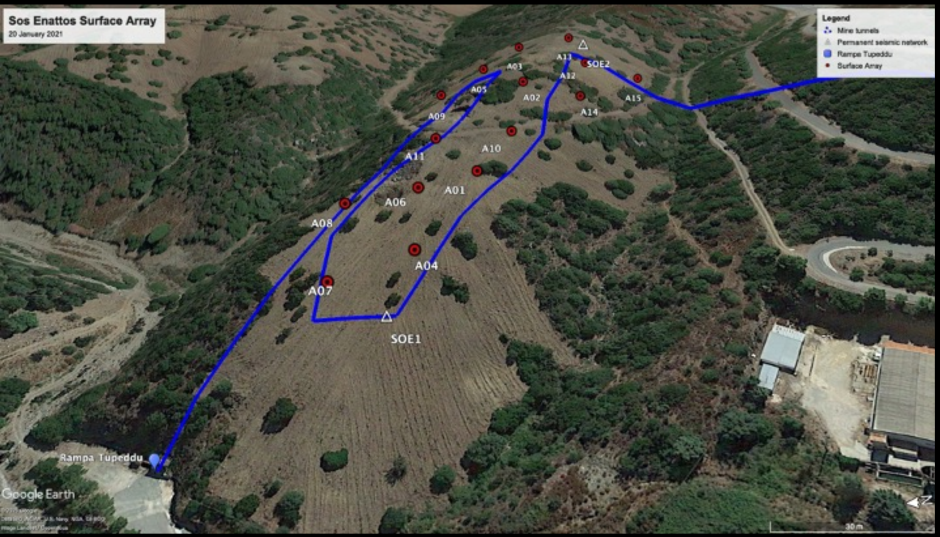


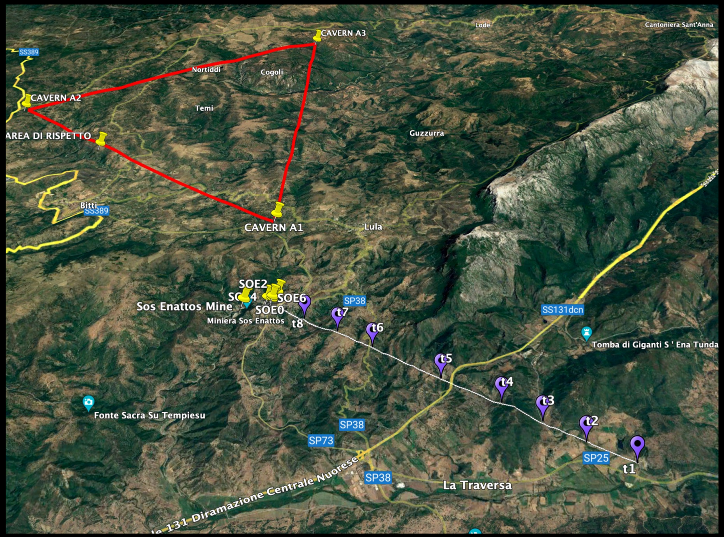


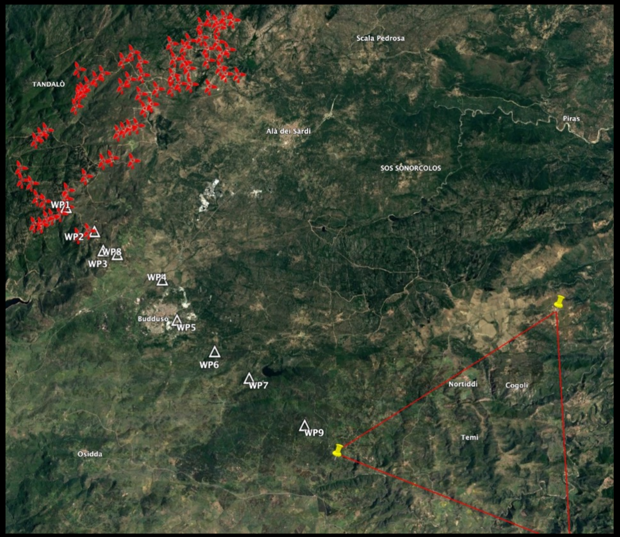
4 broadband seismometers, 3 short-period seismometers, 2 magnetometers, 1 tiltmeter distributed over underground and surface stations, 1 infrasound station

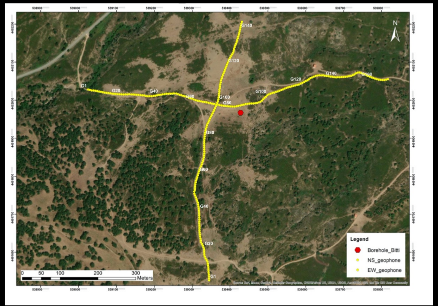
Surface measurement and active campaign

- January-February 2021 - at Sos Enattos: 15 seismometers
- September-October 2021 - at P2 and P3: 23 seismometers + 40 geophones + optical fiber strainmeter + 1 borehole T120 + 1 posthole T120
- January 2022 – surface campaign during cave explosion: 8 seismometers
- March-April 2023 – Wind park noise analysis: 9 seismometers



