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Seismic contribution to dark fringe signal during E3

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1 Data set

As it has been shown previously[1], Virgo acquired during the engineering runs signals from seven seismometers. Five of them were Bruel & Kjaer accelerometers, with too low sensitivity in the frequency region of interest for this study. The two tri-axial Episensors on the contrary give a good signal from frequencies above about 0.4 Hz to few hundreds of Hz. Since the coherence of the signals recorded by the two accelerometers is almost one up to about 10 Hz and remains high at least up to 25 Hz (see for example [2], we will use the signal from a single seismometer, i.e. the one corresponding to the channels Em_SEBDCE01 (WE), Em_SEBDCE02 (NS) and Em_SEBDCE03 (vertical).

The sample used consisted of 12 hours of 50Hz data, acquired during a period of continous locking, starting at GPS time 70578400, local time 18 May 2002, 19:59:47.

The analysis shown here has been made with MATLAB, but a parallel analysis has been made with Framelib and Frvlib routines giving very similar results.

2 Transfer function from soil to dark fringe

Figure 1 shows the coherence between the soil acceleration and the dark fringe signal (channel Pr_B1p_ACq).

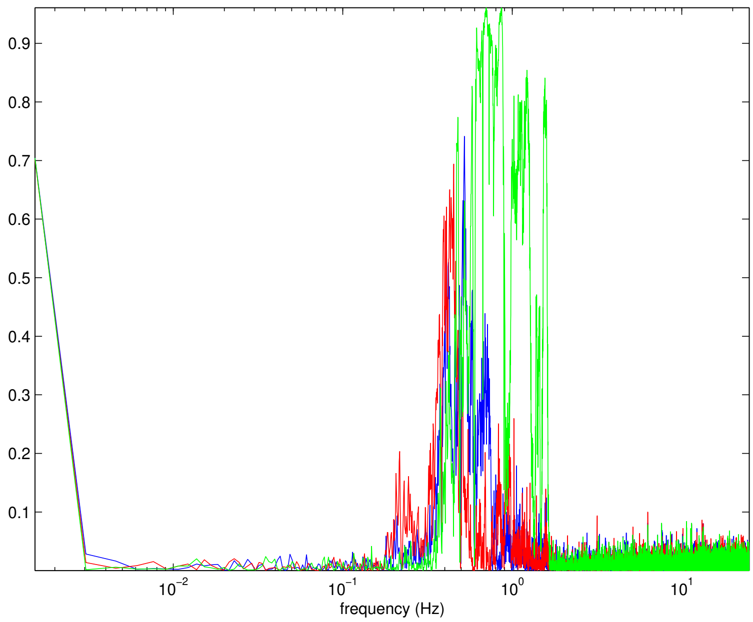

Figure 1: *Coherence between channels E_SEBDCE01 (blue), 02 (green), 03 (red) and the dark fringe signal (Pr_B1p_ACq)*

It is clearly different from zero in a band of width about 1 Hz for all the three directions. The cut at 0.4 Hz is due to the drop of sensitivity of the sensor.

The coherence in this picture has been calculated using chunks of data of length equal to 655.36 seconds (32768 samples): it is interesting to observe that calculating the coherence over shorter times it tends to vanish, while no big changes are detected using longer data chunks. The reason will be clear in the following.

Since the region of interest stops at less than 2 Hz, data have been decimated to 5 Hz, and then high-pass filtered with a cut-off frequency of 0.1 Hz in order to remove the long timescale drift of the sensors. All the quantities shown fron now on have been calculated averaging chunks of 4096 samples, coresponding to 819.2 seconds of data.

Figure 2 shows the seismic noise spectra after decimation, and figure 3 the coherence in the frequency band from 0.1 to 2 Hz .

