# Virgo environmental noise works status

**Irene Fiori**

**European Gravitational Observatory**

**LSC – Virgo Collaboration meeting
Glasgow,  August 29 – Sept 1 2016**

# Outline

- Environmental monitoring
  - sensors, status
  - enhanced ITF infrastructure monitoring
  - naming
- Laser Lab environment
- Magnetic coupling to TM, modelling work and mitigation actions
- Global magnetic noise
- Newtonian Noise

Conclusions

# Environmental monitoring

## Fast sensors

*(R.DeRosa, F.Garufi - INFN-Napoli)*

**Buildings monitoring**

- Ground 3D seismometers (1x4 Bld.s) Guralp 40T-60s
- Magnetometers 3D (3x4 Bld.s) MFS-06 low noise induction coil
- Microphones (1x4 Bld.s) Brüel&Kjaer 4193 infrasound
- RF antenna receivers (1x4 Bld.s x 3 bands) AAS-STA-5-AD
- Mains ((3 IPS + 3 UPS) x 4 Bld.s) custom

**Vacuum tanks monitoring** (Towers, CryoTraps, Links)

- Accelerometers PCB-393B12 and Meggit-731 (1x9 Tow + 1x6 CT)
- Low frequency 1D acc, Kinemetrics Episensor (1x5 **Links**)

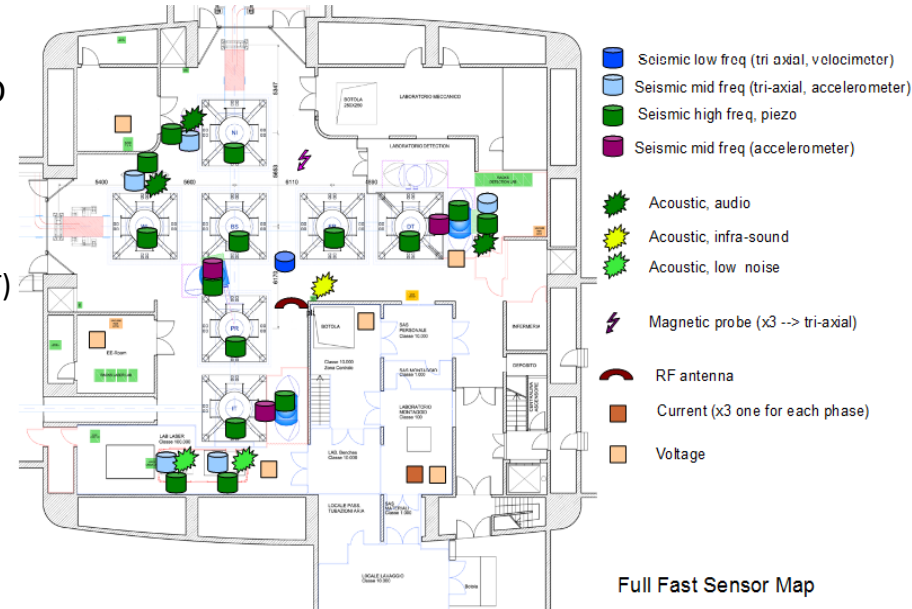**External Optical Benches monitoring**

- Accelerometers (1x 8 Bench )
- Low frequency 3D acc. Episensor (1x6 Bench)
- Sound (1x6 benches, 2 low noise)

**Electronics rooms monitoring**

- Microphones (1 x 5)
- Magnetometers and current probes: on demand

**Installation:** 80% completed, ongoing

**Documentation:** Hardware Inventory DB, http://slwebtest.virgo.infn.it/ifoapp/



Legend:
- Seismic low freq (tri-axial, velocimeter)
- Seismic mid freq (tri-axial, accelerometer)
- Seismic high freq, piezo
- Seismic mid freq (accelerometer)
- Acoustic, audio
- Acoustic, infra-sound
- Acoustic, low noise
- Magnetic probe (x3 --> tri-axial)
- RF antenna
- Current (x3 one for each phase)
- Voltage

Full Fast Sensor Map

**Signal conditioning custom boards**
Differential output, anti-aliasing, calib input

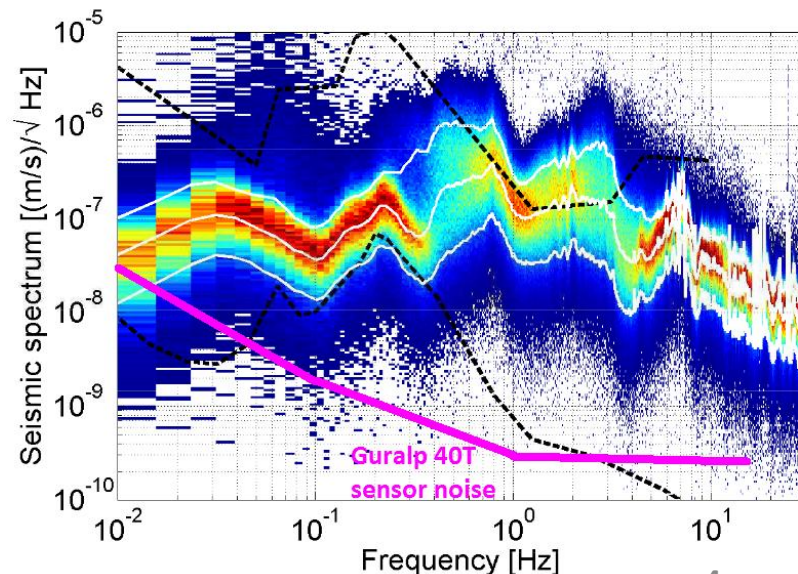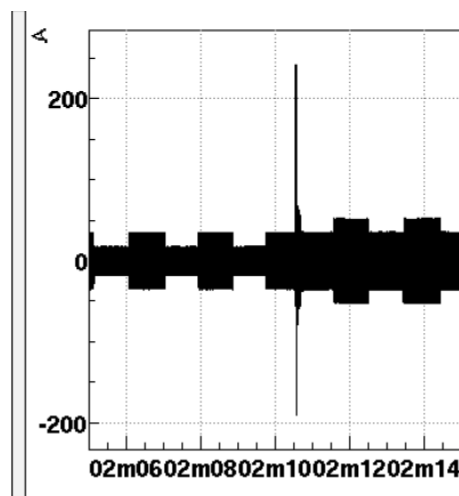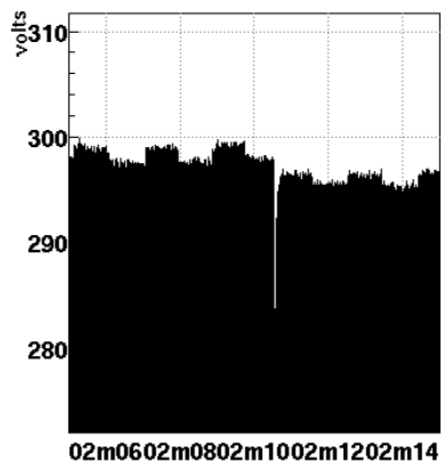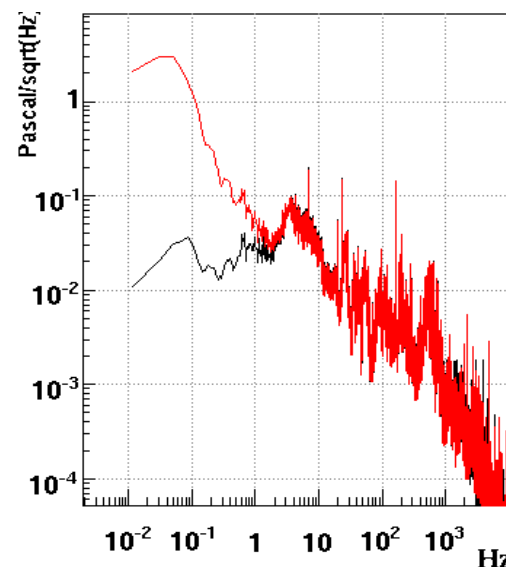# Fast sensors (2)