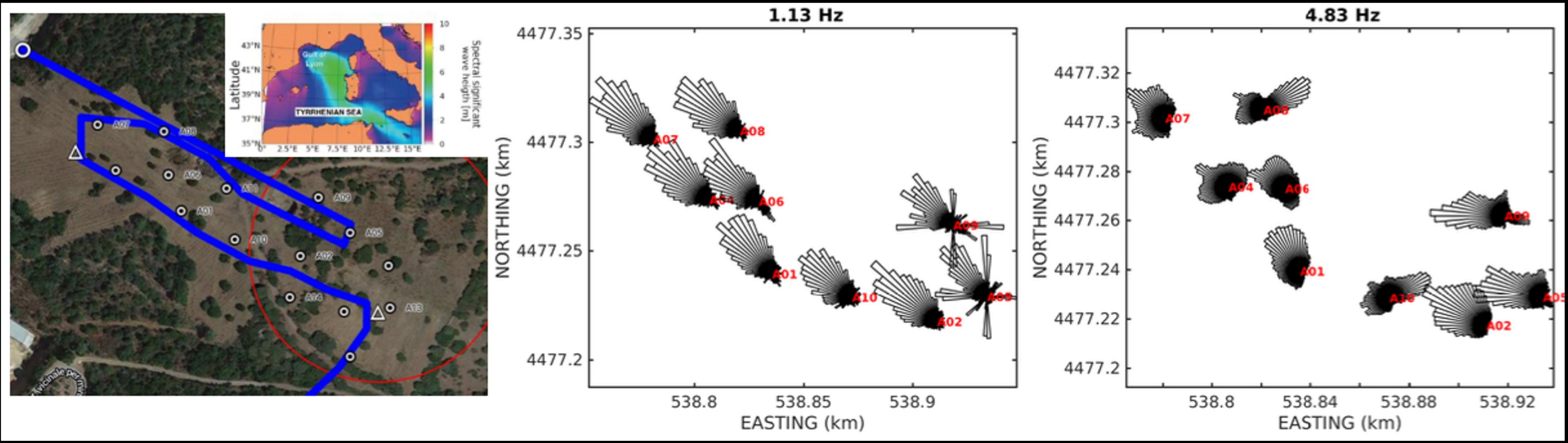




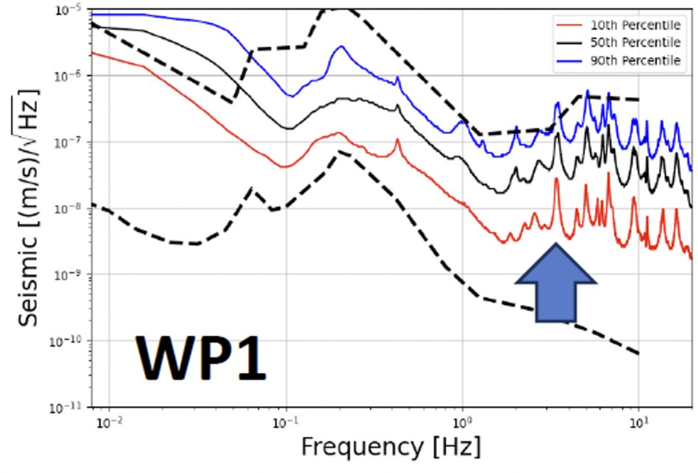


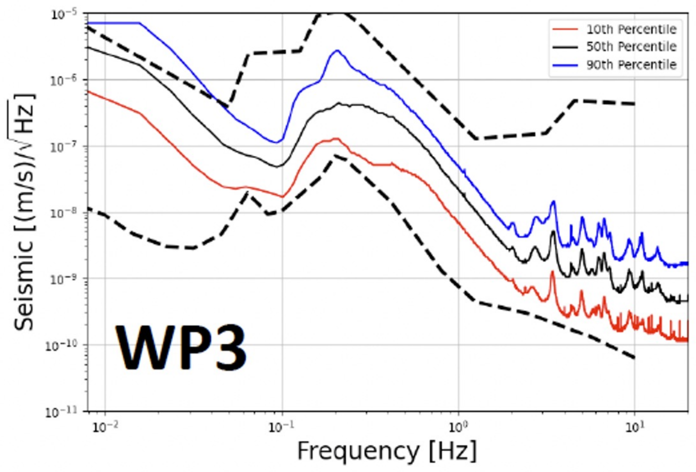
Seismometer array results

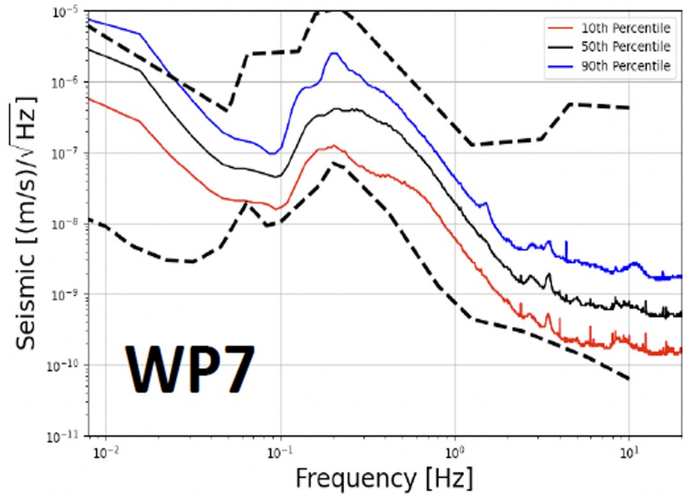
At low frequencies, the polarization directions are rather uniform; they are oriented toward NW (marine micro-seismic source). At higher frequencies, the variability of polarization directions throughout the array deployment indicates a strong influence of topography.

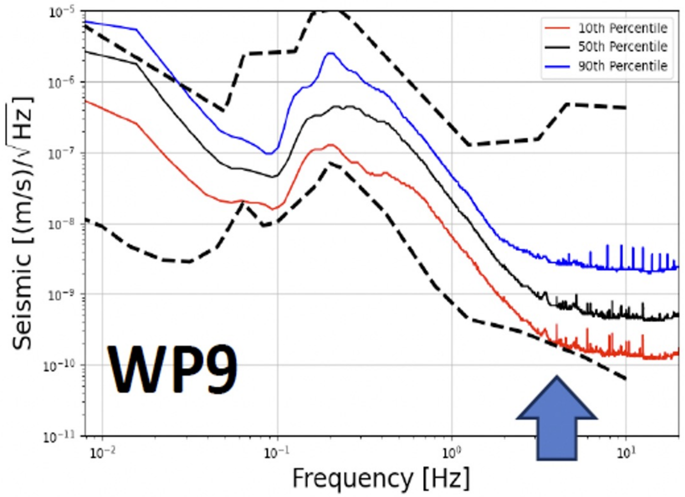


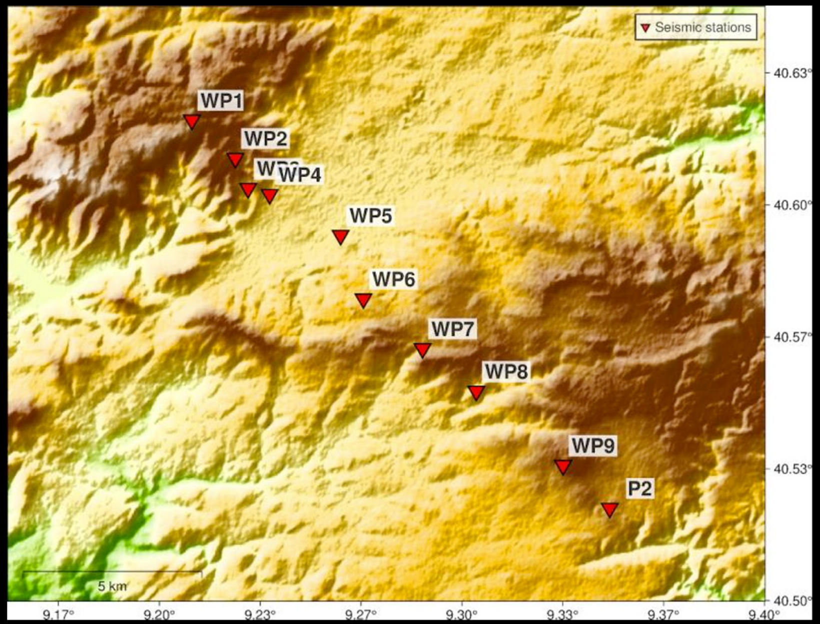
Site preservation: interaction with wind farm