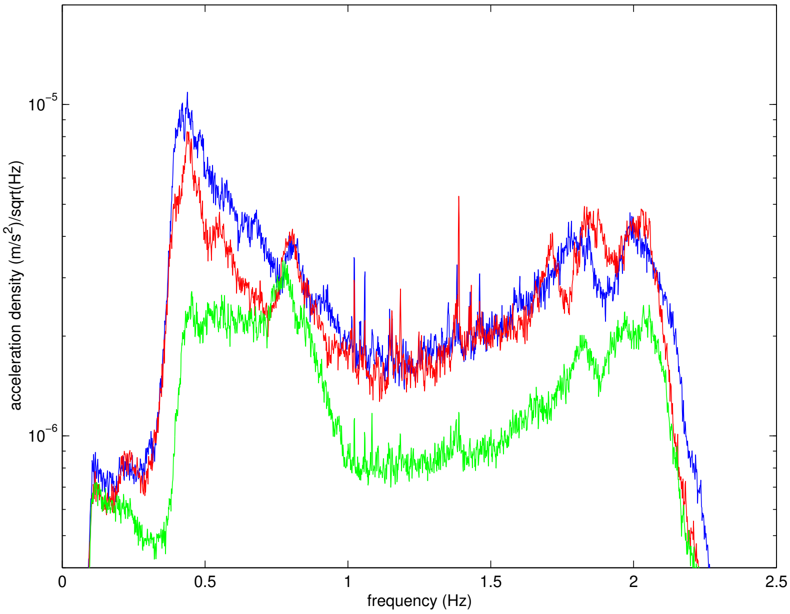

Figure 2: *Spectrum of seismic acceleration (m/s^2) in the 0.1-2 Hz band. Channels E_SEBDCE01 (blue), 02 (green), 03 (red).*

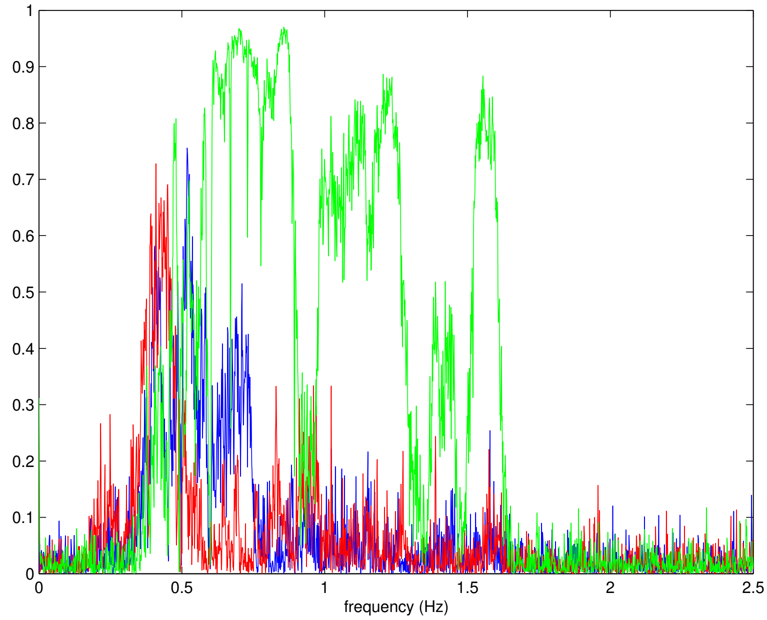

Figure 3: Coherence of seismometers with the dark fringe in the 0.1-2 Hz band. Channels E_SEBDCE01 (blue), 02 (green), 03 (red).

The transfer function modulus and phase from the seismometers to the dark fringe can be shown in Fig4.

