ET Italy – Spain bilateral meeting

22 June 2023

ACTIVE NOISE MITIGATION ACTIVITIES

L. Naticchioni[1], Jan Harms[2]

1. INFN Roma

2. GSSI

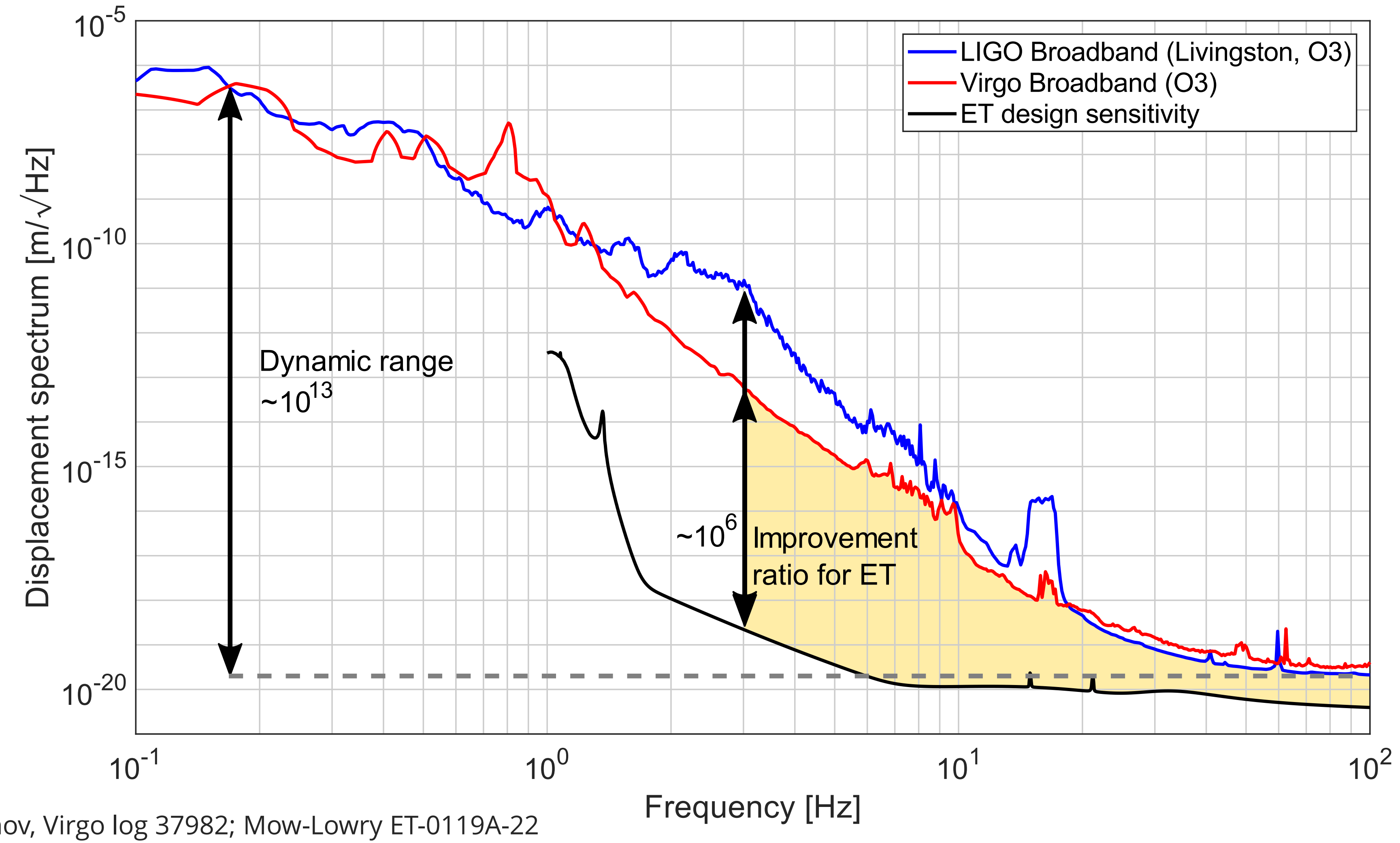
The ANM division in ET

- Division of the **Instrument Science Board** in the ET collaboration;
- Definition of noise mitigation strategies starting from the design;
- Preparation of PBS and TDR: (sub)system design & costs;
- Special attention to Low Frequencies (2 to 20Hz);
- Wiki page: https://wiki.et-gw.eu/ISB/ActiveNoiseMitigation/WebHome.

The ANM division is structured in 5 WPs:

