Earthquake Early Warning System for Virgo: a design study

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Introduction

Virgo is a 3 km laser interferometer for the detection of gravitational waves (www.virgo-gw.eu). The mirror test masses at the extremities of the two 3 km Fabry-Perot optical cavities are seismically isolated by means of compound pendulum structures named superattenuator (SA) which achieve more than ten orders of magnitude of attenuation above 2 Hz. Below 2 Hz the mechanical modes of the SA are actively damped. Large low frequency ground shakes can cause the SA controls to saturate or exit from the linear regime and the optical cavities, and consequently the whole interferometer, to loose the resonant condition (or "go out of lock"). This is the case for earthquakes from regional and teleseismic distances. Moreover, strong events in proximity to the site could also threaten the delicate fused-silica suspensions. A fast, reliable Earthquake Early Warning system (EEWS) is required to issue an alert of incoming ground shaking and leave enough time to counteract against unwanted oscillations of test masses.

First we analyse the effects of past and present earthquakes at Virgo site to assess the parameters (distance, magnitude, azimuth) of the potentially threatening earthquakes and of the possible distance/azimuth-dependent site amplifications. This is accomplished by using data recorded during the O2 run from seismometers located in the Virgo buildings integrated by data from the from INGV network.

We present ideas about the implementation of an EEWS and its requirements in term of new technologies to be developed within the framework of INGV and Ego Virgo collaboration.

EEWS (Earthquake Early Warning System)

Why?

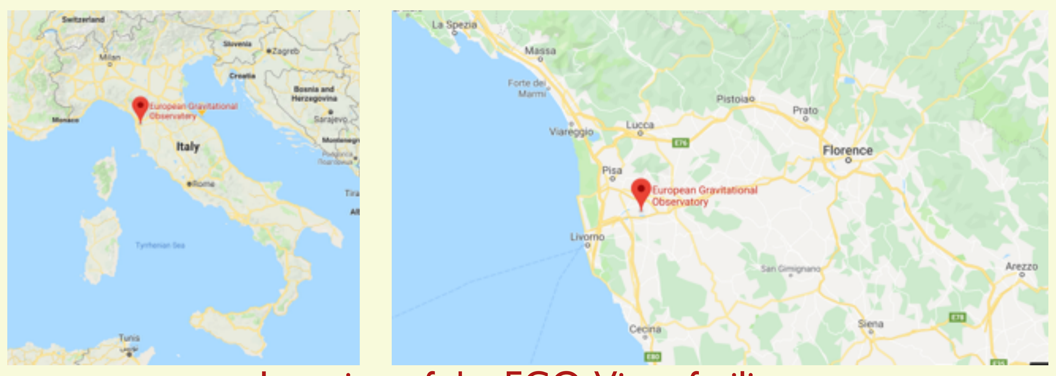
Virgo interferometer is very sensitive to the effect of earthquakes as it was observed during the O2 run when it went "out of the lock" loosing the resonance condition in consequence of some of the large recorded earthquakes. The mirror oscillations can last for minutes/hours and reduce the detection capability over the long term runs. Furthermore, large oscillations can damage the suspended mirrors. Superattenuators, at least for teleseismic earthquakes, can cope with P- and S-waves but not with surface waves (period > 30 seconds and long lasting).

What?

An efficient EEWS can discriminate relevant/not-relevant expected ground shaking at Virgo in consequence of an earthquake and issue a warning well in advance, leaving enough time for counteractions. Requirements:

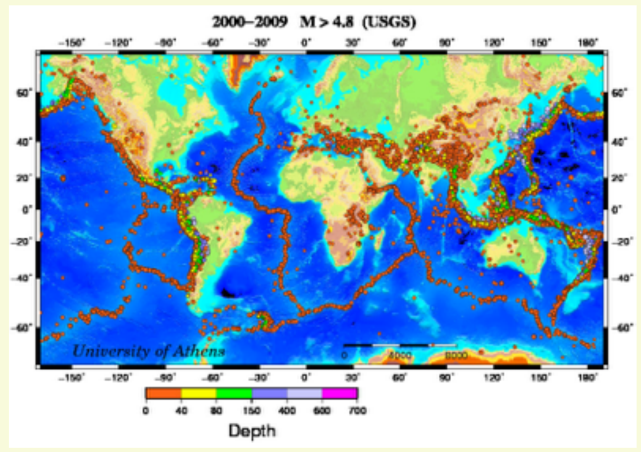
- Low rate of false and missed alerts,
- Long enough warning time (5-10 seconds).

