Introducing the magnetic noise problem of GW interferometers, Virgo and ET

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ET@TO

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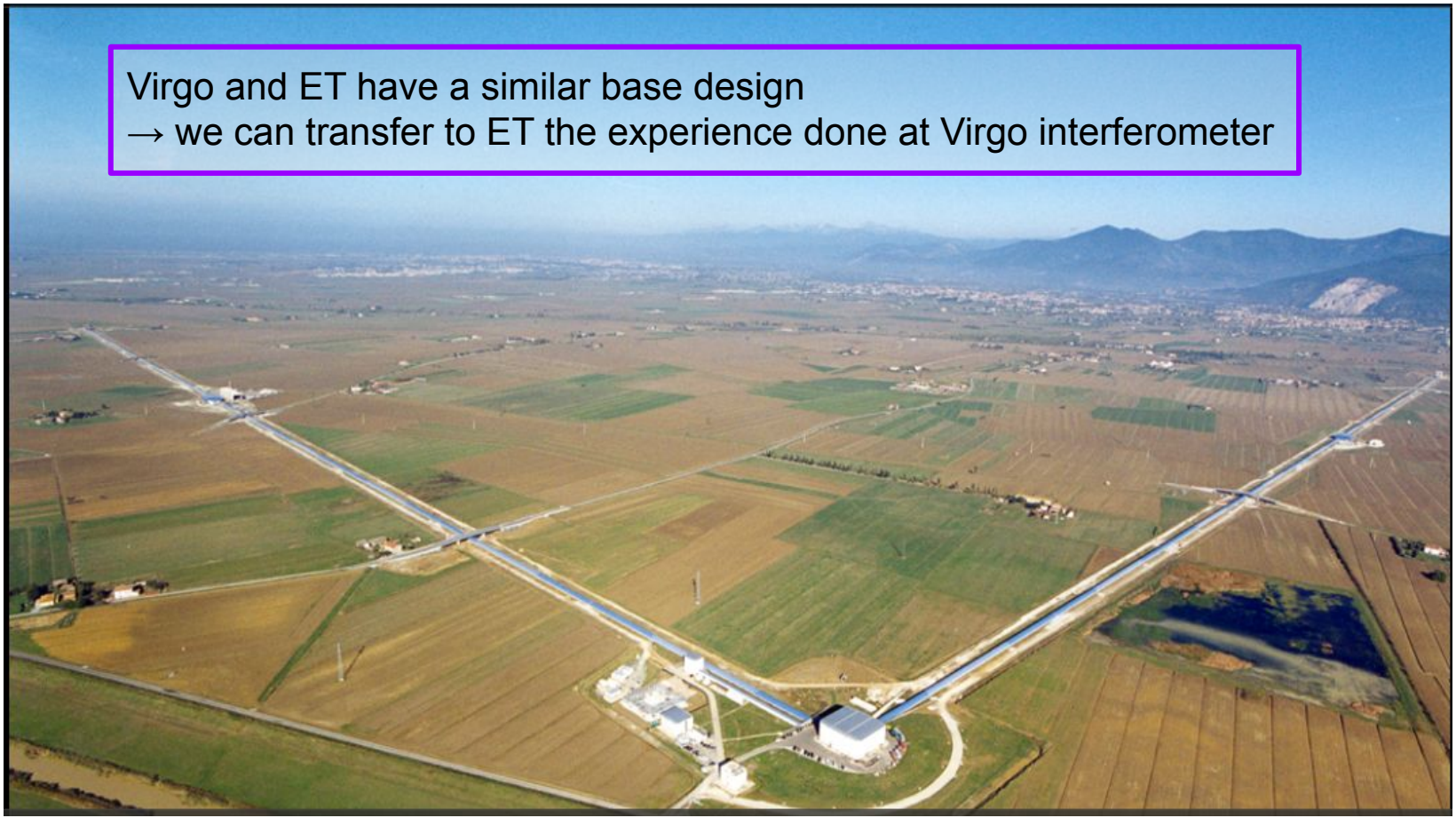
EGO EUROPEAN GRAVITATIONAL OBSERVATORY

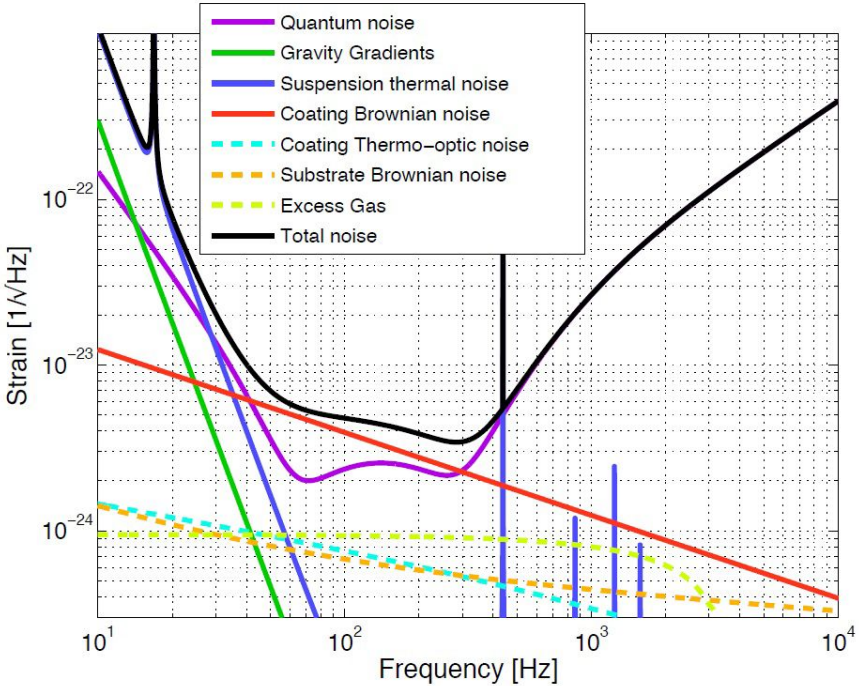
Virgo


Virgo and ET have a similar base design
→ we can transfer to ET the experience done at Virgo interferometer