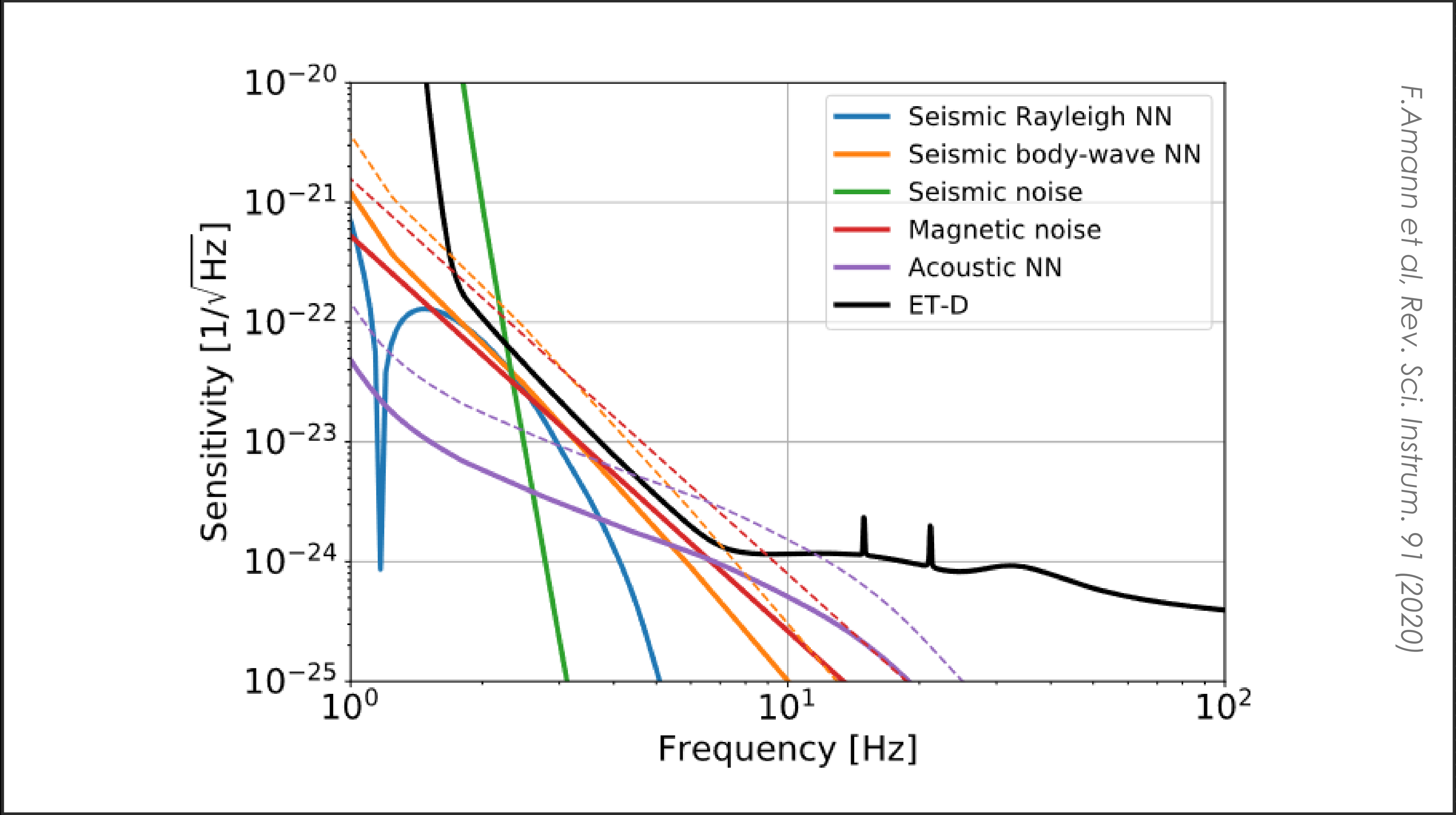
- Newtonian Noise
- Environmental sensors
- Magnetic Noise
- Inter-platform motion
- LF control Noise

The LF challenge



Martynov, Virgo log 37982; Mow-Lowry ET-0119A-22

The LF challenge



F.Amann et al, Rev. Sci. Instrum. 91 (2020)

See also: J. Harms 2022 – ISB workshop

Active Noise Mitigations activities in Italy

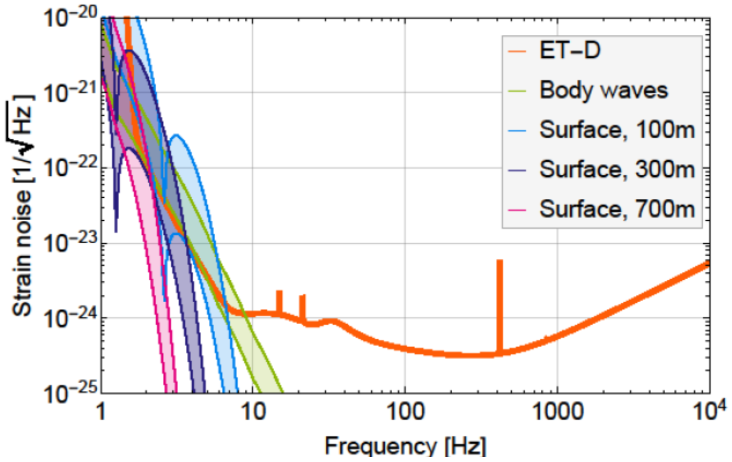
On the Italian side, three WPs involve mainly Italian groups:

- **Newtonian Noise** (co-chairs: **F. Badaracco**, S. Koley): GSSI group (**J. Harms**), Univ. of Cagliari, INFN-Genova, Univ./INFN of Napoli and INFN-Roma.

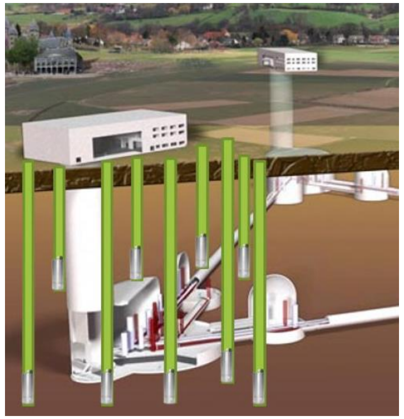
- **Magnetic Noise** (co-chairs: **A. Chincarini, I. Fiori**): INFN-Genova, EGO.

- **Environmental Sensors** (co-chairs: **R. De Rosa**, Mariusz Suchenek)