## FOCUS on a few improvements

Building monitoring

- **Infrasound** microphones (BK 4193): 0.05Hz (-3dB) extended sensitivity

- **Guralp 40T-60s**: 0.015Hz extended seism sensitivity

- **Current probes** on IPS and UPS mains switch-boards: offer high SNR for detecting machines start up
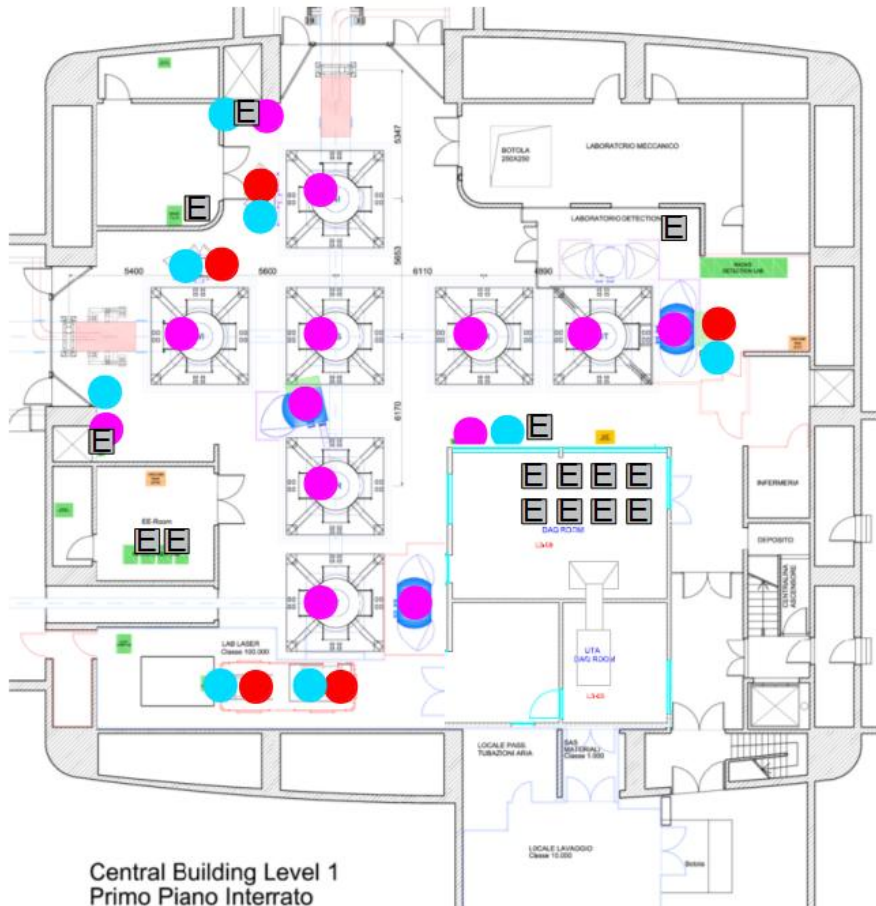
# Environmental monitoring
# Slow sensors (1Hz)

*(R.DeRosa, F.Garufi - INFN-Napoli)*

- **Temperature Probe**
- **Temperature String**
- **Humidity Probe**
- **E** Environmental Module

Central Building Level 1
Primo Piano Interrato

- **Building monitoring**
  temperature probes at 2,4,8,10m heights, pressure, humidity, weather station

- **Towers monitoring**
  in-vacuum T probes, at each SA filter

- **Bench monitoring**
  Temperature and Humidity

**Installation**: completed

**Missing Lightning detector**, plan joining
 www.blitzortung.org

- **New DAQ modules**
  16ch/18 bit ADC, anti-aliasing, decimation, ethernet data exchange protocol
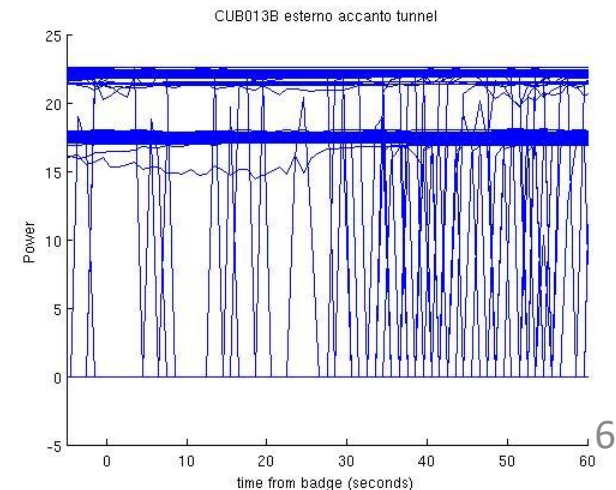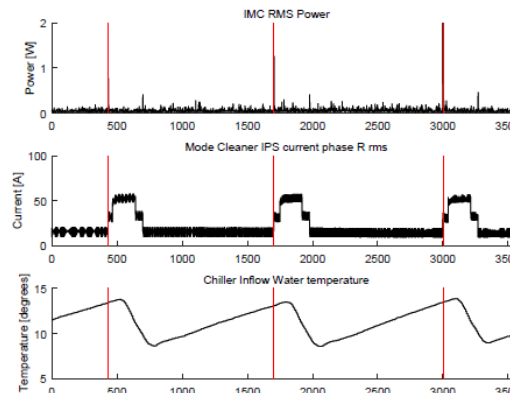  **Cured RF noise emissions experienced in Virgo with old DAQ modules**

# Infrastructure machines monitoring
## extended and improved

*Credits: Roberto Cavalieri - EGO*

- We extended the existing monitoring of HVAC, VAC, UPS systems to help **noise hunting** and add **redundancy** to alarm sys.

- More than 300 sensors, 1Hz, read by DAQ modules: air and water temperature, pressure, flux, over-pressure, HVAC control signals

- **Early noise hunting pointed out correlations of ISYS unlocks /misalignments and switching on-off big INF machines (e.g. water chillers) and with turning on-off E-rooms L-rooms illumination lights**

- NEW:

  **LUX sensors** (Labs, E-rooms, Halls)

  **RMS current sensors** at power switch boards or big load machines





IMC RMS Power

Mode Cleaner IPS current phase R rms

Chiller Inflow Water temperature

CUB013B esterno accanto tunnel

# Channel naming conventions

- Got rid of (most of) old cryptic names and redundant segments, Easing searches also by automated tools

- Set a few general rules, but leave freedom to adapt to sub-sys needs

  - General syntax (following LIGO doc ....)

