LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Initial environmental data from the Hanford facilities

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Beam Tube Data

Table 1: Instruments

instrument	*manufacture*	*freq range*	*bandwidth*	*sensitivity*
		Hz	*Hz*	
Magnetometer	Bartington MAG03	0 - 10K	3K	8.3×10^{-2} gauss/volt 3×10^{-7} gauss/$\sqrt{Hz}$
Microphone	Radio Shack Level Meter	20 - 10K		4.8×10^{-1} dynes/cm^2 /volt on 60 db scale
Accelerome-ter	Endevco	1 - 10K		2.8×10^{-2} g /volt (amp.) 2.8×10^{-8} g/$\sqrt{Hz}$
Seismometer	Guralp CMG-40T	0.1 - 100		2.5×10^{-2} cm/sec/volt
Tilt meter	Applied Geomechanics 520	0 - 4	4	2×10^{-6} radians/volt

Spectrum Analyser

Hewlett Packard 35670A ; Input noise 3×10^{-7} volts / $\sqrt{Hz}$

NOTE: Spectrum analyser used with a Stanford amplifier with 3×10^{-9} volts / $\sqrt{Hz}$ at input to bring the analyser noise to below the level of the transducer noise when needed

Table 2: Frequency scan and bandwidth using Hanning window

range	*bandwidth*
0 - 1.5 Hz	0.00586 Hz
0 - 25	0.09375
0 - 400	1.5

Location of the Measurements

Lvea: All the instruments were placed on the floor at the test mass chamber for the 4km interferometer on the x arm. The magnetometer was held by a tripod 50 cm above the floor. The microphone was placed vertically on the floor.

Xend station: All the instruments were placed on the floor at the location of the test mass chamber. The magnetometer and microphone were placed as in the LVEA.

Beam Tube: All measurements were carried out within 10 meters of utility door #10 on the X1 arm. The accelerometer was electrically insulated from the beam tube to avoid RF interference and electrostatic pickup of the line. All equipment was battery operated and the fan in the spectrum analyser was turned off.

Time and Conditions during the Measurement

The measurements were made in the night (20 - 4 hrs) on January 7 and 8, 1998 under low wind conditions (< 5 MPH) and clear skies.

Summary of the results of the measurements:

The HVAC system in both the LVEA and Xendstation causes broad band motions of the slab in excess of the standard LIGO vibration spectrum by as much as a factor of 5 at frequencies above 5 and below 50 Hz. Both the water circulating pumps and the air handling fans and duct work contribute. The LVEA slab shows strong coupling to the HVAC circulating pumps. The noise is most easily measured by the accelerometers and in the seismometer above 5 Hz. With the HVAC system off, the buildings are remarkably quiet. The major single frequency excitation of the slab are the line and harmonics, most likely from magnetostriction in the power transformers and possibly the transformers and ballasts for the lights. (The separation of these effects requires further measurements.) The narrow band excitation is less than 5×10^{-5} g_{rms} , the specification allowed between 1 to 50 Hz. The broadband specification for motion of the slab is twice the standard LIGO spectrum in amplitude.

The acoustic spectrum of the buildings with HVAC operating satisfies the specification we provided Parsons. Here also, the buildings without the HVAC running are remarkably quiet. The line and line harmonic spikes are acoustic and not magnetic or electric pickup.

The slab motions in both LVEA and the Xendstation exceed the LIGO standard spectrum at frequencies below 1 Hz. The excess motion is measured in all three axes of the seismometer and is not due to the HVAC system. Alan Rohay in his survey of the Hanford site measured a comparable excess so the excess is not due to the existence of the buildings.

The measurements show that the measured tilt spectrum at low frequencies is dominated by horizontal acceleration. A good indication is given by the magnitude of the microseismic peak at 0.2Hz when measured in both the seismometer and the tilt meter. If the tilts are truly due to seismic waves directly, the relation between these measurements should be

$$\theta(f) = \frac{x(f)}{\lambda_{\text{transverse}}} = \frac{fx(f)}{c_{\text{transverse}}}$$

The transverse wave propagation velocity determined from the above relation is only about 1 meter/sec, much to slow. A more succesful relation between the measurements is just

$$\theta(f) = \frac{\omega^2}{g} x(f)$$

where the “tilt” is determined exclusively by the horizontal acceleration. On returning from Hanford and talking with Peter Fritschel, he told us that Gabriela Gonzalez knew this all along. The tilt meter must then be interpreted (alone) as an upper limit on the tilt spectrum.

A true tilt of the LVEA slab was measured when the electric fork lift (approximately a ton) traversed about 6 meters from the tiltmeter and caused a microradian bend in the slab. A simple elasticity calculation gives a result comparable to what is measured for concrete with a Young’s modulus of 10^{11} dynes/cm^2 .

The beam tube has been damped by the insulation. The high frequency acoustic excitations of the beam tube normal modes are at least 1/10 those measured before insulation. (Refer to the report on beam tube dynamics February 3, 1997). The remaining normal modes below 50 Hz are broadened. The strongest mode that remains is the 15 Hz bending mode. The measured motions are smallest at the tube support base ,larger at the support ring and largest on the stiffening ring. The stiffening ring used for the measurement is about 1/3 of a tube length from the static support. The line frequency induced accelerations of the tube are maximally 3 x 10^{-5} g_{rms} and these are now the dominant components of the beam tube motion

Recommendations:.