Where?



Location of the EGO-Virgo facility

Earthquakes and Real-Time monitoring

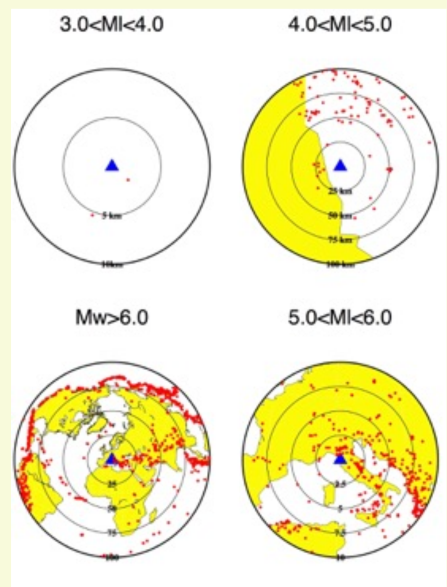


Global seismicity for the period (2000-2009) and for magnitude M>4.8. Color code defines the depth of the earthquakes

Real-time seismic stations currently received at INGV-ONT, this represents the backbone of data on which a global EEWS could be implemented.

Proposed selection rules to discriminate relevant earthquakes

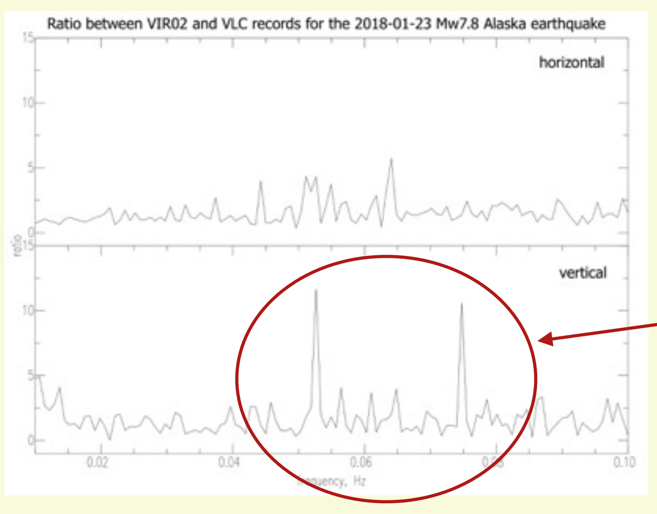
	Epicentral distance	Magnitude
Small	< 10 km	3 < Ml < 4
Medium	< 100 km	4 < Ml < 5
Large	< 1000 km	5 < Ml < 6
XL	< 10000 km	Mw > 6



A tentative selection rule was "theoretically" proposed in order to consider and analyse only the small portion of relevant earthquakes occurring worldwide. Their spatial distribution is shown in the above right figure. The experimental results (bottom left panel) confirm the necessity of an approach more focused on the effects at site than on source parameters.

Geological context and site response

Virgo is sited in the Arno alluvial plain, a thick soft sedimentary layer that could amplify the effects of the earthquakes with strong dependency on size and backazimuth.

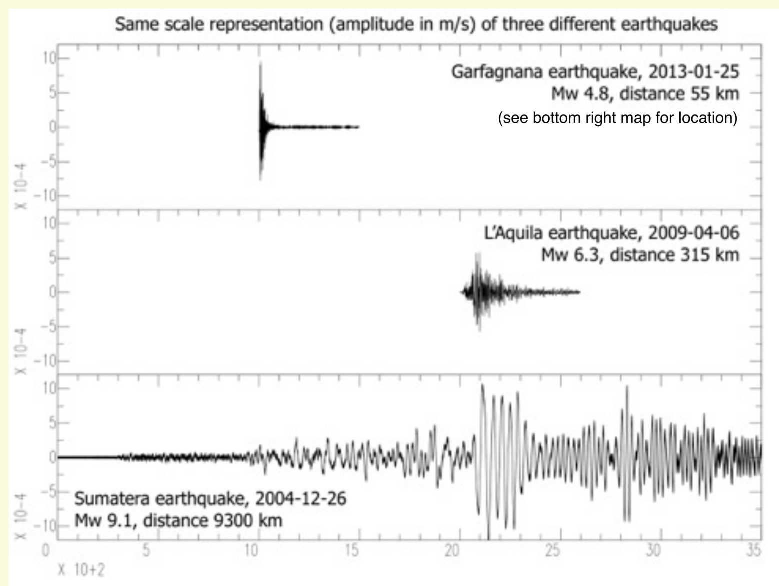


Possible evidence for resonance amplification by the site or by the infrastructure!