    **V1:SUBSYSTEM_XXX_YYY_..._ZZZ**

    Example 1:  V1:ENV_CEB_SEIS_N  (i.e.  XXX = LOCATION, YYY = SENSOR, ZZZ = ORIENTATION )
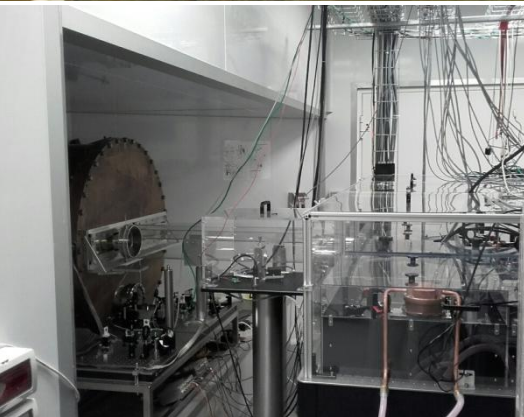    Example 2:  V1:DQ_BRMSMon_BRMS_MAGNETIC_ENV_NEB_MAG_W_32Hz_64Hz  (i.e. XXX = process name)

  - Fragment names **uniquely** defined
  - Defined list of acronyms (rooms, labs, detector parts)
  - Defined **reference systems** and **orientation conventions**
  - See: VIR-0223B-14.pdf
  - DetChar group naming conventions:  https://www.virgo-gw.eu/DataAnalysis/Detchar/projects/channelnaming.html

- Documented in VIC, Virgo Interferometer Channel Database: http://slwebtest.virgo.infn.it/ifoapp/



Gary Hemming - EGO
Didier Verkindt - LAPP

# Laser Lab environment




- Laser and Det Labs are now **ISO 6 clean rooms**
- **Acoustic works**: good isolation from neighbours noisy environment (meet req.). But, acoustic noise from HVAC is still 10dB louder than required. Not presently an issue.
- **Temperature stability**, accuracy is better than 0.1°C p2p over whole room volume, obtained thanks to a patch work to dump oscillations of the inaccessible PID control set up by K&P contractor (Maddalena Mantovani - EGO, eLog 3417)

Temperature and EIB Local Controls accuracy

HVAC acoustic noise



LL walls acoustic isolation



OFF
Reduced flux
Old Virgo
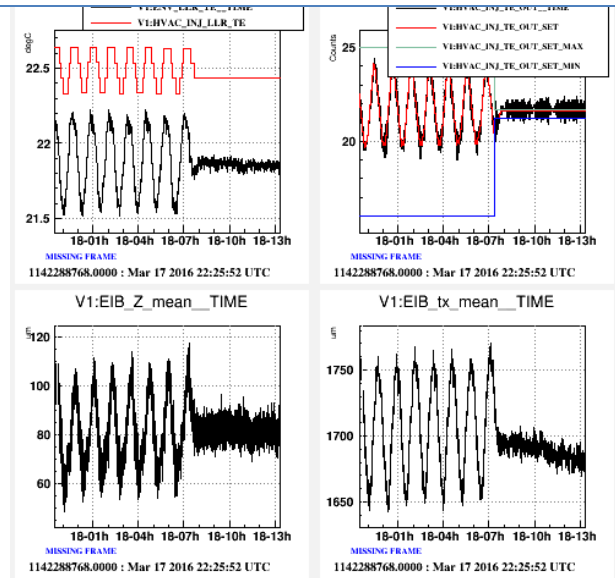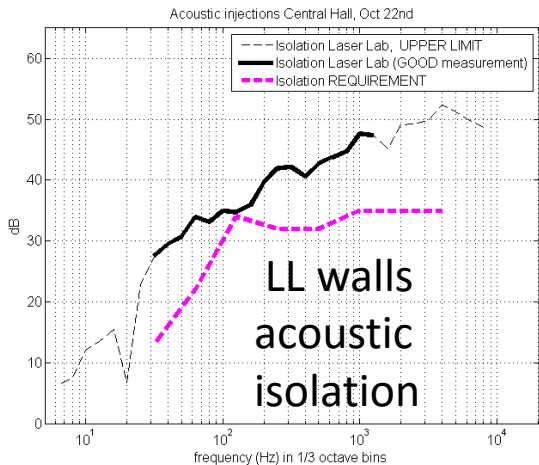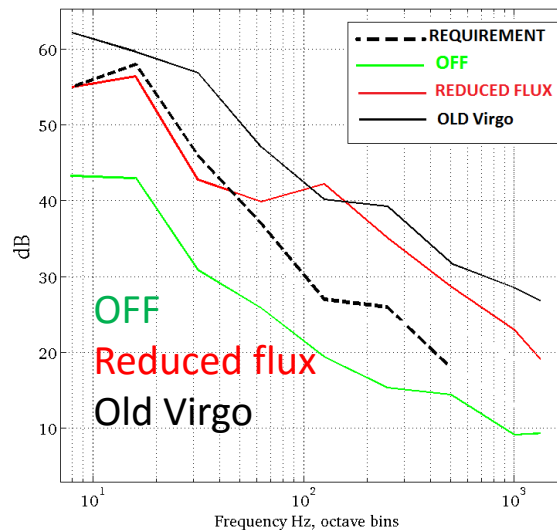
# Magnetic coupling to payloads modelling work

- AdV adopts magnetic actuation on TM, with magnets 5 times smaller than V+, and an optimized design to minimize mag. Gradients (i.e. low $\mu 0$ materials) and shorten Eddy currents paths.

- Residual displacement force from 4 counter oriented magnets arise mainly from: local dishomogeneites in ambient B field gradients, uncertainty in magnets positioning and size.
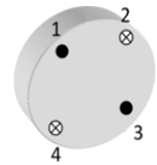
$$h_{noise} = \frac{\sum \nabla(\vec{\mu}_i \cdot \vec{B}_i)}{L\,M\,\omega^2}$$

Measurements on one payload assembly were used to tune a FEM model. Predictions critically depend on electrical "connections" at a few points. General model has more than $2^7$ configurations. Recursive Hadamard matrix minimization over model configurations selects 21 conf. compatible with experiment and mean rel. error < 5%.   *Credits: M.Neri, A.Chincarini, S.Farinon – INFN Genova.  VIR-0018A-16.*
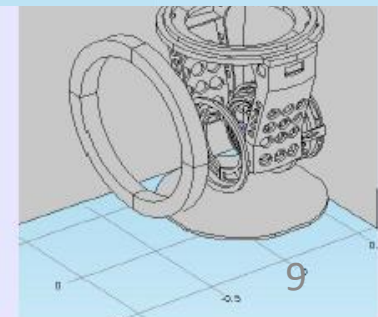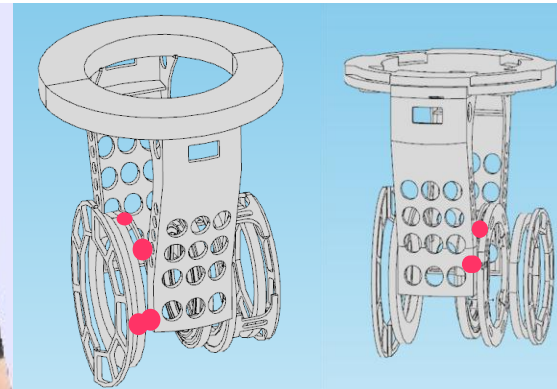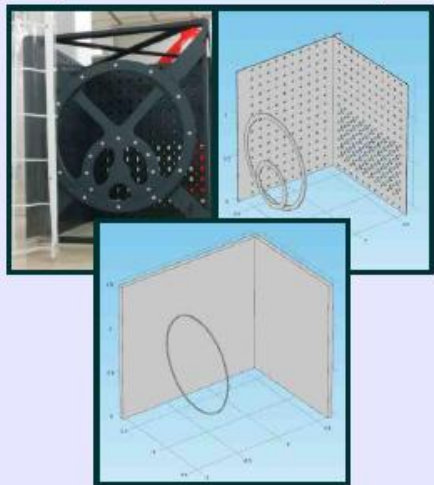