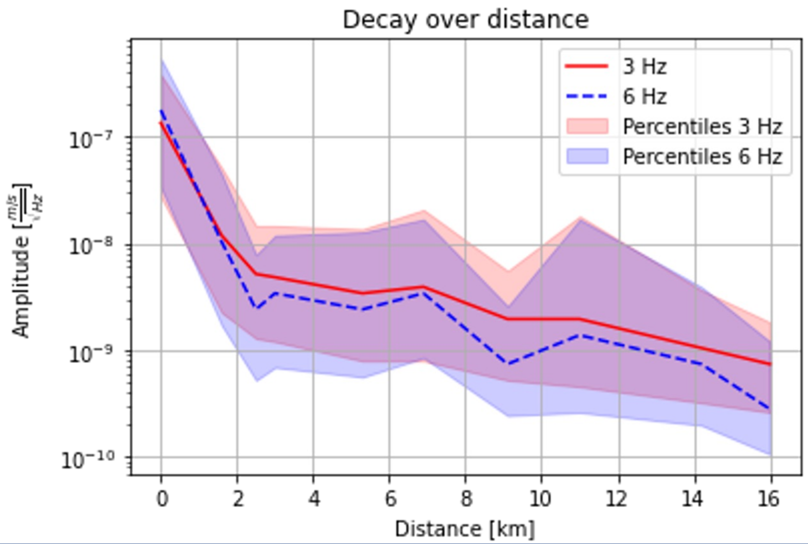








Preliminary results

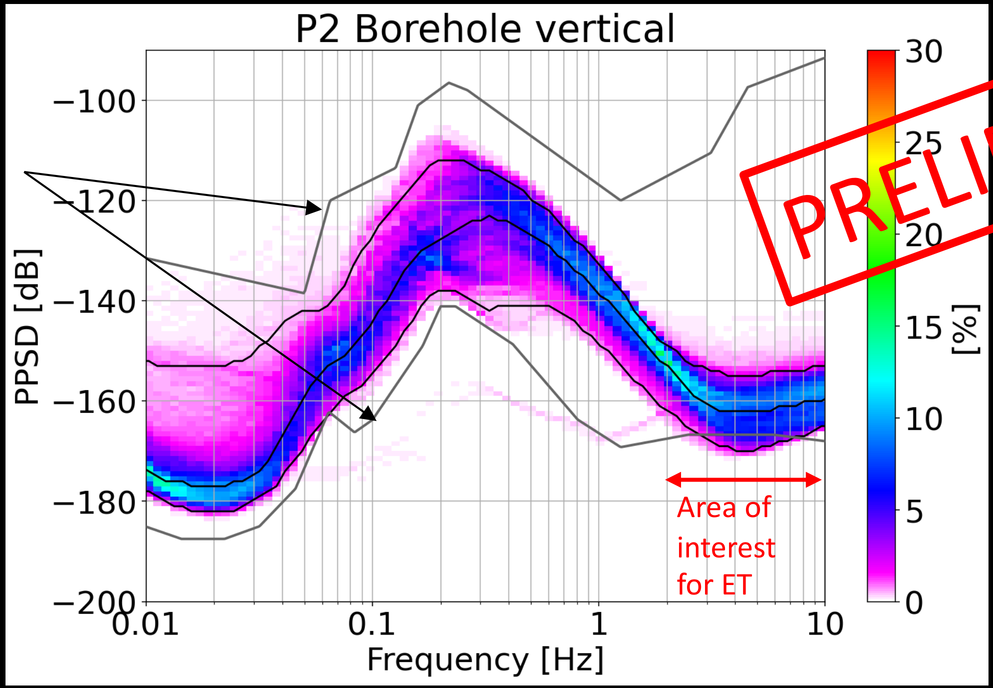


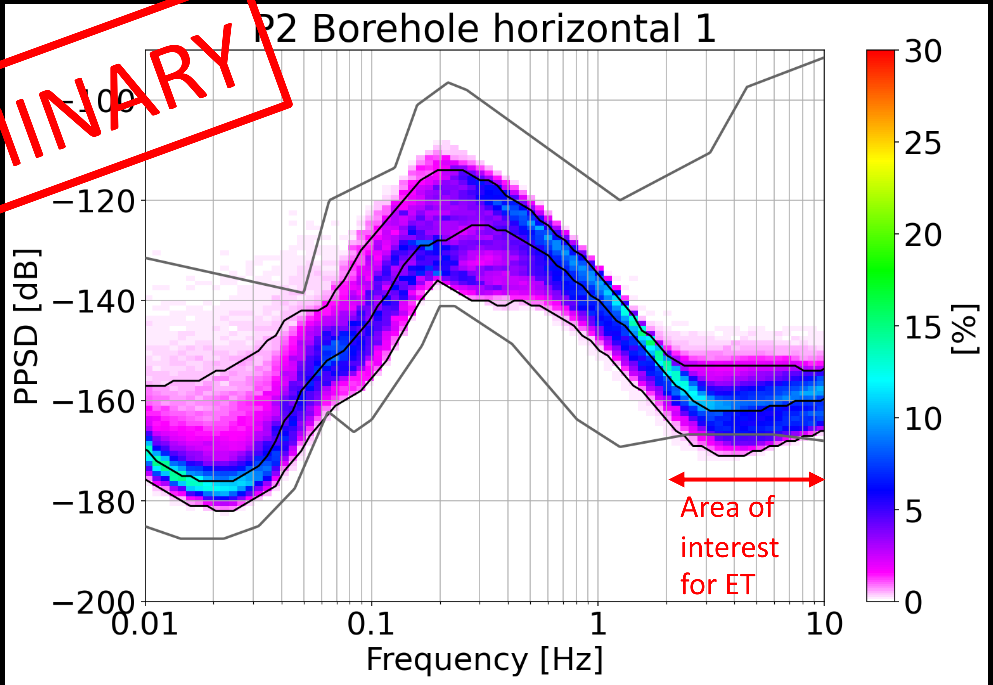
Preliminary seismic results from borehole

About half-year of continuous underground seismic measurements from the P2 and P3 boreholes, e.g.:

P2 (-264m) : 01 October 2021 – 20 March 2022

Seismic noise Peterson's limit





Credits to L. Naticchioni et al.