1) The cart with the equipment and power supplies should be kept together so that further measurements can be made quickly and easily.

2) There is some promise in tuning the HVAC system to bring the noise, especially in the frequency region dominated by the circulating pumps, down. Taming the HVAC system may well turn into more than a casual task for the operators of the site. The measurement cart will prove useful in learning how to control the system.

3) The noise under worse wind conditions needs to be measured.

4) Since the idiosyncracies of the HVAC will be different in each building, it is necessary to carry out these measurements in all the buildings.

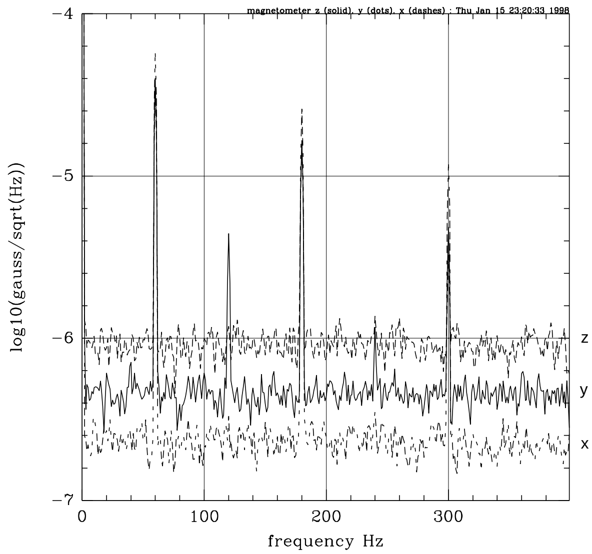

Figure 1: Magnetic field in the LVEA. Magnetometer placed at vertex. Directions: x along x arm, z along y arm , y vertical. Bandwidth of measurement is 1.5Hz. rms values of 60 Hz peaks Bz = 48 microgauss, By = 41 microgauss, Bx = 72 microgauss

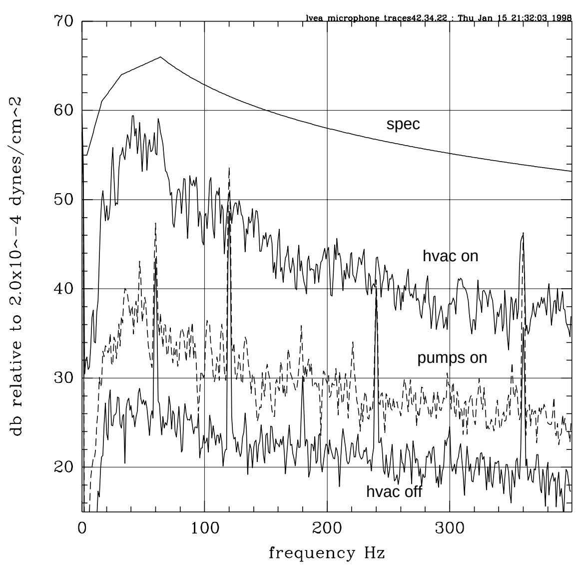

Figure 2: Acoustic field 50 cm above floor near vertex in the LVEA. “Pumps on” designates circulating water pumps operating at the chiller station but the air fans in the LVEA are off.

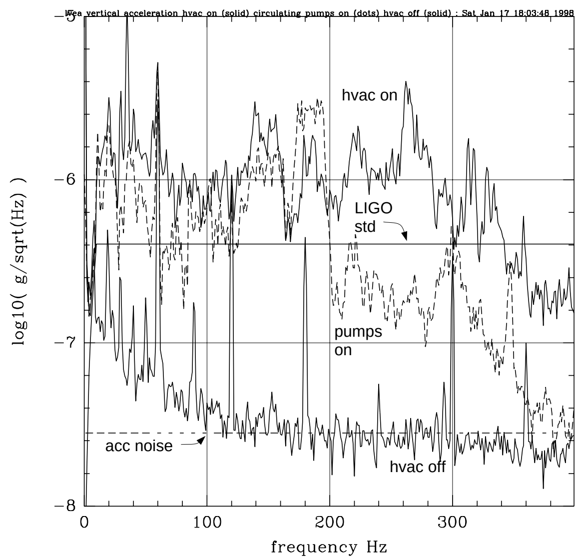

Figure 3a: Vertical acceleration measurements in the LVEA; HVAC off, only circulating pumps on, and HVAC on The acceleration noise is determined by the input noise of the charge amplifier. The LIGO standard spectrum is given in acceleration units.