**Reference measurements**

**Model validation**

**Connections**

# Magnetic coupling to payloads modelling work

- Prediction from MonteCarlo simulation of 21 configurations that best matching experimental measurements (on one payload, assuming all are the same), tolerance of magnetic moment ± 15% of nominal value, +/- 1x1x1 mm³  tolerance in single magnet position around nominal value
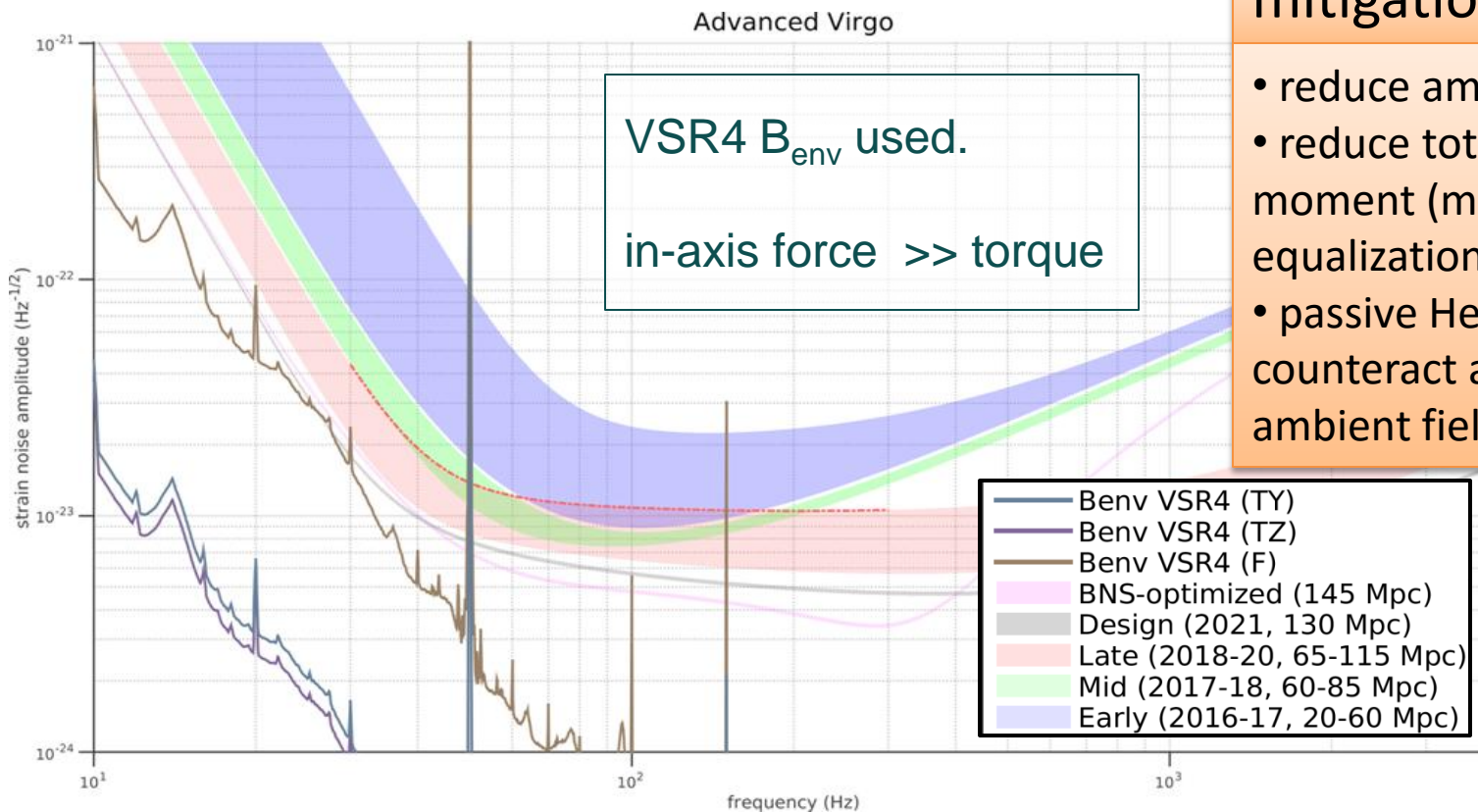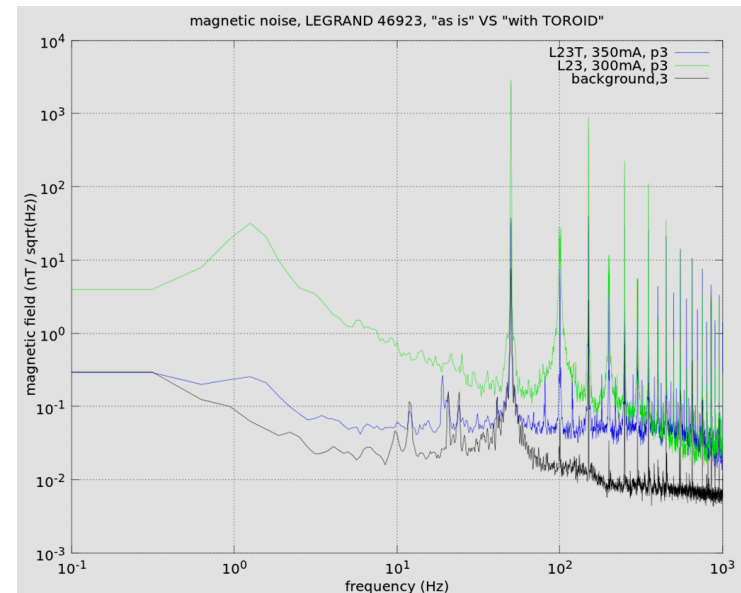
## mitigation strategies
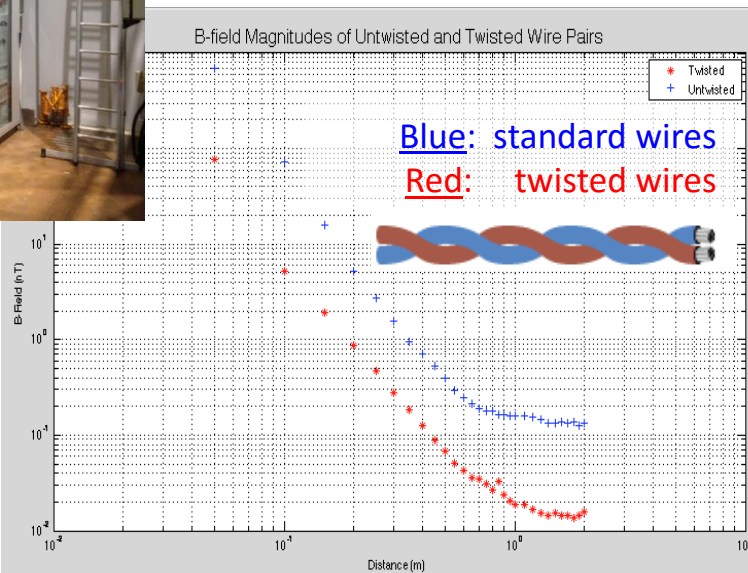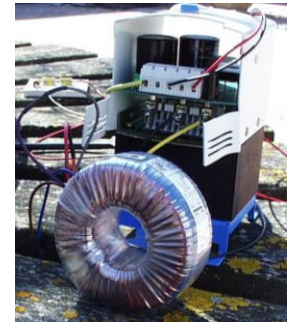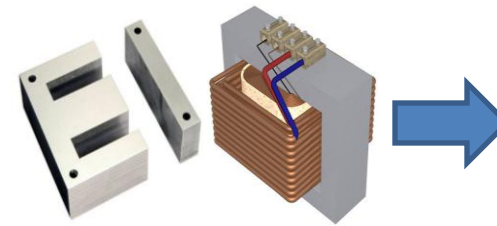
- reduce ambient fields
- reduce total magnetic moment (magnets equalization)
- passive Helmholtz coils to counteract and dump ambient fields ??