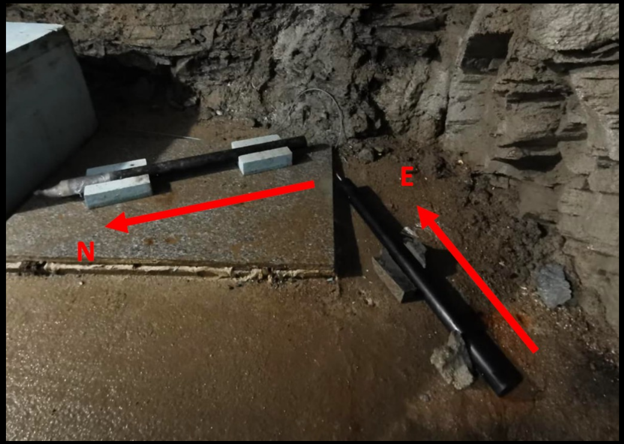
Magnetic measurement

The noise from natural or anthropogenic electromagnetic fields can affect the sensitivity of a gravitational wave interferometer in different ways:

- Direct coupling with actuators of the mirror and suspension system;
- Coupling with electronic devices managing the interferometer.

A special role is played by the Schumann resonances: a world-wide electromagnetic field sustained by the lightining discarges between the Earth surface and the Ionosphere

A magnetometer (N-S orientation) is located on surface



Two magnetometers are installed in SOE2 (-111 m)

Three magnetometers are (three direction N-S, E-W and vertical) located at the two boreholes

Magnetometer probes: Metronix MFS-06/06e), band: 0.25 mHz – 500 Hz

Credits to R. De Rosa et al.

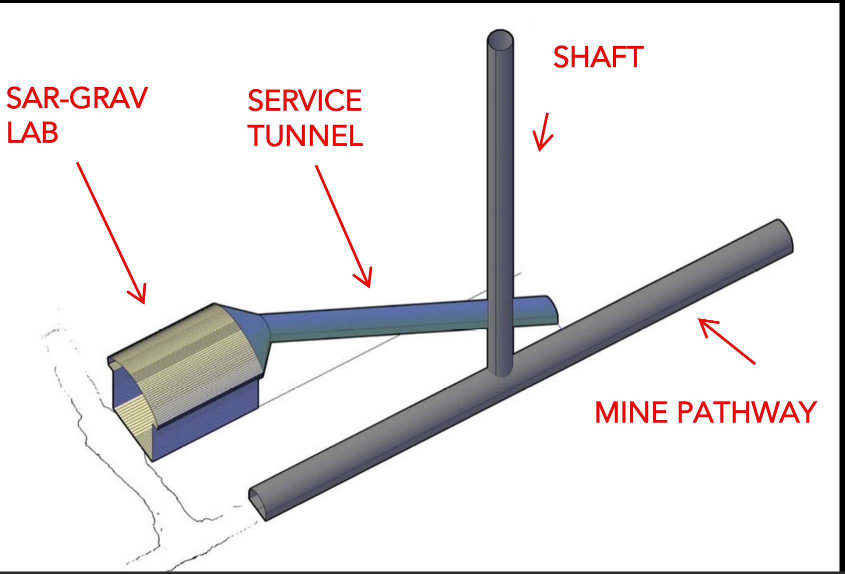
Other measurement

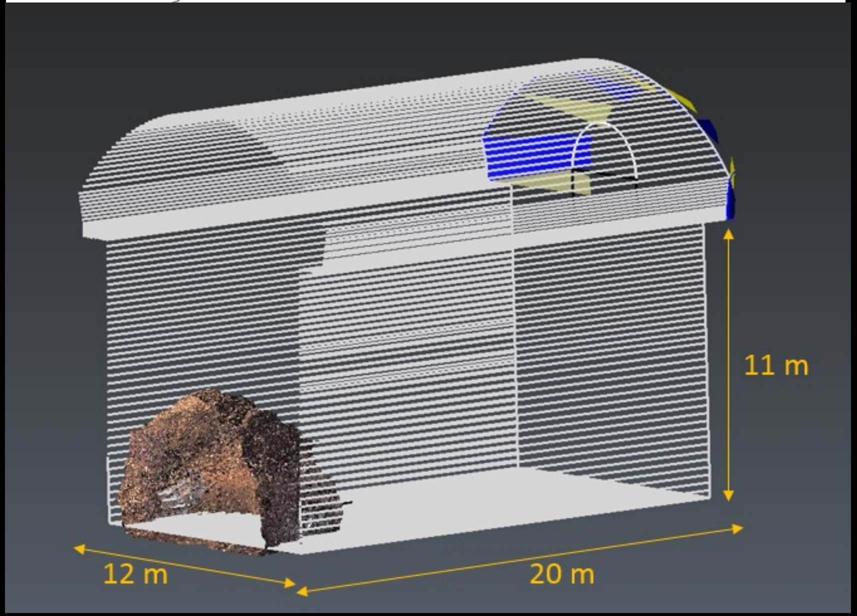
- **Sos Enattos stations**
  - **SarGrav surface Lab+ Control Room**;
  - **SOE0**(surface);
  - **SOE1**, **SOE2**, **SOE3**(-86m, -111m, -160m underground).
- **Sensors currently installed**:
  - 5 broadband triaxial seismometers (*NanometricsTrillium 360, 240, Guralp360 CMG-3TD*);
  - 3 magnetometers (*MF6-06*, N-S at surface, N-S & E-W underground);
  - Several infrasound microphones and microbarometers(surface & underground);
  - 8 short-period triaxial seismometers (*NanometricsTrillium 20PH,* movable array);
  - High Precision Tiltmeter (part of the *Archimedes*experiment @ SarGrav);
  - Weather station (@ SarGravLab).