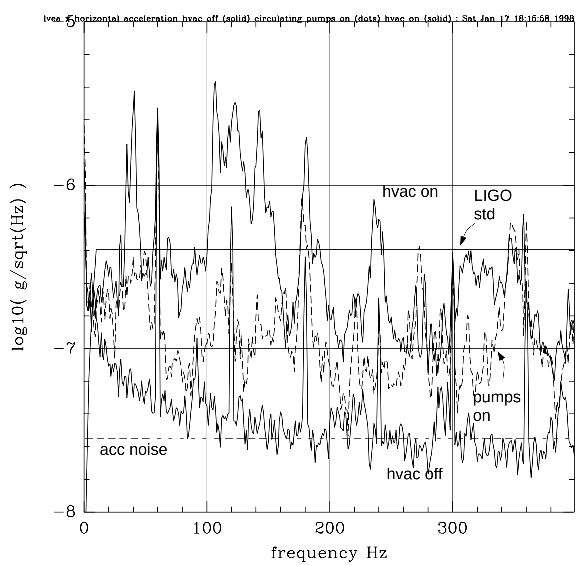

Figure 3b: Horizontal acceleration spectrum along the x direction in the LVEA

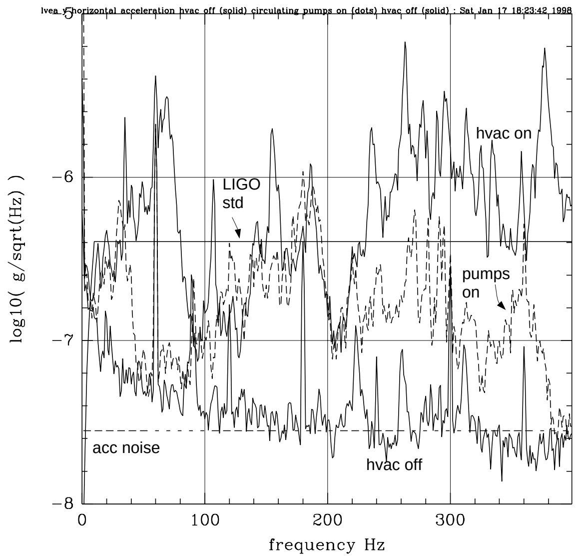

Figure 3c: Horizontal acceleration spectrum in the y direction in the LVEA.

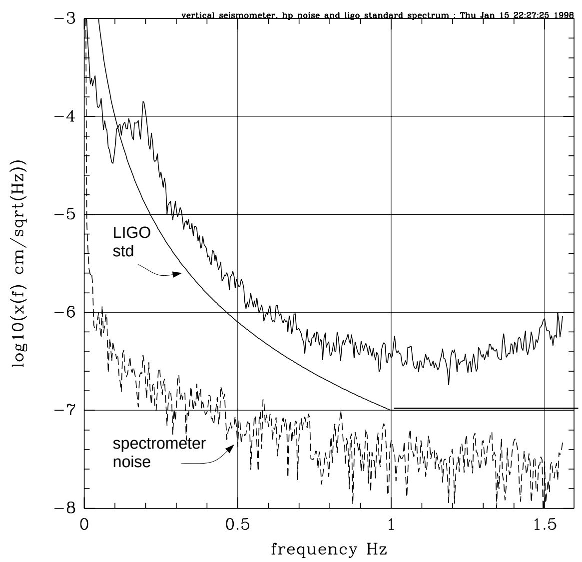

Figure 4a: Vertical displacement spectrum in the LVEA measured by the seismometer. The lower curve is the equivalent displacement noise of the spectrometer.

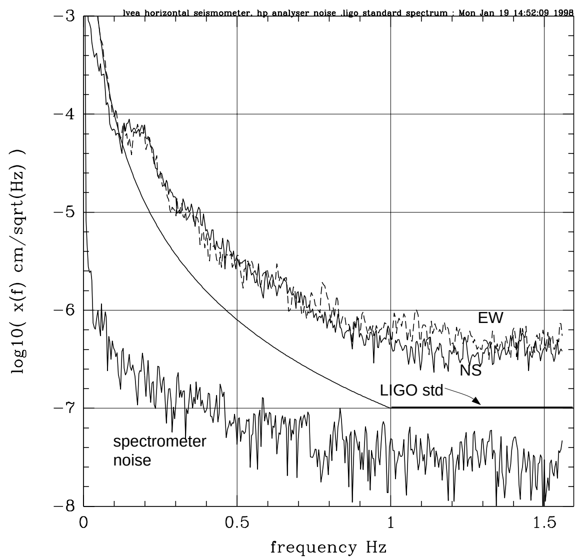

Figure 4b: The horizontal displacement spectrum in the LVEA. The North South NS seismometer lies along the x arm while the East West channel lies along the y arm.

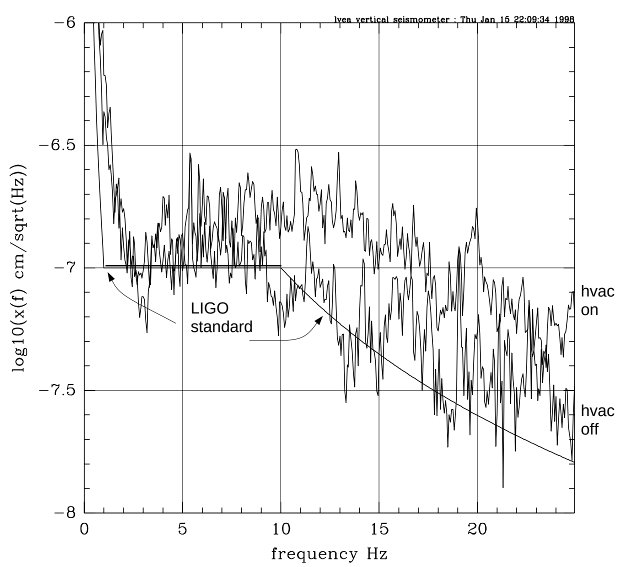

Figure 4c: Vertical displacement spectrum in the LVEA measured by the seismometer. The HVAC is turned on for the upper trace and off for the lower one.