Same scale representation of different earthquakes

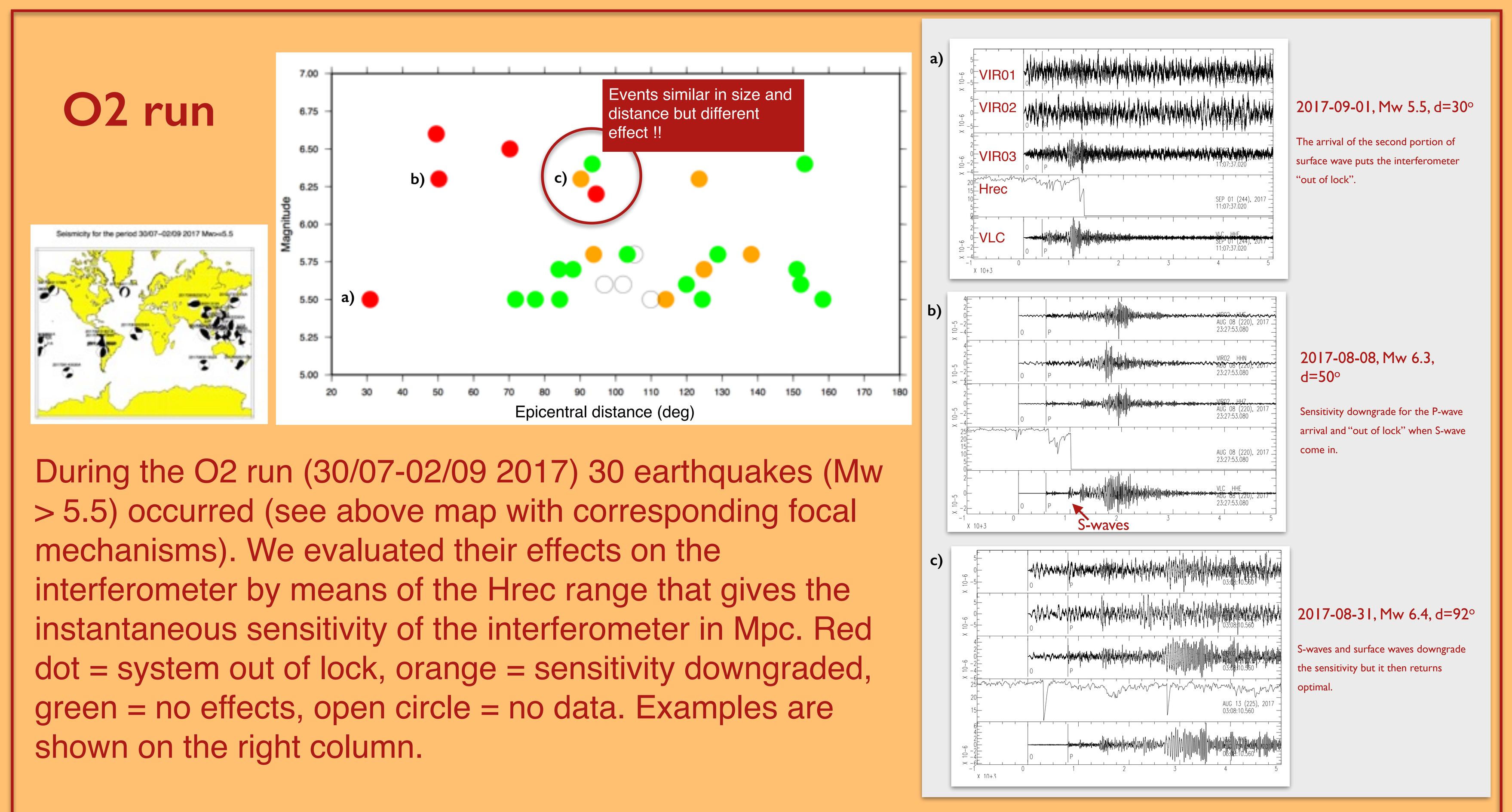
local (Garfagnana, Mw 4.8), regional (L'Aquila, Mw 6.3), and teleseismic (Great Sumatra, Mw 9.1)

The size of the peak velocity appears comparable for the three events and this confirms that we must consider any distance to find the appropriate distance vs. magnitude selection rules. We can also recognise that the dominant period of the peak velocities is longer for teleseismic earthquakes.



