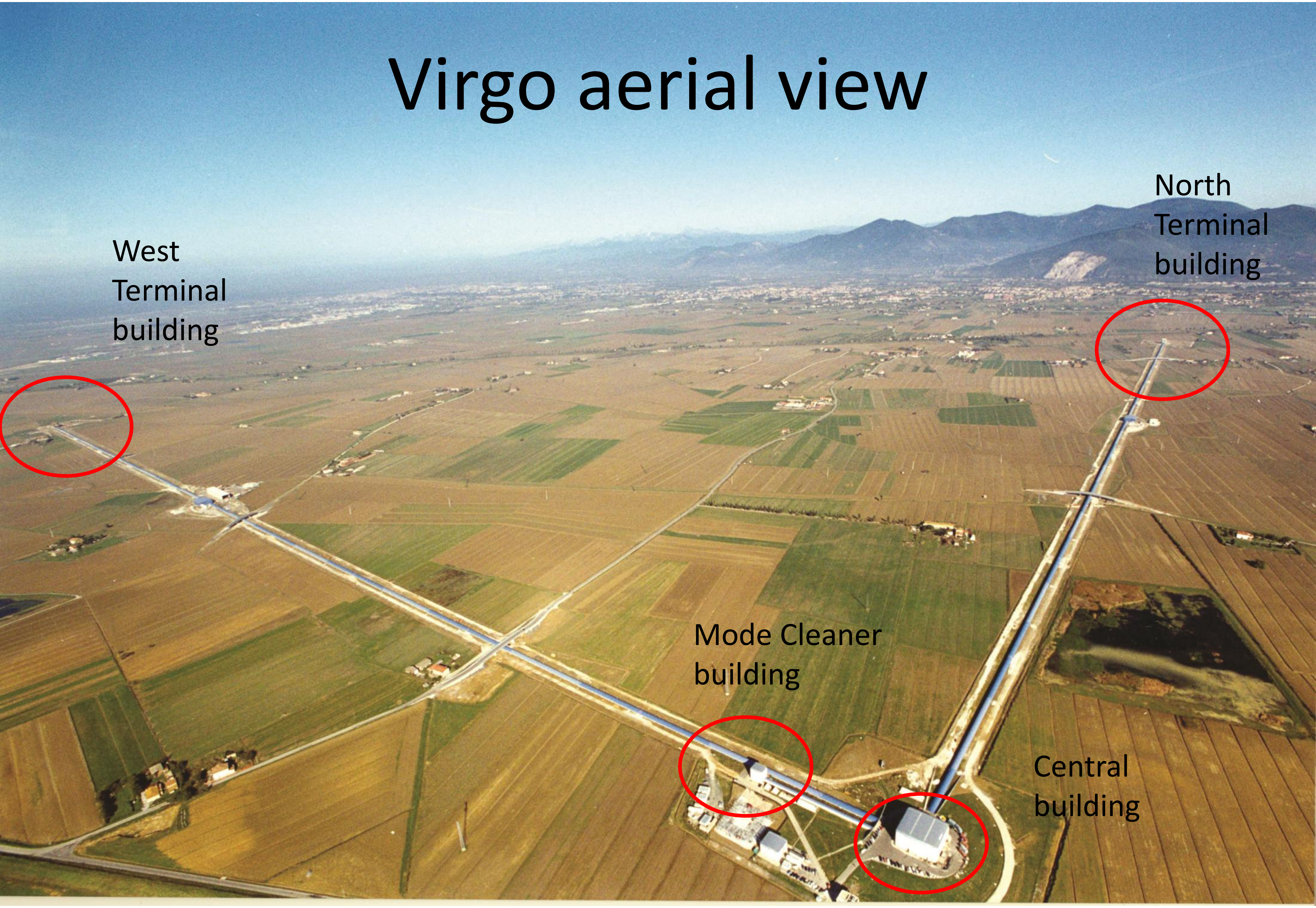
Virgo
commercial seismic sensors and examples of their use

Irene Fiori for the Virgo collaboration
and EGO

Workshop on Geophysics and Gravitational-Wave Detectors,
IPGP Paris, April 17 and 18 2012

Virgo aerial view

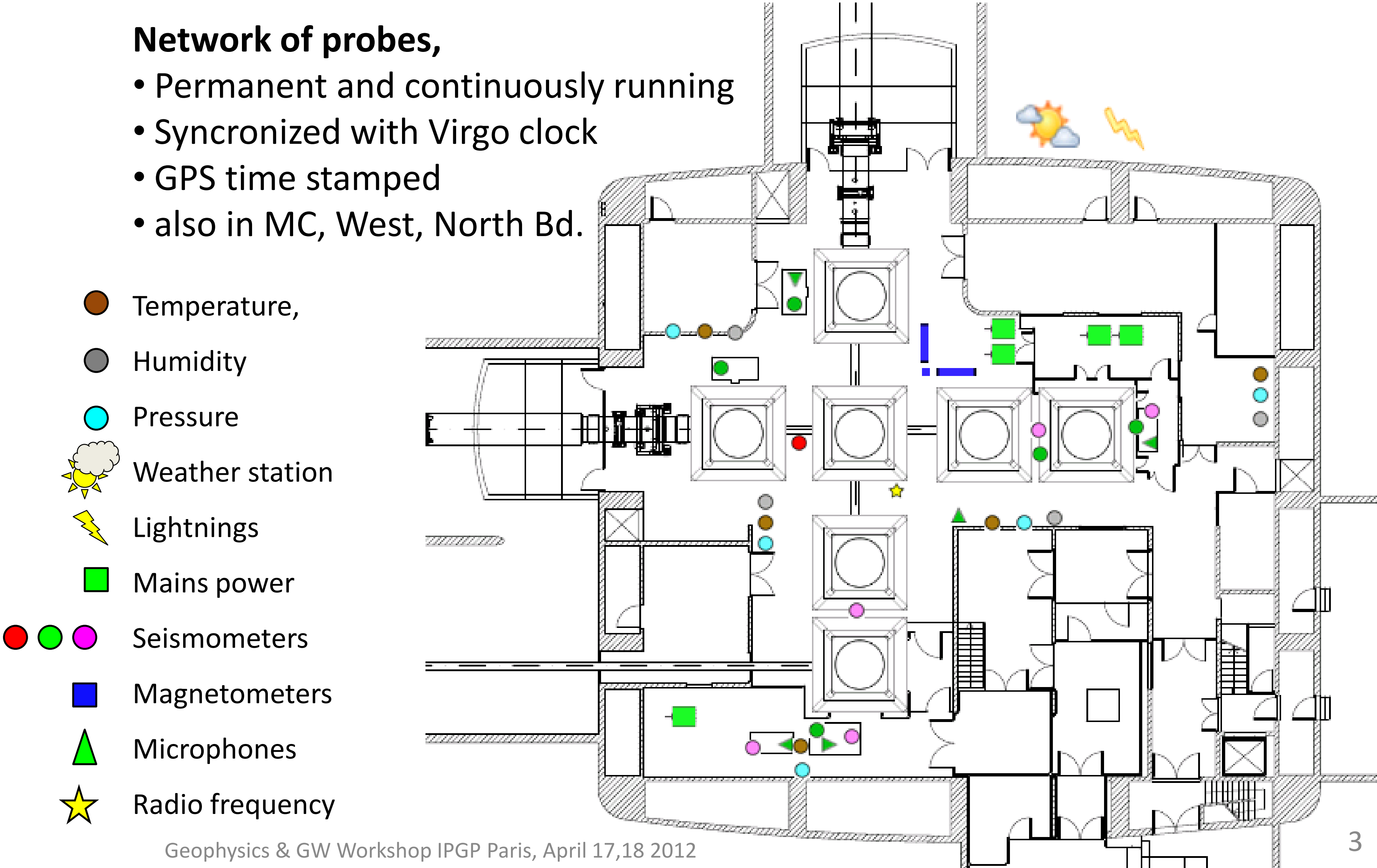


Environmental sensors map, Central Bd.

By INFN Napoli – Barone, R. De-Rosa, F.Garufi, L.Milano

Network of probes,

- Permanent and continuously running
- Syncronized with Virgo clock
- GPS time stamped
- also in MC, West, North Bd.



List of sensors

SLOW sensors (sampling frequency = 1Hz)

- **Weather station,** Vantage Pro2 by Davis (wind speed and direction, external temperature and humidity, rain)
- **Lightning detector**, LD-250 from Boltek (strikes distance and angle up to 400km distance)
- **Temperature probes**, AD 590 MF, 1 μA/K thermocouples, monitor buildings and in-vacuum temperature
- **Humidity probes**, based on polymer capacitance,
- **Pressure probes**, piezoresistive transducers, 45.9 mV/kPa

More INFO: http://wwwcascina.virgo.infn.it/EnvMon/sensors.htm

List of sensors

FAST sensors (sampling frequency 1kHz, 10kHz or 20kHz depending on probe)

Monitor	probe	type	Flat response range (Hz)	Conditioning	No. Of output	No. of probes
Seismic	velocimeter	Guralp CMG-40T (30s)	0.033 to 50 Hz	custom	3	1
Seismic	accelerometer	Kinemetrics Episensor FBA-ES-T	0.1 to 100Hz	custom	3	9
Vibration	accelerometer	Piezotronics 393B12	10Hz to 1000Hz	nexus	1	11
Vibration	accelerometer	B&K – 4378 and Endevco – 7702A	10Hz to 1000Hz	nexus	1	7
Magnetic	Magnetometer	Metronix - MFS-06	4-10000 Hz	custom	1	10
Acoustic	microphone	B&K 4190+2669	0.1-20000	nexus	1	9
Radio Frequency	antenna	ARA-60	4 to 60 MHz	mixer	1	1
Mains	transformer	custom	DC-1000 Hz	custom	1	20

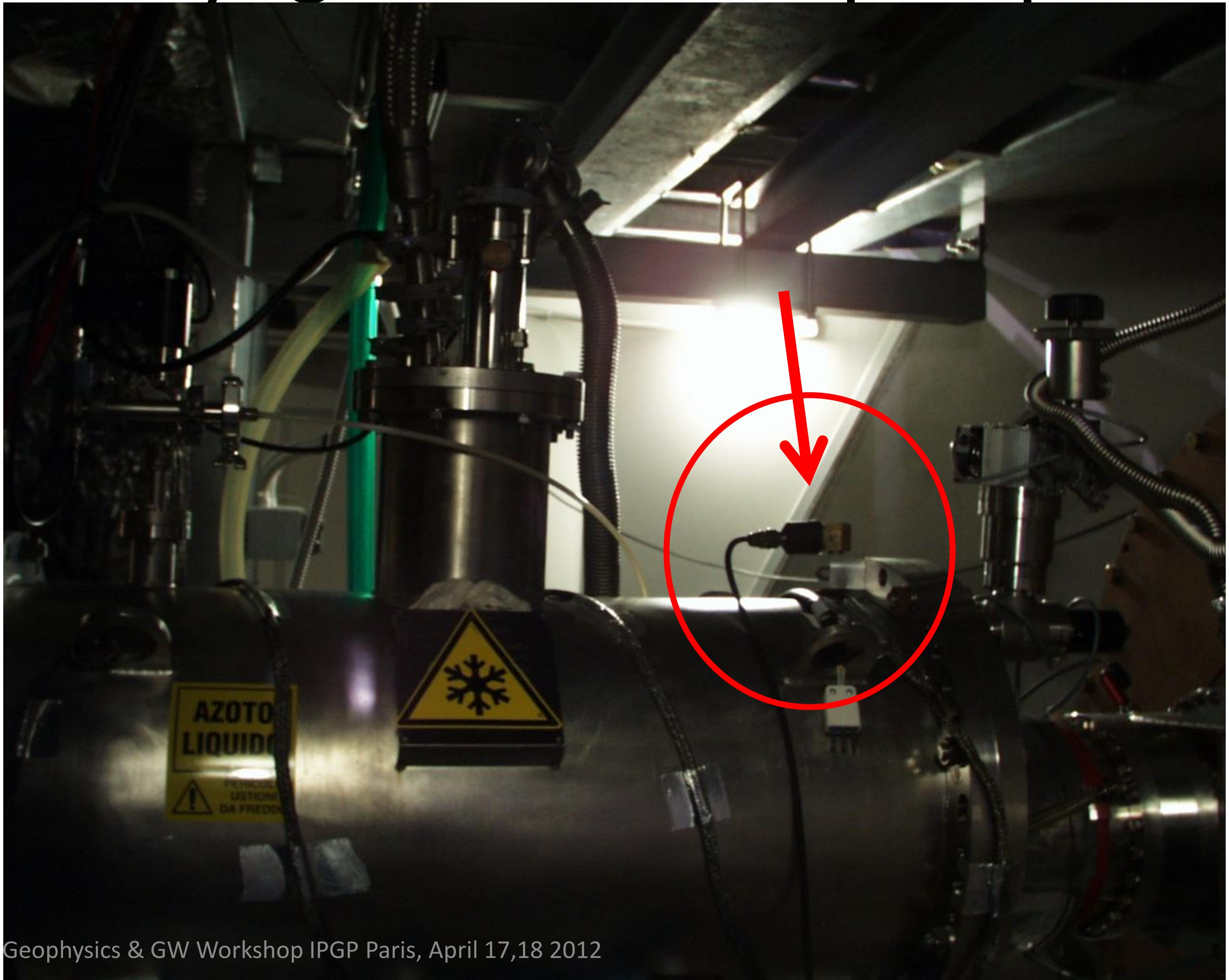
Vibration sensors

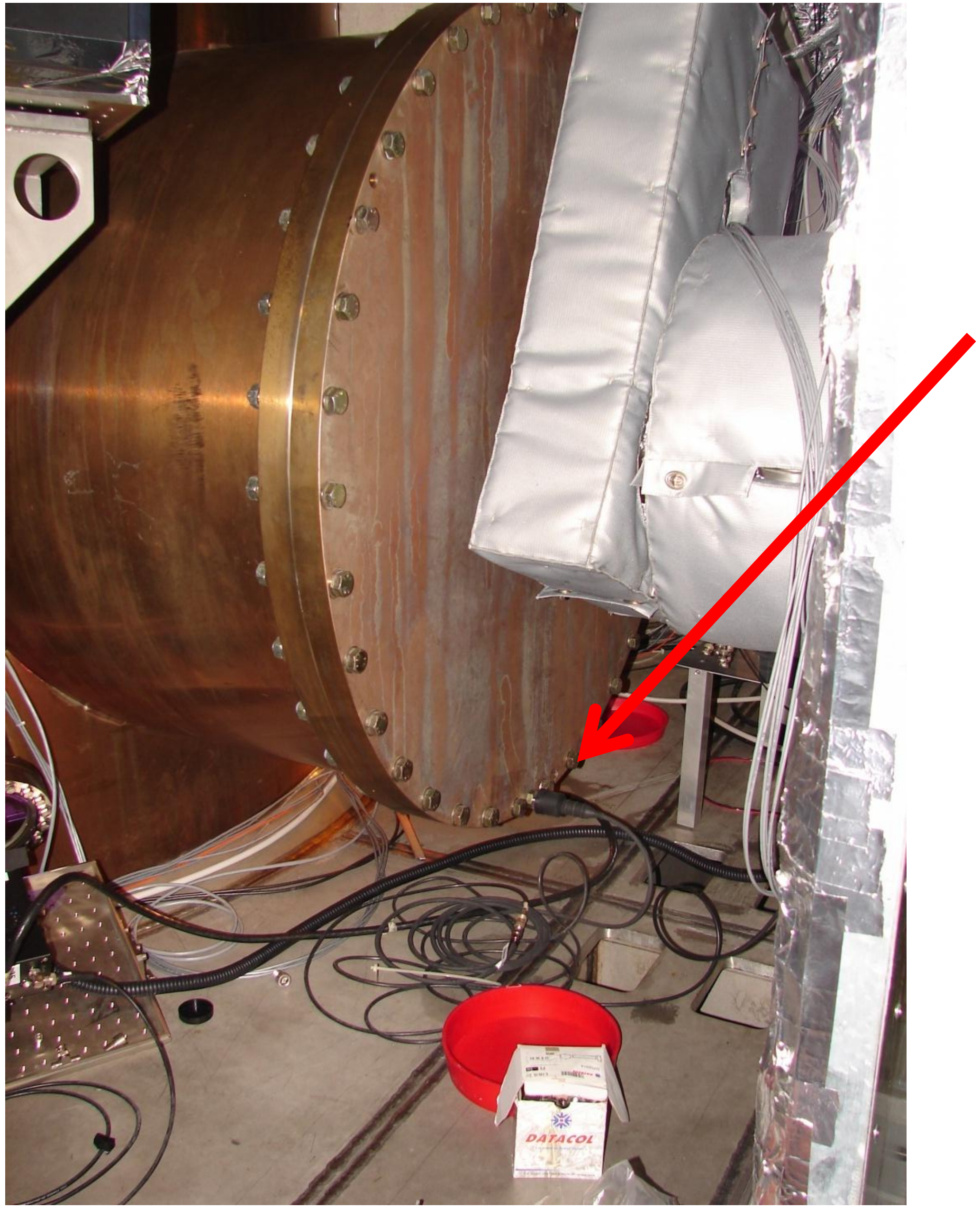
HIGH FREQUENCY:

- PCB-Piezotronics 393B12 , B&K – 4378, Endevco – 7702A accelerometer, single axis, useful bandwidth 10Hz -2000Hz (sampled 10kHz)

  - 18 sensors, anchored to "critical" interferometer components, such as Vacuum tanks, pipes, external benches.