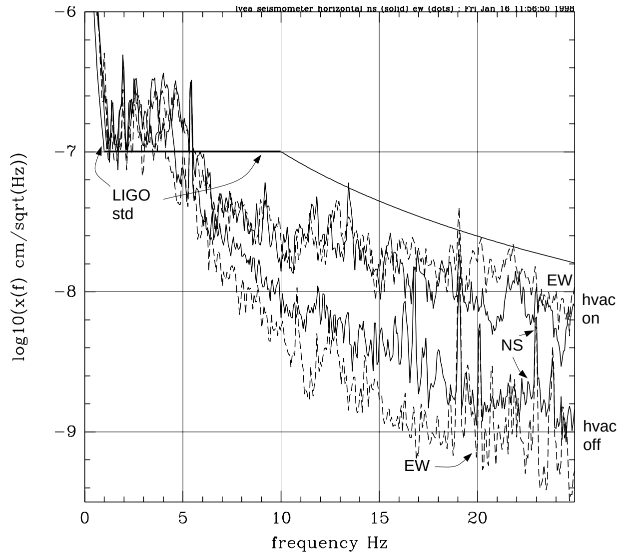

Figure 4d The horizontal displacement spectra in the LVEA with HVAC on/off.

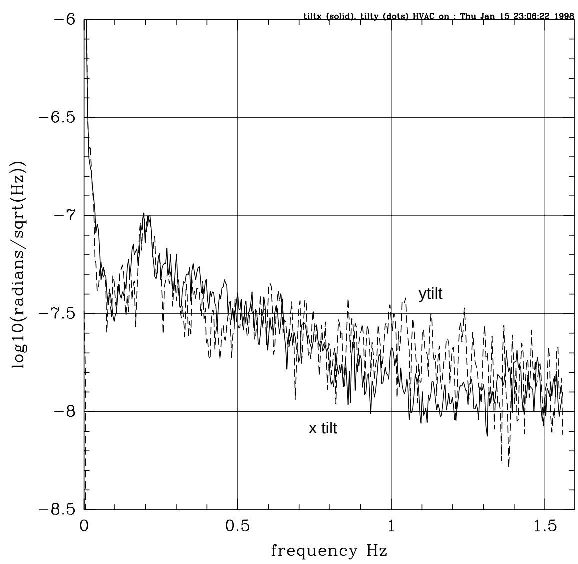

Figure 5a: The x and y tilt spectra in the LVEA. The x tilt measures rotations about the y arm as axis and the y tilt measures rotations about the x arm as axis.

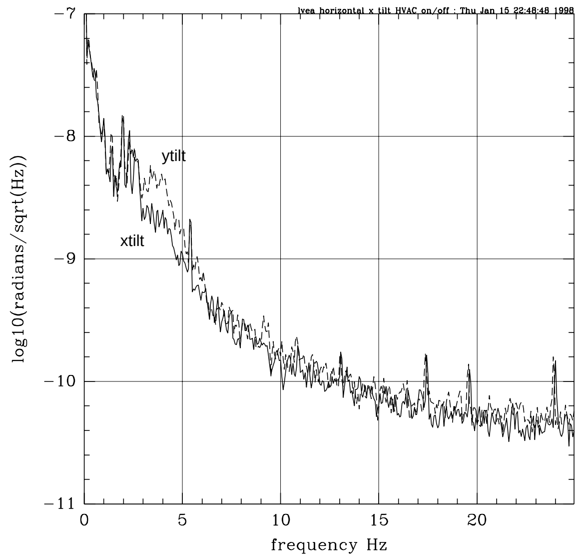

Figure 5b: The x and y tilt spectra in the LVEA

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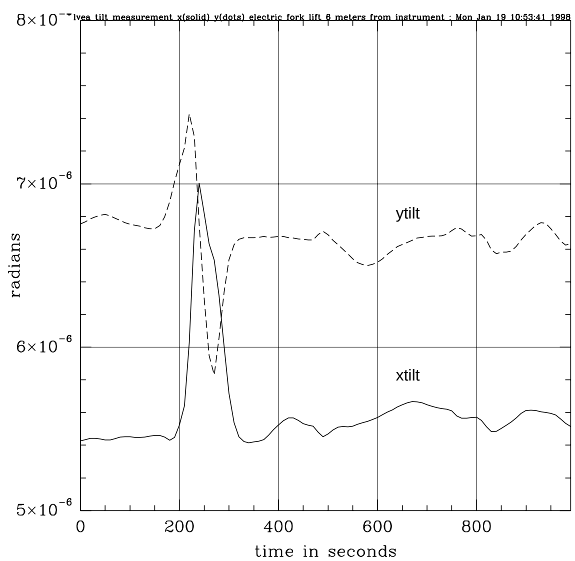

Figure 5c: x and y tilt vs time on the LVEA slab. An electric fork lift (approximately 1 ton) moved in a straight line past the tiltmeter at a closest approach of about 600 cm. The data was filtered with a 10 second time constant and sampled every 10 seconds. The data is consistent with a Young's modulus of the LVEA concrete slab of 10^{11} dynes/ cm2 .