Analysis of the past and current seismicity from the Virgo perspective

O2 run



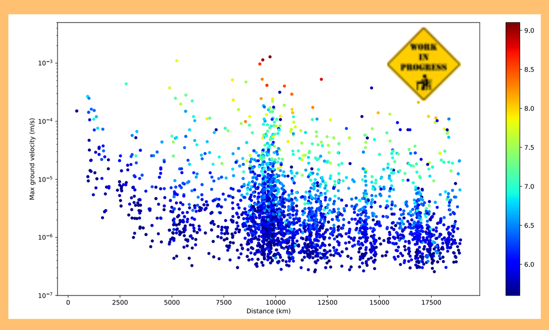
During the O2 run (30/07-02/09 2017) 30 earthquakes (Mw > 5.5) occurred (see above map with corresponding focal mechanisms). We evaluated their effects on the interferometer by means of the Hrec range that gives the instantaneous sensitivity of the interferometer in Mpc. Red dot = system out of lock, orange = sensitivity downgraded, green = no effects, open circle = no data. Examples are shown on the right column.

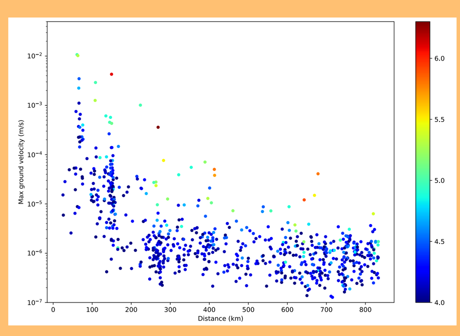
Peak velocity at MN.VLC (ongoing research)

MedNet station VLC (Villa Collemandina, Garfagnana). It is characterised by extreme care about site selection and installation type, providing high-quality recordings. We use it as a proxy to evaluate the impact of large earthquakes on Virgo site and to determine Magnitude/distance selection rules. On this base, we can discriminate those teleseismic and regional earthquake harming the Virgo interferometer.

Events selection (GLOBAL):
- time period [Jan 2002 - Dec 2018]
- Magnitude Mw > 5.0
- Depth < 70 km
- +40,000 events

Data Analysis:
- time window for surface waves
- Instrument response removed
- measure of Peak ground velocity
- period T > 10s, peak removed





Events selection (Regional):
- time period [Jan 2001 - Dec 2018]
- Magnitude Mw > 4.0
- Depth < 70 km
- 875 events

Data Analysis:
- time window for body waves
- Instrument response removed
- measure of Peak ground velocity

Objectives:
- to assess the effects of the different earthquakes in terms of local ground shaking
- to improve site effects determination at Virgo
- Upgrade from Magnitude/distance selection rule to effective ground shaking at site
- Limit the number of false alerts that would unnecessarily force the interferometer to be switch off.