Cryogenic vacuum pump




DATACOL

Seismic sensors

LOW FREQUENCY:

- Guralp CMG-40-T, velocimeter, tri-axial, nominal bandwidth (-3dB corner frequency) 0.033Hz to 100Hz, 1kHz sampling

  1 sensor

  deployed on central building concrete ground floor

>>>> Advanced Virgo plans to have 4, one per building

Seismic sensors

LOW FREQUENCY:

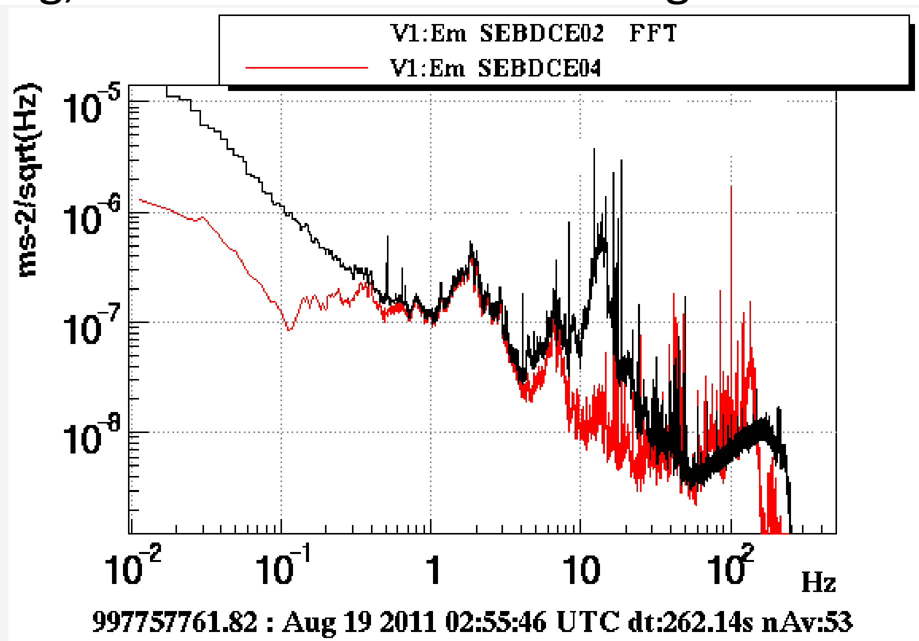
- Episensor FBA-ES-T, accelerometer, tri-axial,

  nominal bandwidth 0.1Hz to 100Hz , 1kHz sampling

  9 sensors:

  - 1 sensor anchored to MC building concrete ground floor
  - 8 sensors anchored on top of external optical benches: 6 in Central Building, 1 in West terminal Building, 1 in North terminal Building

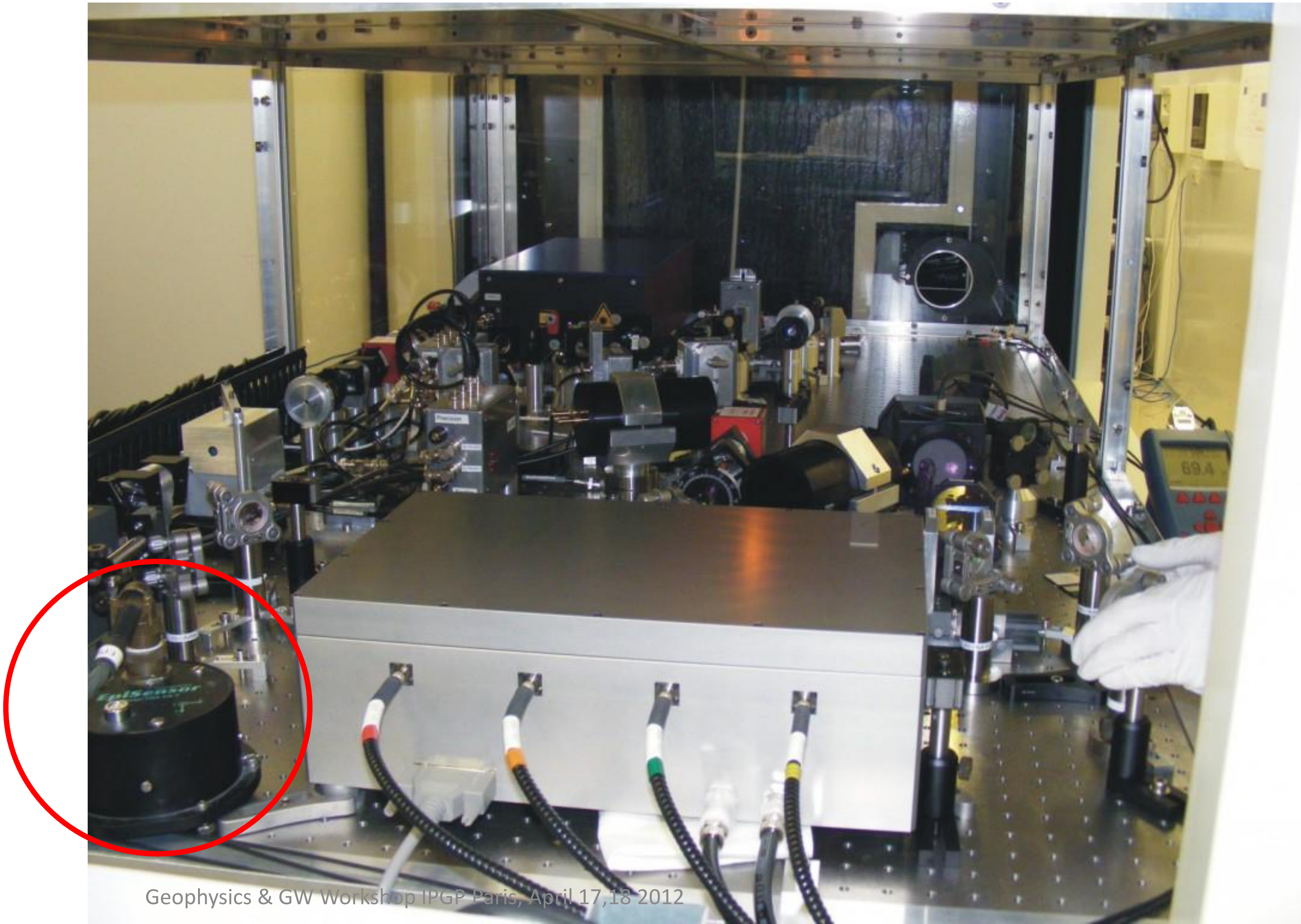
Sensors on optical benches move as Bd floor ground from DC to up to about 5Hz, above 5Hz sense bench mechanical modes



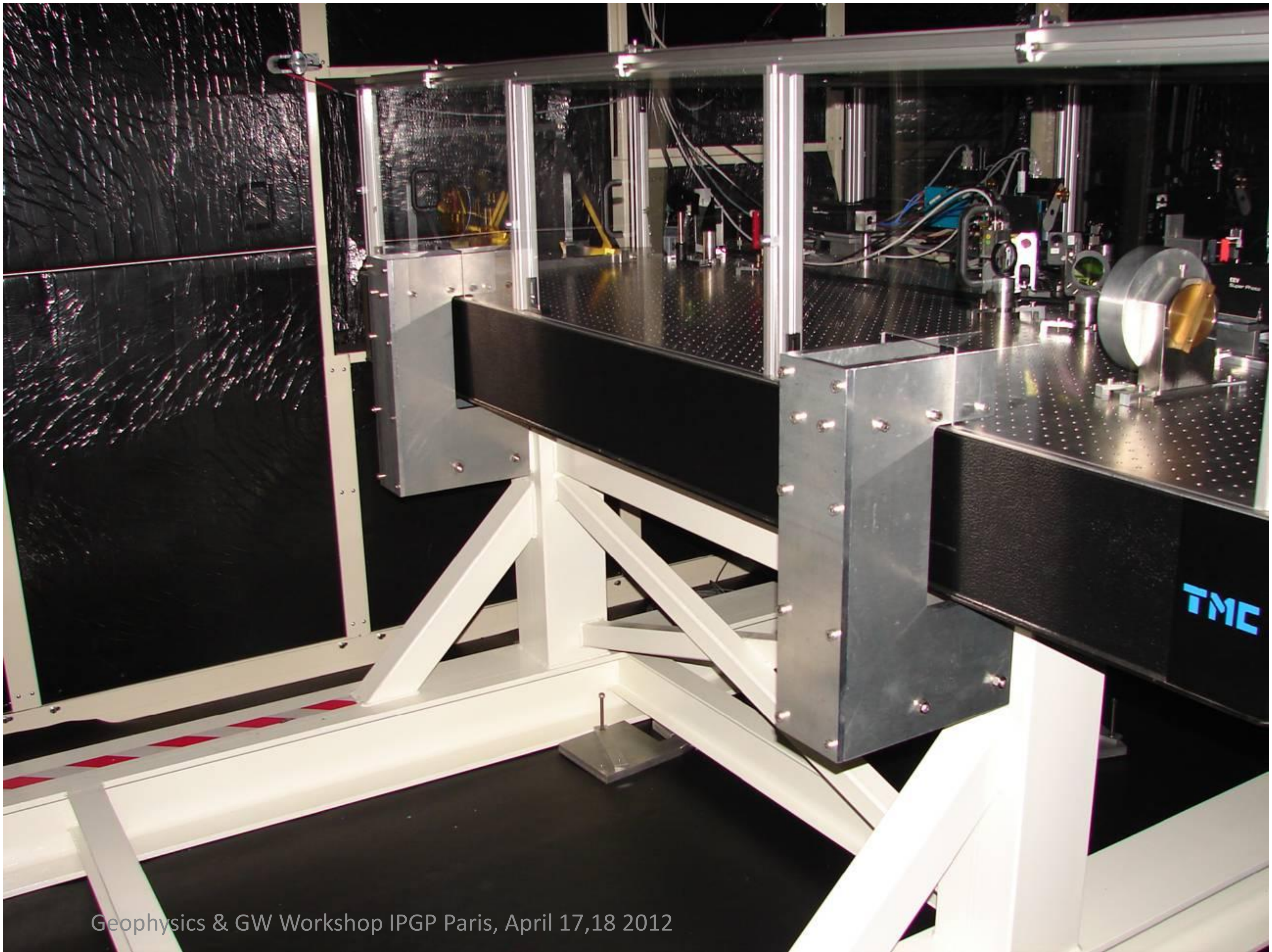
Guralp 40T-30s

MC

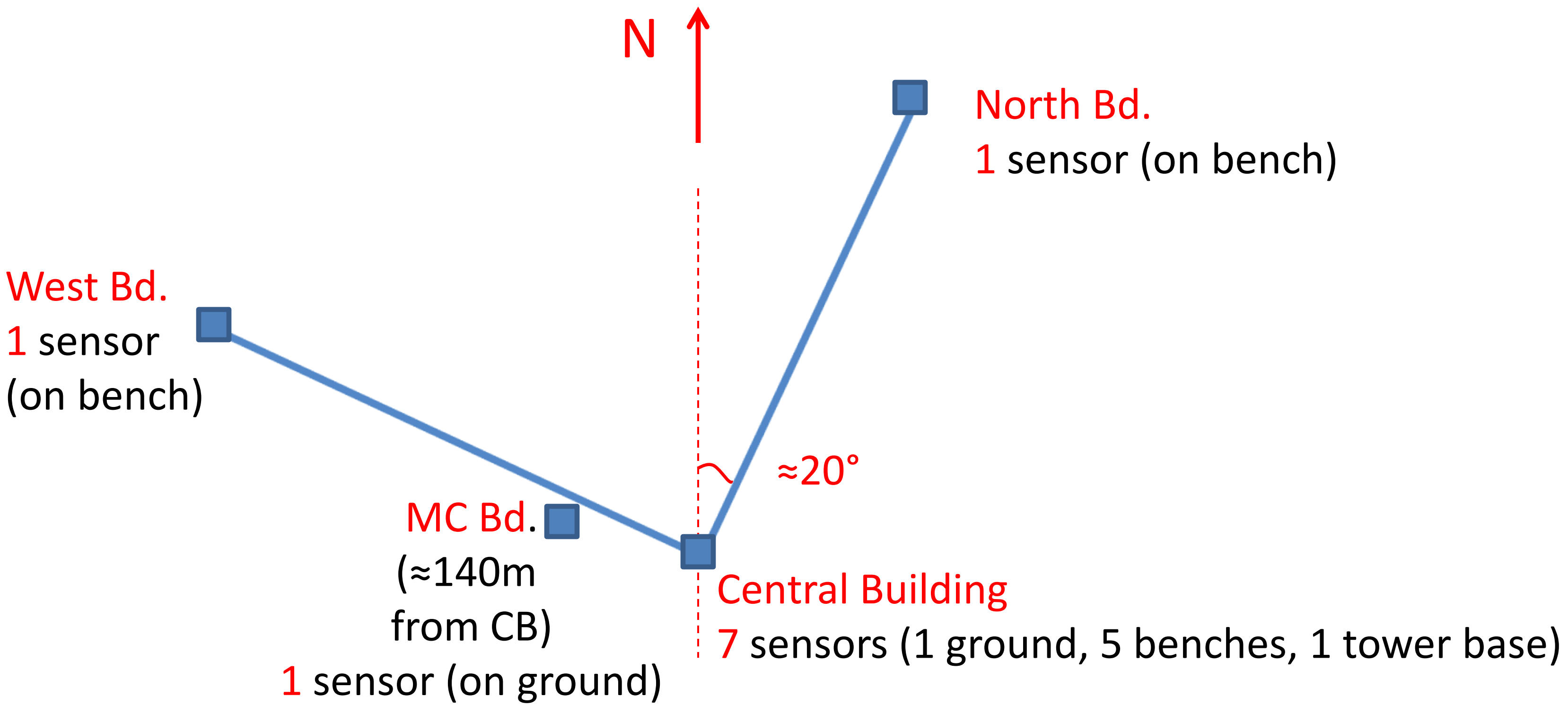
Laser bench



North end bench



Seismometers Location



ORIENTATION: same for all tri-axial sensors

Horizontal axis are oriented along Virgo interferometer arms:

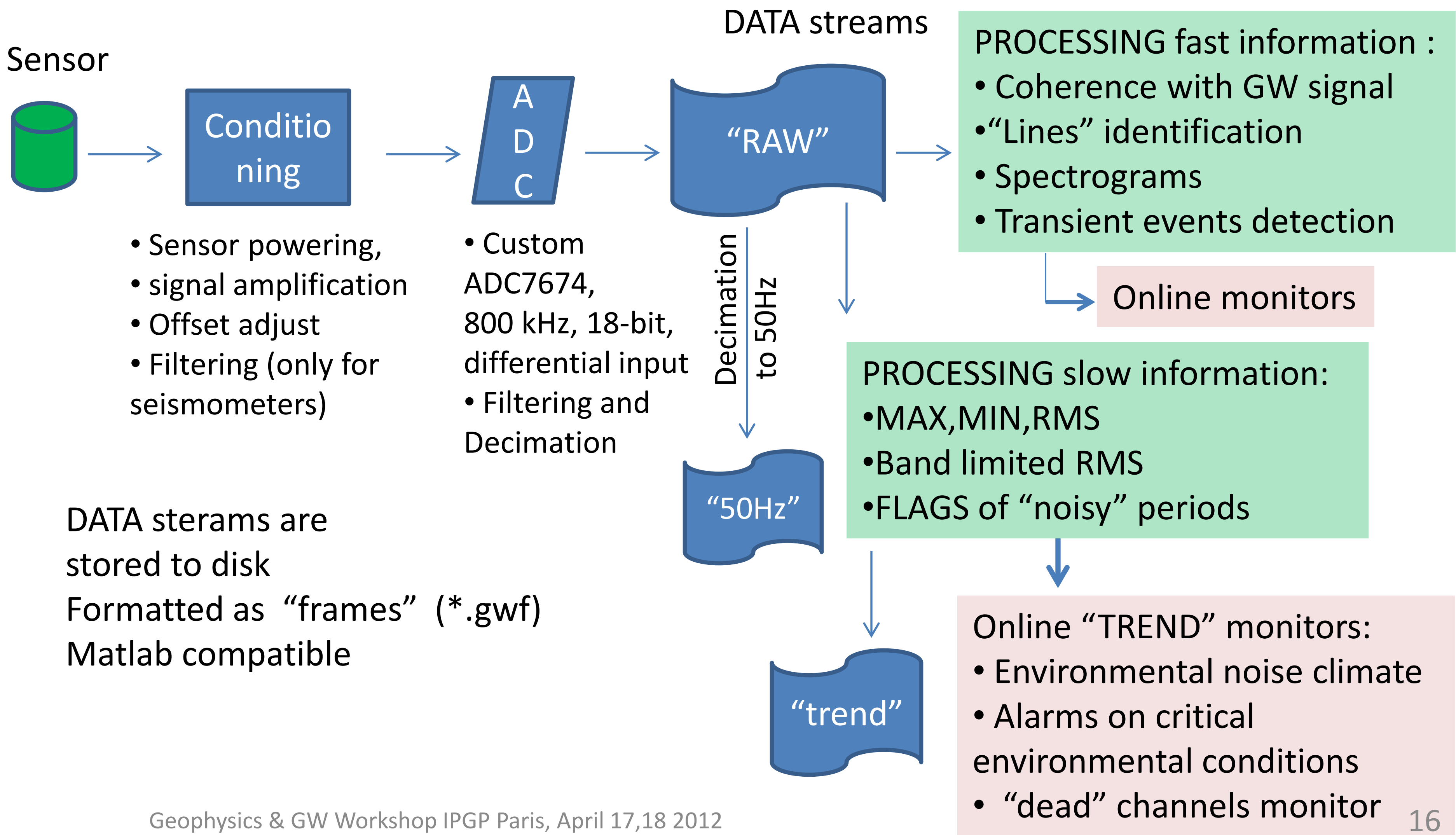
“X” is along “Virgo West arm”

“Z” is along “Virgo North arm”

“Y” is VERTICAL

Data acquistion and Online processing

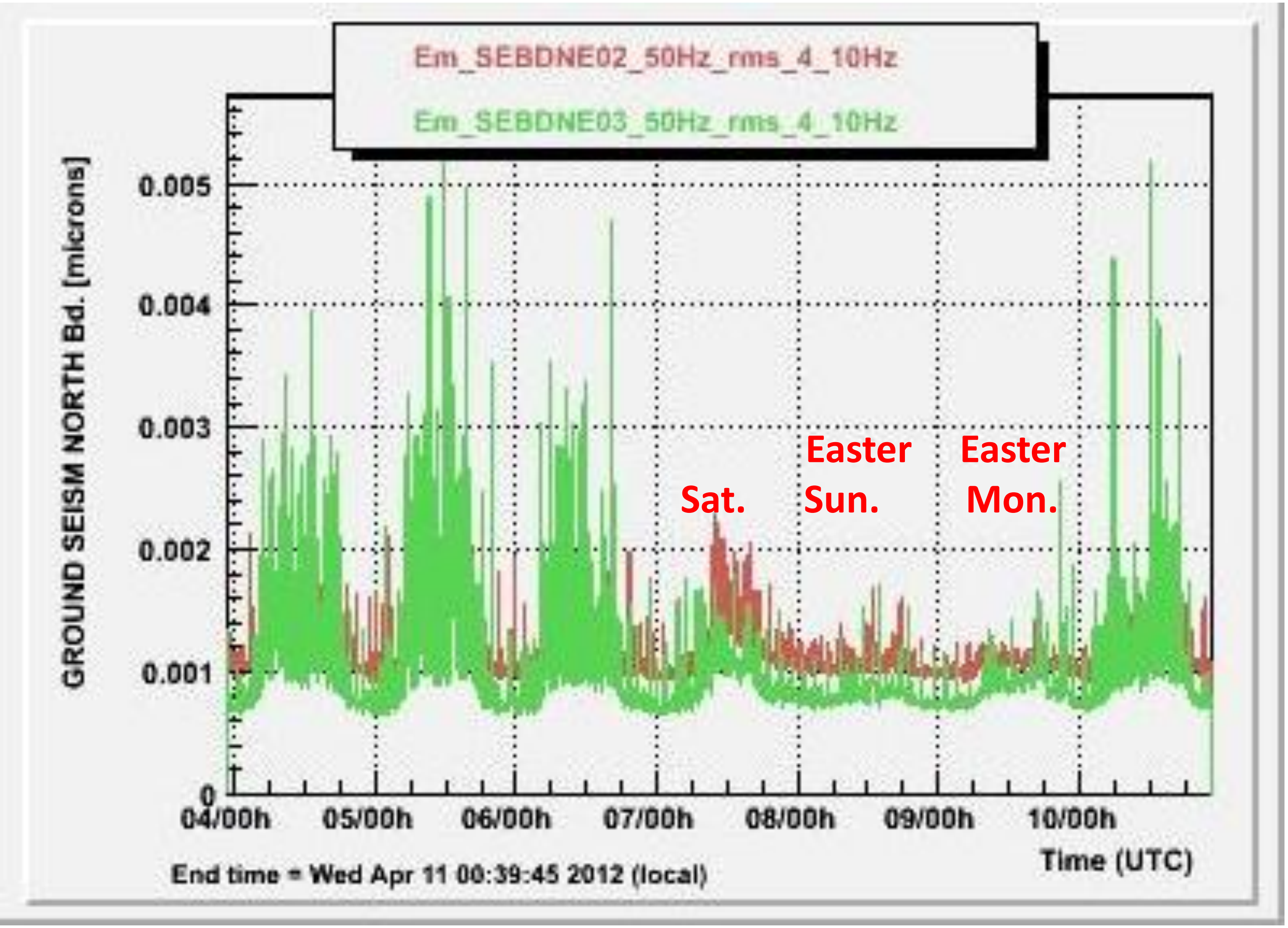
- How sensors data are acquired, processed for online GW data quality monitors, and stored:



DATA sterams are stored to disk
Formatted as "frames" (*.gwf)
Matlab compatible

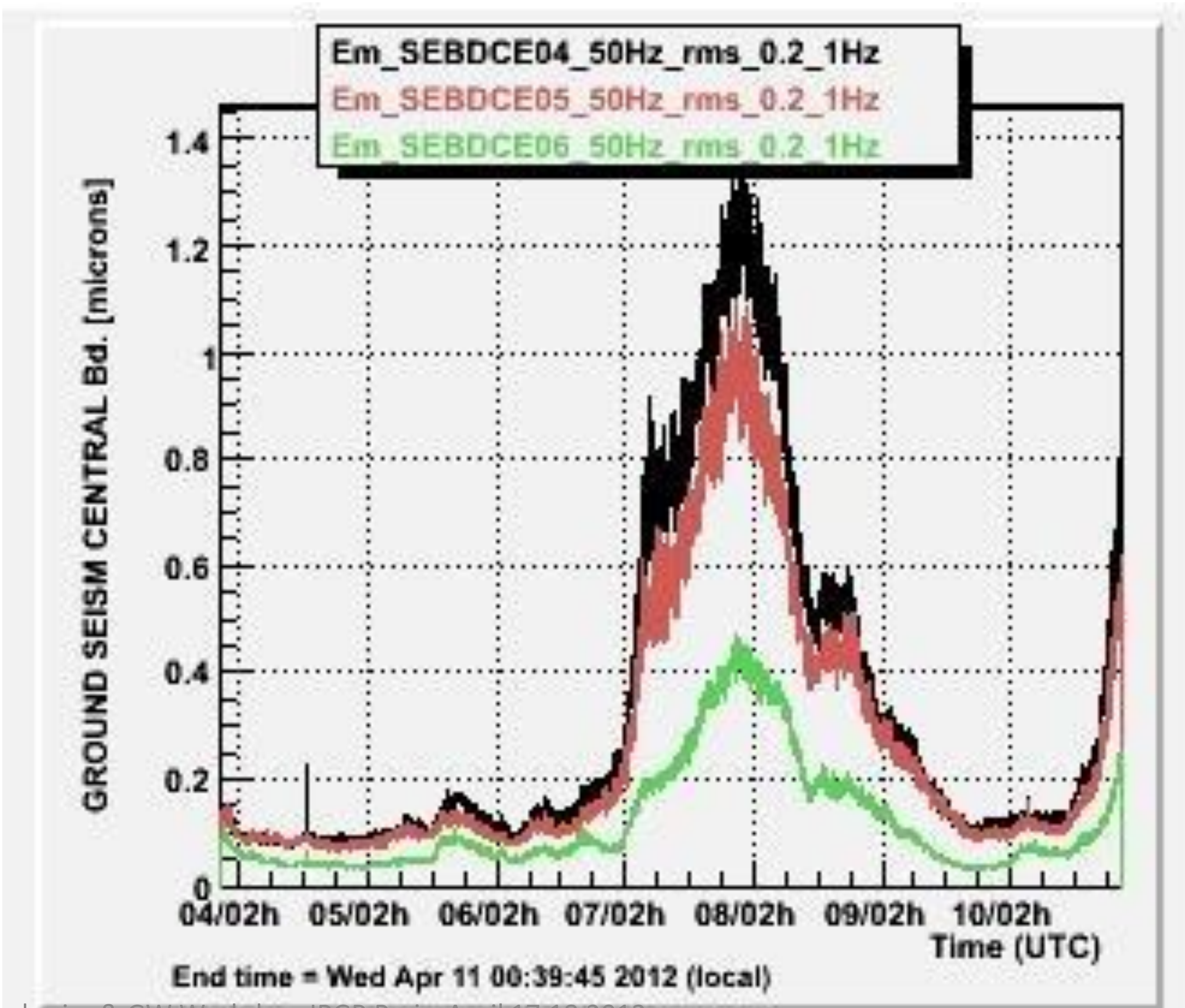
Trend Monitor, examples:

- Traffic activity: band limited RMS 4Hz to 10Hz



Trend Monitor, examples:

- Sea activity: band limited RMS 0.2Hz to 1Hz



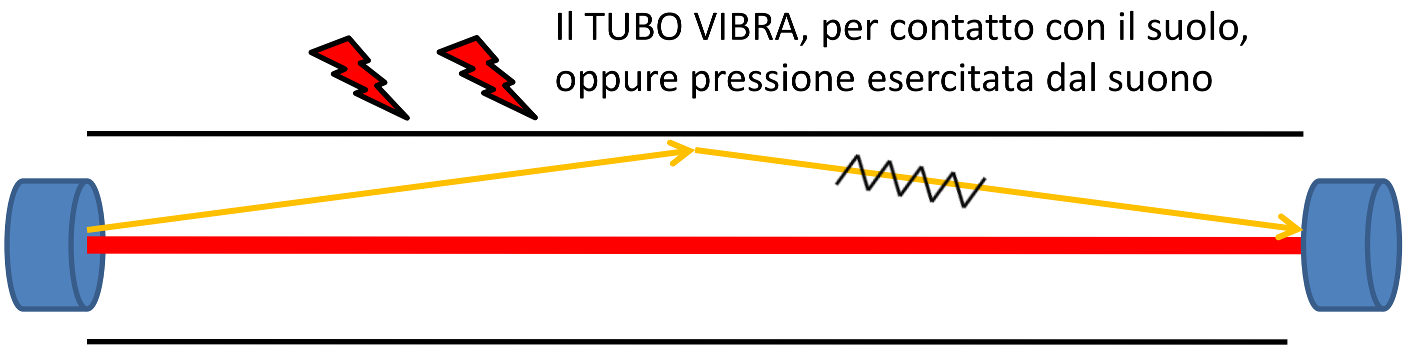
- Short tour of seismic noise “hunting” at Virgo

How seismic noise couples to GW signal ?

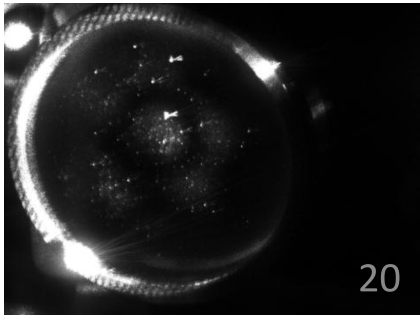
- **Scattered light**

  tiny fractions of light happen (unlucky!) to be scattered off the main beam path and inpinge on seismically excited surfaces (i.e. vacuum pipes, optics mount on external bences) and then scattered back into the main beam path. The back-scattered beam is phase modulated by the scatterer vibration and couples this noise to the GW signal.