Advanced Virgo

VSR4 $B_{env}$ used.

in-axis force  >> torque

Benv VSR4 (TY)
Benv VSR4 (TZ)
Benv VSR4 (F)
BNS-optimized (145 Mpc)
Design (2021, 130 Mpc)
Late (2018-20, 65-115 Mpc)
Mid (2017-18, 60-85 Mpc)
Early (2016-17, 20-60 Mpc)

# Magnetic Mitigations (1)

**Limit stray fields  close to payloads**

*Credits: Federico Paoletti, Massimo D'Andrea – EGO*

- Optimize power cable paths, maximize  ratio (distance from TM)/(current).  Removed and reroute power cables who were in floor trenches around towers

- Adopt **twisted  wires** cables for powering racks in experimental halls

- Use AC-DC voltage converters with **toroidal core** in place of standard E-I core



B-field Magnitudes of Untwisted and Twisted Wire Pairs

Blue:  standard wires
Red:   twisted wires



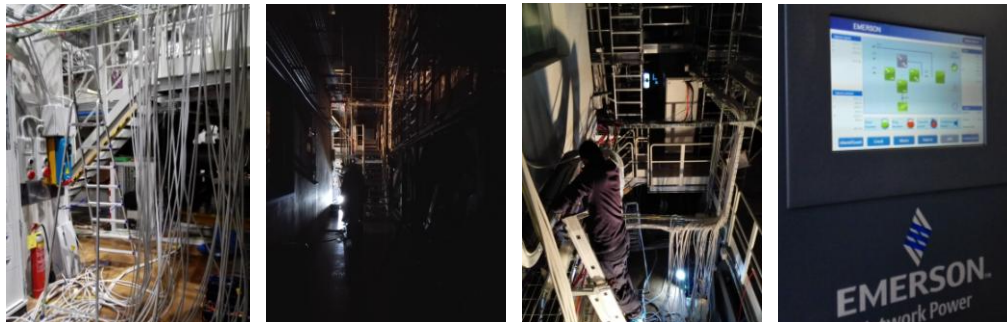magnetic noise, LEGRAND 46923, "as is" VS "with TOROID"

# Magnetic Mitigations (2)

## Reduce UPS noise

- At Virgo we use **Uninterruptible Power Supplies** to power all sensitive electronics, to guarantee power continuity in case of power outage.

- The voltage noise of the *UPS reconstructed 230VAC - 50Hz sinusoid is the progenitor of stray magnetic fields in experimental areas*
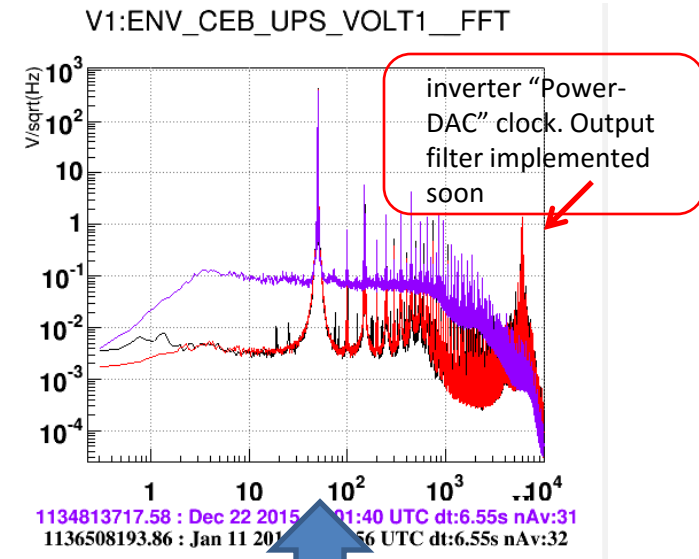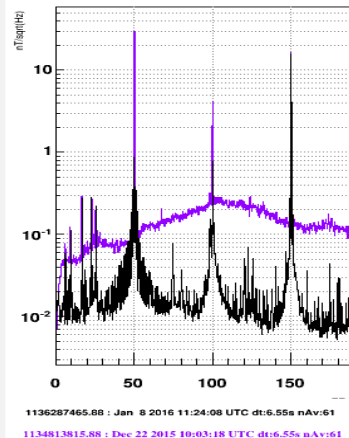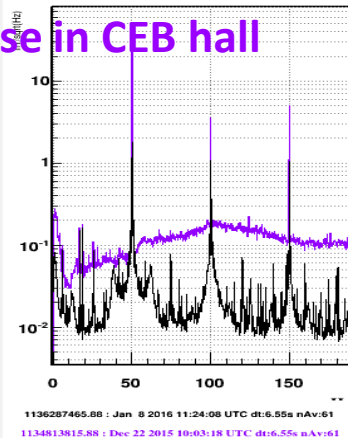
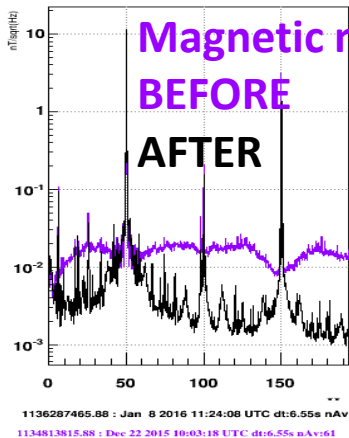**New UPS installed during Christmas break 2015**



V1:ENV_CEB_UPS_VOLT1__FFT

inverter "Power-DAC" clock. Output filter implemented soon

1134813717.58 : Dec 22 2015 01:40 UTC dt:6.55s nAv:31
1136508193.86 : Jan 11 2016 56 UTC dt:6.55s nAv:32

Voltage noise, CEB UPS

V1:ENV_CEB_MAG_N__FFT

V1:ENV_CEB_MAG_NI_W__FFT

V1:ENV_CEB_MAG_IB_N__FFT

**Magnetic noise in CEB hall BEFORE**
**AFTER**

1136287465.88 : Jan 8 2016 11:24:08 UTC dt:6.55s nAv:61
1134813815.88 : Dec 22 2015 10:03:18 UTC dt:6.55s nAv:61

**Magnetic noise reduced a factor 5 to 10**
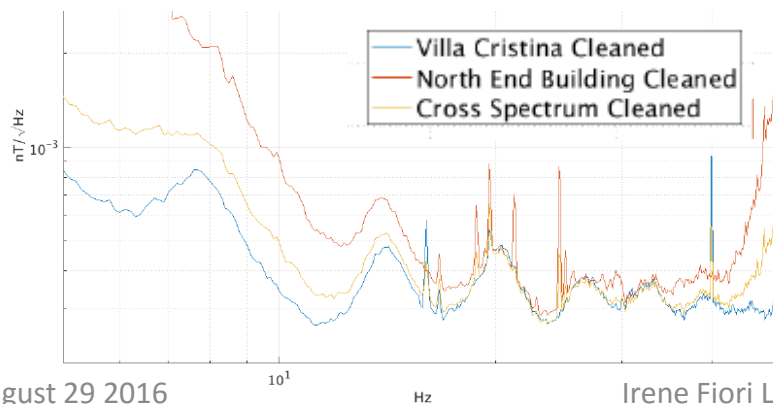
# Global magnetic noise (1)

**We surveyed the Virgo site and surroundings looking for sufficiently magnetically quiet locations to detect global magnetic noise.**

Melissa Guidry (IREU 2015) Tristan Shoemaker (summer stage 2016)

- **Villa Cristina**, scout house 12 km from Virgo, 7 Schumann peaks detected with >90% duty cycle!