Newtonian Noise

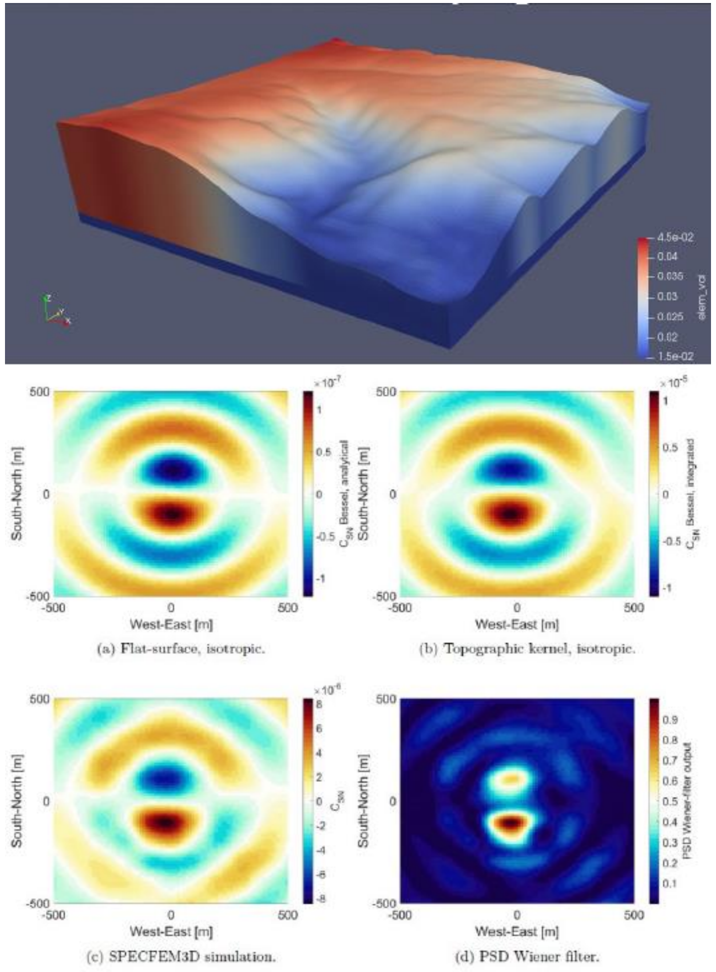


Underground infrastructure: NN reduction, but not cancels completely the atmospheric and seismic NN



Sensor 3D array: NN subtraction will be based on 3D sensor arrays around test masses/main caverns. Hundreds of sensors, boreholes, optimal array configuration… complex (and costly) task.

Optimal design is crucial!



Simulations: FEM + seismic correlation for array optimization

Adapted from: J. Harms 2022 – ISB workshop

Newtonian Noise

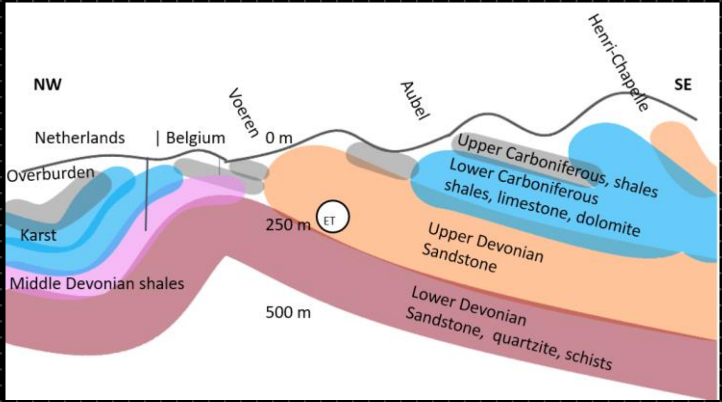
Simulations of the seismic fields must take into account (carefully) the geological features of the site..

e.g.: the complex geological setup of the EMR site

Results not fully compatible with analytical lower limit of NN expectation

Newtonian-noise characterization at Terziet in Limburg—the Euregio Meuse–Rhine candidate site for Einstein Telescope

Maria Bader[1,5], Soumen Koley[1,2,*], Jo van den Brand[1,3,5], Xander Campman[4], Henk Jan Bulten[1,5], Frank Linde[1,6] and Bjorn Vink[7]



VS

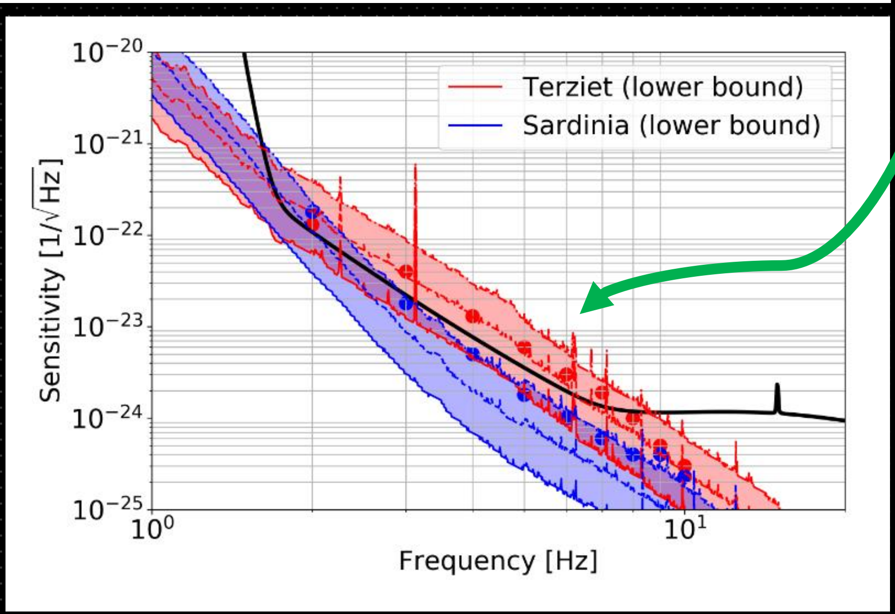
Eur. Phys. J. Plus (2022) 137:687
https://doi.org/10.1140/epjp/s13360-022-02851-z