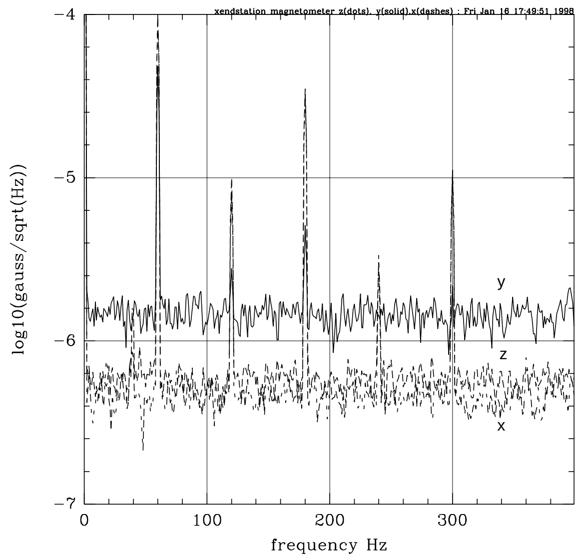

Figure 6: Magnetometer measurement in the Xendstation. The orientation of the magnetometer is x lies along the x arm of the beam tube, z lies along the y arm and y is vertical. The 60 Hz rms values are: Bz = 117 microgauss, By = 59 microgauss, Bx = 116 microgauss

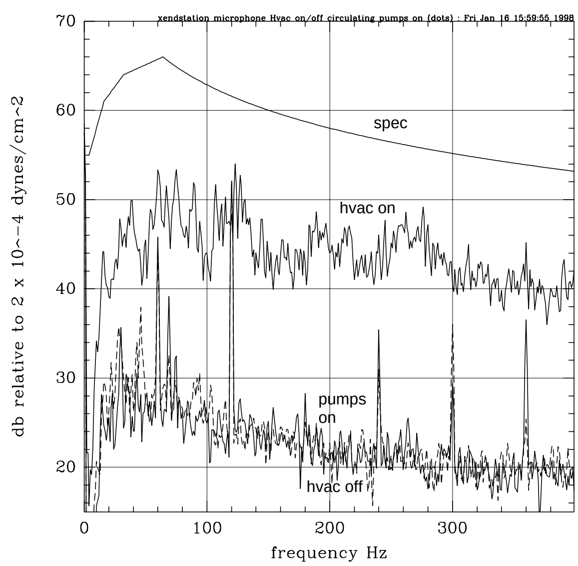

Figure 7: Acoustic spectra from the Xendstation with HVAC off, circulating pumps on, full HVAC system on.

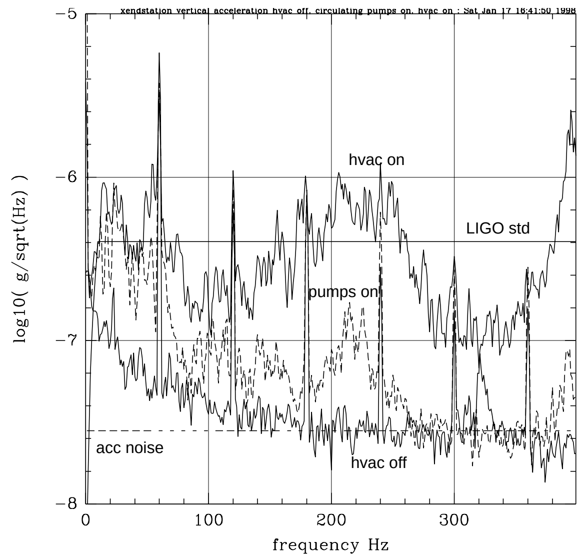

Figure 8a: Xendstation vertical acceleration spectrum with HVAC off, circulating pumps on, full HVAC system on.

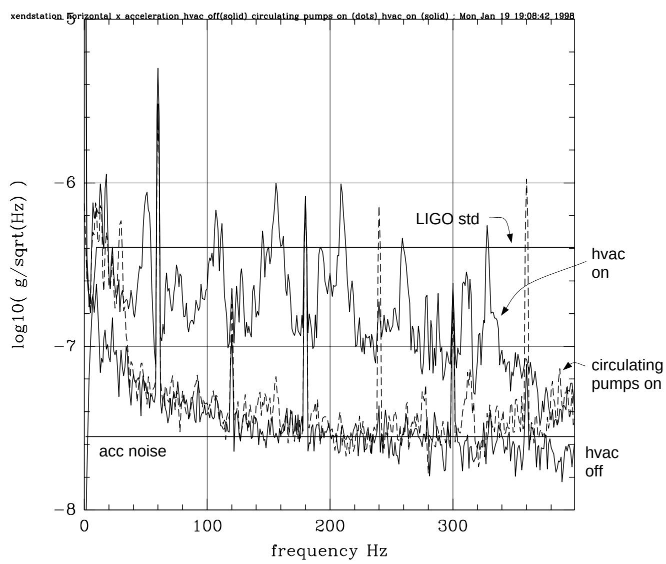

Figure 8b: Xendstation horizontal acceleration spectrum along x pointing along the x arm. Spectra with HVAC off, circulating pumps on and the entire HVAC system on.