10th, 50th, 90th percentiles
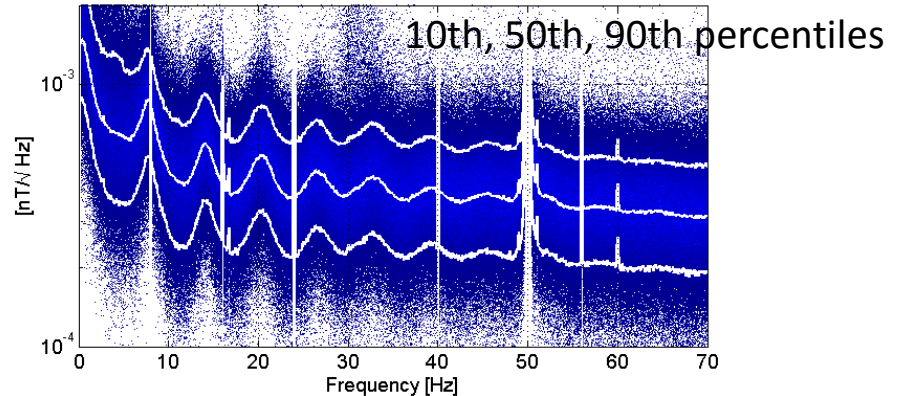
- **Virgo site**, outside buildings: noisier, yet 14, 21, 28 Hz peaks detected with approx. 30% duty cycle

24hrs outside NEB          selected data



Villa Cristina Cleaned
North End Building Cleaned
Cross Spectrum Cleaned
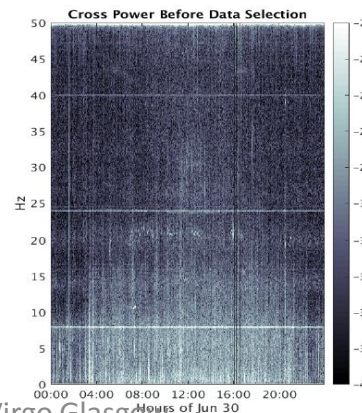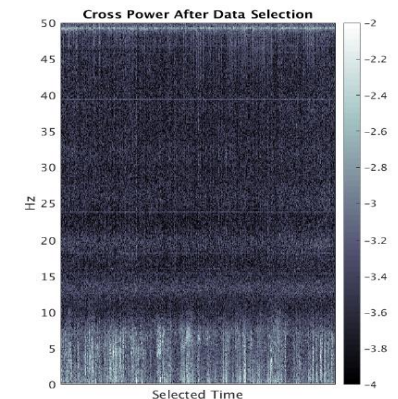
# Global magnetic noise (2)
## Inter-sites correlation studies

Credits: M.Coughlin, N.Chistensen, E.Thrane, J.Harms, K.Somiya and KAGRA team, Krakow ELF group

- **Coincident measurements** with a net of low noise magnetometers at **Villa-Cristina, KAGRA and ELF stations in Poland and Colorado (July 21-22, 2016). NS and EW directions.**

- **Goal is studying correlation distance of global magnetic noise, inter-site correlation, noise subtraction studies using one magnetometer as mock GW detector**

- KAGRA also took short datasets with **few kilometres distant magnetometers,** to study correlation at the distance scale of ITF end-stations.

*Preliminary*

Coherences (VillaCristina – KAGRA)
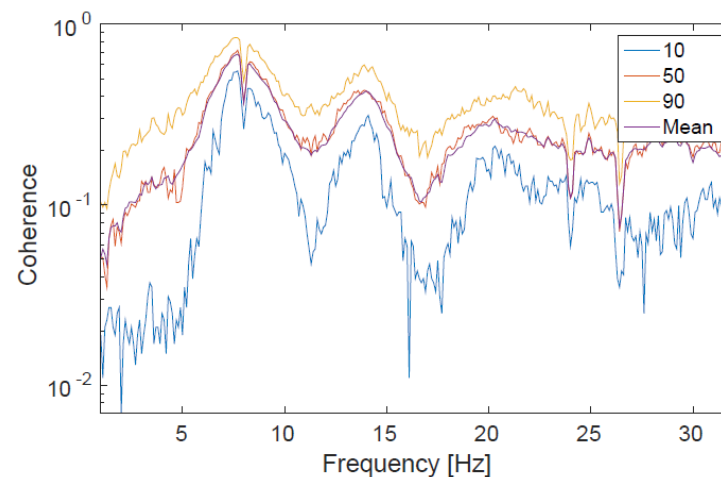
# Newtonian Noise  (1)
## characterization studies

Credits: Jan Harms,  Susan Blackburn (IREU 2016)

**Preliminary study of Virgo Building floor seismicity aimed at NN modelling: seismic levels, correlation lengths, seismic sources.**

- Modelling Virgo Bld. s is not simple,  each building  has two independent floor slabs: the first  (aka "TM floor") supports the TM vacuum tank and  has 50m deep poles, it  also includes a hollow space below TM hosting CleanRoom); the second surrounding floor (aka "Building floor") is disconnected from TM floor and has shallower foundations, it  supports all noisy devices (HVAC, VAC pumps, racks).