THE EUROPEAN PHYSICAL JOURNAL PLUS

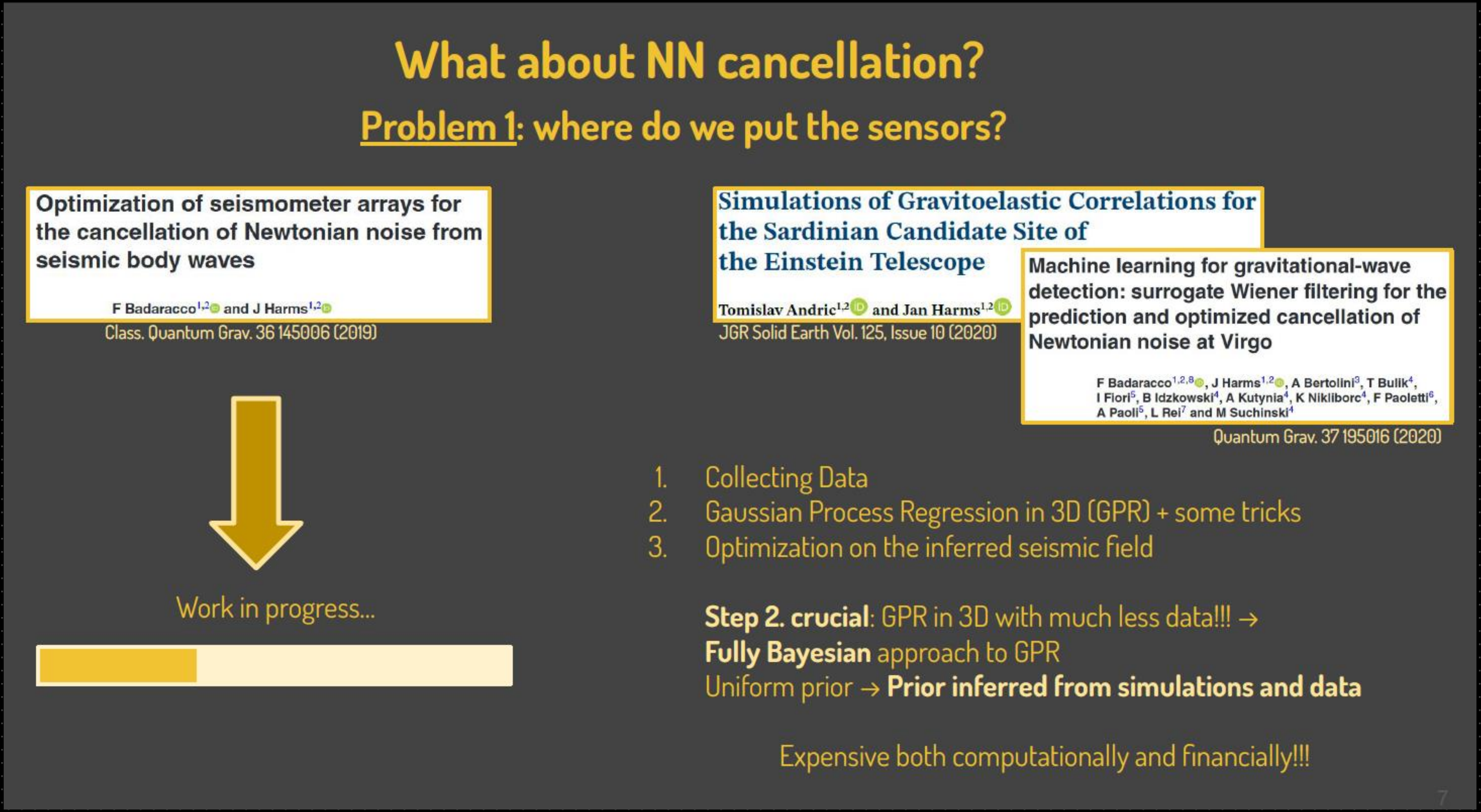
Regular Article

A lower limit for Newtonian-noise models of the Einstein Telescope

Jan Harms[1,2,a], Luca Naticchioni[3], Enrico Calloni[4,5], Rosario De Rosa[4,5], Fulvio Ricci[3,6], Domenico D'Urso[7,8]