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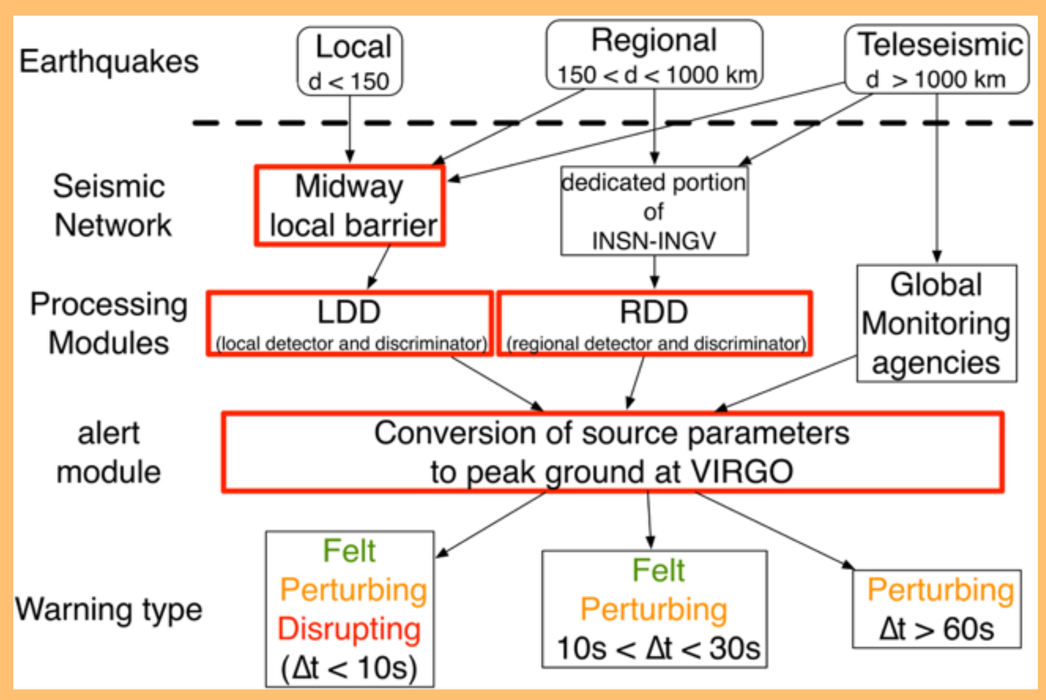
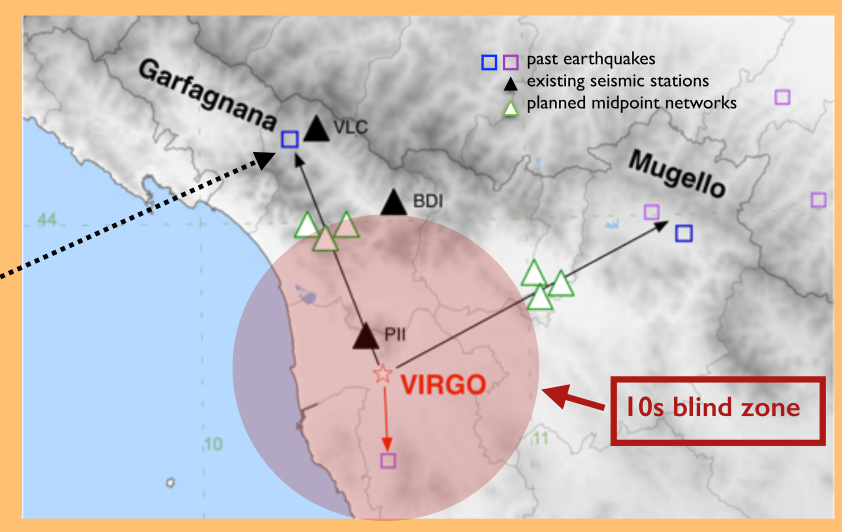
"Flow chart" for an EEWS dedicated to Virgo

Work in Progress ASPIS project
POR FSE 2014/2020 Regione Toscana

Different earthquakes (local, regional and teleseismic) require different approaches to be rapid and accurate:
- **Local,** complicated by the short time span between Origin_Time and S-wave arrival at Virgo. The approach is described in the below frame below. Regional discrimination, crucial!
- **Regional,** will use the closest stations of the INGV network. Virgo is exposed to the West (Ocean Bottom Seismometers, would help?). Improved quick analysers are needed since national agency alerts come too late.
- **Teleseismic**, alerts from international agencies are fine. Peak oscillations are from surface waves that are very slow.





Sketch for a possible EEWS dedicated to local earthquakes:

- **potential earthquake sources:**
Garfagnana and Mugello, respectively 80 km to the North and 100 km to the East from Virgo.
- **EEWS strategy:**
A network of at least three stations (green triangles) at midpoint can be used to read P-waves (and eventually S-waves), estimate the magnitude, evaluate the expected ground shaking at Virgo and issue a warning.

Expected travel times and warning times for the two potential local sources

	@ Virgo			@ midpoint network		
	Distance	P -wave travel time	S-wave travel time	P-wave travel time	S-wave travel time	**Warning time**
Garfagnana	80km	10 s	20 s	5 s	10 s	**> 10 s**
Mugello	100km	12 s	25 s	6 s	12 s	**> 12 s**

Remark: 10 seconds warning time would imply a 35-40 km blind zone!

Workshop on Observatory Synergies for Astroparticle physics and Geoscience
11-12 February 2019, IPGP, Paris