- Deployed 3 seismic arrays of 9 Meggit-731 vertical accelerometers each
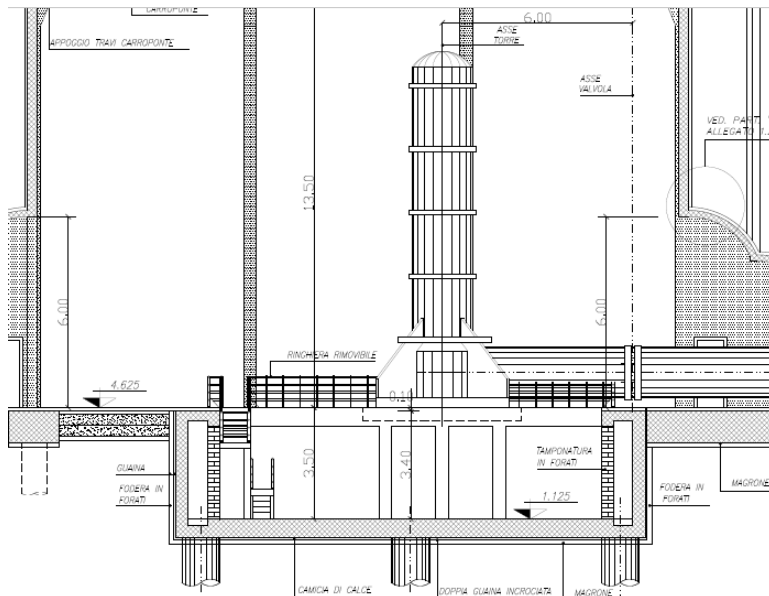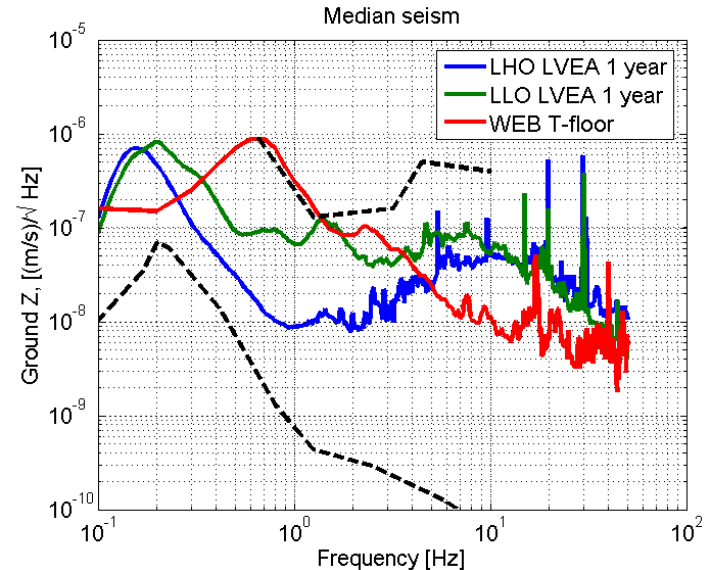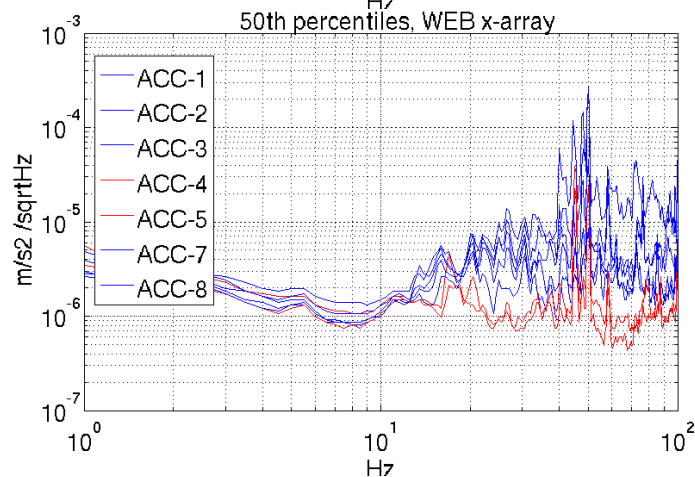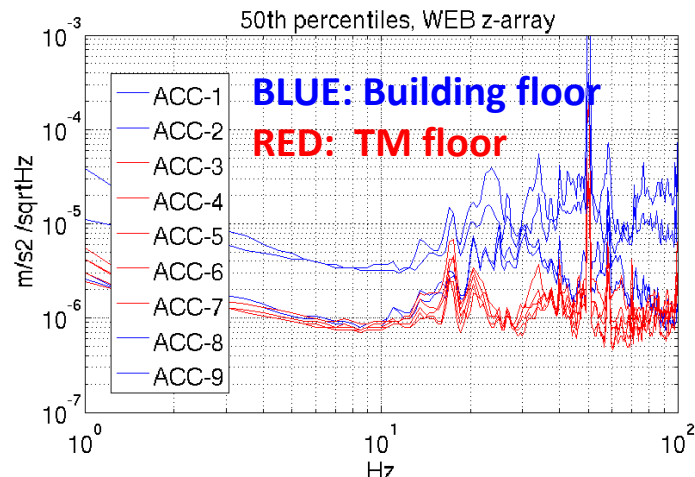
**WE building**      • • • Accelerometer arrays
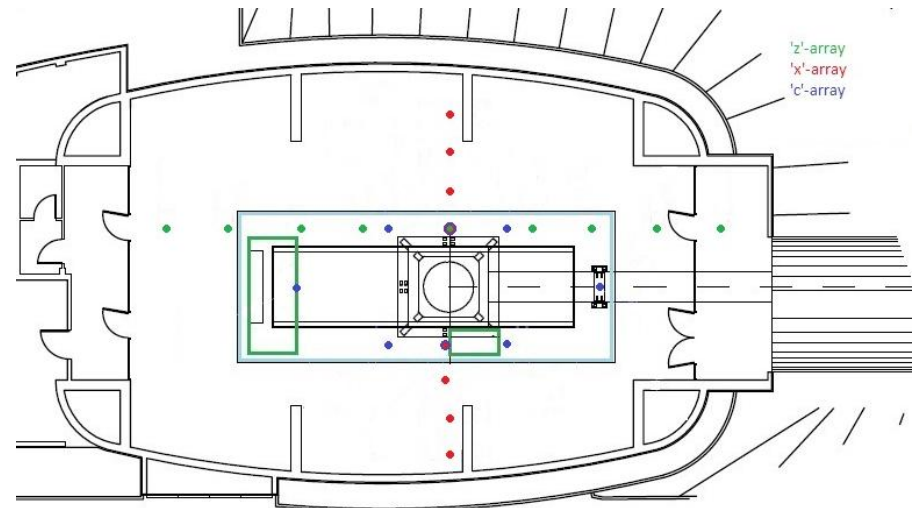
# Newtonian Noise (2)
## characterization studies

**Comparing all accelerometers on TM floor slab with all accelerometers on Building floor, and comparing Virgo TM floor (one location) with LIGO LVEA floor.**



50th percentiles, WEB z-array

**BLUE: Building floor**
**RED: TM floor**



50th percentiles, WEB x-array



Median seism

- Virgo **TM floor is seismically quieter than Building floor** above 10Hz. TM floor filters noisy devices placed on Building floor slab.
- Virgo **TM floor is seismically quieter** (factor 5-3 above 5Hz) **than LIGO LVEA** (source J.Harms)

# Newtonian Noise  (3)
## sources characterization (preliminary)

- k-f maps provide rough indications on source location and wave velocity, sources confirmed by switching off devices or hunting with portable probes

  HVAC contributes a bit 15-30Hz

  17Hz from SWEB clean room fans, wave speed 350 m/s

  12 Hz bump, coherent through whole building, suspect it originates from outside, traffic??

- Except for 12Hz noise, seismic waves from other sources have **short correlation length** (less than Jan measured for LIGO floors). It might indicate significant wave scattering .... likely makes NN sensing and subtraction a tougher job!
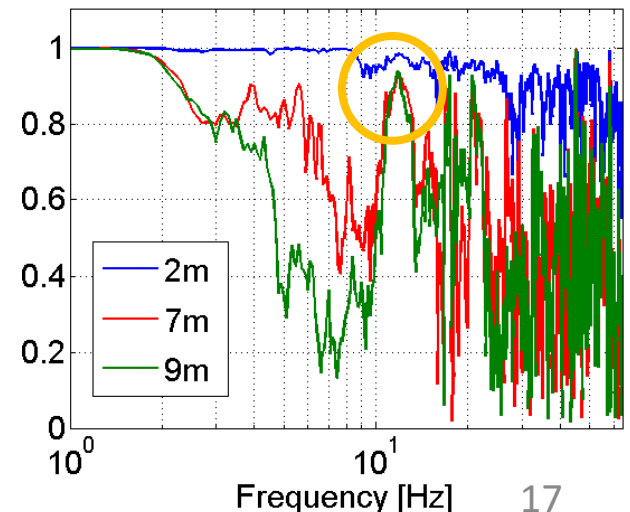