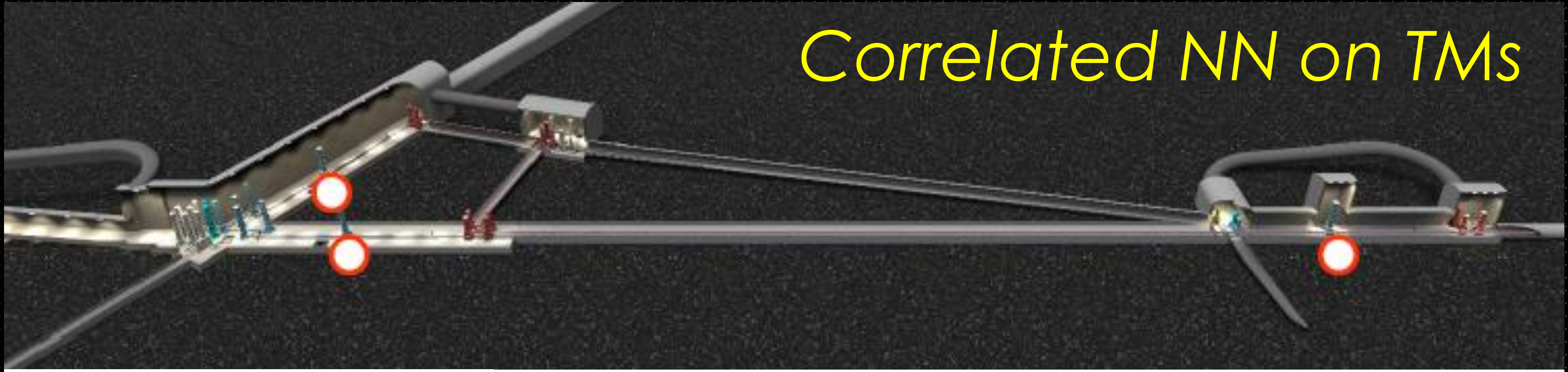


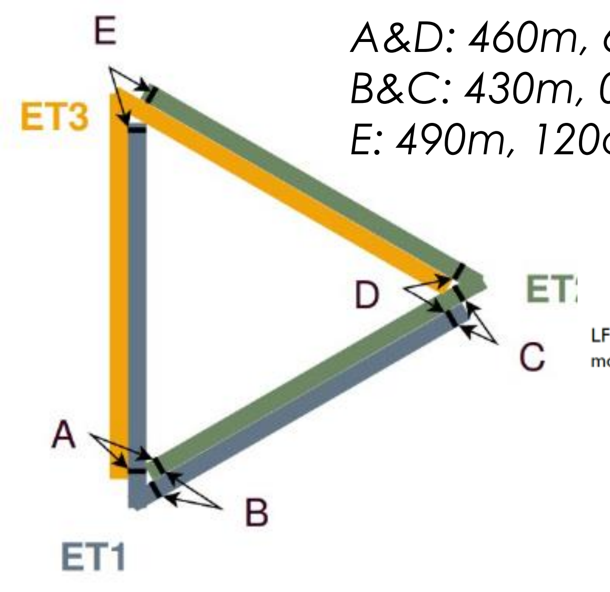
Newtonian Noise

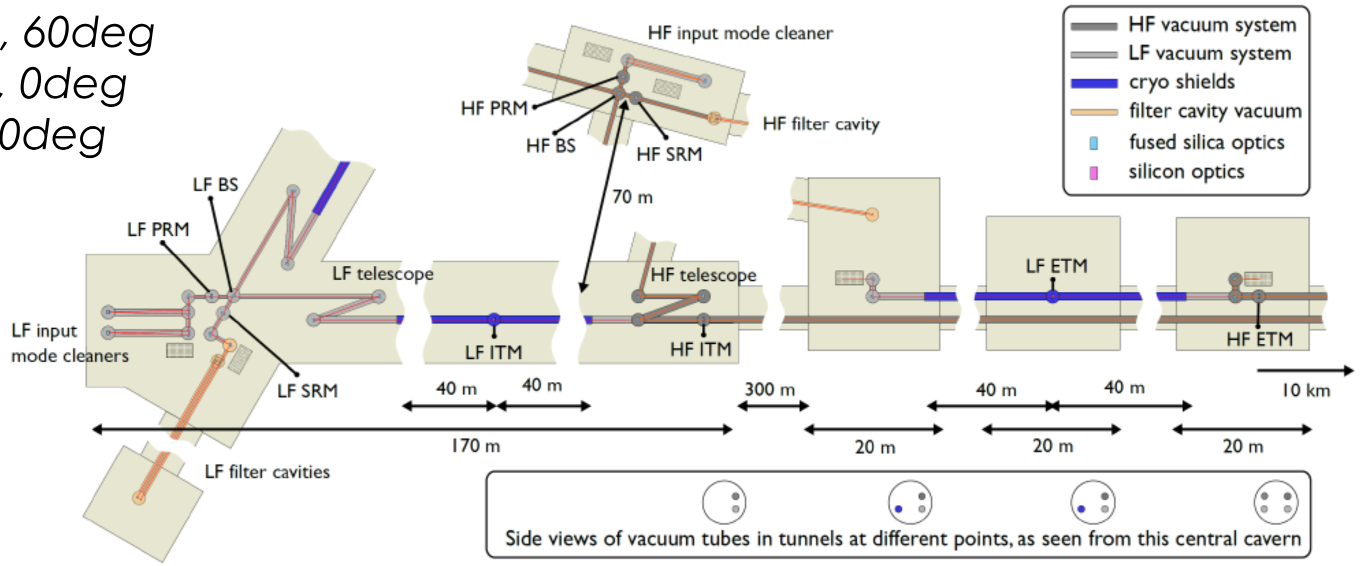


From: F. Badaracco – XIII ET Symposium

Newtonian Noise







Adapted from: [J. Harms 2022 – ISB workshop]

Newtonian Noise

Possible contributions from the Spanish side:

- **Models & Simulations?**
- **Computational resources?**
- **LIDAR test for atmospheric Newtonian noise cancellation**

Contact: francesca.badaracco@ge.infn.it , jan.harms@gssi.it

Magnetic noise

ANM-MN WP main tasks:

- Identify magnetic noise sources;
- Identify ITF components where coupling occurs;
- Define mitigation strategies to reduce ambient noise, especially close to ITF sensible spots;
- Define mitigation strategies to reduce ITF magnetic susceptibility, to eventually comply with ET design;
- Lay out the plan for the design, implementation, monitoring and management of the MN mitigation infrastructure.

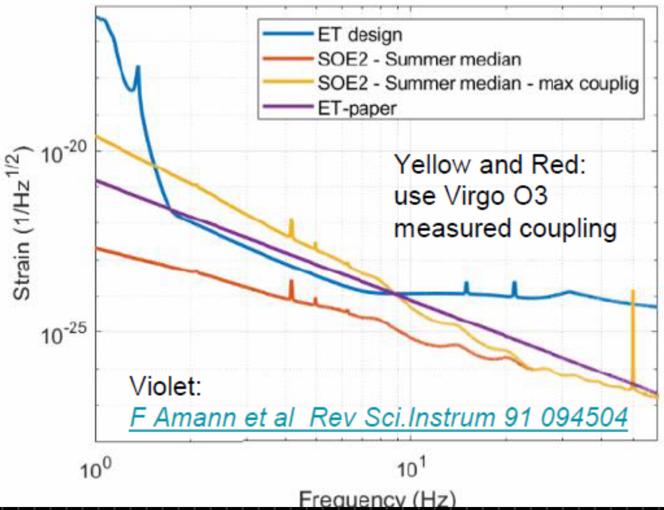
Magnetic noise

The ET magnetic noise issue

- Magnetic noise has been studied and addressed by Virgo and LIGO A. Cirone et al Class.Quant.Grav. 36 (2019) 22] A.Cirone et al Rev Sci Instrum 89, 114501 (2018), B P Abbott et al 2016 Class. Quantum Grav. **33** 134001, P Nguyen et al 2021 Class. Quantum Grav. **38** 145001
- Noise projection has 2 ingredients:
  - Ambient noise level: Earth noise (Schumann Resonances) + sources close to ITF (Self-inflicted noise)
  - Strength of coupling to ITF (at sensitive locations)
- Expectation for ET is based on the extrapolation of measurements done in Virgo O3, M C Tringali et al Galaxies 2020 8(4) 82

  Warning: measurements are only partially supported by models. No direct measurement below 10Hz
- Challenging **noise reduction goals**:
  - Ambient noise reduced at level of Earth noise
  - and Coupling reduced by a factor 10^2-10^3 wrt current ITFs
  - Similar requirements from stochastic correlated noise study, K Janssens et al PhysRevD 104 (2021) 122006

ET magnetic noise projection, assuming ambient noise is just Earth noise.