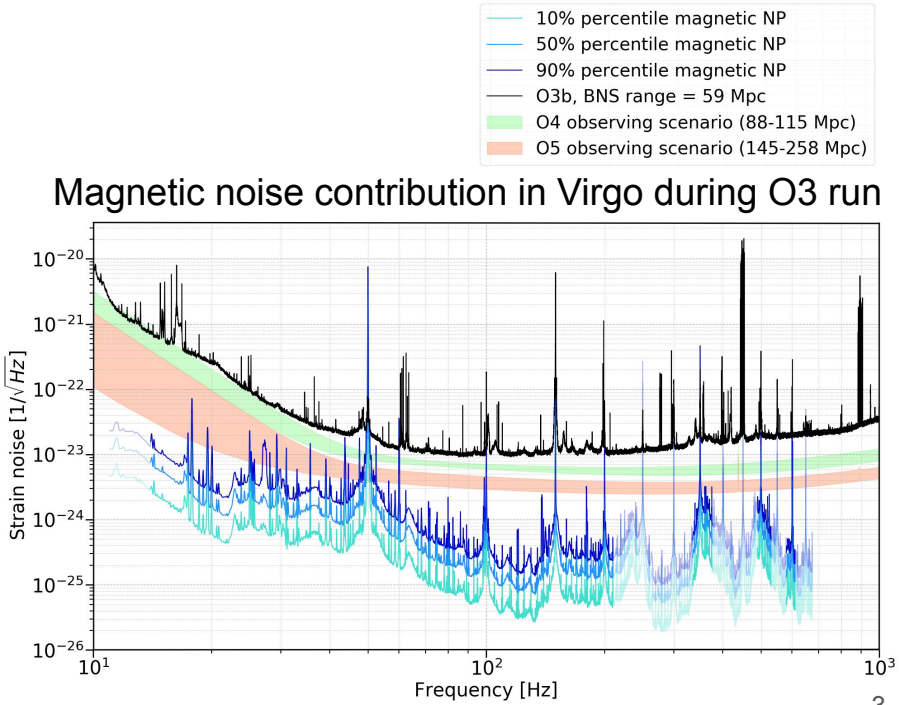
The sensitivity curve of Virgo

Low frequency is though! Several limiting noises. Among which is magnetic noise.

Design noise budget of AdV+



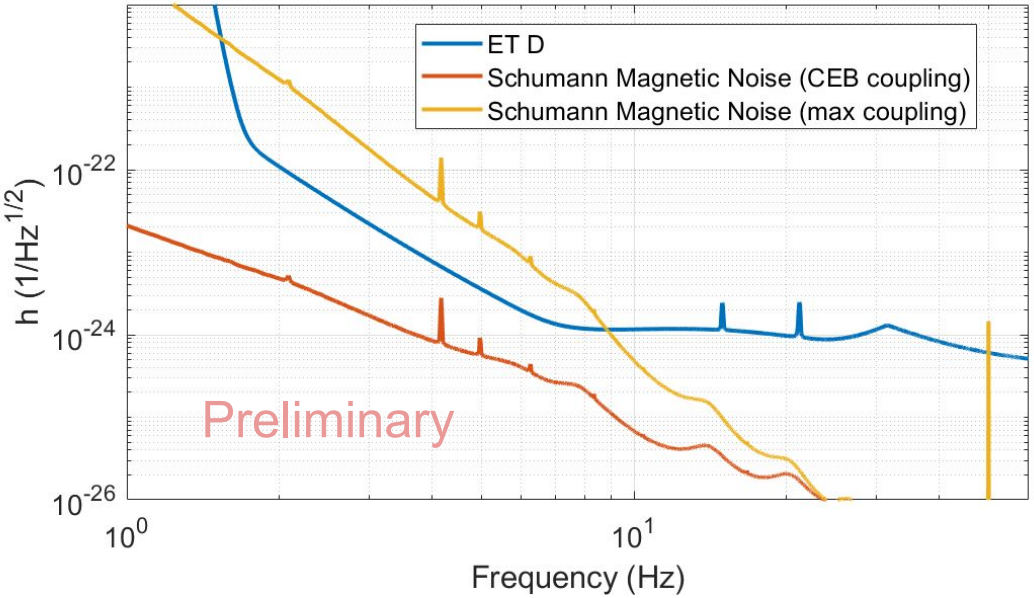
Magnetic noise contribution in Virgo during O3 run



Magnetic noise in ET (tentative)

Tentative magnetic noise extrapolation to ET - by Rosario De Rosa @SPB meeting, April 2022.

Magnetic noise can be a limiting factor for ET !!!



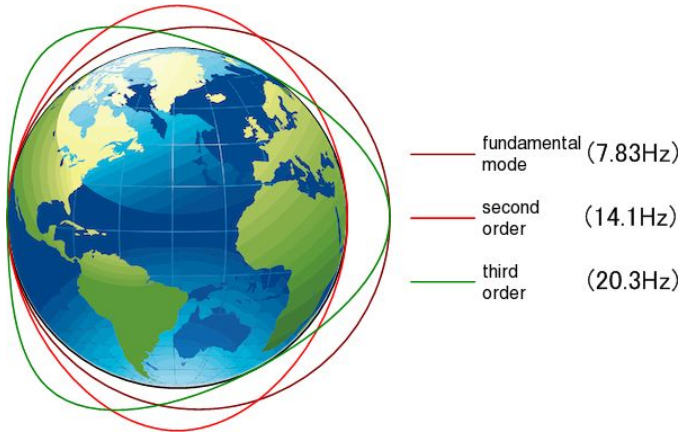
OPTIMISTIC:
assumes the magnetic noise in ET will be at the level of Schumann's magnetic field (like in quietest places on Earth)

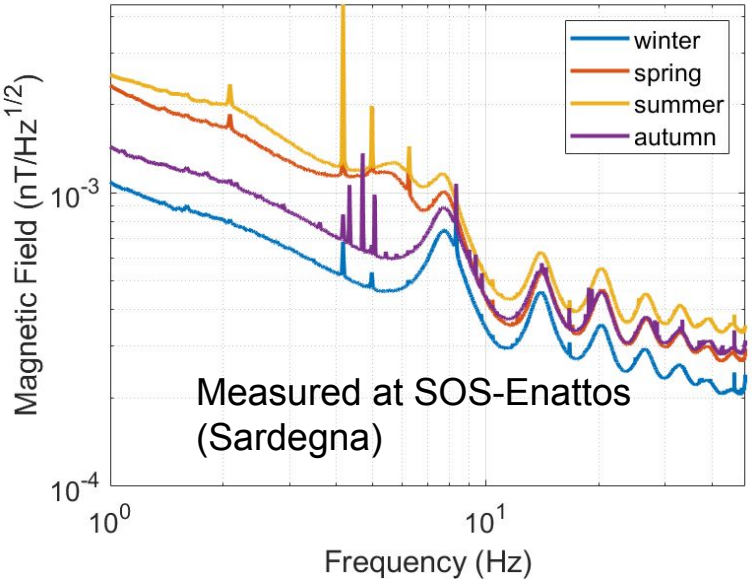
Schumann’s resonance magnetic field

Resonance modes of the cavity formed by the Earth’s surface and the ionosphere.

Sensed in the most quietest places with no pollution of anthropic EM fields.

Are used as target magnetic ambient noise for ET.