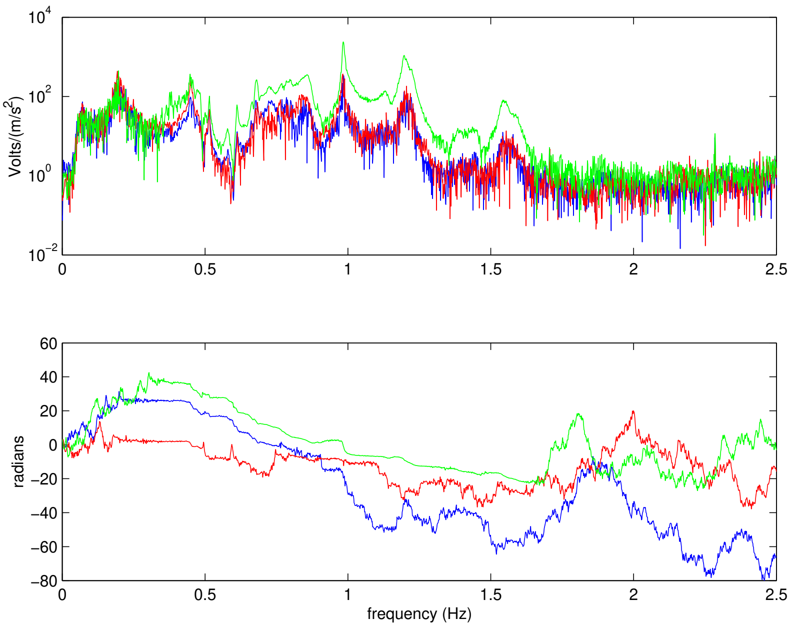

Figure 4: *Trasfer function from seismometer to the dark fringe: top, modulus; bottom: phase. Seismic hannels are Em_SEBDCE01 (blue), 02 (green), 03 (red). The units are m/s^2 for acceleration, Volts for the dark fringe and radians for the phase.*

The impulse response of the system can be calculated by applying the inverse Fourier transform to the trasfer function (Fig.5): it can be seen that a seismic pulse reaches the darks fringe signal after some second, and produces a ringing which lasts about 4 minutes: this explains why the correlation between the two signal is large only if calculated on long chunks of data.

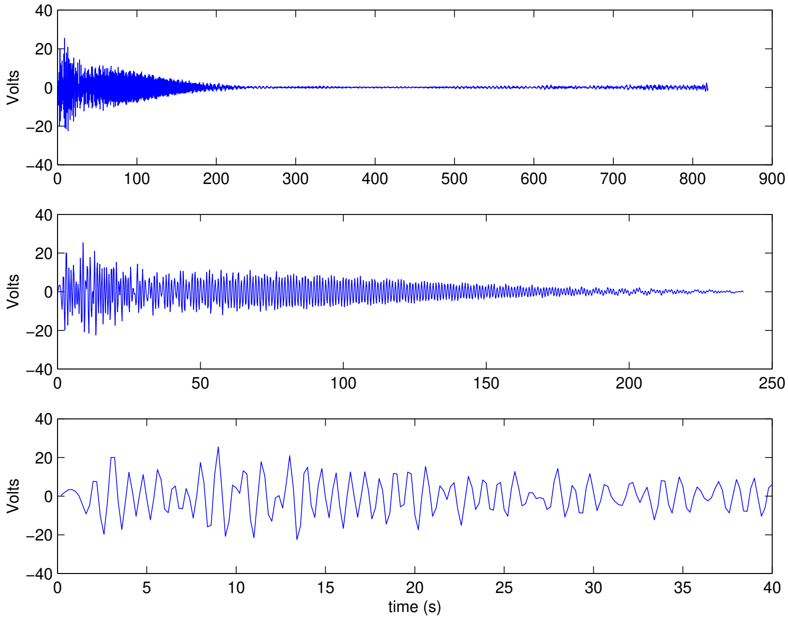

Figure 5: *Transfer function from channel Em_SEBDCE03 to the dark fringe, in different time intervals. As can be seen, the decay time is very long (minutes), and there is a small delay (seconds) between the impulse and the presence of a signal in the photodiode.*

To obtain the noise contribution to the dark fringe, one can multiply the seismic noise spectrum by the modulus of the transfer function (see Fig.6).