A. Chincarini, I. Fiori, 2023

Magnetic noise

Couplings to ITF

Coupling of ambient fields is not uniform throughout the ITF

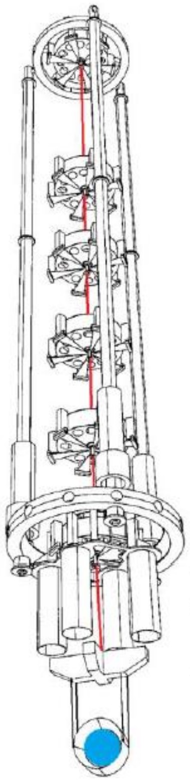
Most critical coupling sites are the suspended elements carrying permanent magnets: test masses, optical benches and their suspension systems

Critical components:

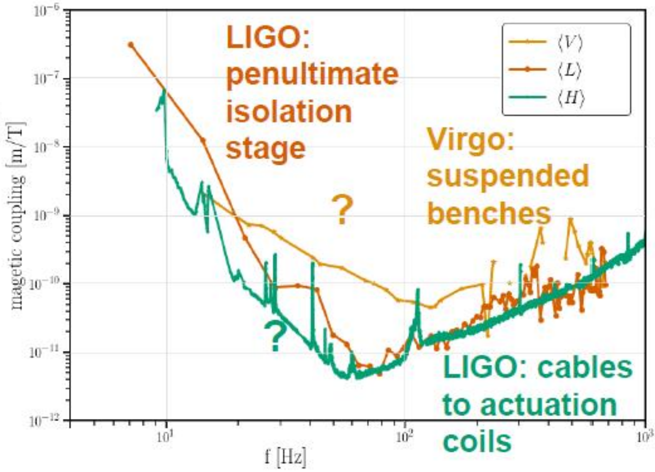
- Coil magnet actuators, Faraday isolators, pico-motors
- Cables (e.g. coil drivers), electronics, connectors (induced currents)
- Conductive parts close to actuation magnets, because of eddy currents, e.g. Virgo payload cage, *A.Cirone et al Rev Sci Instrum 89, 114501 (2018)*

Some rough indications from Advanced Virgo and LIGO

Currently under study in AdV+



Magnetic coupling functions measured in O3



A. Chincarini, I. Fiori, 2023

Magnetic noise

Mitigation strategy

Challenging mitigation goals:

- ★ Preserve environmental noise at Schumann noise level (~0.3 pT/sqrtHz,10-50 times less than Virgo)
- ★ Reduce couplings by factor 100-1000 with respect to present ITFs.
- ★ Focus on coupling sites

Actions (pursue both):

1. Global shields (also multiple shields) to protect critical coupling sites (TMs, optical benches …)
2. Ad-hoc strategies for sources close to critical coupling sites (e.g. cables, vacuum devices, cryogenic devices …)

Main lessons learned from Virgo:

- ★ Reduce noise by design - build a low-magnetic-noise infrastructure. Attention to site facilities (HVAC, UPS) and experimental equipments
- ★ Use robust and maintenance-free technologies

A. Chincarini, I. Fiori, 2023

Magnetic noise

Overview of mitigation solutions

	passive shielding			active shielding	
	magnetostatic	eddy currents	source canceling	exotic solutions	active cancelling
Freq.	better @ low f	better @ high f	independent	solution specific	solution specific
How	high permeability ferromagnetic materials	highly conductive materials	set of permanent magnets in suitable configuration	metamaterials superconductors composites	feedback circuit consisting of sensors, dsp, amplifiers and conductors in various configurations

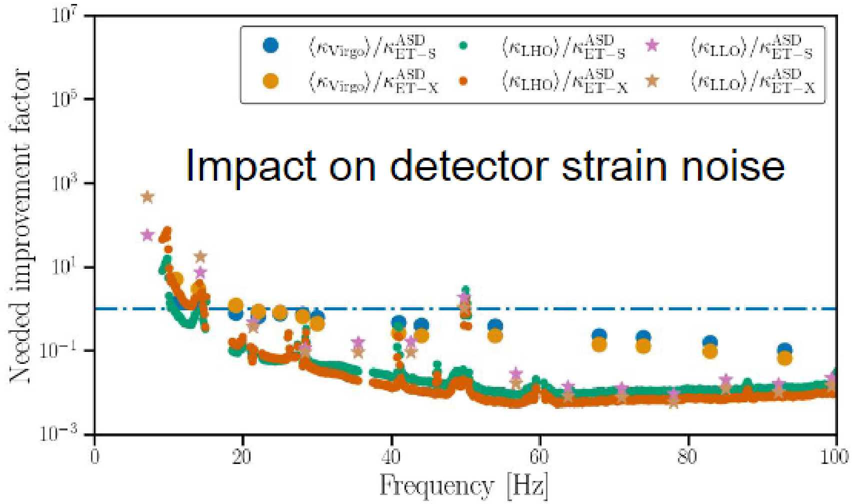
Prefer passive solutions: PRO: simplicity, operational stability, safer (no generated extra fields), no need of maintenance … and cheaper. CONS: smaller shielding factor

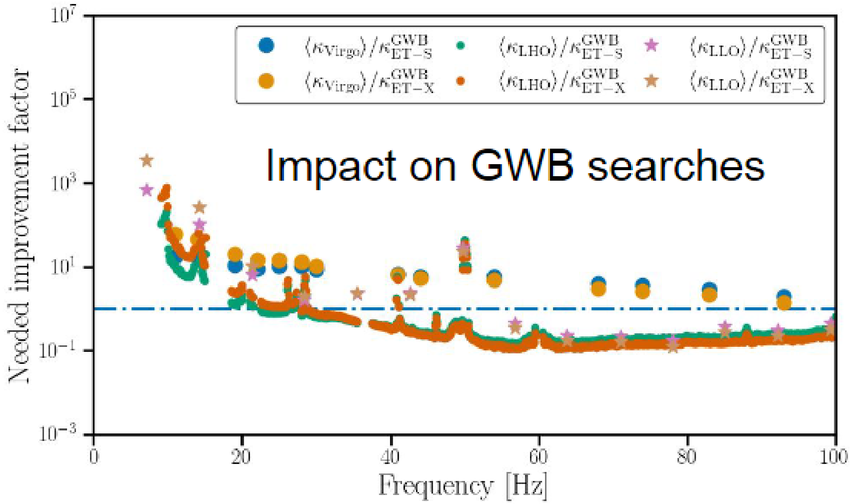
A. Chincarini, I. Fiori, 2023

Magnetic noise

Recent evaluation [K. Janssens et al, **Phys. Rev. D 104, 122006**] indicates that ”... to comply with the sensitivity target below ~30 Hz it will be necessary for the Einstein Telescope, magnetic isolation coupling to be two to four orders of magnitude better than that measured in the current Advanced LIGO and Virgo detectors.”