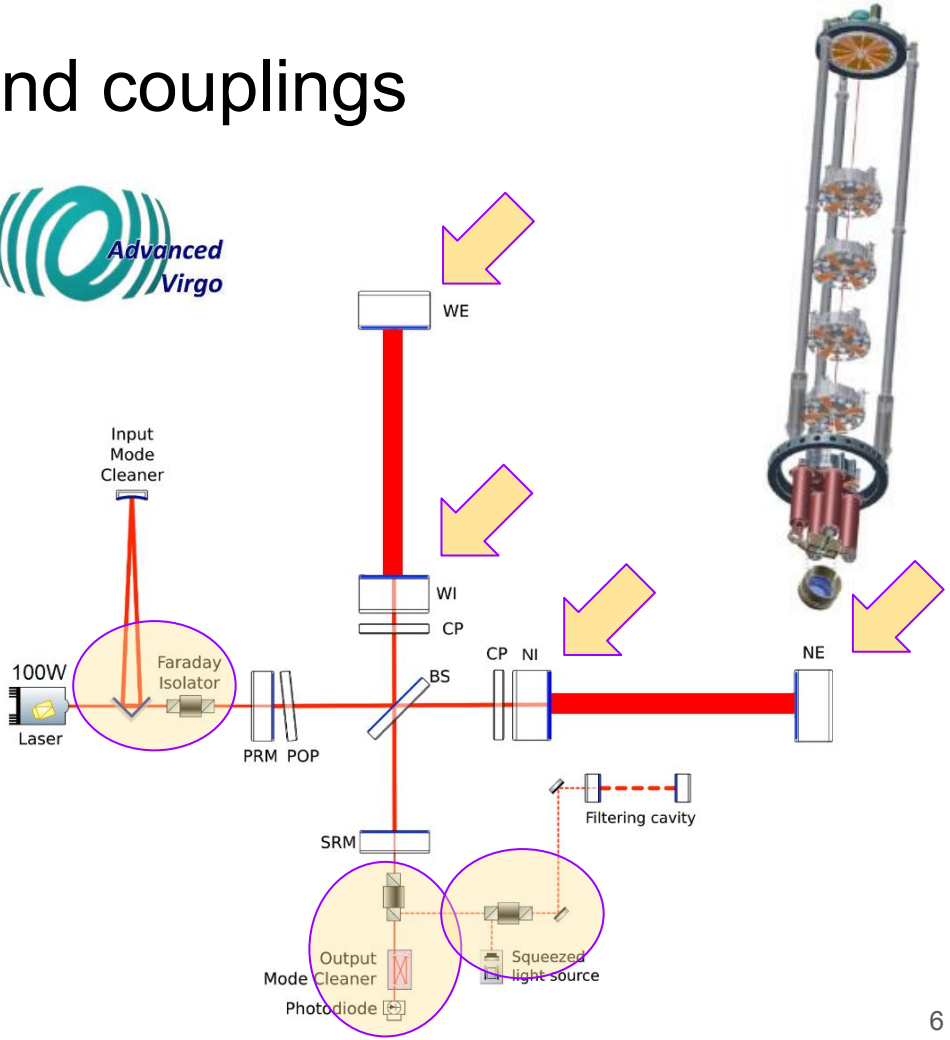




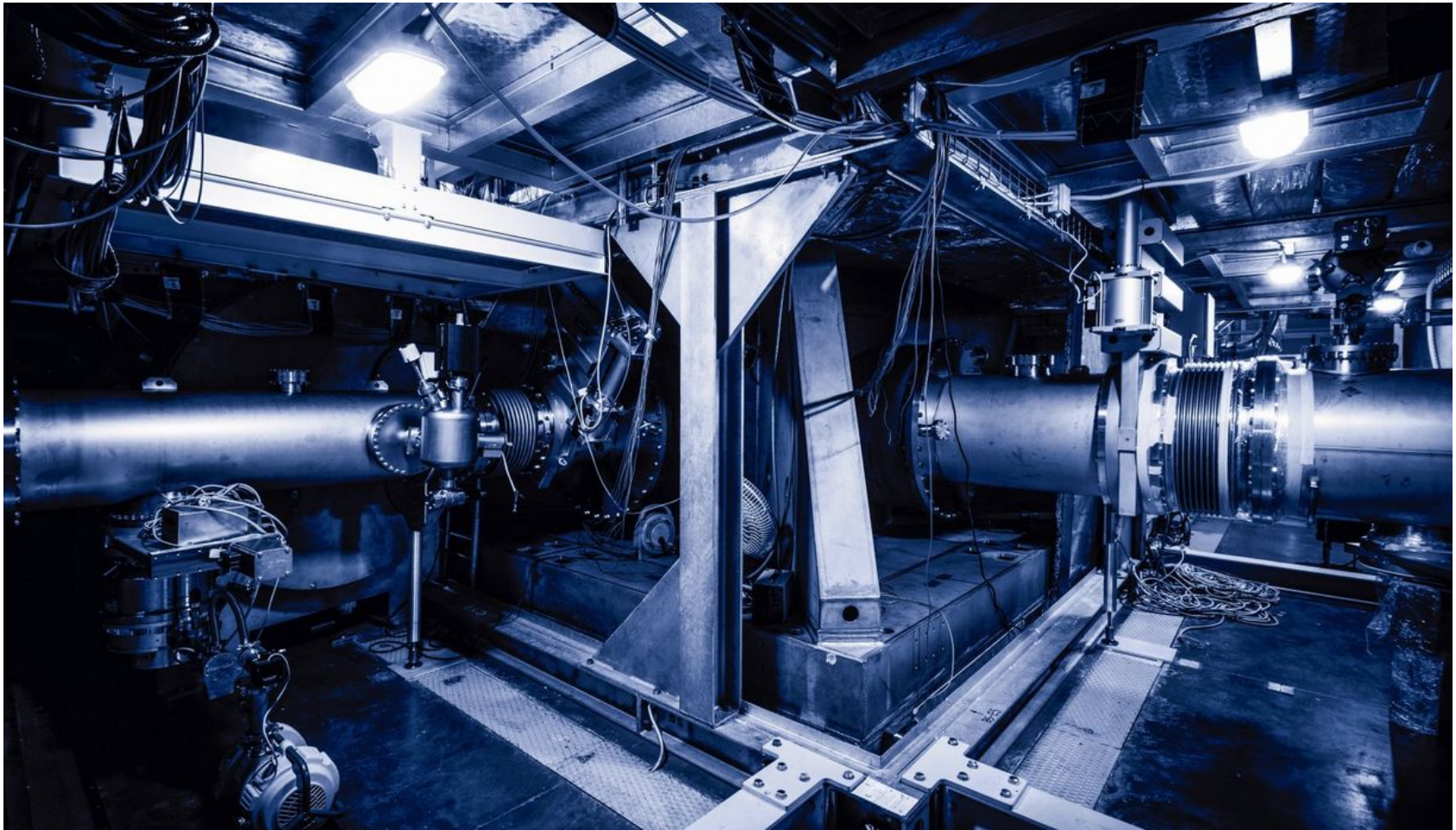
Two ingredients: sources and couplings

Sources -
the interferometer is surrounded by plenty of devices that are part of its infrastructure and emit magnetic fields