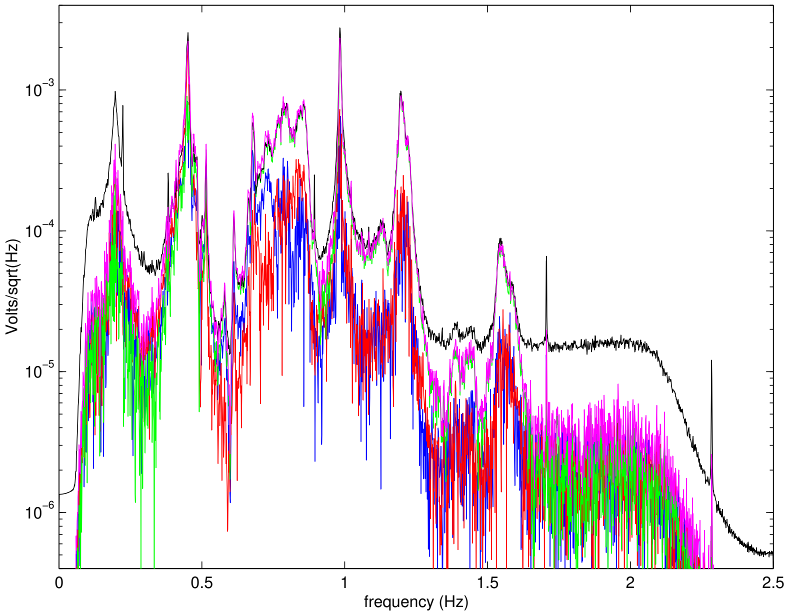

Figure 6: *Noise contribution to the dark fringe from the seismic noise.Channels Em_SEBDCE01 (blue), 02 (green), 03 (red). The black line is the dark fringe spectrum; the magenta line is the quadrature sum of the three seismic contributions.*

It is clear that for frequencies under 1.6 Hz the seismic contribution can explain almost all the dark fringe noise observed. It is interesting to note that the vertical motion gives the greatest contribution, while horizontal motion is reduced by the inertial dumping.

3 Where does the noise come through?

There are in principle two possible ways in which the seismic noise could reach the mirrors: besides the machanical coupling through the superattenuator, there is also the possibility that some noise could come through the angular controls.

The coherence between the seismic sensors and the angular control signal is very low, except in the region between 0.4 and 0.5 Hz (Fig.7) . Moreover, the correction signal seems to be correlated more with the horizontal soil movements than with the vertical ones.

On the contrary, the coherence between the seismometer vertical signal and the vertical accelerometers placed on the top of the inverted pendulum is very high in the region of interest (see Fig.8): moreover, the signal coming from the accelerometers placed on the top of two different towers show great coherence among themself.

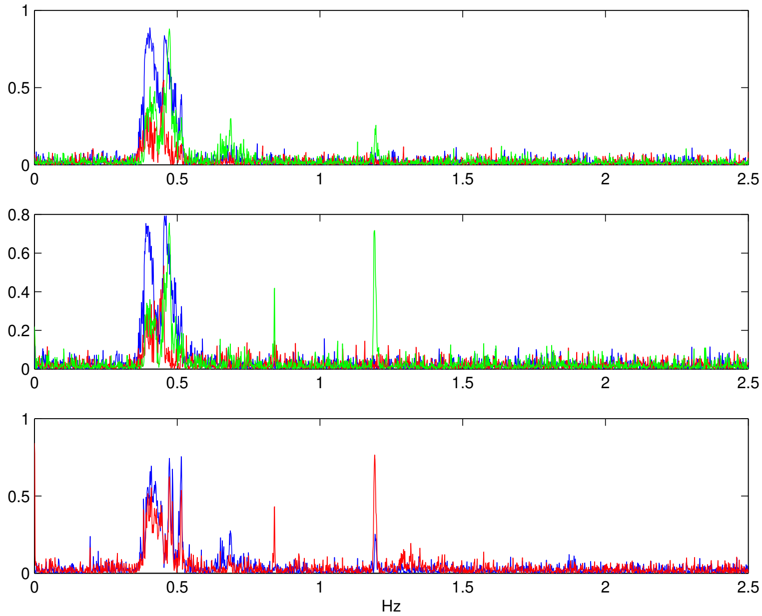

Figure 7: *Coherence between seismic sensors and local control correction signals in the BS tower. Top: coherence of the three seismic channels with* θ_x*. Middle: coherence with* θ_y*. Colors are the same used for previous plots. Bottom: correlation between* θ_x *(red) and* θ_y *(blue) correction signals and the dark fringe.*