Underground Cryogenic & Low noise Laboratory

INFN, INGV and INAF are ready to start the realization of an Underground Cryogenic and Low Noise Lab

- 10 M€ from RAS (INFN, INAF and INGV will add a similar amount of funds)
- The feasibility study preceding the final design is ready
  - 3D modelling activity is completed
  - Rock characterization analysis is completed
  - Modelling of the excavation and consolidation phases is completed
  - Geometry of lab and service areas are defined
  - Technological and safety infrastructures defined





Results already published

- L. Naticchioni *et al.*, ***Microseismic studies of an underground site for a new interferometric gravitational wave detector***, **CQG**, 2014, https://doi.org/10.1088/0264-9381/31/10/105016
- L. Naticchioni *et al.*, ***Characterization of the Sos Enattos site for the Einstein Telescope***, **JPCS** 1468, 2020, https://doi.org/10.1088/1742-6596/1468/1/012242
- M. Di Giovanni *et al.*, ***A seismological study of the Sos Enattos Area – the Sardinia Candidate Site for the Einstein Telescope***, **SRL**, 2020 https://doi.org/10.1785/0220200186
- A. Allocca *et al.*, ***Seismic glitchness at Sos Enattos site: impact on intermediate black hole binaries detection efficiency***, **Eur. Phys. J. Plus** , 2021 https://doi.org/10.1140/epjp/s13360-021-01450-8
- M. Di Giovanni *et al.*, ***Temporal variations of the ambient seismic field at the Sardinia candidate site of the Einstein Telescope***, **Geophysical Journal International**, 2023, https://doi.org/10.1093/gji/ggad178
- G. Saccorotti *et al.*, ***Array analysis of seismic noise at the Sos Enattos mine, the Italian candidate site for the Einstein Telescope***, **Eur. Phys. J. Plus**, 2023, https://doi.org/10.1140/epjp/s13360-023-04395-2
- L .Naticchioni *et al.*, ***Results of the site characterization in Sardinia for the Einstein Telescope***, **PoS Proc. Sci.**, 2023, in preparation

The first experiment hosted: ARCHIMEDES

<u>Experimental Goal</u>: measurement of the interaction between vacuum fluctuations with gravity weighting a Casimir multi-cavity while changing the reflectivity of its layers. A change in the reflectivity corresponds into a variation of the internal vacuum state energy.

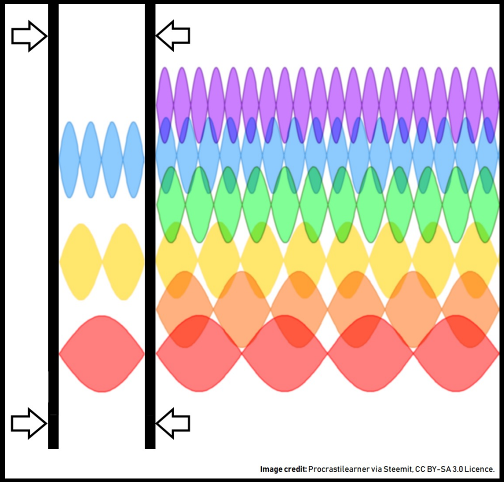
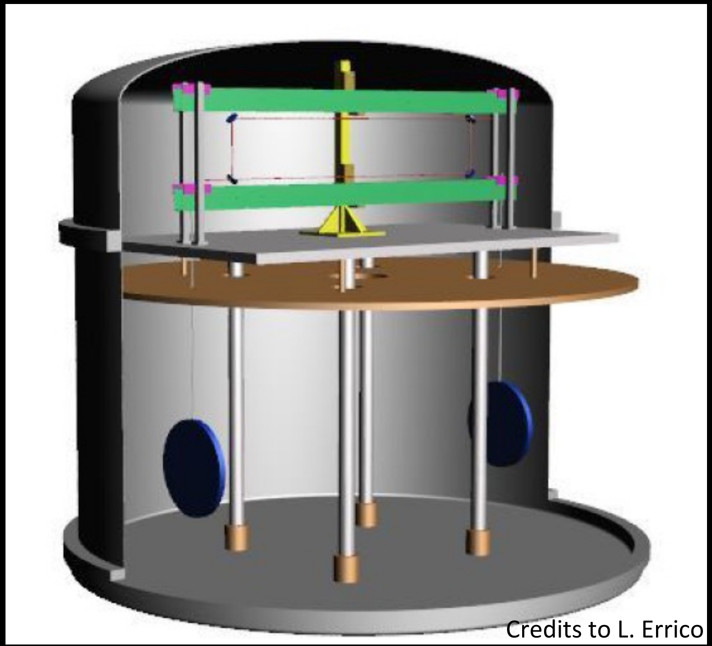


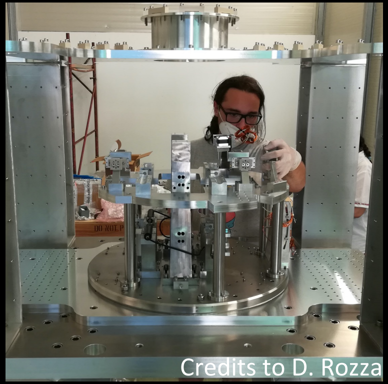
Image credit: Procrastilearner via Steemit, CC BY-SA 3.0 Licence.


Credits to L. Errico

<u>Apparatus</u>: high sensitivity balance working in cryogenic conditions (~90 °K).