Couplings -
the interferometer has many locations in which the magnetic noise can “add” to the gravitational wave signal

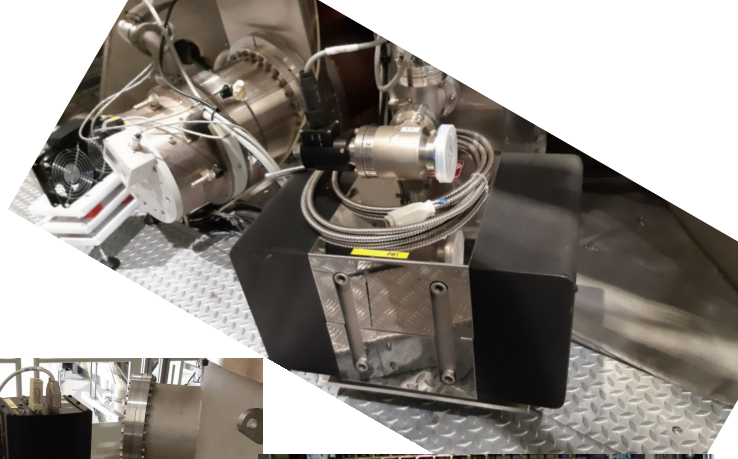


Sources of magnetic fields



Sources of magnetic fields

Sources of magnetic fields



>> Any device which carries an electric current … 😉

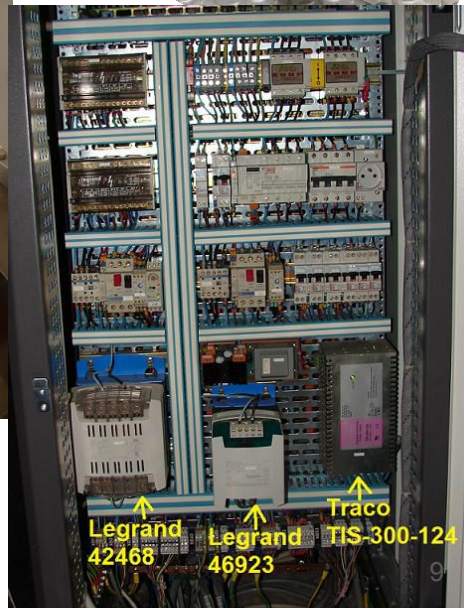
Figure of merit: $\frac{\text{Electric power [W]}}{\text{Distance [m]}}$

Devices with large electric power

- Air Conditioning systems (HVAC): pumps, motors, heaters, chillers
- Power supply modules (e.g. for the vacuum equipment)
- Cryogenic systems for ET (compressors, circulation pumps …)

Devices that need to stay close to suspended or auxiliary optics

- Vacuum devices: pumps, gauges, valves …
- Optical devices: translation and rotation stages, laser beam profiler …
- Electronic modules, cooling fans, digital communication devices (PLC) and their wires, …
- Electricity distribution circuits, illumination …



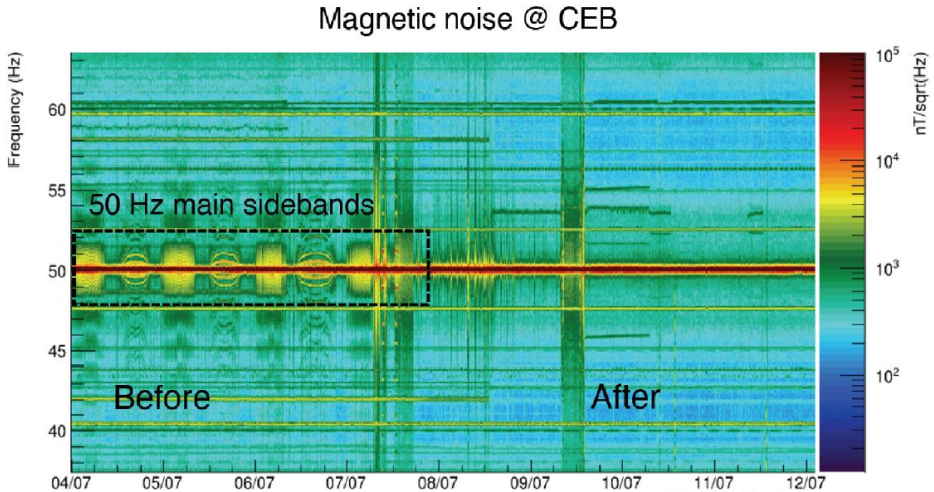
Each device needs to be carefully examined for ad-hoc mitigation solution

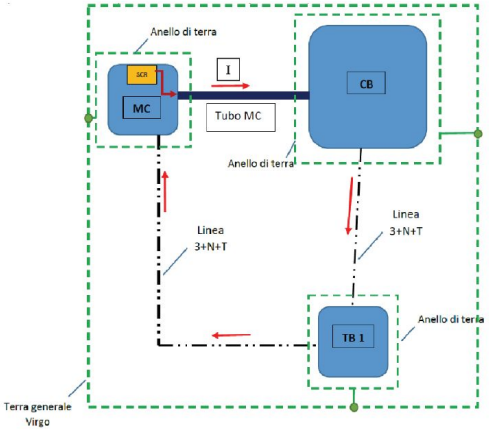
One non-obvious source…

Current flow in the Mode Cleaner vacuum pipe (140m, stainless steel).

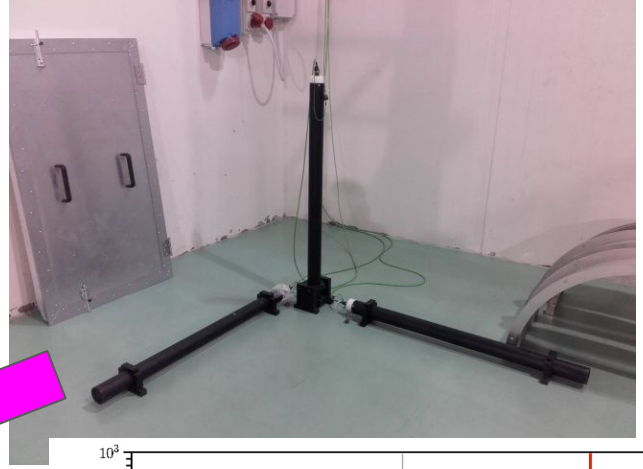
The pipe was the lowest resistance connection between the Central building and the ModeCleaner building.