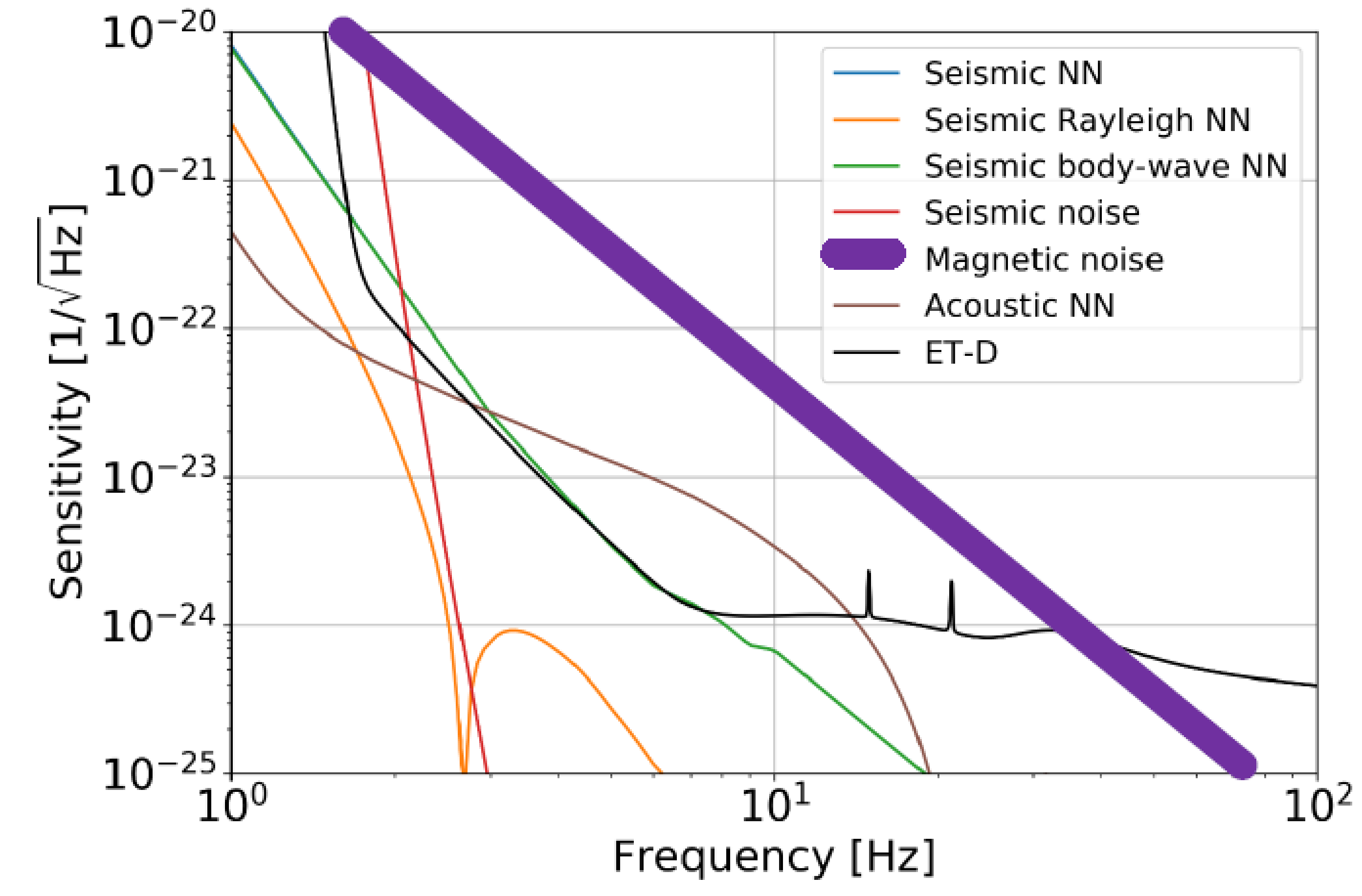
NOTES: no estimate below ~5 Hz. Green lines are the target 10 times below ET design. These improvements are based on fundamental noise sources, that is Schumann resonances field at low frequencies and correlated noise at high frequencies. Local noise at interferometer could make things worse.