**17 Hz line**  ACC-2  **HVAC off**

**12 Hz bump**  ACC-5  **HVAC off**
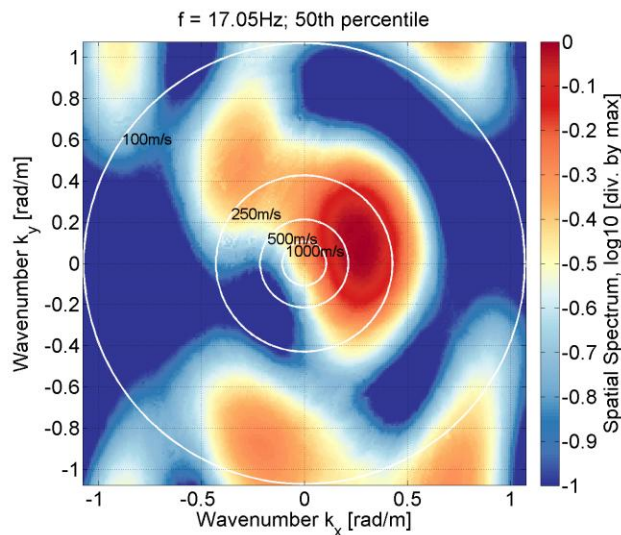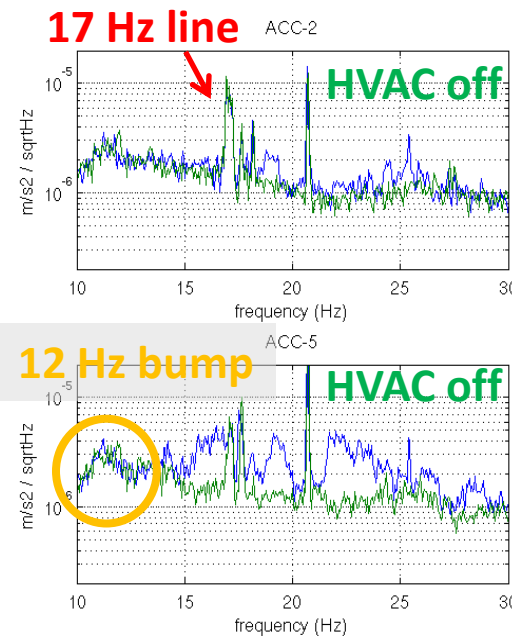
Coherence between two Trillium-C20 on TM floor, increasing distance

2m
7m
9m

# NN, next

- August: Soumen Koley and Maria Bader - Nikhef **deployed array of 70 geophones** covering an area of 1.5 km radius centred at Virgo. Two weeks data taking, ongoing.

  Very interesting data, to study Virgo soil transmission properties, do sources triangulation (like 12 Hz noise).





SOLO-5 1850Ω 5 Hz Sen=80 G = 24dB
— Measured noise
--- NLNM/NHNM
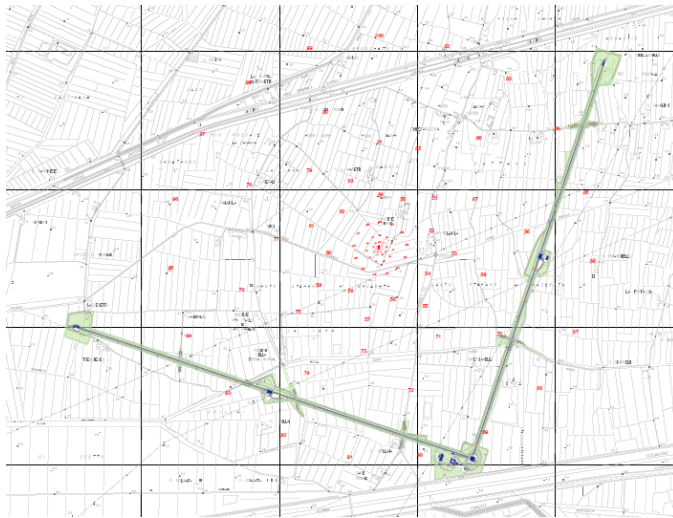


- September: Donatella Fiorucci - APS will perform preliminary measurements at EGO with **infrasound microphones**.

  Study of inside – outside correlations, NN infrasound modelling and subtraction tests.
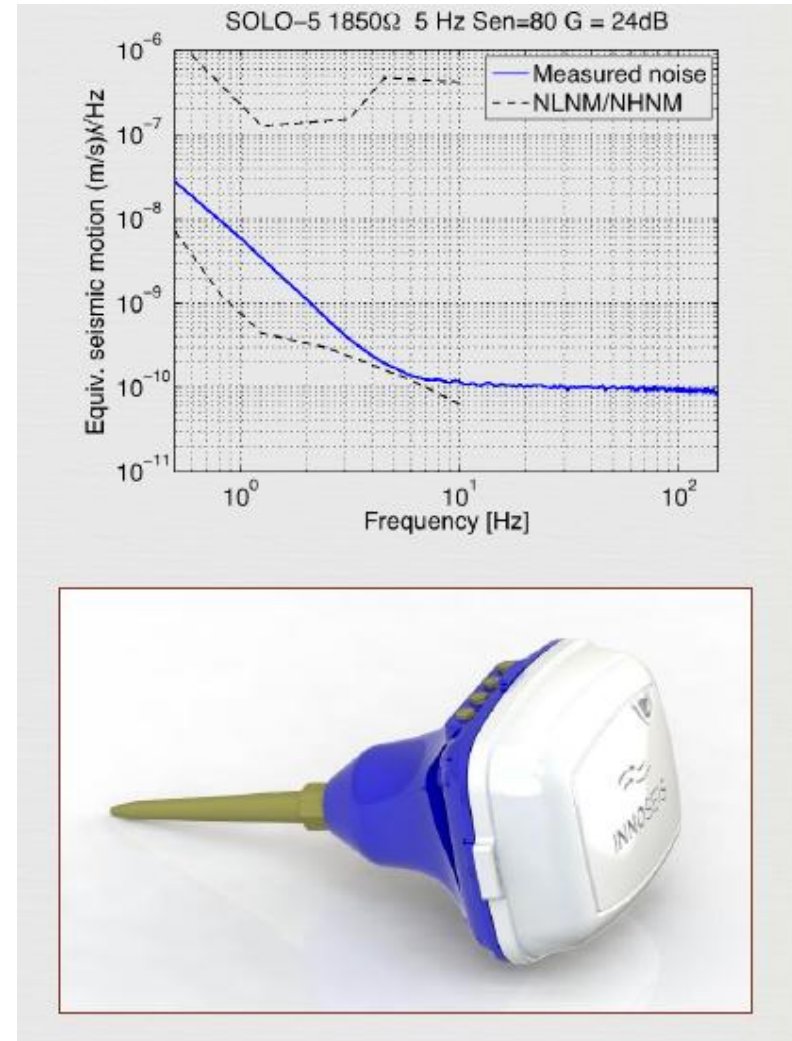
# Conclusions

- Environmental sensor network installation is almost completed, enhanced monitoring of infrastructure devices to help commissioning

- Magnetic coupling to payloads: modelling works and ambient noise reduction give us confidence about it

- Schumann noise: quiet detection possible within few km from Virgo site. First inter-site correlation studies ongoing

- First steps in site seismic characterization aimed to NN subtraction studies. Virgo TM floor is relatively quiet at NN frequencies, but the short correlation length might require more dense subtraction arrays. Presently Nikhef array is recording a detailed seismic map of Virgo site external ground, promise interesting data.

- .... looking forward to real noise hunting on full ITF!

...warming up tools!

Thank you
for your attention