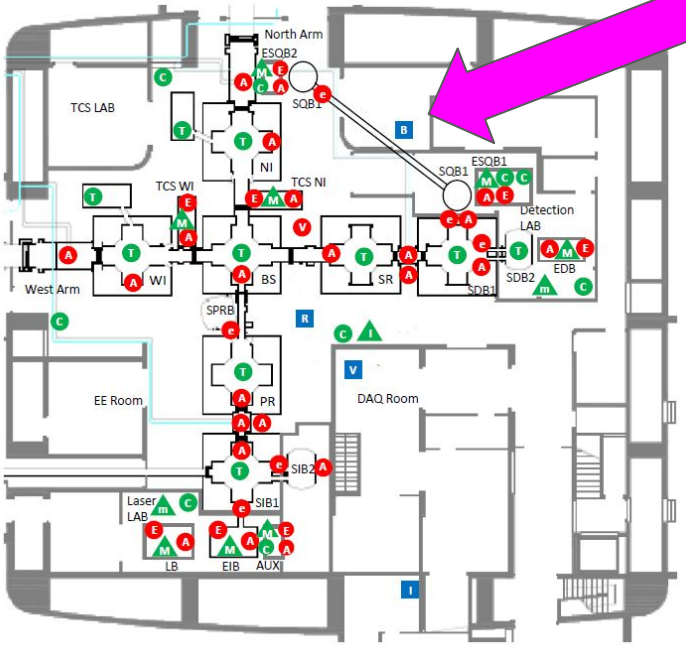
Solved by creating a new local ground inside the MCB building with the use of a triangle-to-star insulating transformer.

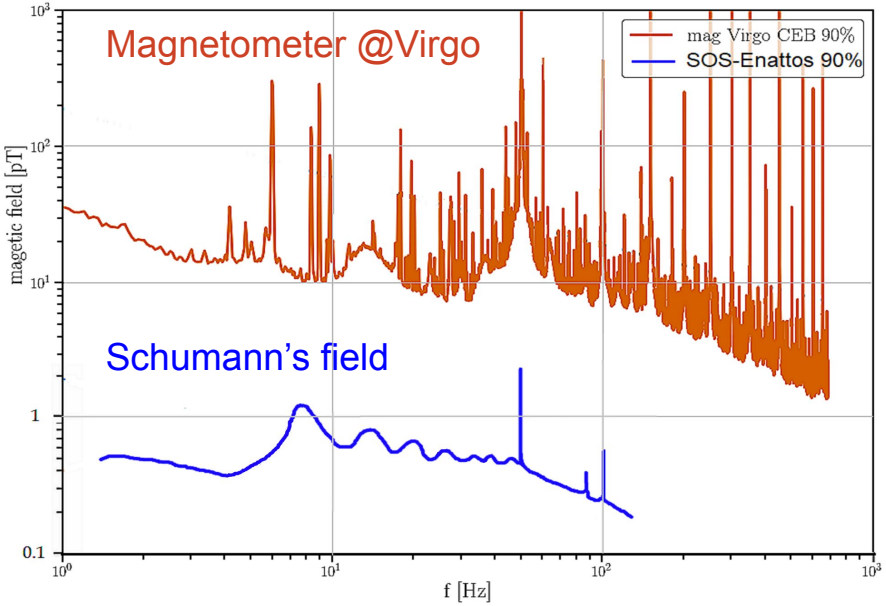




Magnetic noise in the Virgo Central Building







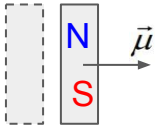
Short-term activity for ET: Environmental source catalogue

- Define guidelines for ET: where to put sources, what to do/not-to do, techniques to mitigate emissions.
- Start with most known and obvious sources: i.e. vacuum devices (pumps and gauges, wires …) and infrastructure devices (air handling units, motors, water chillers, …)
- Characterize source field shape (coarse estimate) and intensity versus distance
- To do in the magnetic test facility laboratory we are setting-up at EGO (see Federico Paoletti's talk)

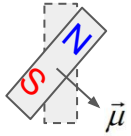
Magnetic effects

$\overrightarrow{B}_{environment}(t)$ ⟺ Permanent magnet (or any obj. with residual magn.) ⇒ Force, Torque

$$\vec{F} = (\vec{\mu} \cdot \vec{\nabla})\vec{B}$$



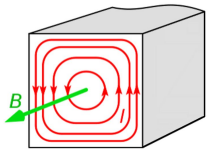
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$



$\overrightarrow{B}_{environment}(t)$ ⟺ Electric conductor ⇒ eddy currents in the conductor body ⇒ Force, Torque

on magnetized body, or warp the local magnetic field (enhancing B gradients)

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$



Then, Forces cause displacement of the body carrying the magnetized component …
and noise in the interferometer !!!

Coupling locations (@Virgo)

Mirror test masses (the most “touchy” parts of Virgo!): carry tiny magnets (2.5mm dia, 1T, Sm2Co17) used as actuators

Super-attenuators: suspension stages have magnet-coil actuators, or magnetic anti-springs.

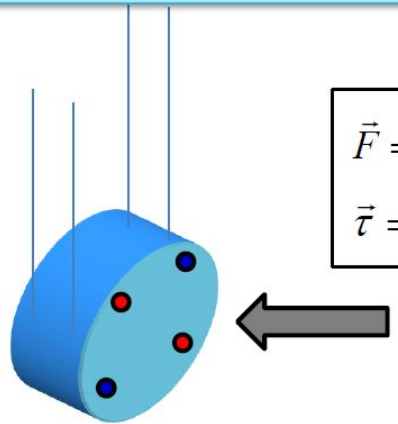
Faraday Isolators on input and output suspended benches: optical diodes to prevent light to be reflected back

Eddy currents in the metallic parts of the payload

Coupling locations

Mirror test masses (the most “touchy” components of Virgo!)