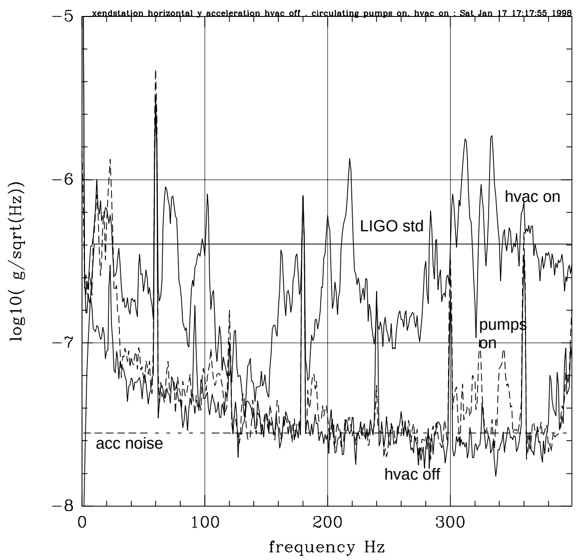

Figure 8c: Xendstation horizontal acceleration spectrum along y. Spectra with HVAC off, circulating pumps on and the entire HVAC system on.

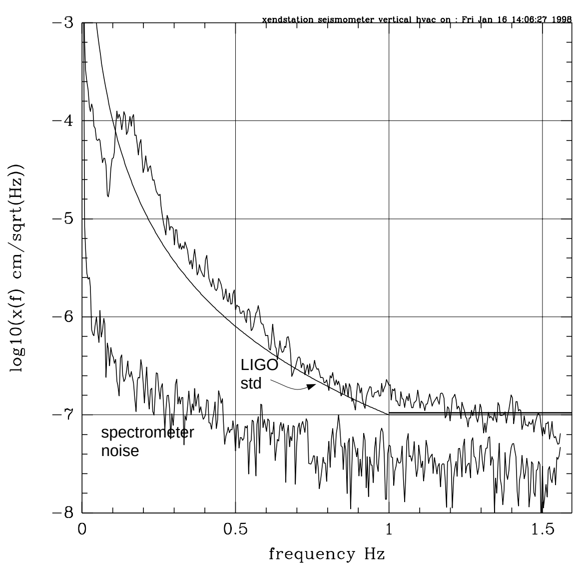

Figure 9a: Xendstation vertical displacement spectrum and the equivalent input noise of the spectrum analyser.

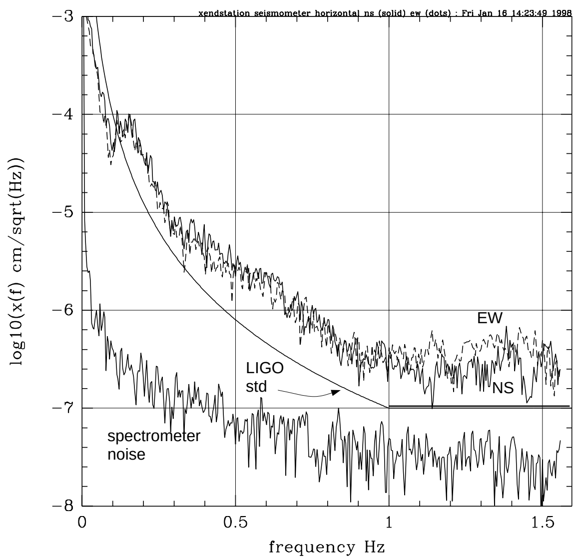

Figure 9b: Xendstation horizontal displacement spectrum .The x arm lies along the NS direction, the yarm along the EW direction.

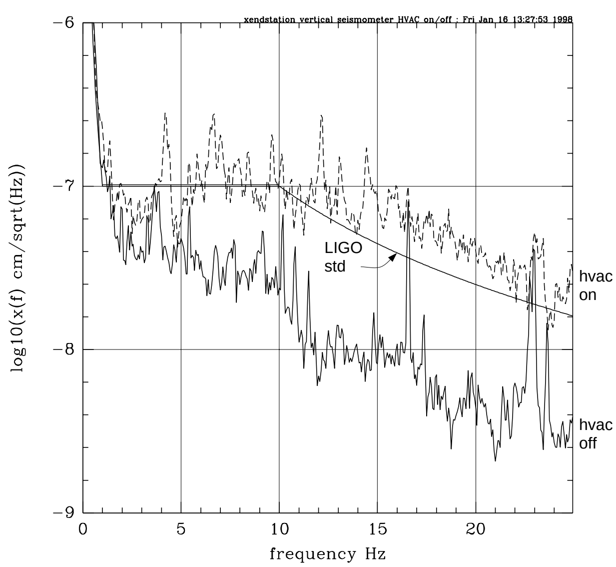

Figure 9c: Xendstation vertical displacement spectrum with HVAC off and HVAC on.