Example, scattered light from vacuum pipe wall:

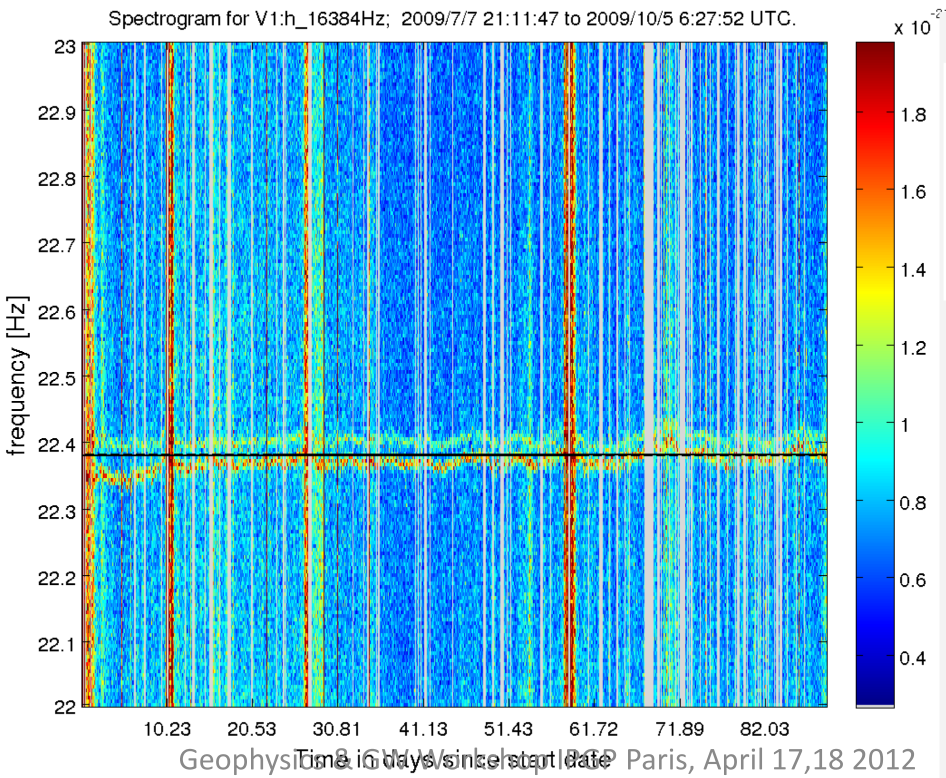


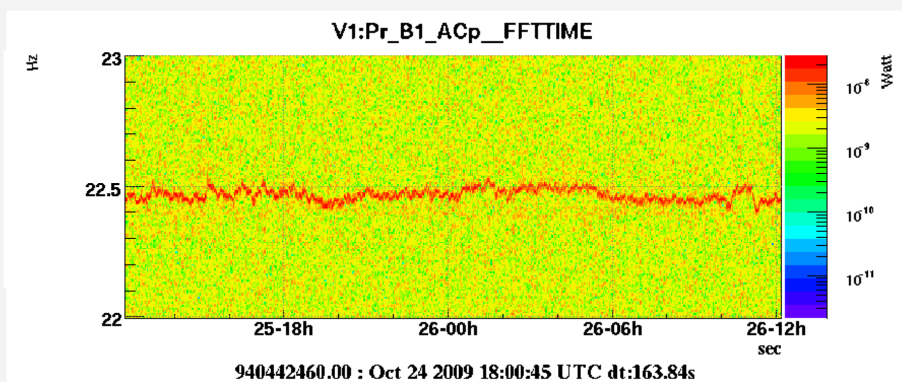
Similarly, we can have light scattered by the optics sitting on external benches, which receive pick-off beams for ITF control purposes:

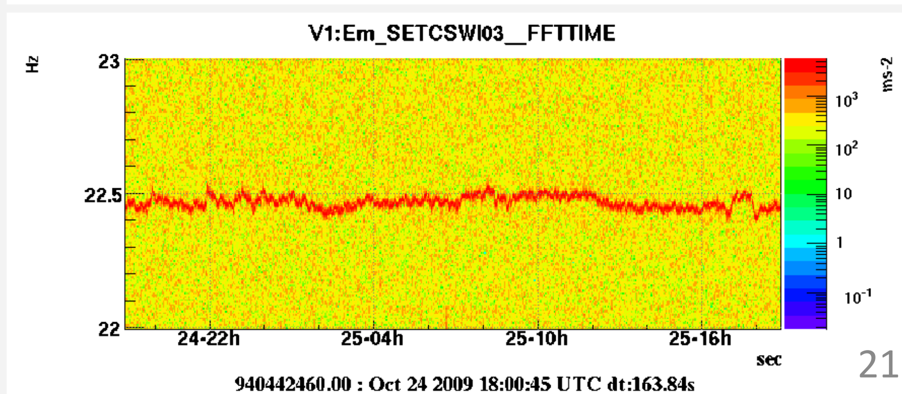


Example of periodic noise: “VELA killer”

- Periodic vibrations reducing sensitivity at the GW signal from the VELA pulsar (expected at 22.38Hz)
- Sources were engines of TCS laser CHILLERS, then cured.



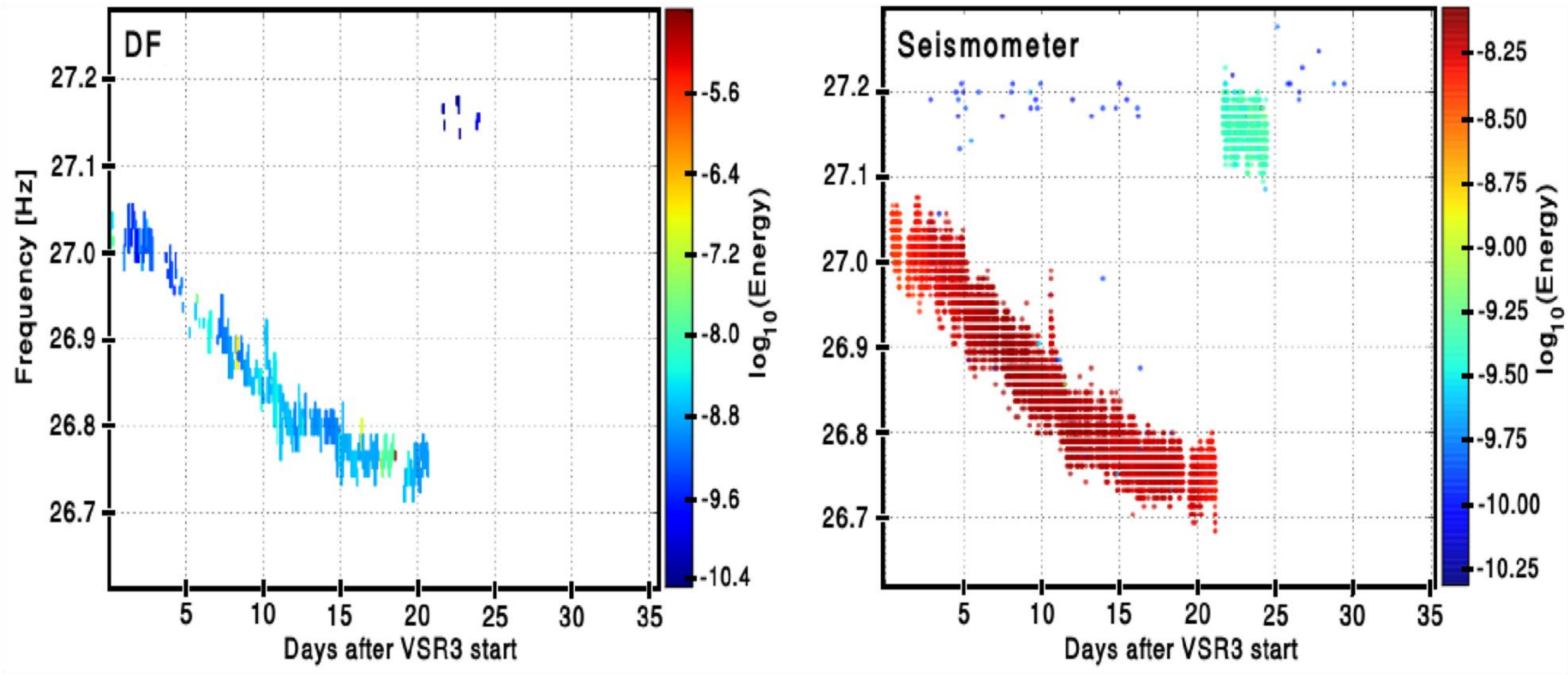




Example of airco. fan vibration

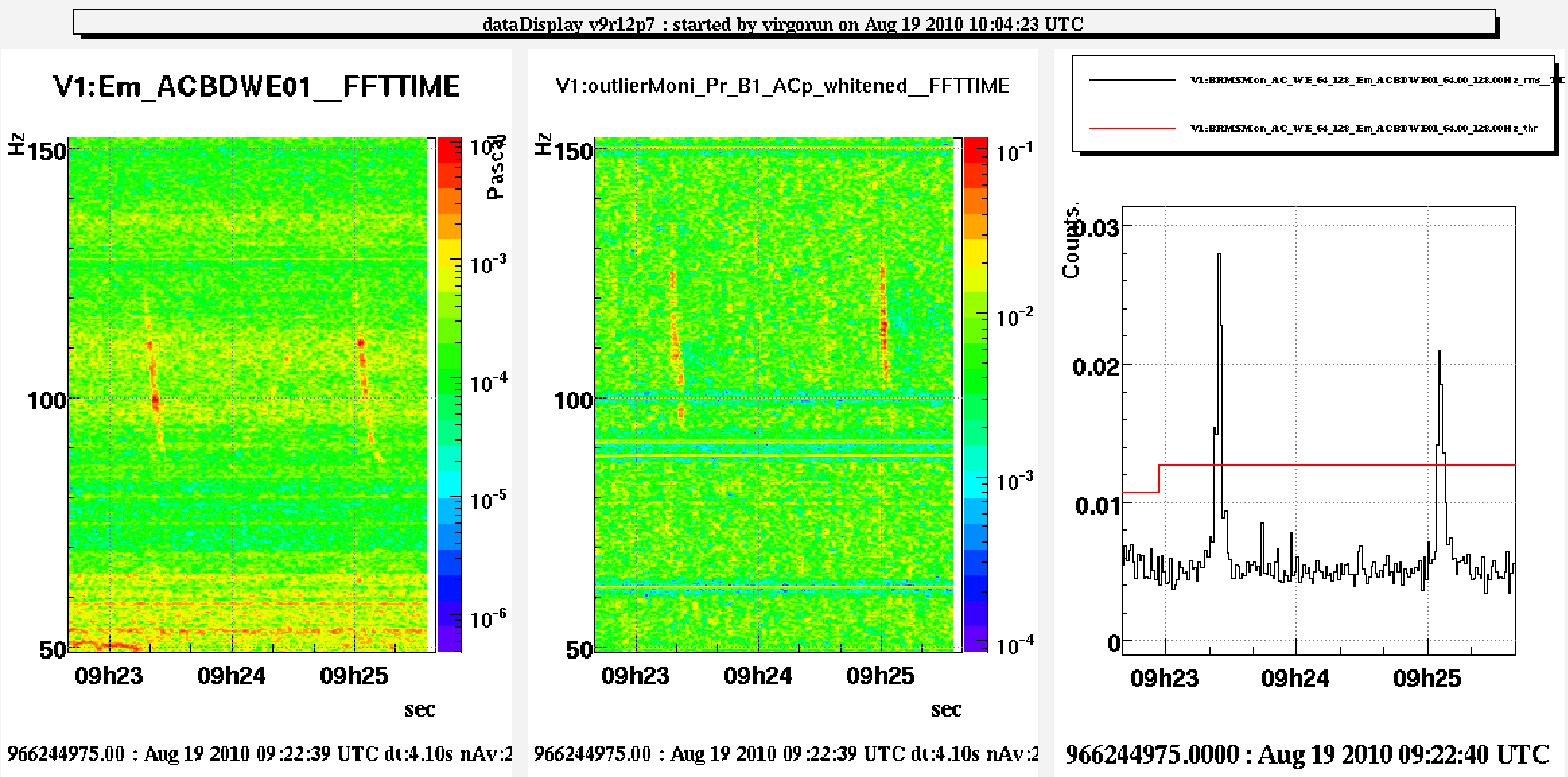
Plots from the "Line monitor"

GW signal



Transient noise: aircrafts

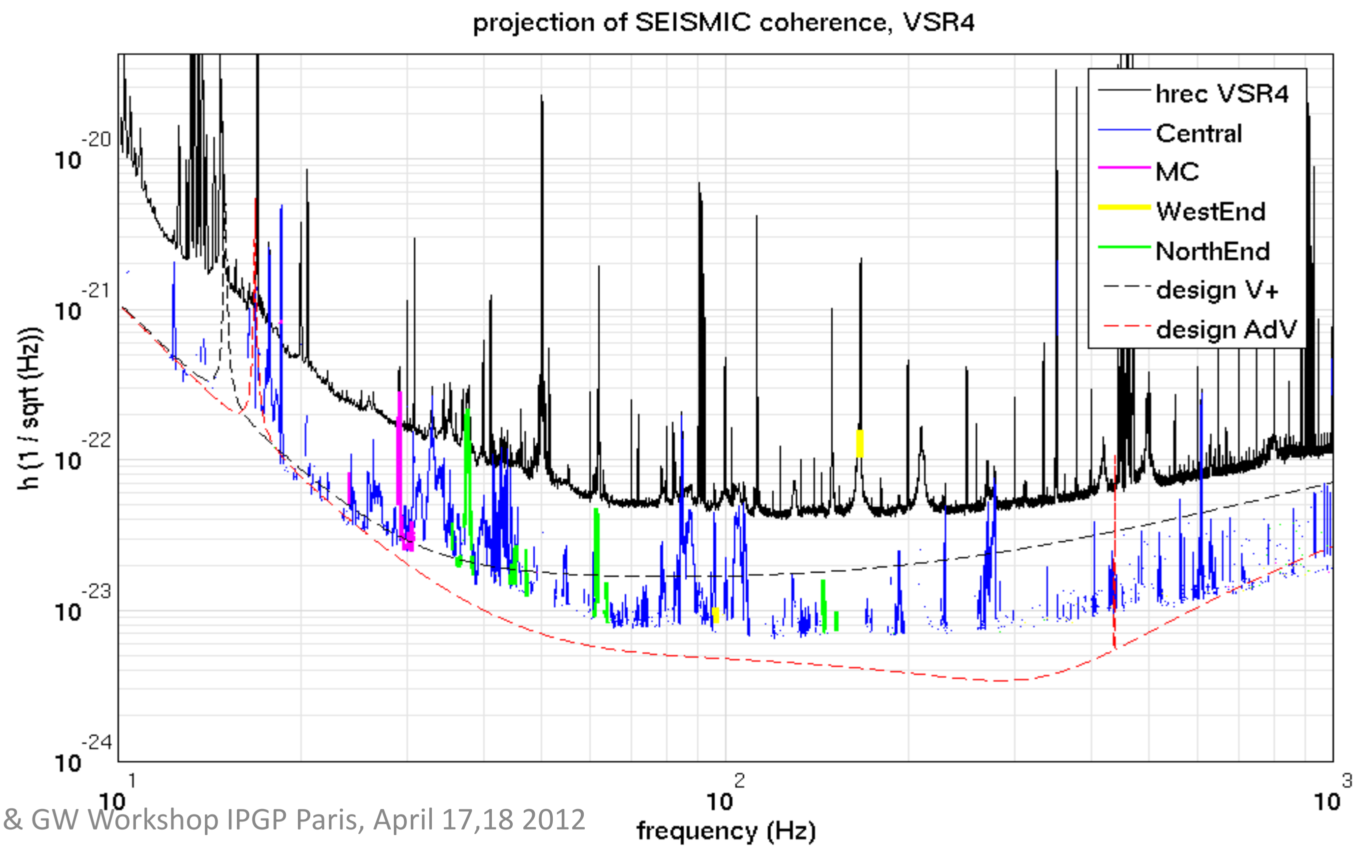
- Vibration noise induced by sound pressure waves, couples as diffused light (particularly critical during VSR3 science run)



Seismic noise polluting the Virgo detection bandwidth

- 10-1000 Hz coherent seismic noise projected to Virgo sensitivity
- Sources are close to ITF, mainly pumps, cooling fans, HVAC...

(Have plans to drastically reduce this noise in Advanced Virgo, reducing back scattered light, using in vacuum and suspended optical benches, mitigating sources)



- And what about
  low frequency (<1Hz) seismic noise?

Low frequency seismic noise? It is also important to us!