- **4 tiny magnets** are glued on Virgo mirrors surface and used for position control (coil-magnet actuation)
- **External magnetic fields** can exert a force on the magnets → mirror displacement noise



$$\vec{F} = \vec{\mu} \cdot \nabla \vec{B}$$

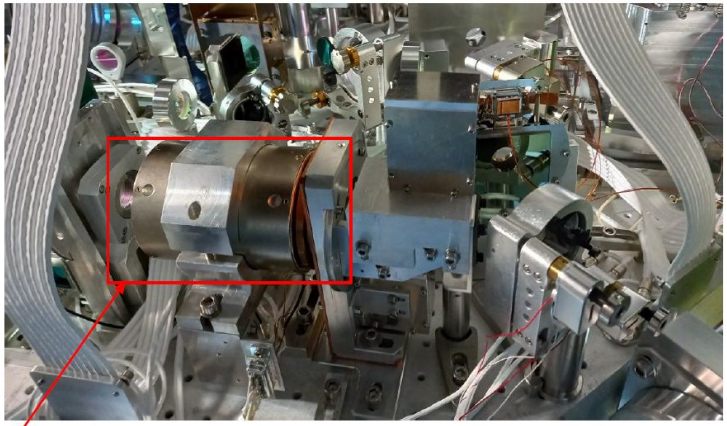
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Magnets in antiparallel configuration

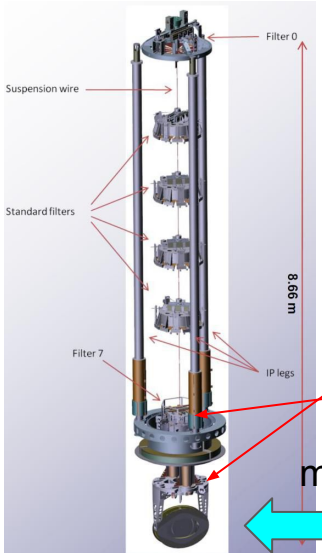
2.5mm dia. 1T SmCo

Coupling locations (more)

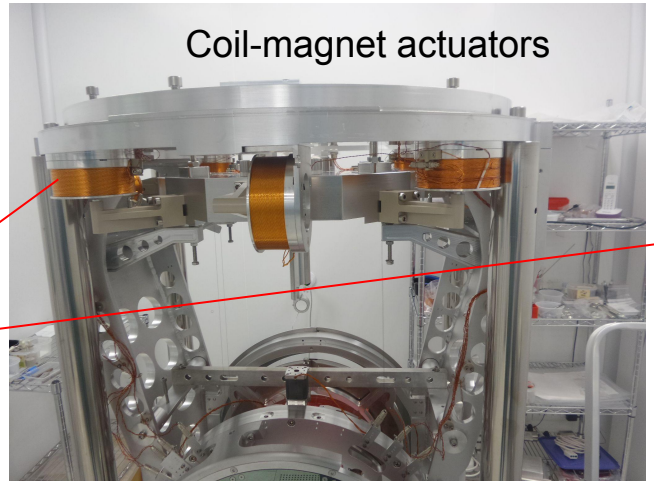
- Super-attenuators: some attenuation stages have magnet-coil actuators, or magnetic anti-springs.
- Faraday isolators: optical diodes to prevent light to be reflected back
- Eddy currents in the metallic parts of the payload



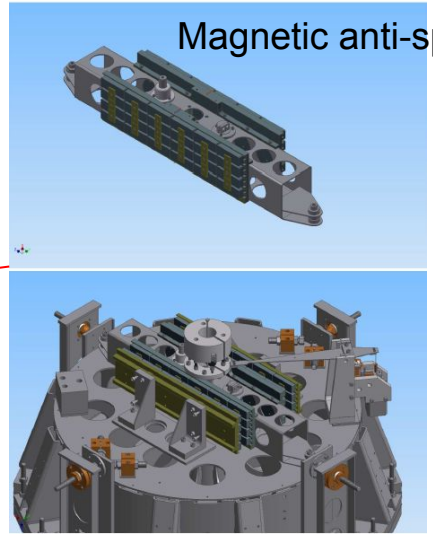
SDB1 Faraday Isolator (1T)



mirror



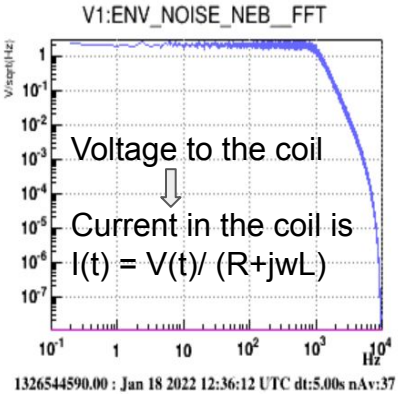
Coil-magnet actuators

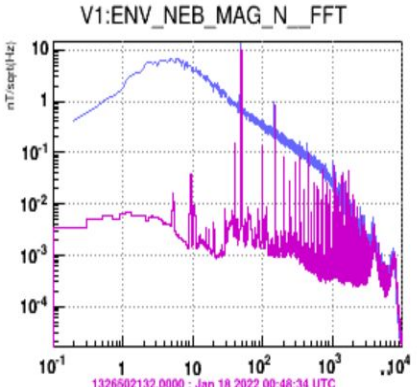


Magnetic anti-springs

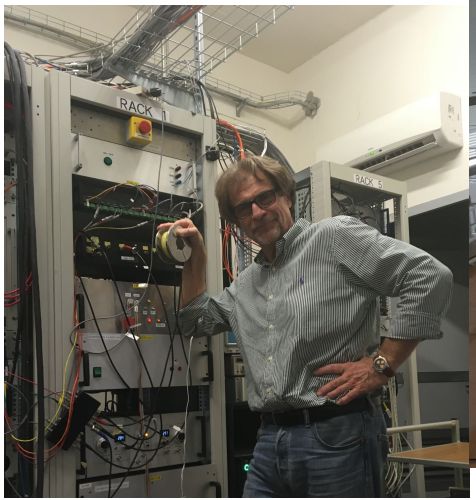
Measure the coupling

Use coils to “inject” magnetic fields well above the normal ambient level, and measure the effect produced in the interferometer