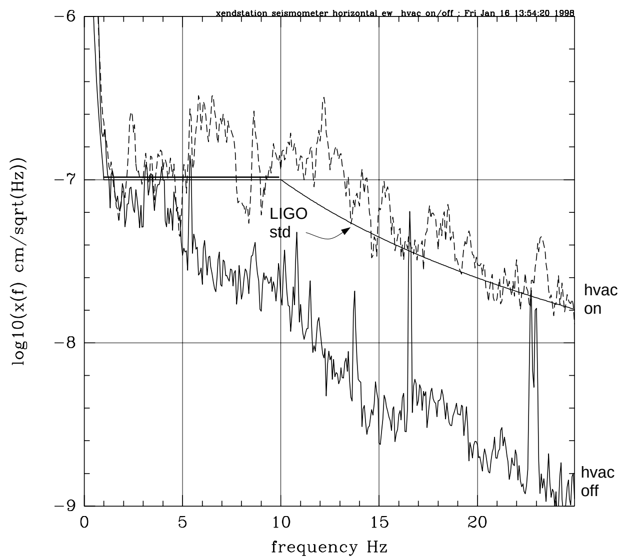

Figure 9d: Xendstation horixontal displacement spectrum along x arm with HVAC off and HVAC on.

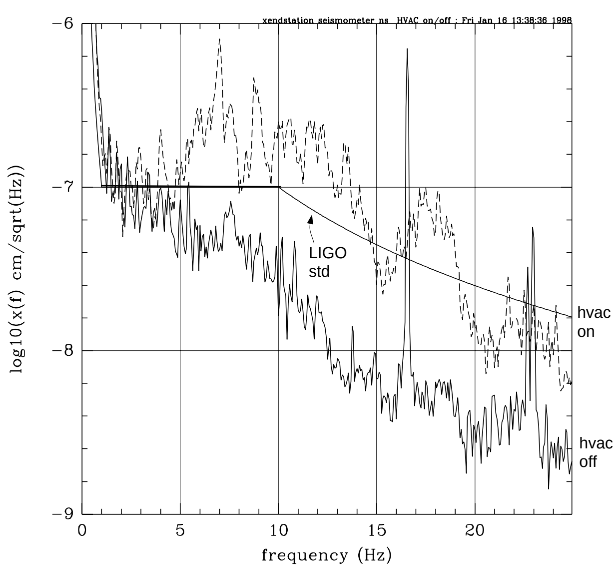

Figure 9e: Xendstation horizontal displacement spectrum along y with HVAC off and HVAC on.

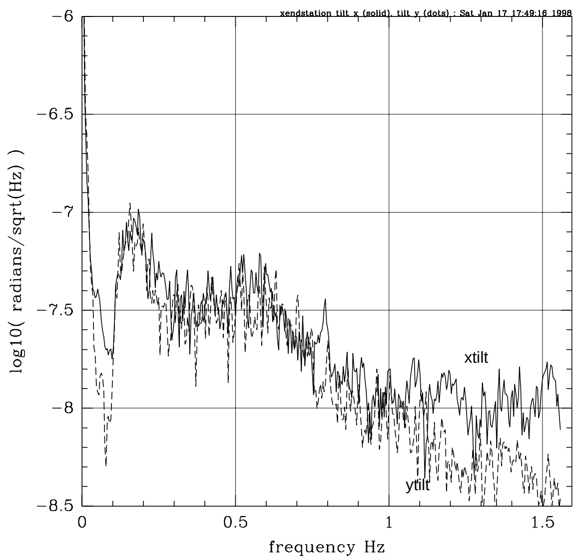

Figure 10a: Xendstation tilt spectra. x tilt corresponds to rotations about the y arm, y tilt to rotations about the x arm.