4 Conclusions

The dark fringe noise is dominated by the seismic noise in the frequency region from 0.4 to 1.6 Hz. Below 0.4 Hz, the noise is likely to be of seismic origin too, but seismometers are not sensitive enough to permit a clear demonstration. As it has been shonw by an earlier work[3], the noise in this region comes mainly from microseism and is possibly correlated with methereological conditions, while the human actvity in site and outside the site should contribute only to higher frequencies.

Horizontal soil movements reach the mirrors mainly through the camera control signal, in the band 0.4-0.5 Hz. From 0.5 to 1.6 Hz the vertical movements propagating thorough the mechanical chain give the bigger contribution to the dark fringe signal, supporting the need of the implementation of the inertial damping of the inverted top stage also in vertical direction.

References

[1] R. De Rosa, I. Ferrante, F. Fidecaro, G. Losurdo, F. Paoletti: A first look to seismic data - Seismic channels and sensors and the aliasing problem, VIR-NOT-PIS-1390-184

[2] I. Ferrante, Properties of an earthquake signal recorded by the Virgo equipment, NOT-PIS-1390-209 07/06/02

[3] I. Fiori, E. Chassande-Mottin, I. Ferrante, G. Losurdo, Seismic noise studies with run E2 data: a first attempt to monitor daily variations, NOT-FIR-1390-212 20/06/02

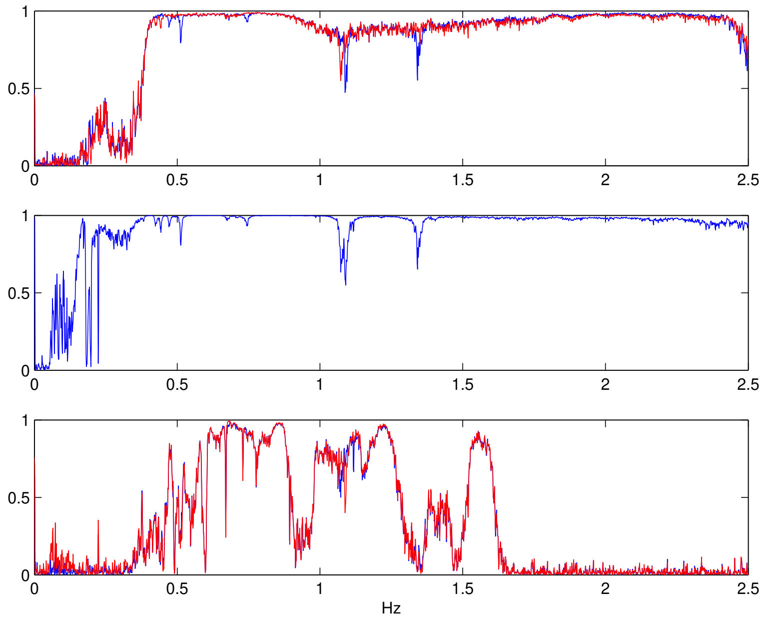

Figure 8: *Top: coherence between vertical acceleration (channel SEBDCE03) and the signal from vertical accelerometers placed on the top of the inverted pendulum: Blue, BS tower; red: PR tower.*
Middle: coherence between two IP acceleromètes placed on top of the BS and PR towers.
Bottom: coherence between IP vertical accelerometers and the dark fring signal.Blue, BS tower; red: PR tower.