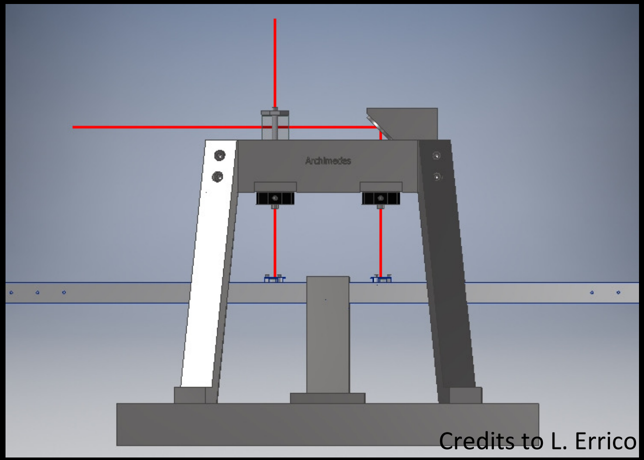

Credits to D. Rozza

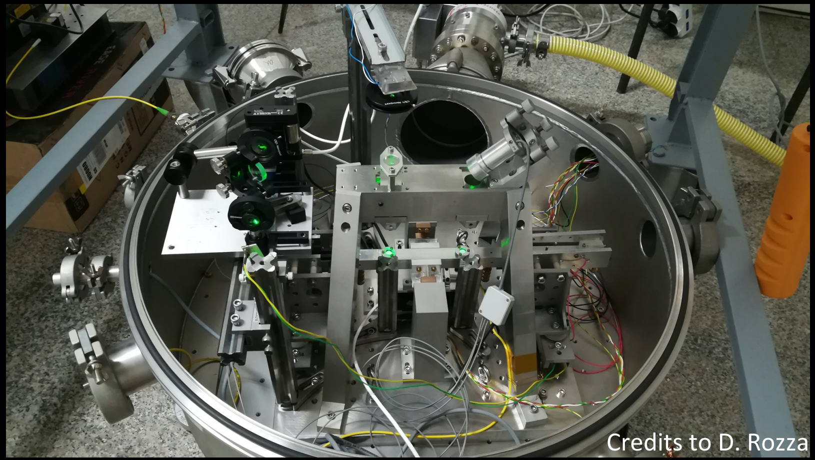

Credits to M. Perciballi


Credits to D. Rozza

The first experiment hosted: ARCHIMEDES

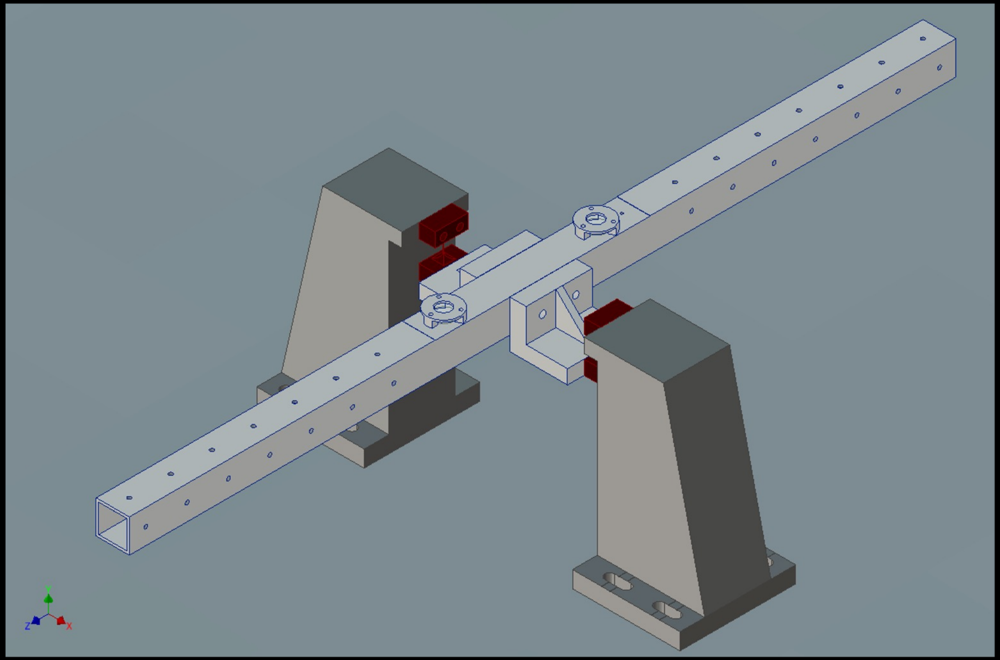
At the same time, Archimedes (and its prototype) can characterize the Sos-Enattos site to host ET:



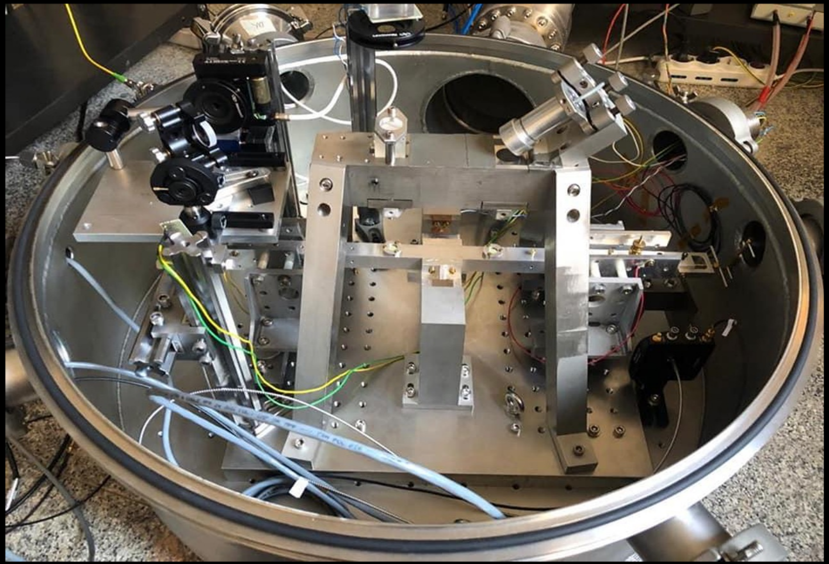


- Direct tilt measurement from 2 Hz to 20 Hz (region of interest for ET)
- Best sensitivity in the world for a tiltmeter in this frequency range
- Contribution to Newtonian Noise Cancellation
- Quality check of the site with a fundamental physics experiment
- Possibility to verify how to implement underground cryogenic and vacuum systems without degrading the site.