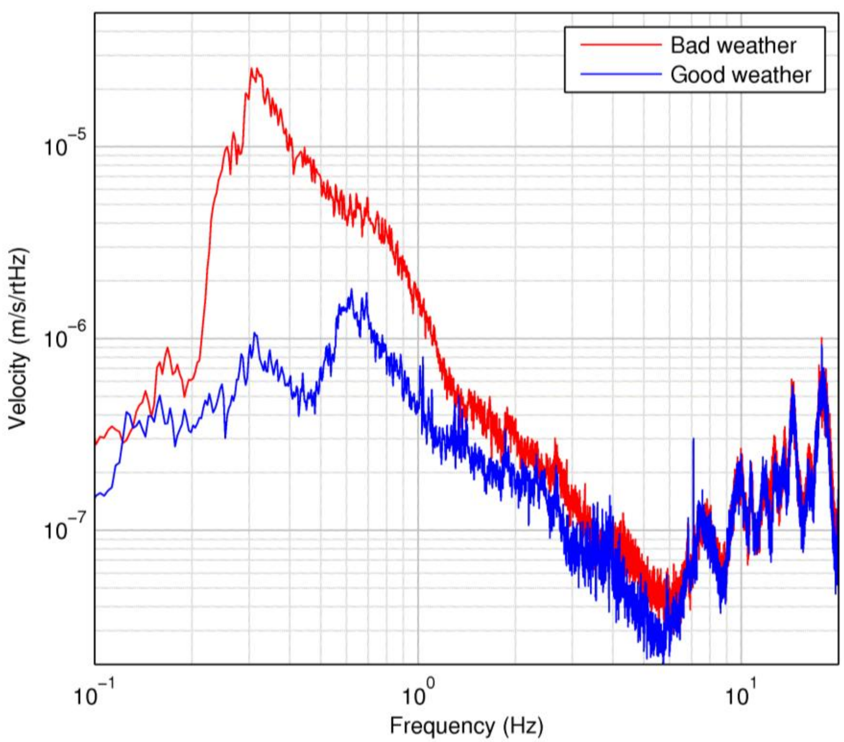
- Back-scattered ligh coupling is non-linear, and can up-convert low frequency seismic vibrations into the Virgo detection bandwidth

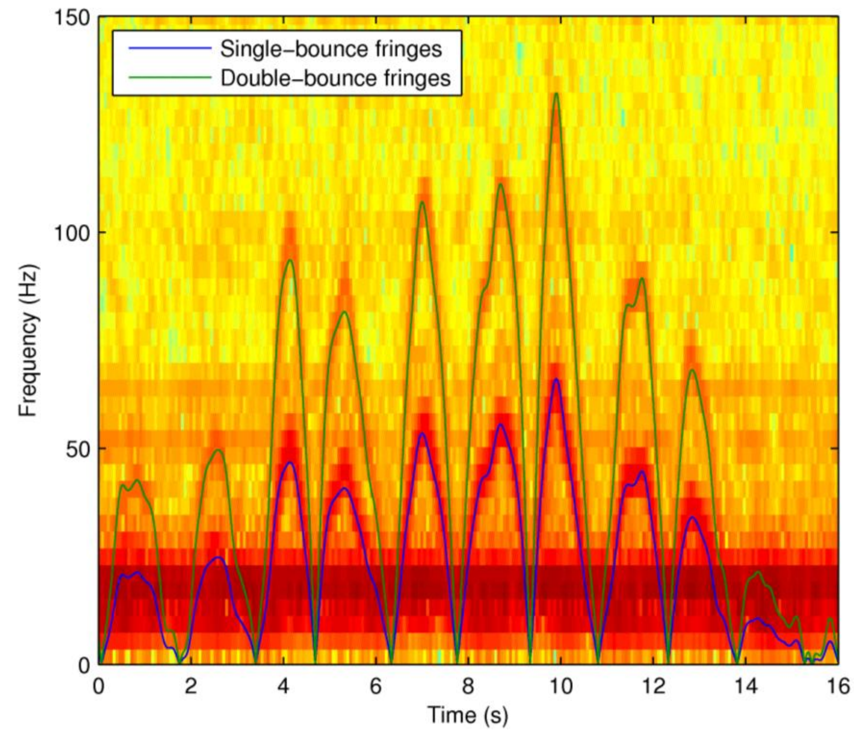
Example, up-conversion of Sea microseism:

$\mathcal{V}_{sc}$ (t) = scatterer velocity

f_{fringe} (t) = frequency of GW noise

$$f_{fringe}(t) = \left|2\frac{v_{sc}(t)}{\lambda}\right|$$





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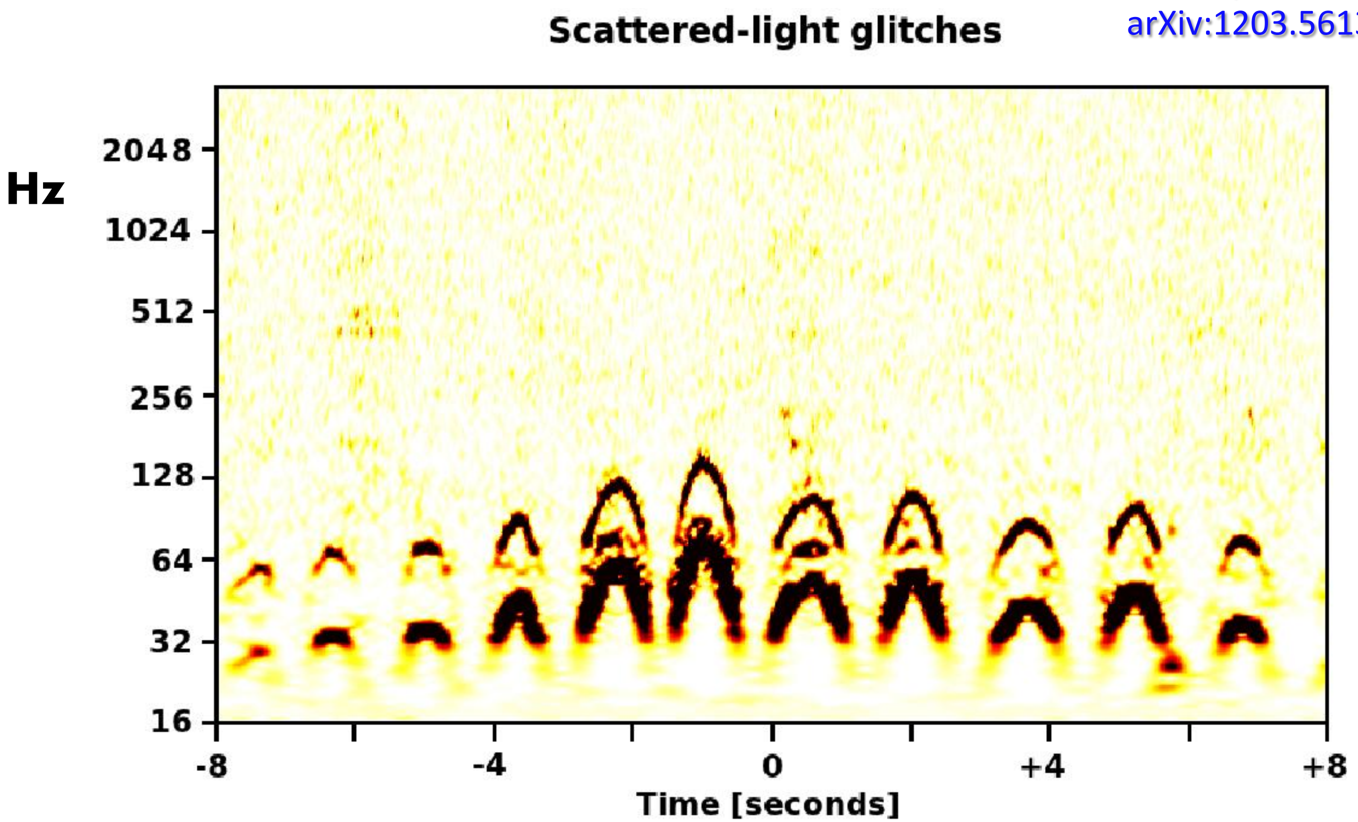
T. Accadia et al. Class. Quant. Grav. 27, 194011 (2010)

Microseismic noise “arches”

- These events are identified and “FLAGGED” as “NOISY DATA” by looking at ground seism velocity measured by seismometers (or SA Lvdt sensors)
- These are excluded from GW search analyses

J. Aasi et al. Virgo data characterization and impact on gravitational wave searches, arXiv:1203.5613v1 2012

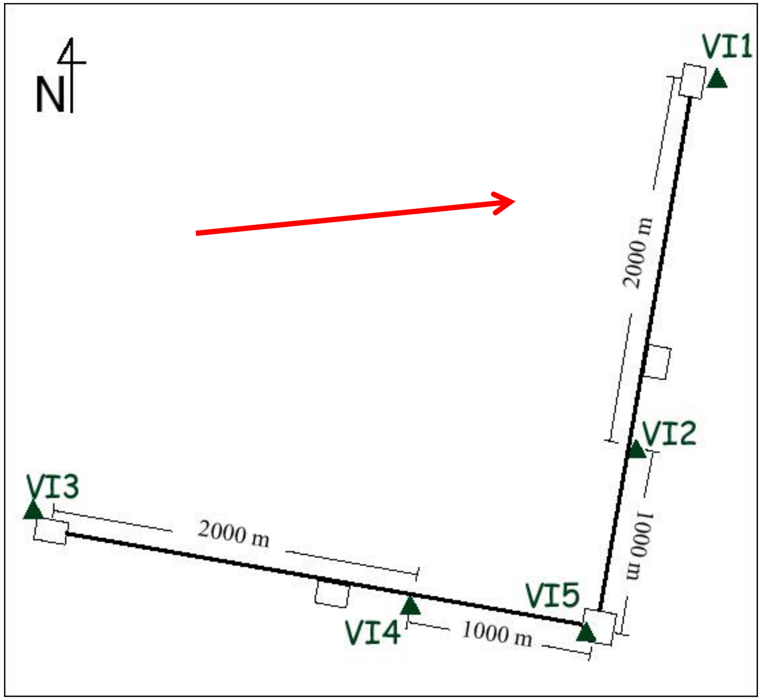


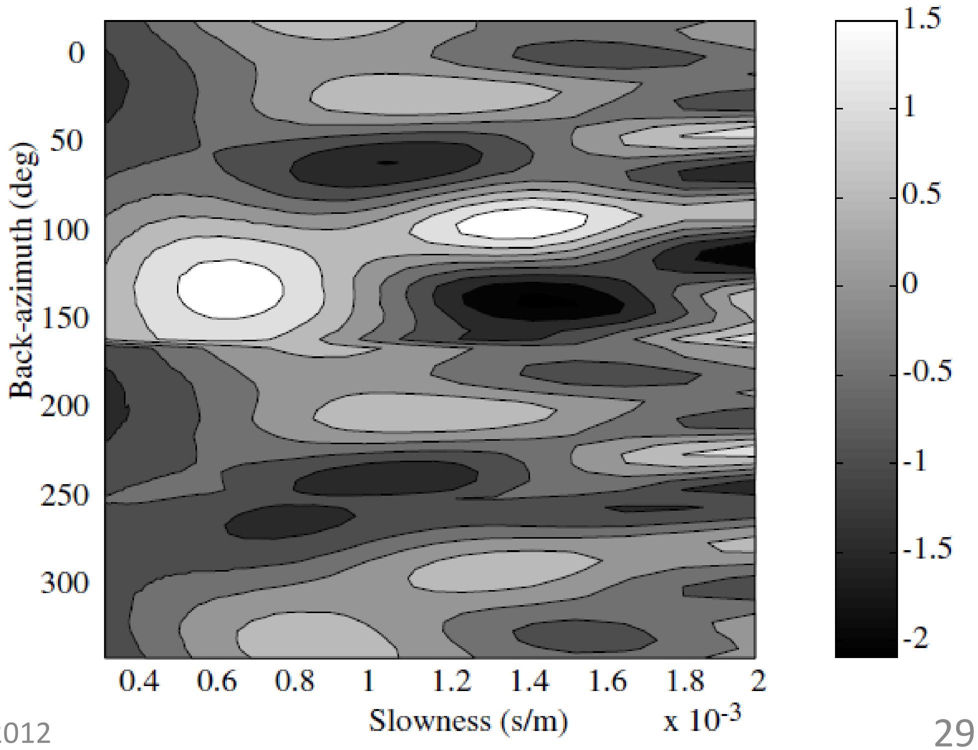
- Short tour of studies on seismic sources near to EGO-Virgo site >>>>

Sources: 0.1-1Hz, Sea microseism

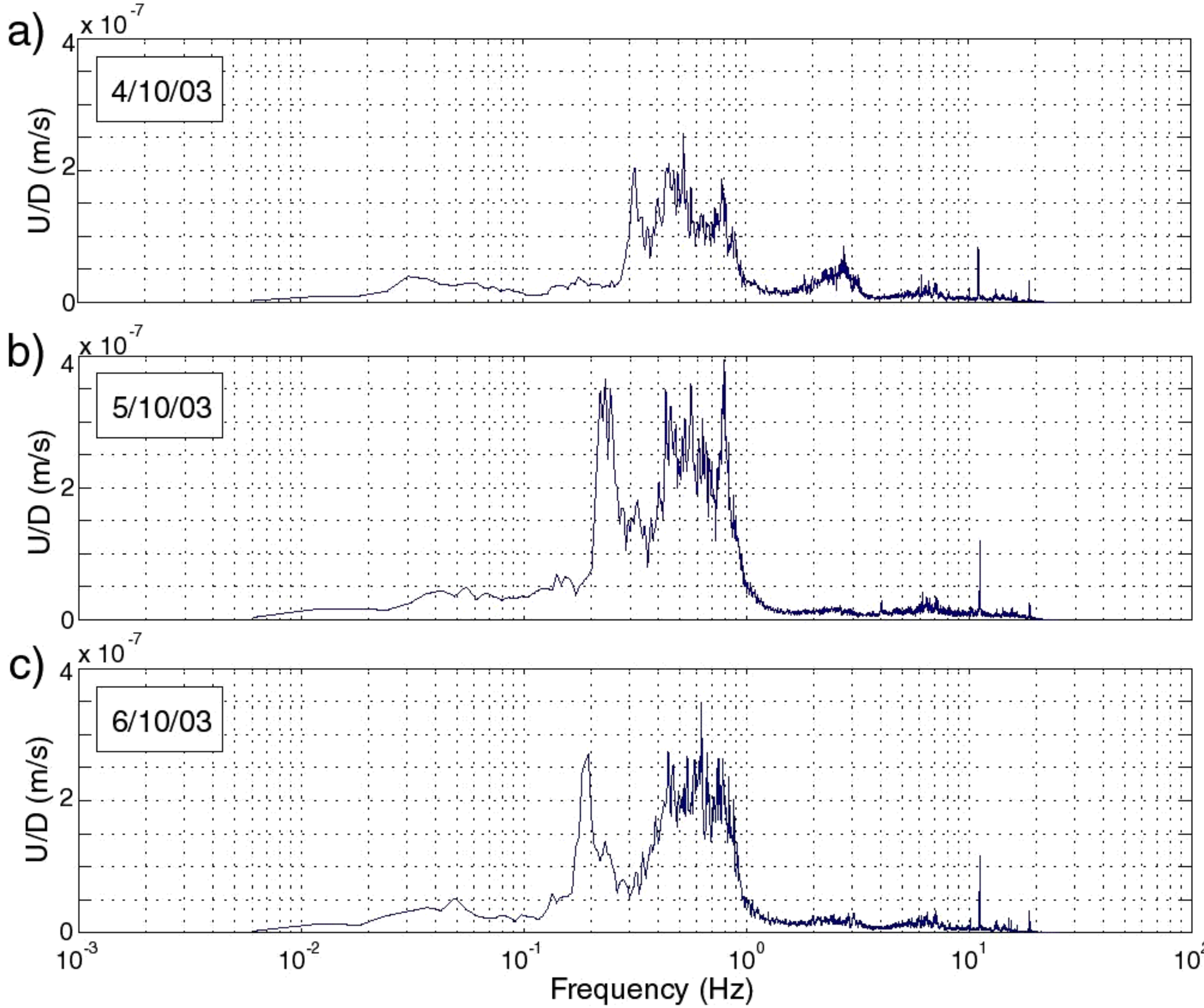
- Most intense and persistent peak at 0.3-0.4Hz, seasonally (after large swells) it moves to 0.1-0.2 or 0.8Hz.
- Peak amplitude varies from 0.5µm to 20µm
- Seismic array study, measured wave velocity and propagation direction:

plane wave field from West, 700 m/s or 1600 m/s (E.Marchetti, M.Mazzoni, Acernese F et al. Class. Quantum Grav. 21 S433 (2004))