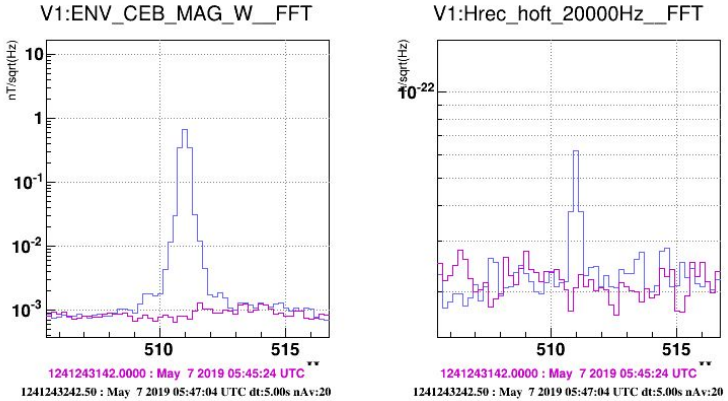


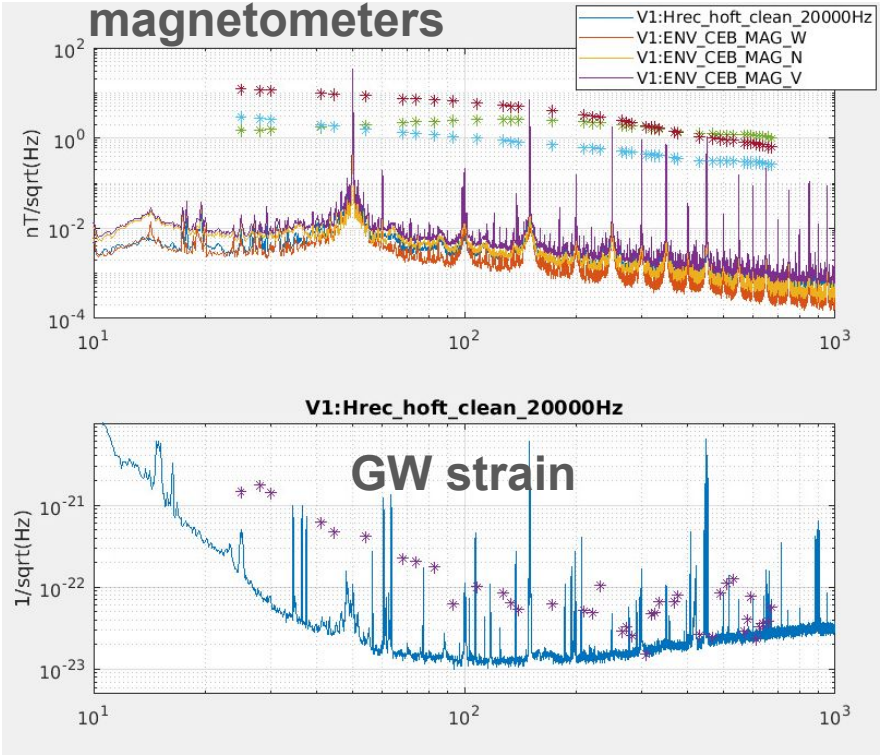
Magnetic field in the experimental hall



Magnetic injection (example)

Noise injected: sinusoidal signal at different frequencies from ~20 Hz to 600 Hz.





Magnetic couplings measured in Virgo, during O3 run

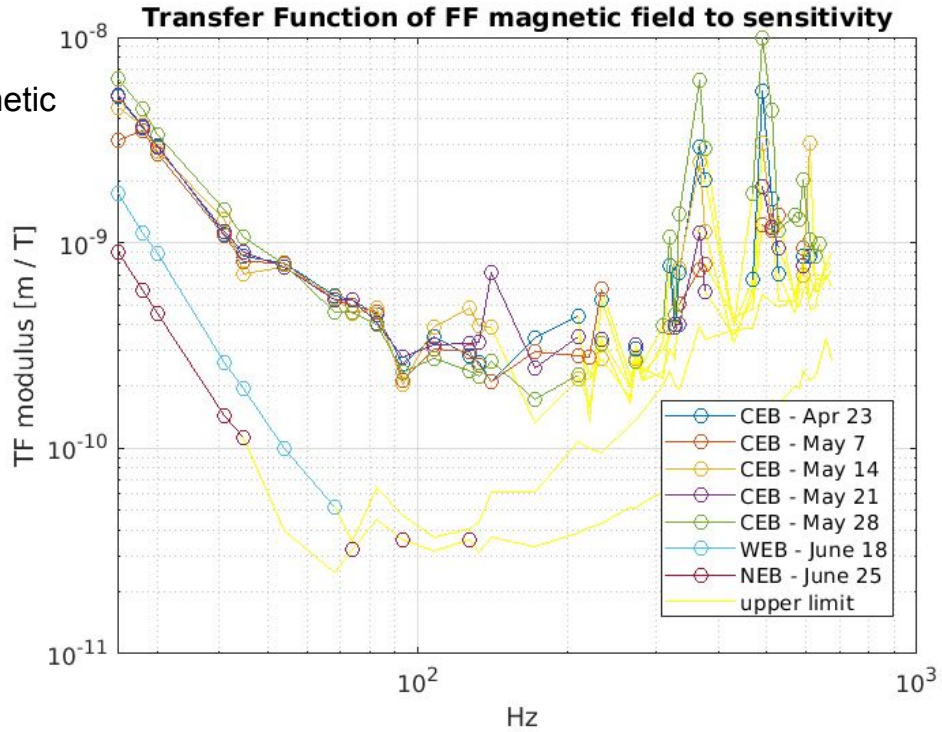
Transfer Function

$h_{noise\ magnetic}$

$$TF_{measured} = \sqrt{\frac{h^2_{inj}(f) - h^2_{bkg}(f)}{B^2_{inj}(f) - B^2_{bkg}(f)}}$$

$$TF_{upperlimit} = \frac{h_{bkg}(f)}{\sqrt{B^2_{inj}(f) - B^2_{bkg}(f)}}$$

3 Virgo buildings: Central, North, West



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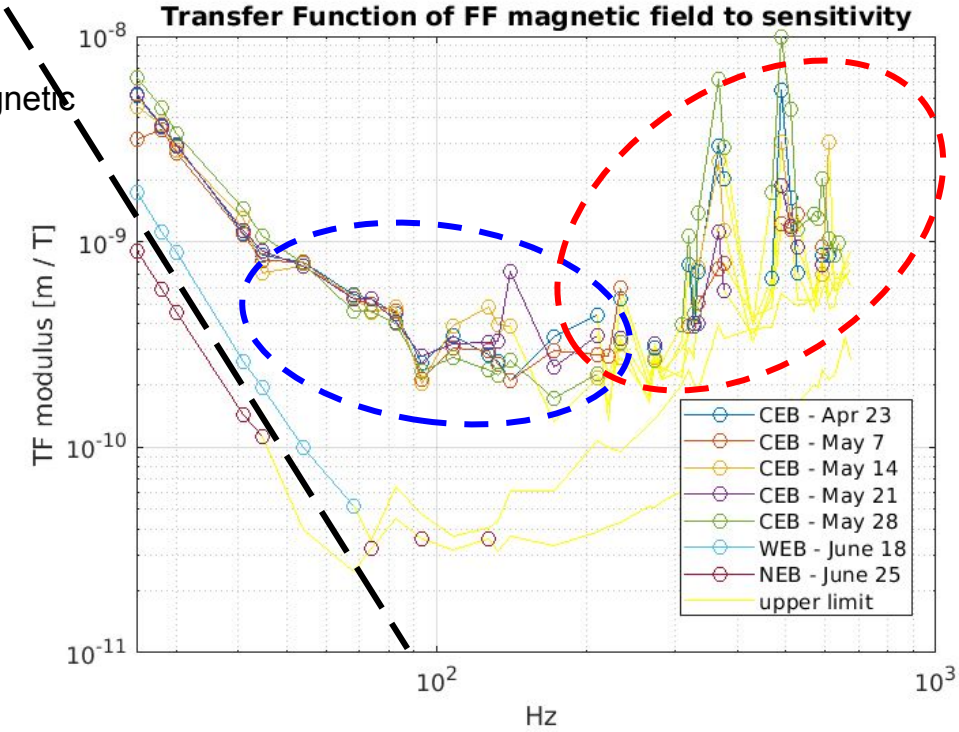
Couplings from different locations add-up