The ARCHIMEDES prototype

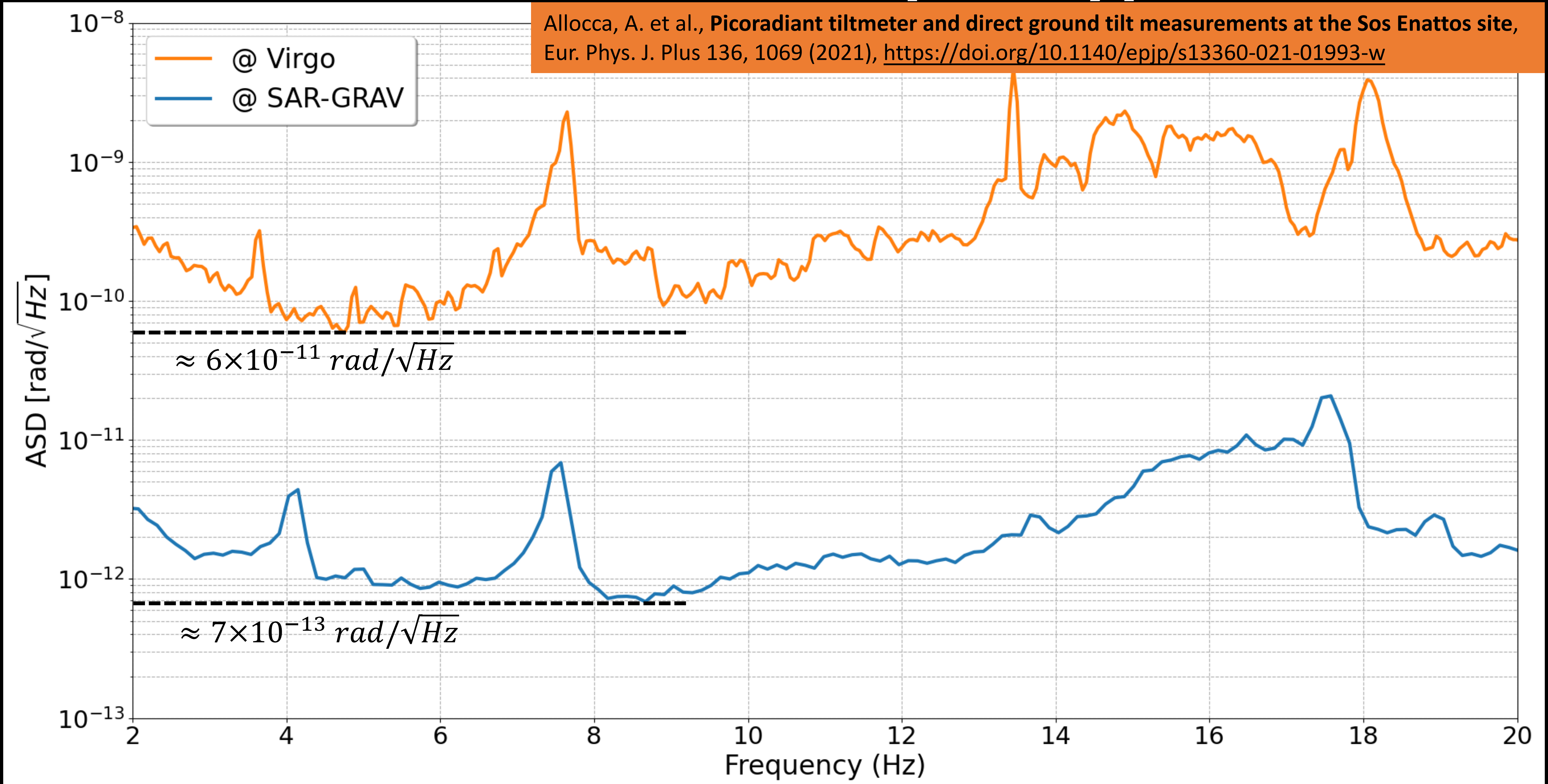


- 50 cm long arm with low momentum of inertia
- suspended through thin flexible joints (Cu-Be, 100 µm x 500 µm), similar to LIGO tiltmeters (Venkateswara et al. 2014)
- Balance center of mass positioned as close as possible to bending point (~10 µm) to minimize the coupling with ground motion



- Resonance frequency ~20-30 mHz
- Installed at the Sar-Grav surface laboratories in Lula (NU) Sos-Enattos mine

The ARCHIMEDES prototype



Allocca, A. et al., **Picoradiant tiltmeter and direct ground tilt measurements at the Sos Enattos site**, Eur. Phys. J. Plus 136, 1069 (2021), https://doi.org/10.1140/epjp/s13360-021-01993-w

The ARCHIMEDES balance

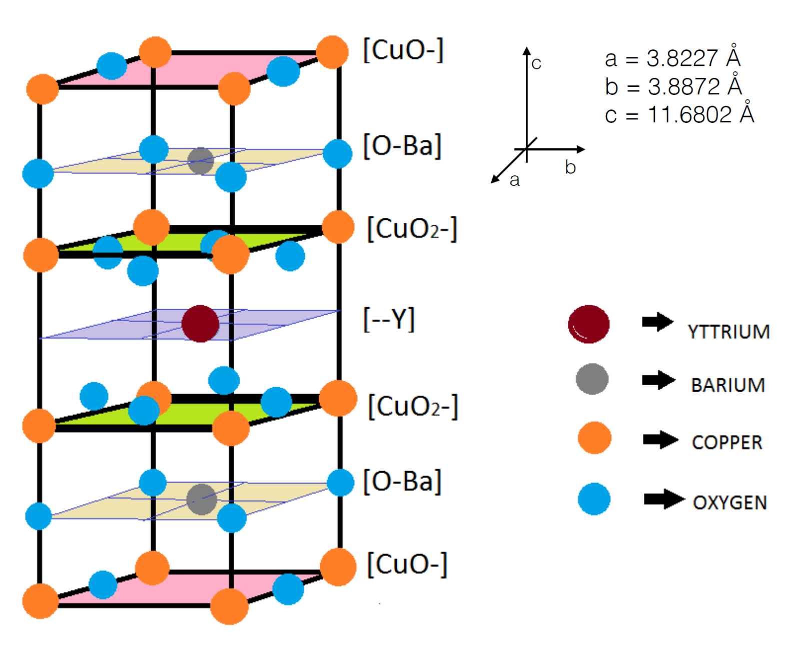
- Some crystals (i.e. YBCO, GdBCO) are natural multi-layered Casimir cavities

$$\text{for YBCO: } T_c \simeq 92\text{ K}, \quad \frac{\Delta\mathcal{E}_{\text{cas}}}{\mathcal{E}_{\text{cas}}} \simeq 10^{-4}$$

- The variation of Casimir energy could be detectable

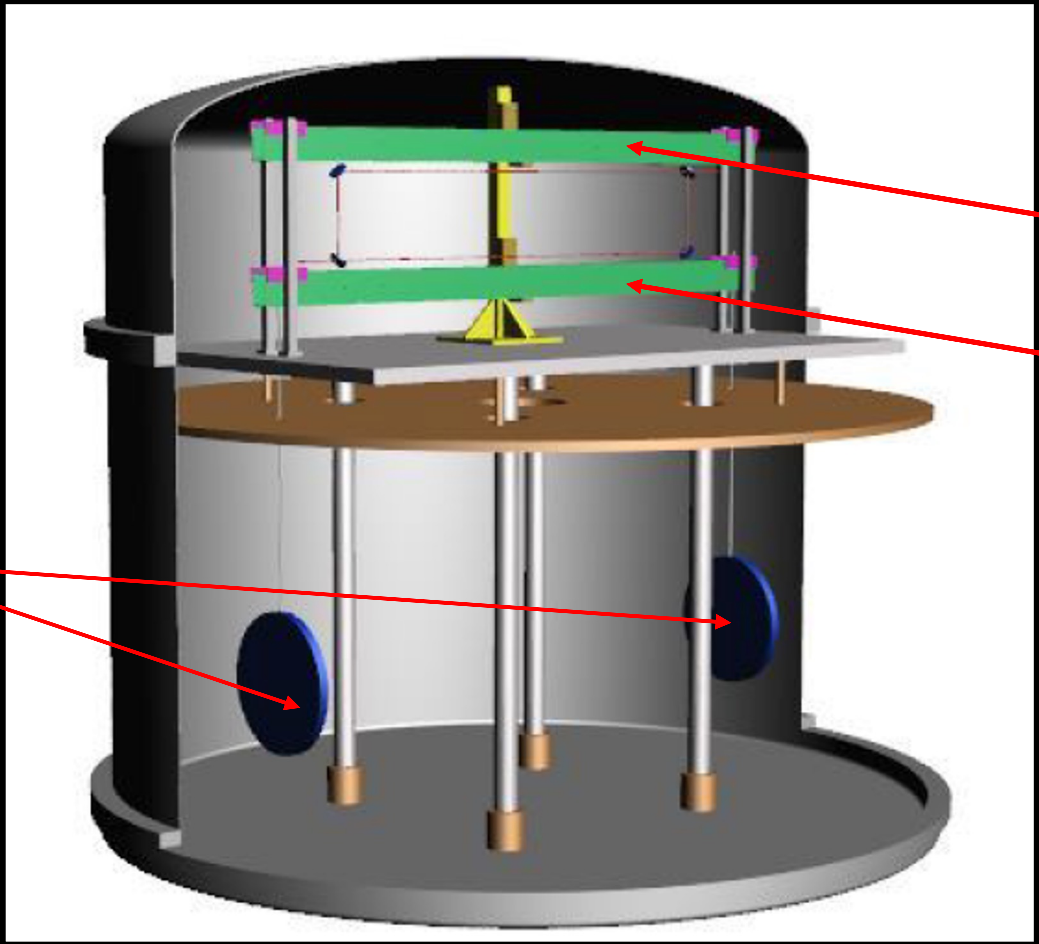
→ a disk-shaped YBCO with R = 5 cm, thickness 5 mm