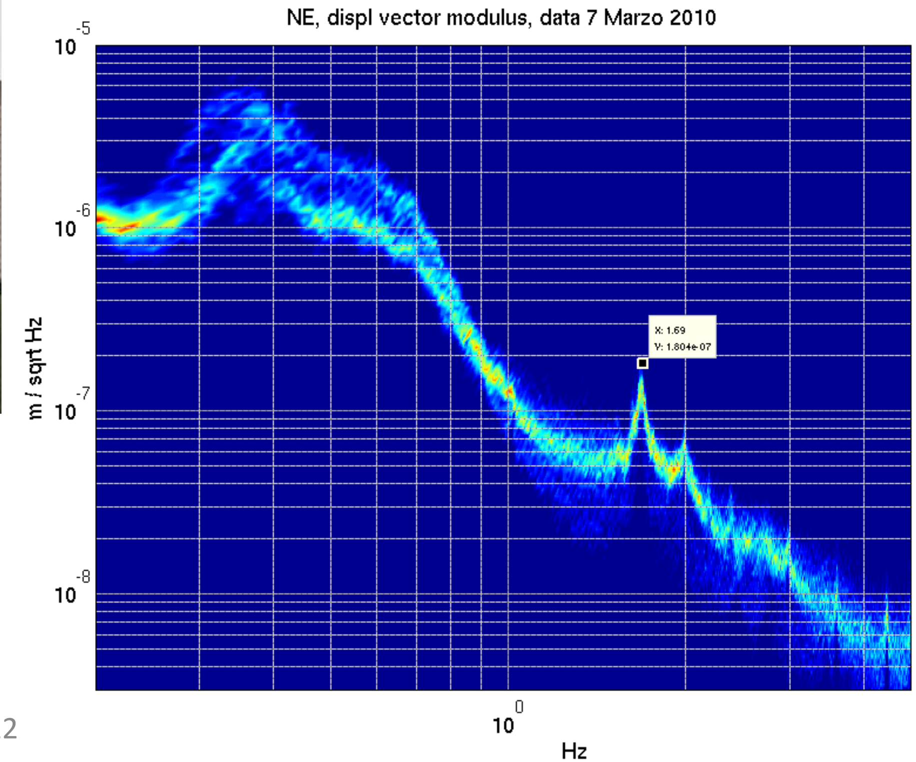


Low frequency seism evolution during a sea swell



Wind turbines

- 1.7Hz seismic vibration from a wind farm 6km distant

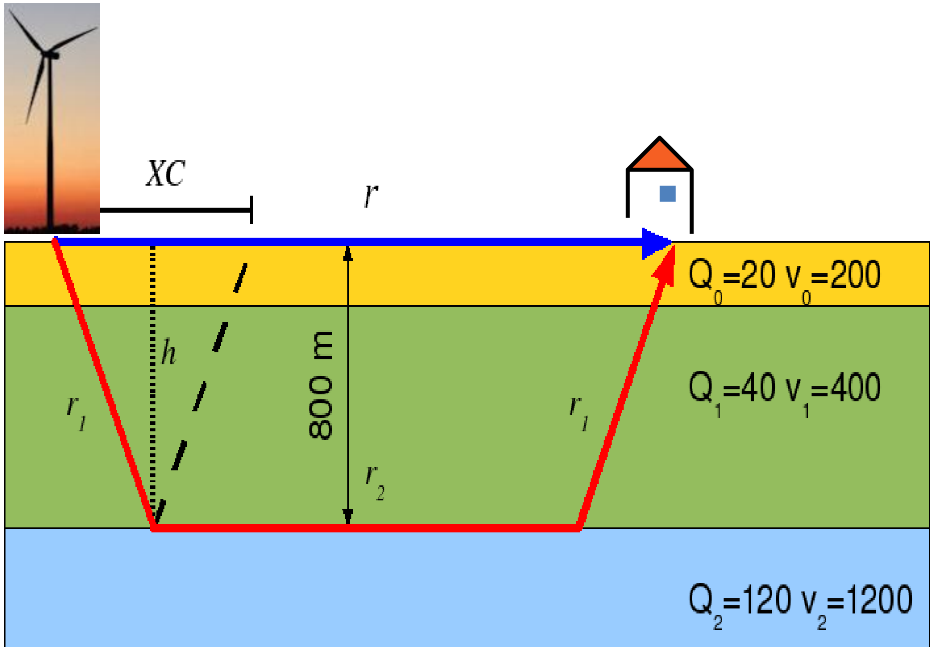


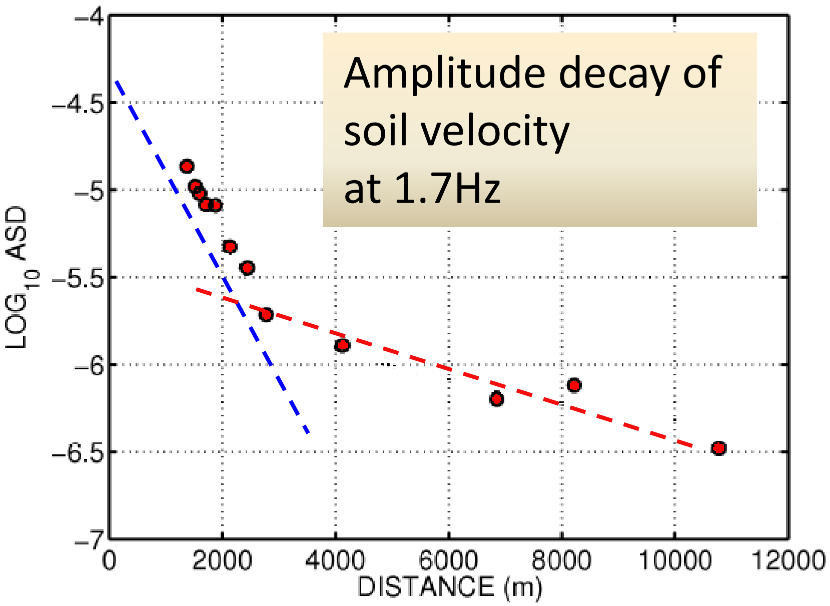
Study of wind turbines signal

By “Istituto Nazionale di Geofisica e Vulcanologia” and EGO,
(G.Saccorotti et al. *BSSA*, April 2011; v. 101; no. 2; p. 568-578)

- 14 stations, with Lennartz LE3D-5s (0.2-40Hz) or CMG-40 (0.03-50Hz) seismometers, or EpiSensor FBA ES-T (0.1-100Hz)
- Some kept fixed, other arranged in temporary array configurations
- Wind speed recording: atop Virgo control building,10m height

Seism propagation model

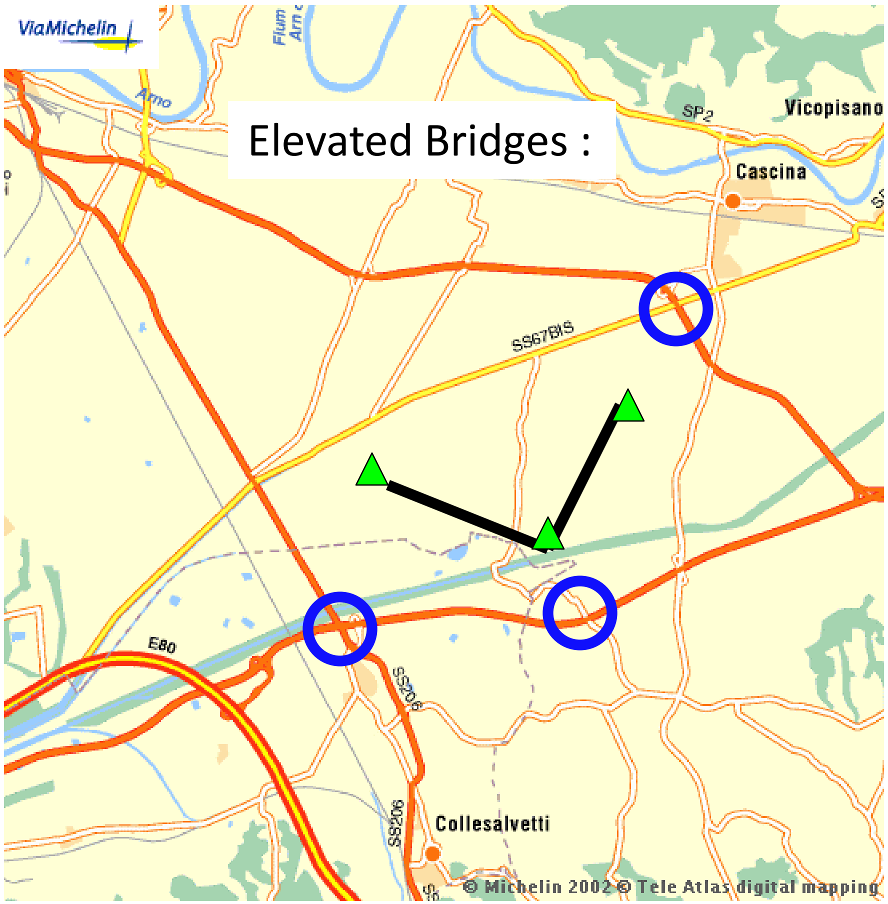




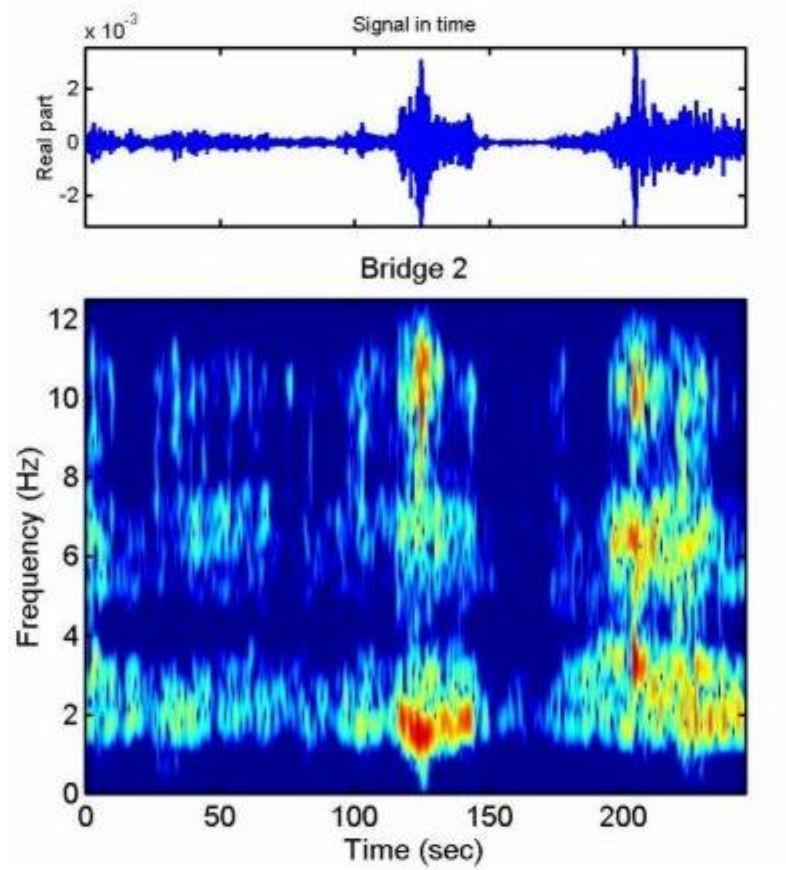
SUM of two components:

- (1) **DIRECT SURFACE WAVE** in the shallowest layer characterized by slow velocity and large absorption (velocity v=200m/s, and quality factor Q=20: MEASURED in this study).
- (2) **REFRACTED BODY WAVE**, travelling through the intermediate layer and continuously refracted by the 800m deep carbonate layer interface (velocity and Q factors from litterature and data fit).
- Simplifying assumptions: energy is equally parted in direct and refracted waves, velocity structure of soil is laterally homogeneous, negligible local amplification effects.

Sources: 1-10Hz
bridges oscillations



Seismometer underneath bridge:



L.Holloway, Fiori, VIR-NOT-FIR-1390-251

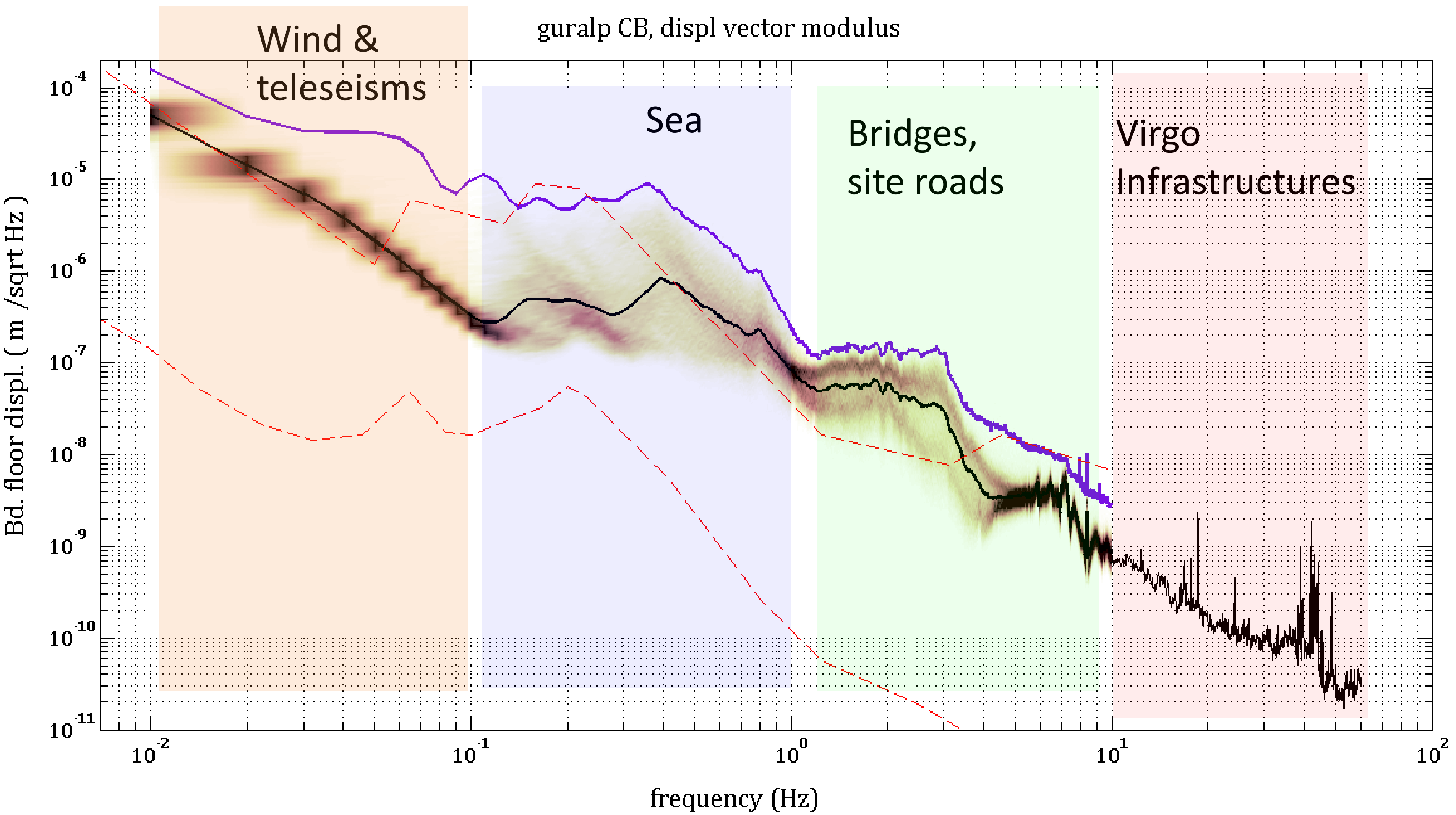
Virgo site seism

Central Building floor, Guralp 40T

SHADOW = spectral noise variation density based on 1-year data

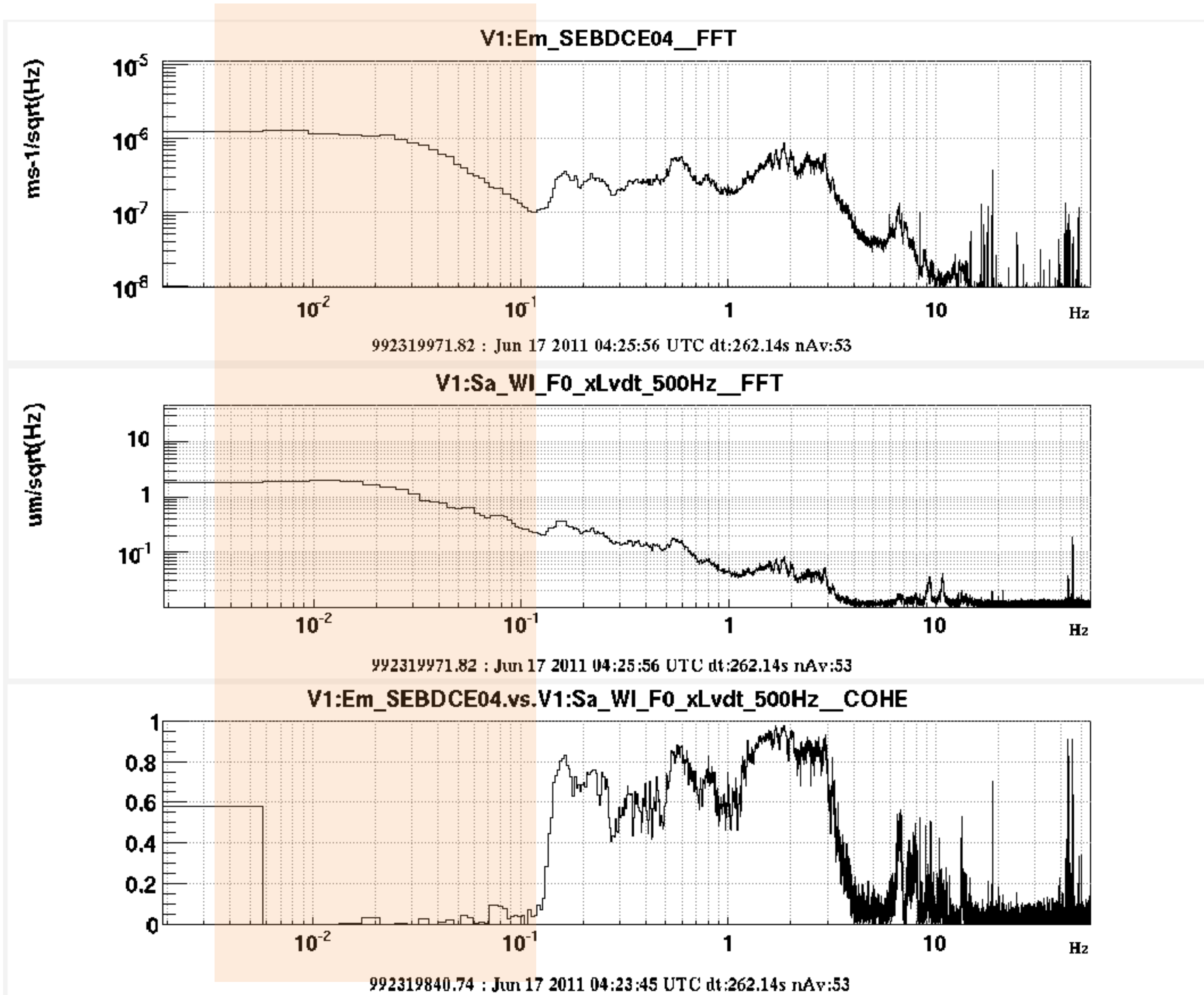
SOLID BLACK = median

PURPLE = 99% of time seism is below this curve, RED = Peterson's Low High Noise models

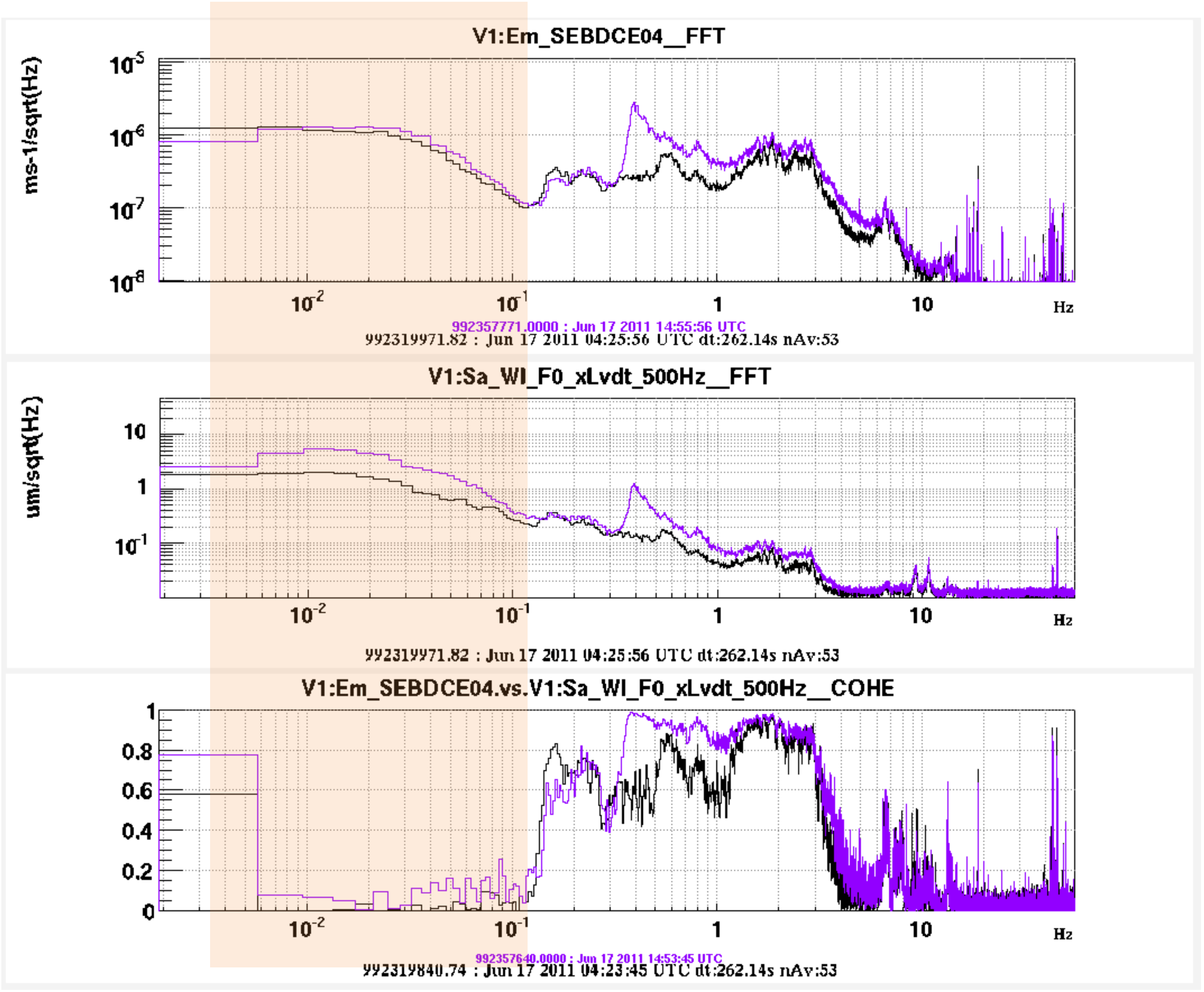


- our Commercial sensors “versus” Super-Attenuator sensors

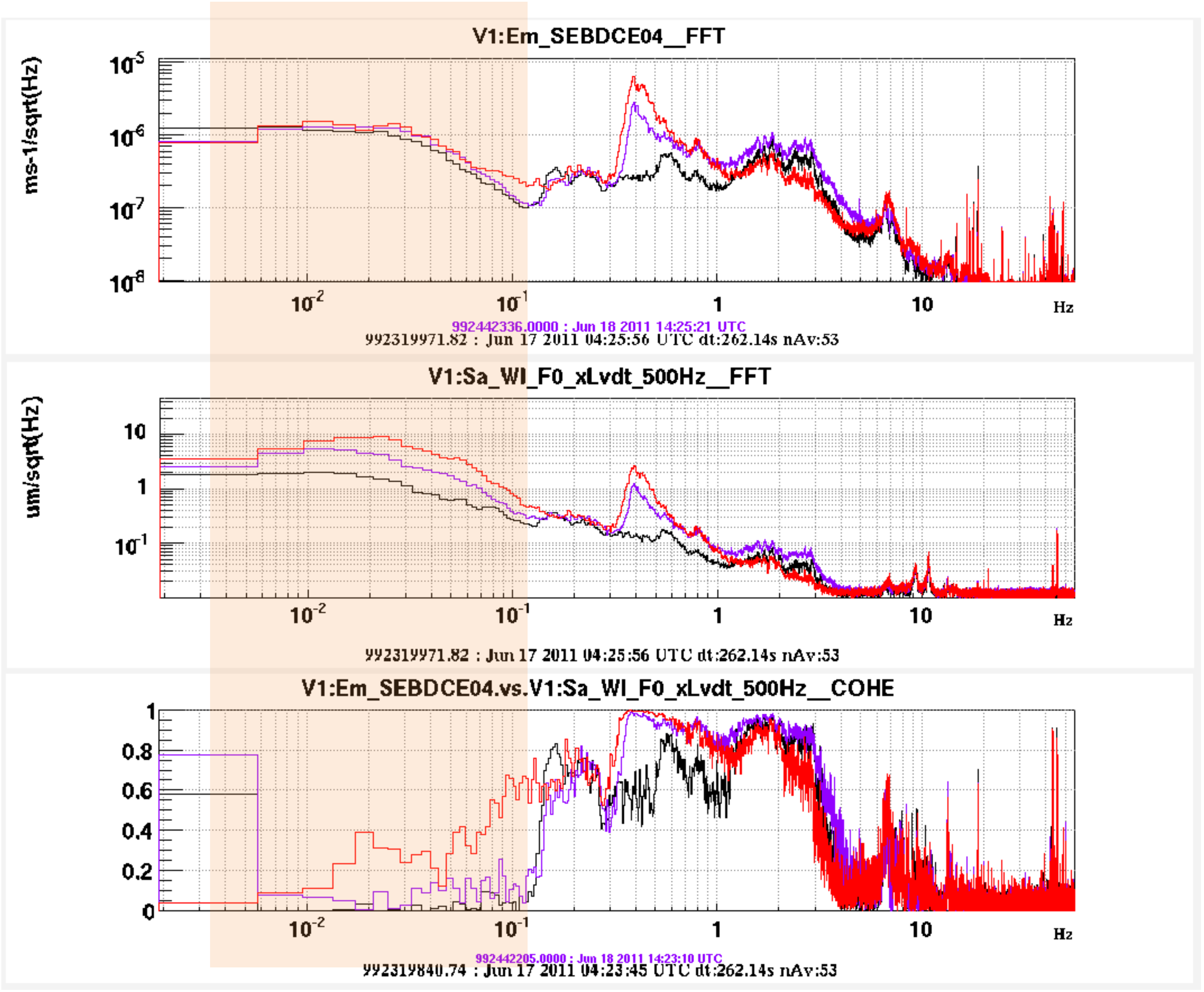
Quiet night


V1:Em_SEBDCE04__FFT
ms-1/sqrt(Hz)
Hz
992319971.82 : Jun 17 2011 04:25:56 UTC dt:262.14s nAv:53
V1:Sa_WI_F0_xLvdt_500Hz__FFT
um/sqrt(Hz)
Hz
992319971.82 : Jun 17 2011 04:25:56 UTC dt:262.14s nAv:53
V1:Em_SEBDCE04.vs.V1:Sa_WI_F0_xLvdt_500Hz__COHE
Hz
992319840.74 : Jun 17 2011 04:23:45 UTC dt:262.14s nAv:53

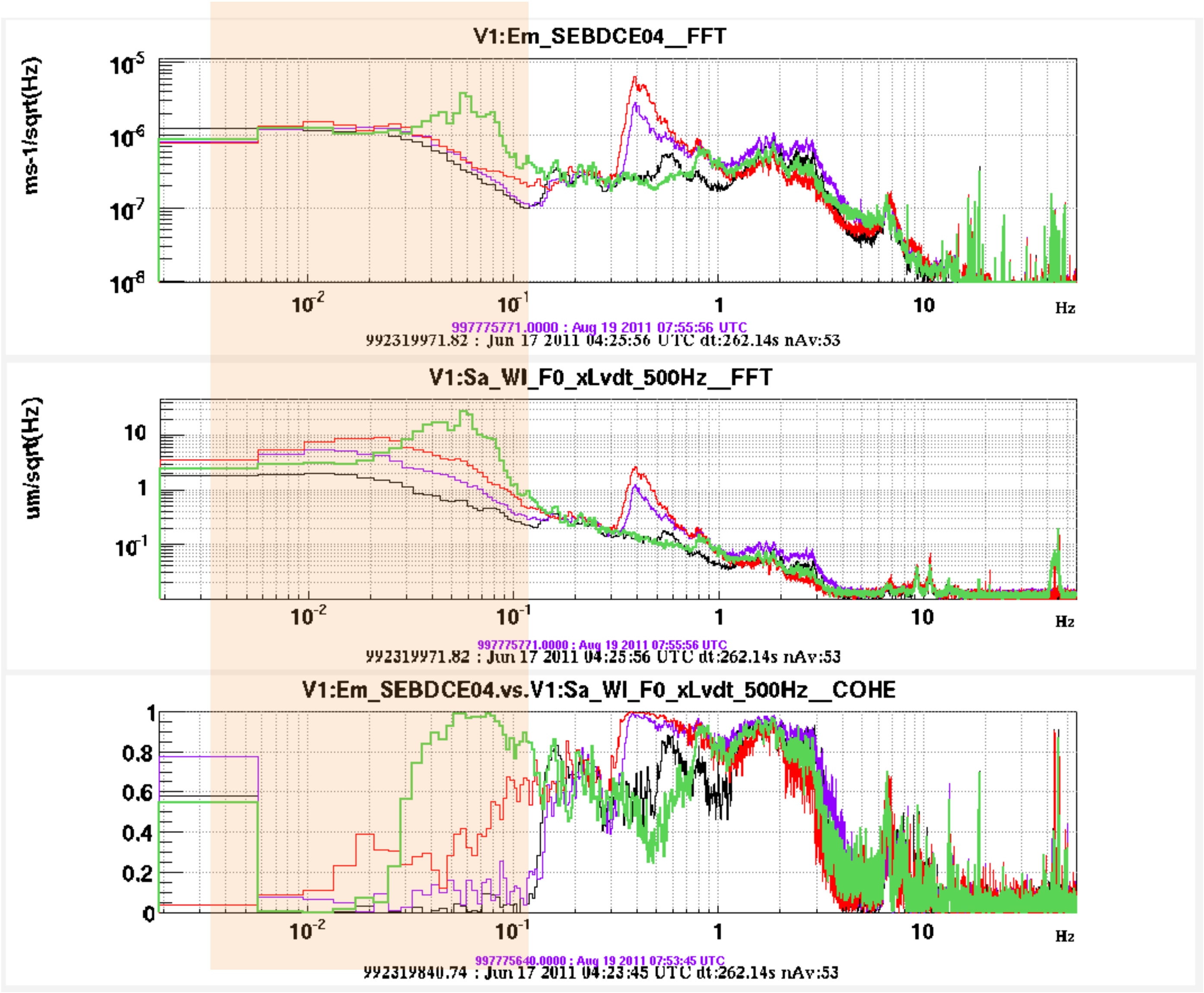
Some wind (few km/h)



Stronger wind (>15km/h)



