Properties of seismic noise at Virgo

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Seismic Monitoring Network

- **Low Frequency Accelerometers**
  - Tri-axial, 0.2-200 Hz
  - (Kinemetrics - “Episensors”)

- **High Frequency Accelerometers**
  - Vertical Piezo, 10-10000 Hz
  - (Bruel&Kjaer)

Also:
- Microphones
- Magnetometers
- Pressure probes
- Humidity
- Temperature

**Diagram:**
- Virgo Central building
- MC End b.
- West End b.
- North End b.
- Anti-aliasing filters
- Other chs.
- ETHERNET LINK
- C1, C2, DISK
Seism General Properties

Seism amplitudes (m)
- $10^{-5}$ @ 0.1 Hz
- $10^{-7}$ @ 1.0 Hz
- $10^{-9}$ @ 10.0 Hz

Displacements (m/$\sqrt{\text{Hz}}$)
- $10^{-7}$ $f^2$ (m/$\sqrt{\text{Hz}}$)

Acceleration spectral amplitudes
- $x$-$y$-$z$ directions
- Tri-axial accelerometer
- On concrete floor of Virgo Central B.
- 0-200 Hz
- Approx. flat acc. spectrum in 3D

Seism amplitudes (m)
- $10^{-5}$ @ 0.1 Hz
- $10^{-7}$ @ 1.0 Hz
- $10^{-9}$ @ 10.0 Hz
**Daily Seismic Variations**

- **DAY vs. NIGHT** seism accelerations
  - Human & Natural seismic sources below $\approx 10$ Hz

- **NIGHT vs. WINDY NIGHT**
  - Wind & Sea Waves seismic sources below $\approx 1$ Hz
Monitor of RMS Seismic Motion

\[ RMS = \left( \int_{f_1}^{f_2} |\tilde{a}(f)|^2 df \right)^{1/2} \]

in 3 frequency bands: \( 0.2 \text{–} 1 \, \text{Hz} ; \ 1 \text{–} 4 \, \text{Hz} ; \ 4 \text{–} 10 \, \text{Hz} \)

- **0.2 – 1 Hz**: slow motion \( \rightarrow \) correlated with wind & sea-waves?
- **1 – 4 Hz**: day-night-weekend variations \( \rightarrow \) local traffic?
- **4 – 10 Hz**: spikes between 10AM-6PM \( \rightarrow \) human activities on-site.
On-line seismic monitor

- Continuously running on 50Hz re-sampled data
- 1 week data at 10 minutes steps

Earthquake shakes

http://wwwcascina.virgo.infn.it/commissioning/Monitoring_50Hz
Two shakes recorded at Virgo site:

31 Oct. 2002, Magn. 5.9, 540 km SE from Virgo

2 Nov. 2002, Magn. 4.2, 270 km E from Virgo
Investigating the 0.2-1 Hz seism: Oceanic MicroSeism?

SEISMIC ARRAY ANALYSIS

SEA 15 km

5 tri-axial velocimeters (Lennartz 3D/5 sec)

- Coherent spectral peak at \( \approx 0.3 \) Hz
- Signals are band-pass filtered (0.1÷0.5 Hz)
Oceanic MicroSeism at Virgo

- Peak freq. is double the sea waves freq. [R.A. Haubric et al.]
- Peak freq. changes slightly with weather conditions [T. Braun et al.]
- Plane wave-front
- Peak frequency $\approx 0.3$ Hz
- Speed 750-800 m/s

Consistent with OMS typical properties:

Travel time between each pair of stations:

- Vi1
- Vi2
- Vi3
- Vi4
- Vi5

$\approx$ East $\rightarrow$ West

Vi1  Vi2  Vi3  Vi4  Vi5

0  200  400  600

Time (seconds)

LAG (seconds)
Investigating the 1-4 Hz seism: Local Traffic?

- “bursts” at ≈ 3 Hz
- approx. 20 s long
- ≈ 1 / minute during daytime
- Minimum at 2AM (local)
- Very reduced during week-ends

Hypothesis: Trucks exciting oscillations of nearby bridges
Road bridges around Virgo

- 1-3 km far from Virgo arms ends

Ground vibrations under bridge:

- Resonant frequencies: 2, 6, 11, ... Hz
Road bridges around Virgo

- 1–3 km far from Virgo arms ends

Correlation measurement (preliminary):

- @Virgo
- @bridge
- Filtered 1÷4 Hz

x-correlation
Road bridges around Virgo

- 1-3 km far from Virgo arms ends

Bridges Oscillations 3/3

Sedimentary soil at Virgo:

\[ Q = 2-10, \, v \approx 1 \, \text{km/s} \]

\[ A(s,\omega) = A_0 \exp\left(-\frac{\omega s}{2vQ}\right) \]

- \[ A(6\text{Hz})/A(2\text{Hz}) < 0.1 \ (@1\text{km}) \]
- Only 2 Hz component survives at 1 km and seen by Virgo seismometers
- \[ A(3\text{km})/A(1\text{km}) < 0.1 \ (@2\text{Hz}) \]
- “bursts” are not coherent among seismic stations at Virgo arms ends
Which seismic sources are relevant for Virgo?
Seismic isolation at Virgo

Super Attenuator: (SA)

- Multiple mechanical pendulum
  = I.P. + 5 filters + marionetta + mirror

Low pass filter in all d.o.f.

Ground seism attenuation:
\[ \geq 10^{13} \text{ @ } 4 \text{ Hz} \]

- Inverted Pendulum
  = Ultra-low frequency oscillator

- Actively controlled to damp horizontal SA resonances below 2. Hz
  (“Inertial damping”)
Seismic isolation at Virgo

GOAL: seismic noise below thermal noise above ≈2 Hz

Seismic noise versus other noise sources

- Seismic noise
- Newtonian noise
- Thermal noise
- Shot noise
- Quantum limit
- Sensitivity curve

Crossing point
Seismic noise accounted for all of the DF noise below 1.6 Hz
(→ mainly Oceanic MicroSeism)

- Entered exciting IP Vertical resonances:
  → improvements for final Virgo from implementing IP vertical control
Two recent results: a good one, ... and a not-so-good one
Other seismic sources

Coherence DF vs. seism (CITF - Run E4)

Ground vibrations due to motor devices in Virgo CB

10⁻¹⁰⁰ Hz

Coupling mechanism still under investigation

NOT through SA towers

Importance of seism coherence analyses!

43.7 Hz

46.89 Hz

DAQ ROOM AIR-COND SYS

ON

OFF
SA performance during an earthquake shake

June 30th 2003 - Magnitude 4.1 Richter - 20 km West of Tirrenia

[Graph showing acceleration vs. time and FFT spectrum]
SA performance during an earthquake shake

- ID control was active on NI tower
- Tower top stage displacement ≈ 400 µm peak-to-peak

> Control was not lost!!

> Usual RMS (≈ 0.3 µm) recovered in 3-4 minutes
Summary

• Ground motion at Virgo site agrees with empirical law:
  \[ A / f^2 \text{ with } A = 10^{-7} \text{ m}/\sqrt{\text{Hz}} \]

• Seism daily variations due to human\&natural sources
  occur mainly below 10 Hz

• Main seismic sources below 10 Hz:
  - oceanic micro seism, peaking at 0.3-0.4 Hz
  - local traffic within 1- 4 Hz

• At Virgo CITF
  - seismic noise contributed to Dark Fringe noise below \( \approx 1.5 \text{ Hz} \)
  - mainly due to vertical seism,
    that was not actively damped at low frequencies

• Other (potentially dangerous) sources: motor devices
  (AC, pumps, rack fans …)