$$\boxed{\left|\vec{F}\right| \simeq 5 \cdot 10^{-16}\text{ N}}$$



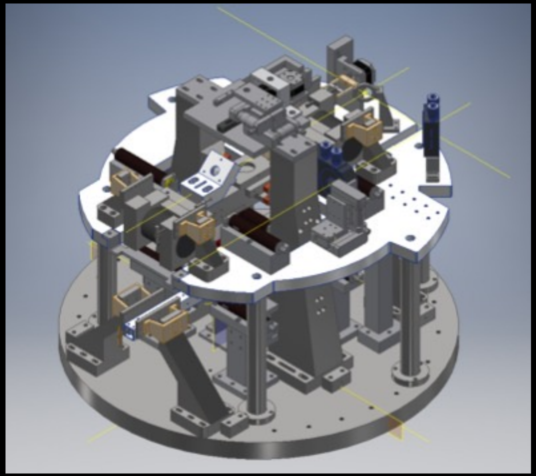
The ARCHIMEDES balance

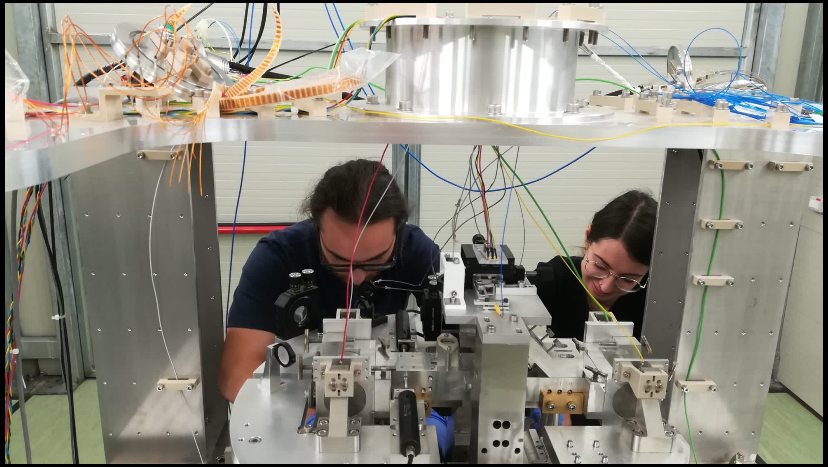
- Extremely sensitive cryogenic balance in very quiet seismic environment (Sos Enattos mine - SAR-GRAV laboratory - LULA - Sardinia)



- Timescale: 5 years starting from 2020 - (after 2018 and 2019 being devoted to feasibility prove)

The **ARCHIMEDES** balance





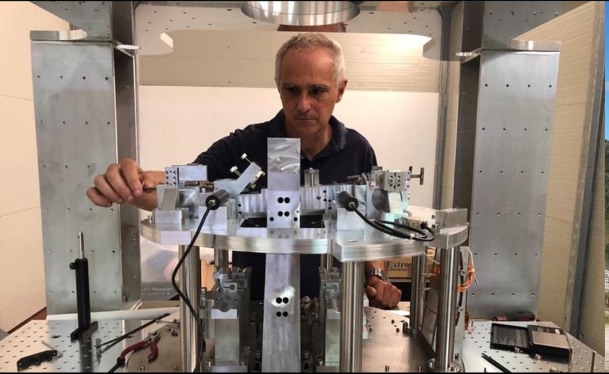
- Mechanics – completed(1)
- Electrical cabling and vacuum feedthroughs – completed
- Optical components and cabling and vacuum feedthroughs – 3 optical feedthroughs being machined in EGO
- Temporary Acquisition and Control system – ready and cabled
- Vacuum system – on site
- **18-19 July 2023 experimantal chamber closed** The first run at room temperature and in vacuum will start soon.

Ready to go under vacuum

(1) Samples are not suspended yet

Results already published

- Relativistic mechanics of Casimir apparatuses in a weak gravitational field - Phys. Rev D 76:025008 (2007)
- Casimir Energy for two and three superconducting coupled cavities: Numerical Calculations – Eur. Phys. J. Plus 132 (2017) 11, 478
- Variation of Casimir Energy from a Superconducting Transition - Nucl.Phys.B 726 (2005) 441-463
- Toward Measuring variations of Casimir Energy by a Superconducting Cavity - Phys. Rev. Lett 94 (2005) 180402
- High-bandwidth beam balance for vacuum-weight experiment and Newtonian noise subtraction - Eur. Phys. J. Plus136, 335 (2021)
- Picoradiant tiltmeter and direct ground tilt measurements at the Sos Enattos site - Eur. Phys. J. Plus 136, 1069 (2021).
- Quantum zero point electromagnetic energy difference between the superconducting and the normal phase in a high-Tcsuperconducting metal bulk sample - Phys.Rev.B 106 (2022) 13, 134502
- Casimir energy for N superconducting cavities: a model for the YBCO (GdBCO) sample to be used in the Archimedes experiment - Eur. Phys. J. Plus 137, 826 (2022)



THANKS FOR THE ATTENTION