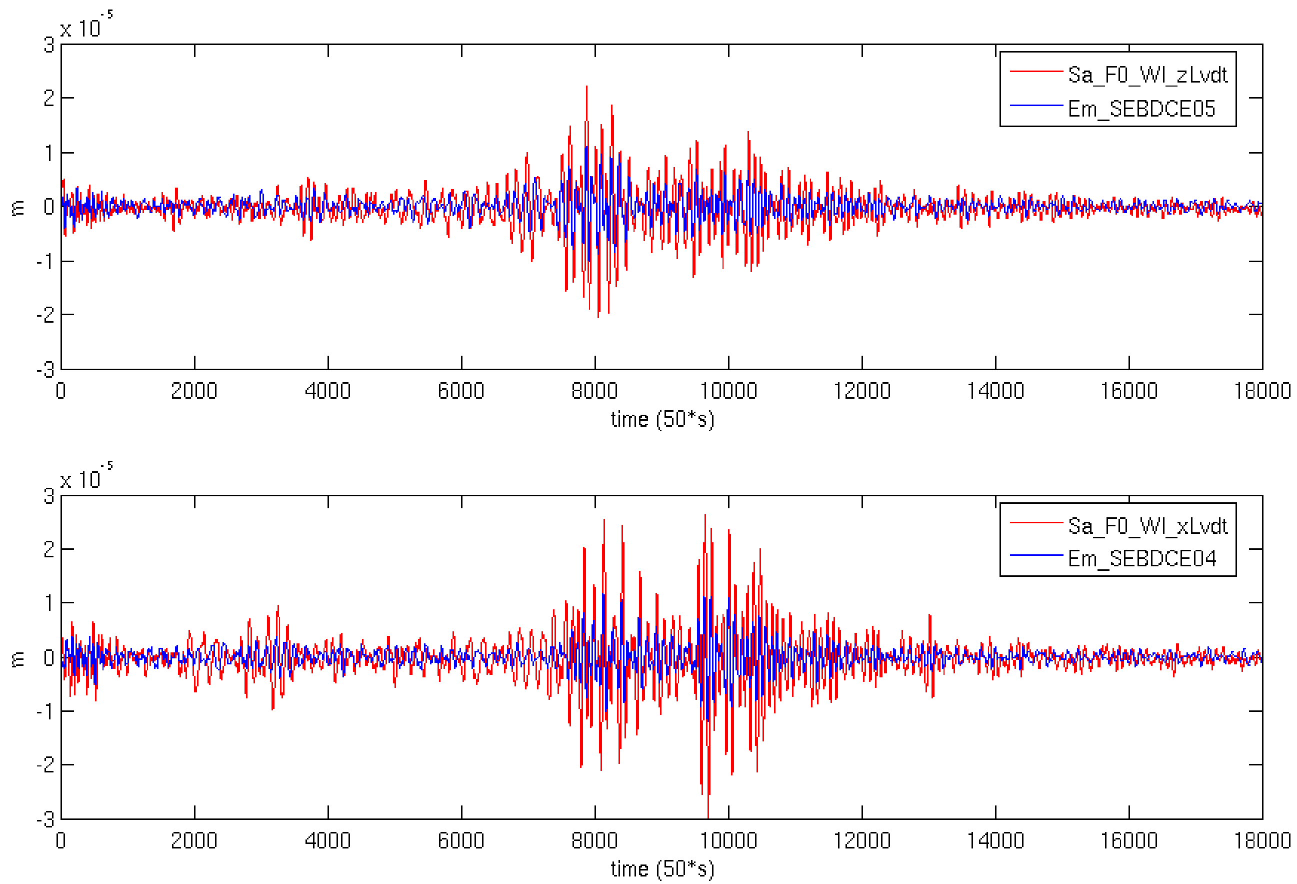
and one Earthquake (6.2 Japan)



Same Earthquake, time

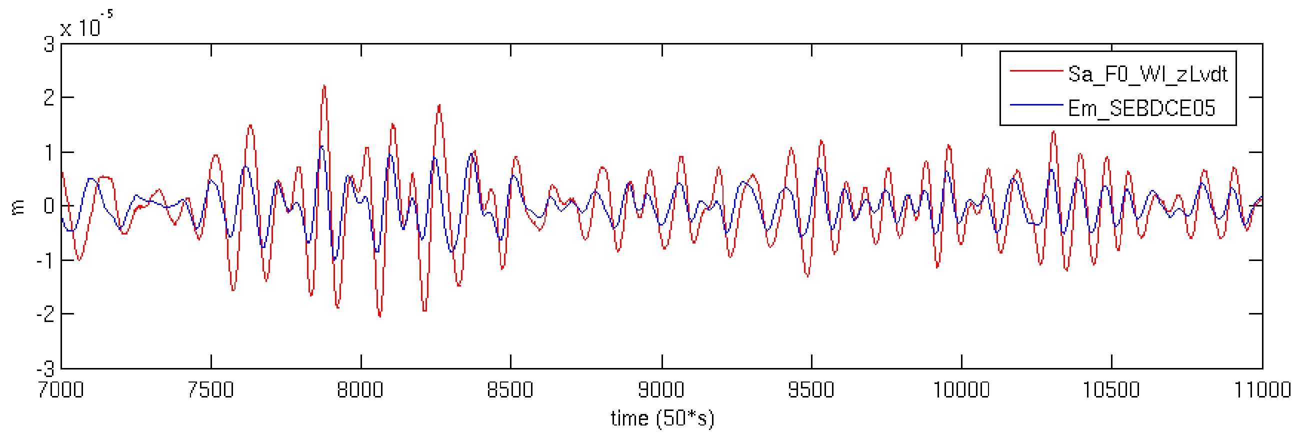
RED = WI super-attenuator top stage “x” and “z” sensors

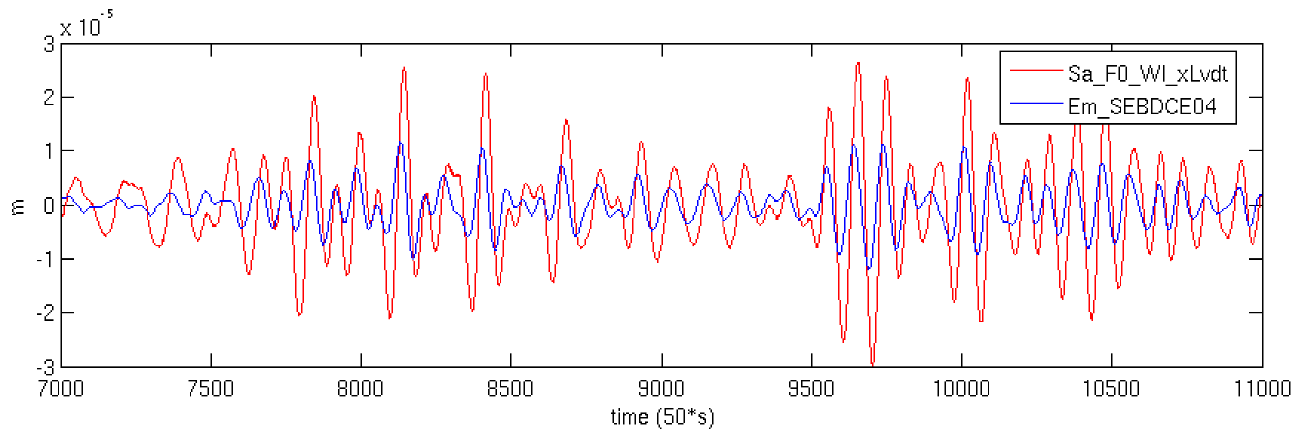
BLUE= Guralp 40T sensor.



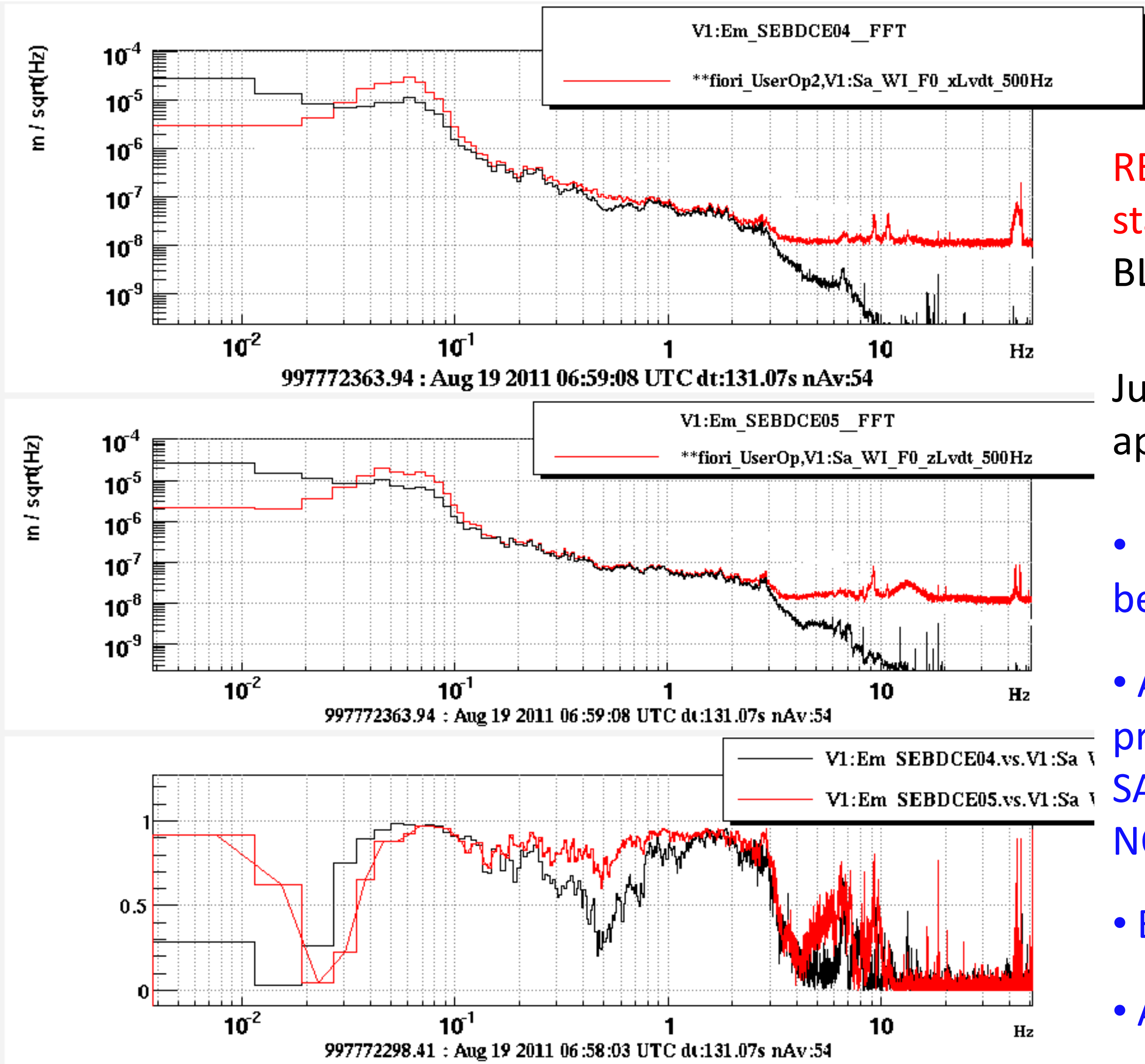
Same Earthquake, time zoom-in

RED = WI super-attenuator top stage “x” and “z” sensors
BLUE= Guralp 40T sensor (integrated to go from vel → displacement)
No compensation for *sensors frequency response* applied.





Same Earthquake, spectrum

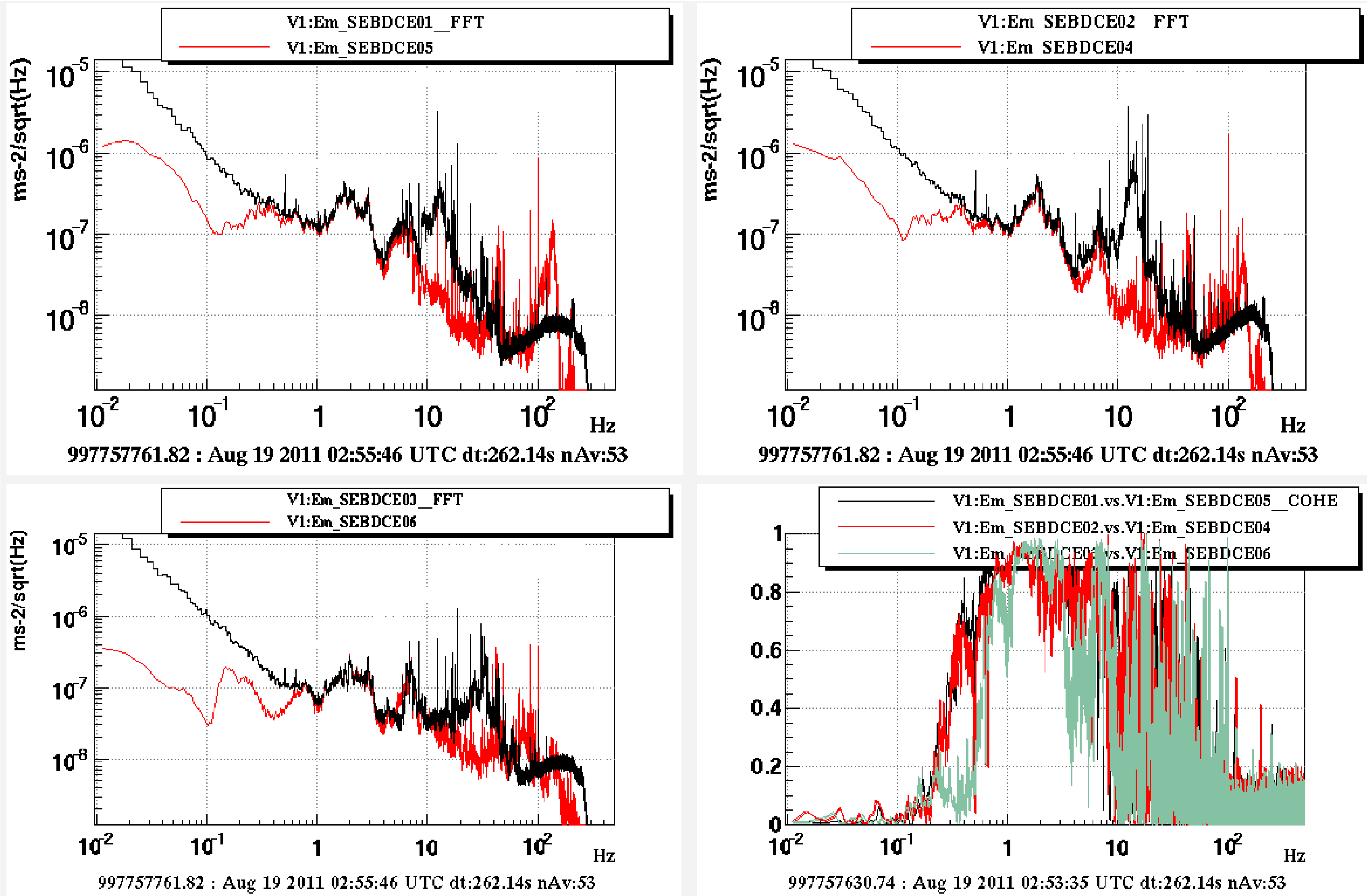


RED = Super-Attenuator top stage “x” and “z” sensors (WI)
BLACK= Guralp 40T sensor.

Just simple time integration applied to Guralp (vel -> displ).

- Similar response between 0.1 and 2 Hz
- Around 0.1 Hz difference is presumably due to SA control loop which here is NOT compensated.
- Below ≈0.03Hz, Guralp is noisy
- Above 3Hz, SA sensor is noisy

Episensor vs Guralp40T



Conclusions

- Commercial sensors monitor Virgo Buildings floor.
- Their major scope and use has been to correlate to GW signal for noise hunting (above ≈1 Hz).
- These sensors can be trusted to measure real seism down to ≈0.1Hz, also in the quietest noise conditions .
- Below 0.1Hz, teleseisms of magnitude ≥6 are sensed as well.
- In this range of frequency and intensity, Virgo commencial sensors can be used together withSA sensor.