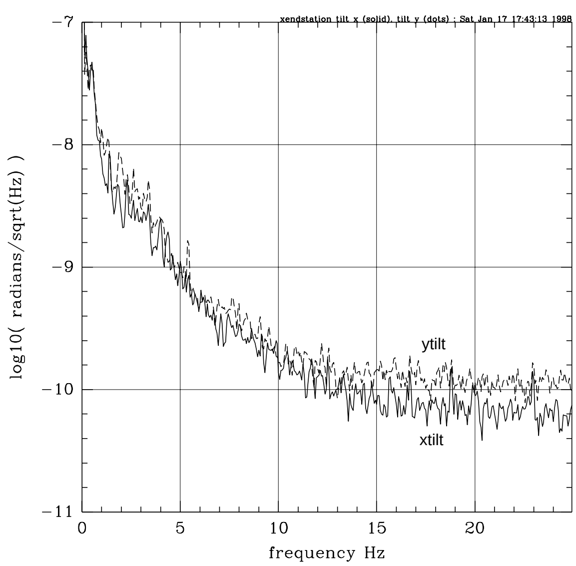

Figure 10b: Xendstation tilt spectra

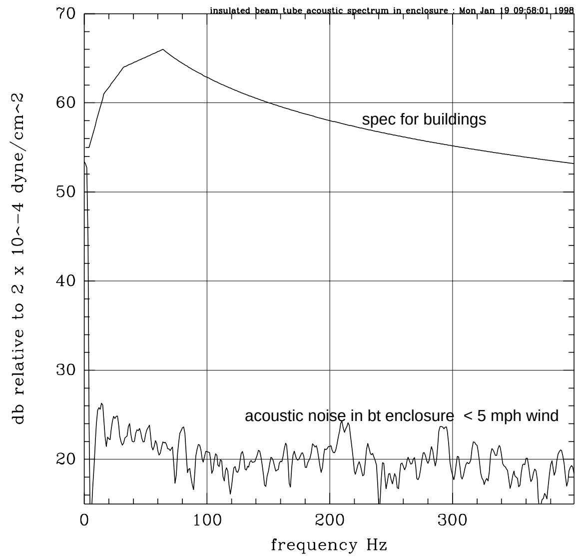

Figure 11: Acoustic measurements inside the beam tube enclosure at service door #10 on the X1 module. The beam tube is insulated.

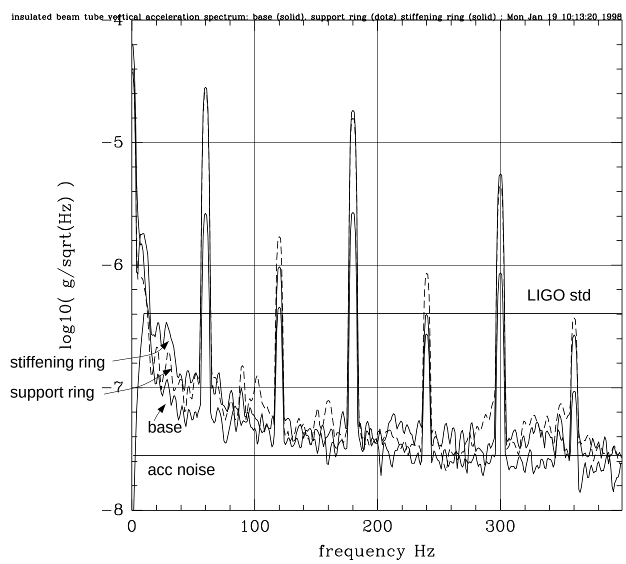

Figure 12a: Vertical acceleration measurements made at the base of a fixed support, on the support ring attached to the insulated beam tube and on a stiffening ring about 1/3 of the beam tube length from the fixed support.

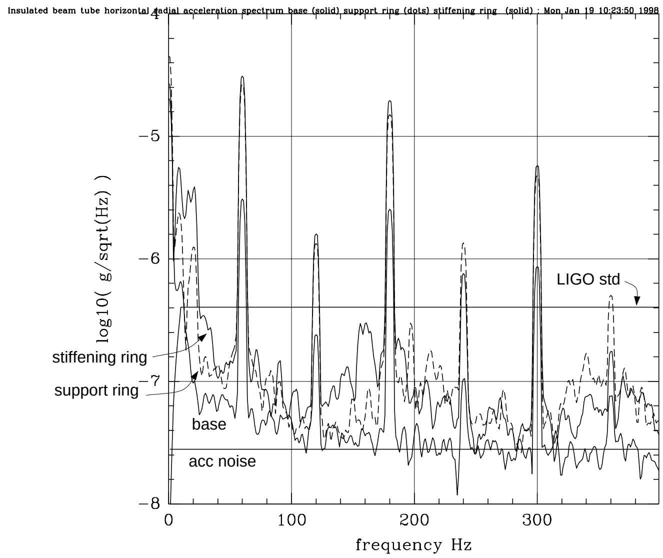

Figure 12 b: Radial acceleration in the horizontal plane measured on the base, support ring and a stiffening ring of the insulated beam tube.

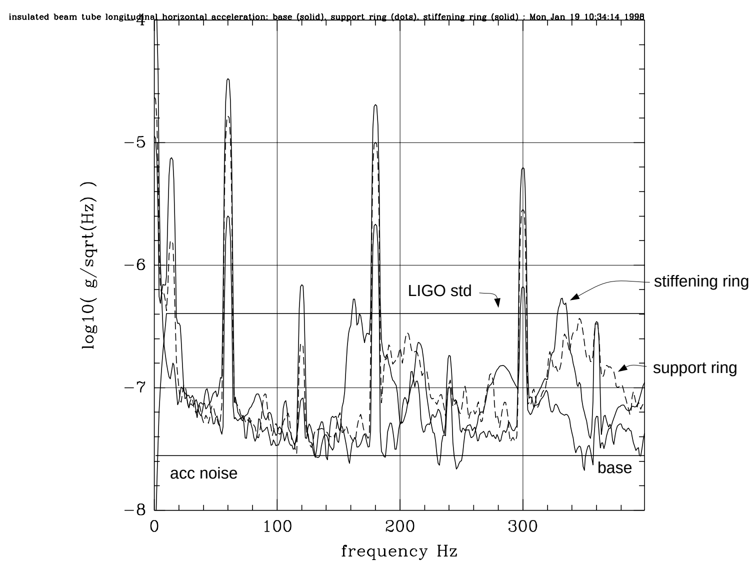

Figure 12c: Longitudinal (along the beamtube length) acceleration spectrum measured on the base, support ring and a stiffening ring of the insulated beam tube.