Need to disentangle

3 Virgo buildings: Central, North, West

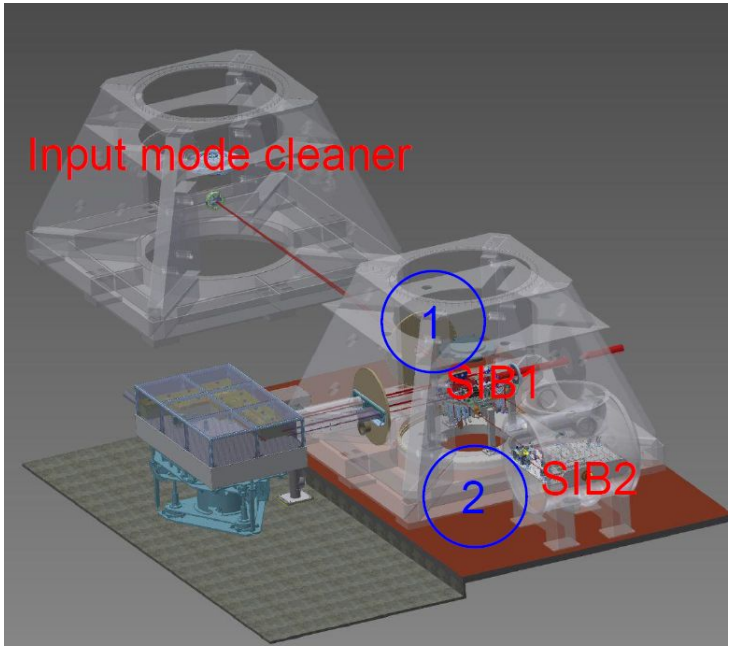


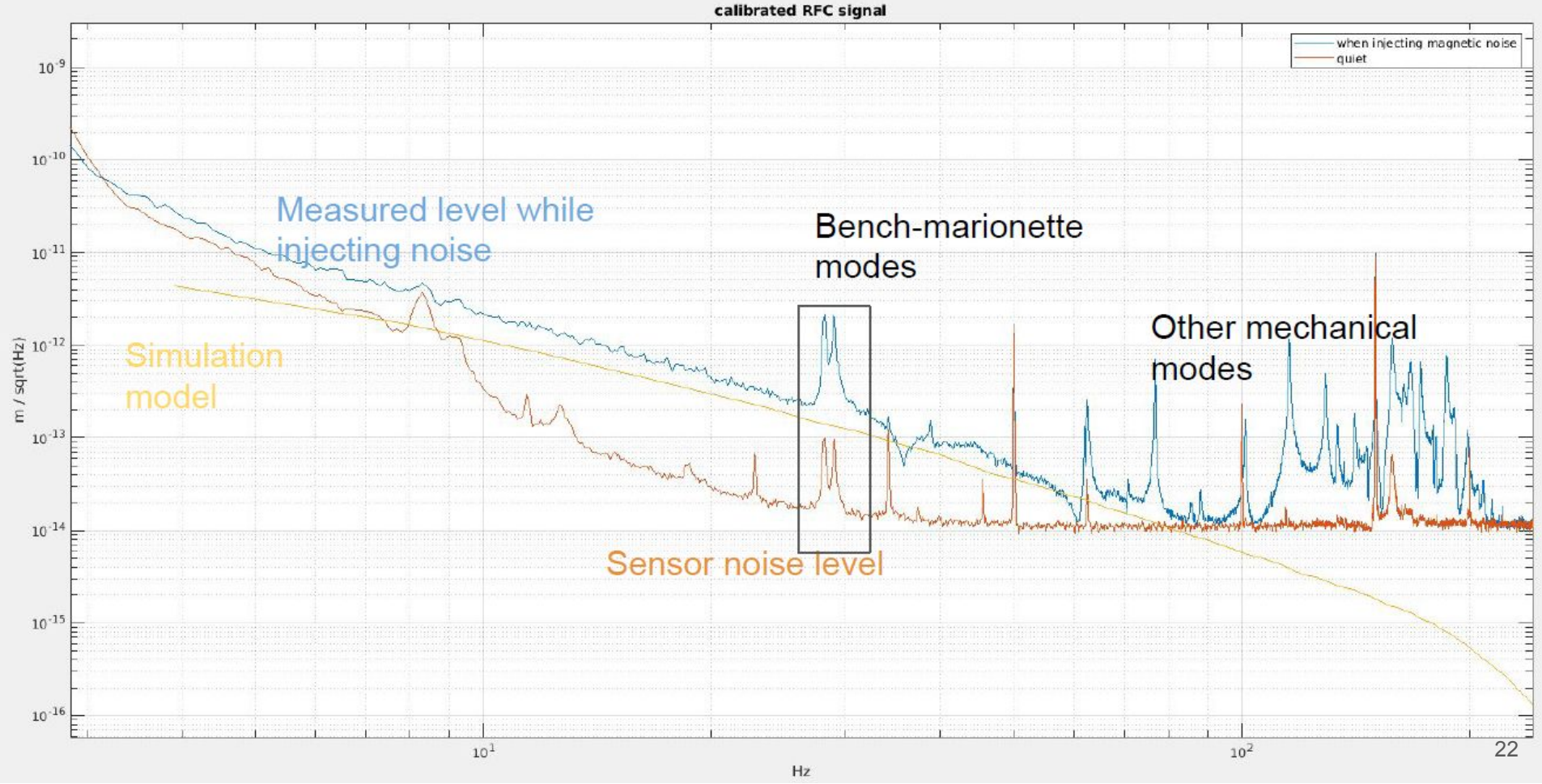
Global vs Local injections

Global injections excite multiple paths (with different unknown weights)

New strategy: measure coupling of single ITF components, with pair of coils

Jean-Loup Raymond @ GWADW2022




calibrated RFC signal
when injecting magnetic noise
quiet
Measured level while injecting noise
Bench-marionette modes
Other mechanical modes
Simulation model
Sensor noise level
m / sqrt(Hz)
Hz

Short-term activity for ET: phenomenological modeling of the coupling function [on AdV]

- Measuring campaign of global and local injections on AdV+
- Measure the coupling of each detector part and build up a parametric noise budget for AdV+ which can be transferred to ET.

Pending … a working AdV+ interferometer: October?

The End

www.virgo-gw.eu

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