from I. Fiori 2022, https://apps.et-gw.eu/tds/?content=3&r=17802

Magnetic noise



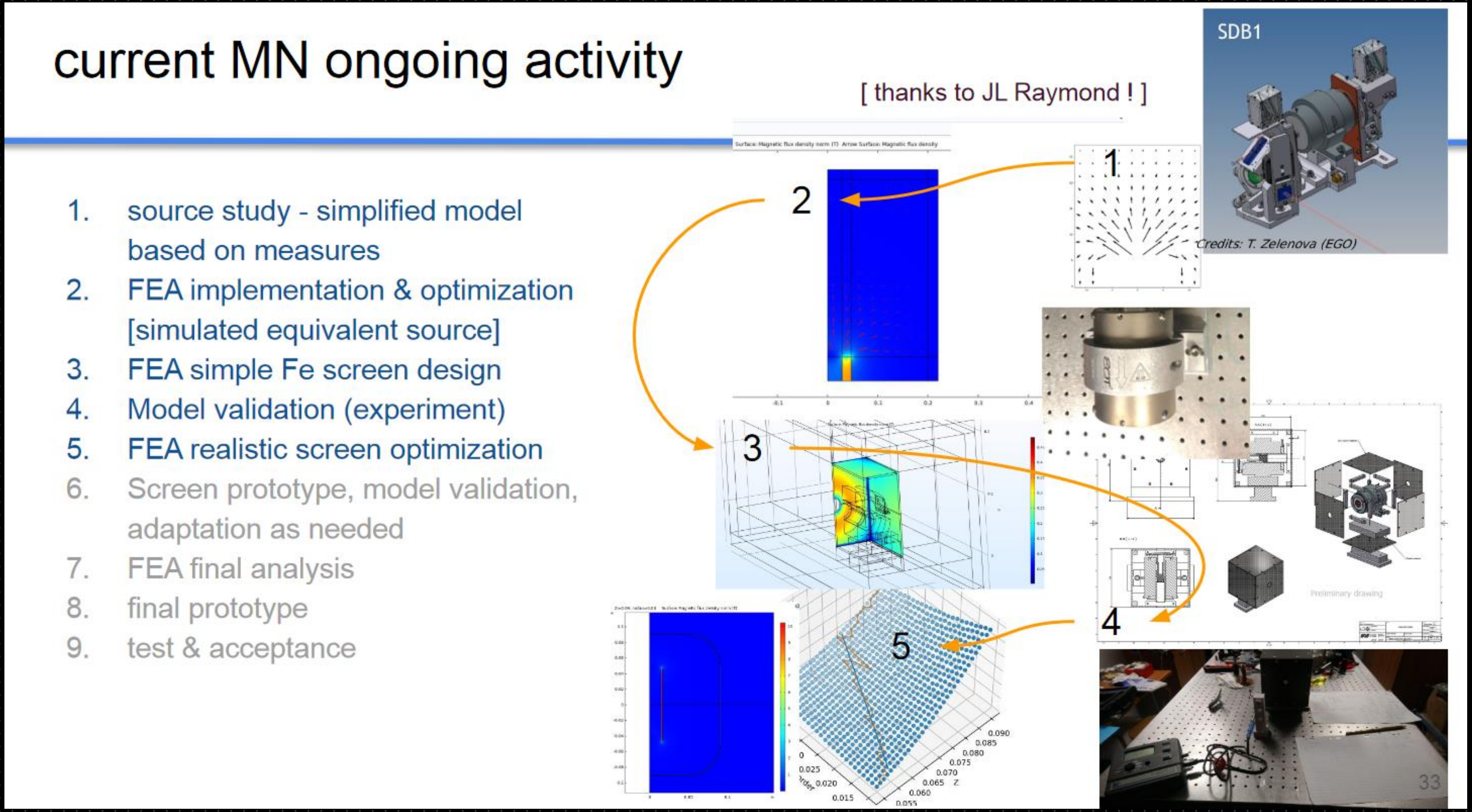
Magnetic noise could be a showstopper reaching the ET sensitivity target.

Magnetic Noise mitigation strategy will be crucial at LF.

From: J. Harms 2022 – ISB workshop

Magnetic noise

FEA, models, simulations…



from I. Fiori 2022, [*https://apps.et-gw.eu/tds/?content=3&r=17802*](https://apps.et-gw.eu/tds/?content=3&r=17802)

Magnetic noise

FEA, models, simulations…

Simulation works

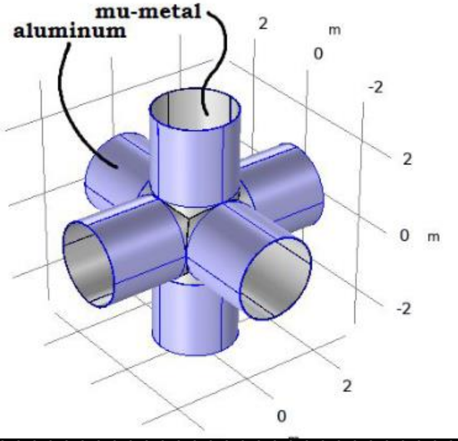
10

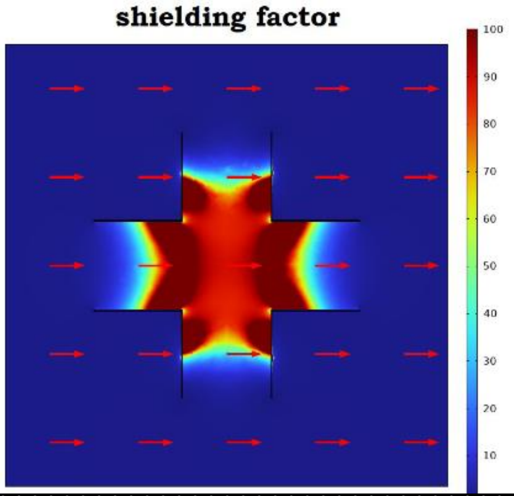
Objective: shield the sensitive volume of suspended elements from external fields (payloads, detection benches, …)

Double shielding:

1. Magnetostatic shielding: mu-metal layer added to steel vacuum chamber
2. Eddy current shielding: aluminum hollow cylinders

Federico Armato's talk & poster





from I. Fiori et al. XIII ET Symposium 2023 and Armato et al. 2023

Magnetic noise

Possible contributions from the Spanish side:

- **FEA/FEM?**
- **Computational resources?**
- **PhD students & postdocs who can work on simulations and prototypes.**

Contact: andrea.chincarini@ge.infn.it , irene.fiori@ego-gw.it

Environmental Sensors

ANM-Environmental Sensors WP main tasks:

- Define sensor requirements (sensitivity, range, electronics…);
- Select suitable sensors;
- Characterization of chosen sensors;
- Design of the sensor network;
- Project of conditioning electronics;
- R&D on new sensors (tiltmeters, LIDAR, optical fibers…).

Environmental Sensors

Possible contributions from the Spanish side:

- **Custom DAQ systems?**
- **Electronics?**

Contact: rosario.derosa@na.infn.it