

Violin modes in the S1 data

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Introduction

Violin resonances are one of the line noise sources in the LIGO interferometers. They are produced by vibration of the mirrors suspension wires made of material with high quality factor (quartz). There are two wires per mirror therefore four violin modes are expected for each suspended mirror. In the LSC-AS_Q channel the violin modes from four test masses, beam splitter and recycling mirror should be visible (24 modes if they are not degenerated). Using the S1 data we conducted the following studies of the violin noise:

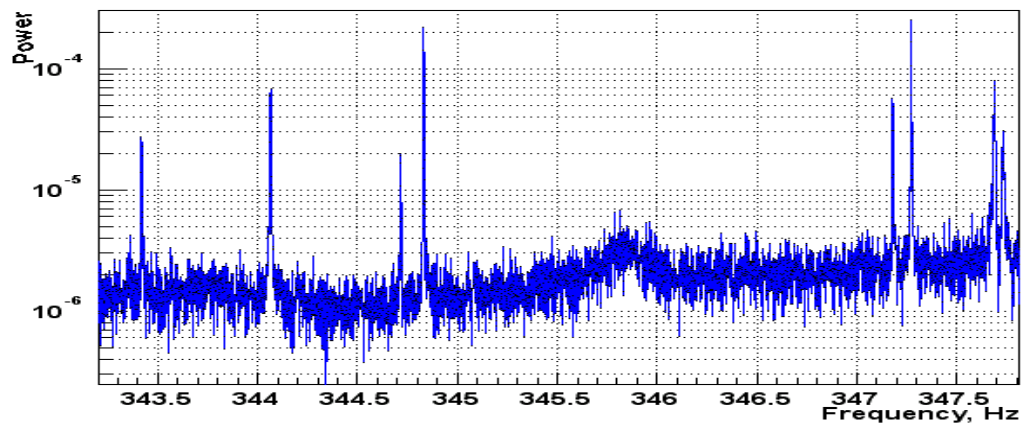
- measurement of the frequencies and widths of the violin modes
- characterization of the violin noise strength

1. Measurement of the violin modes parameters.

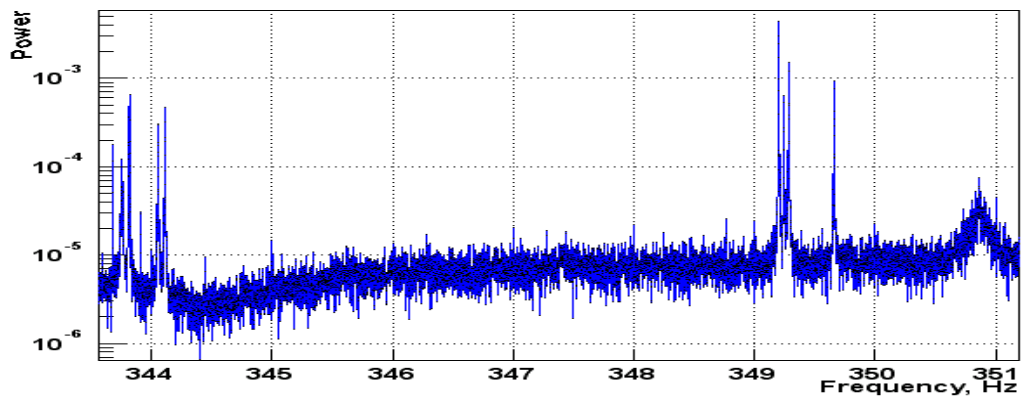
To measure of the violin frequencies we performed the FFT of the long (1024 seconds) locked segments of the S1 data. Total 10 segments with 1 mHz resolution were analyzed. Figure 1 shows the power spectra for all three interferometers in the frequency band where the first violin harmonics are located. Table 1 shows the measured mean value of frequency and the width of the violin peaks.

H1			H2		L1		
frequency, Hz	width, mHz	f/2	Frequency, Hz	width, mHz	Frequency, Hz	width, mHz	f/2
343.418	5.2		343.100	2.6	343.063	4.9	
344.064	6.6		343.681	1.8	343.482	3.3	
344.716	3.8		343.755	4.5	343.652	6.2	
344.831	2.3		343.815	4.5	344.423	4.6	
347.179	5.0		343.913	2.7	346.651	3.4	
347.272	2.2		344.051	5.0	346.880	11.8	
346.687	4.8		344.110	3.2	346.926	5.2	
347.733	2.8		349.201	3.1	346.975	4.1	
664.972		332.486	349.244	3.1	347.043	3.1	
688.290		344.145	349.281	3.1	663.627		331.814
689.742		344.871	349.658	3.5	686.145		343.073
					687.061		343.531
					687.394		343.697
					688.878		344.439
					693.429		346.715
					693.933		346.967
					694.003		347.002
					694.098		347.049
					700.495		350.248

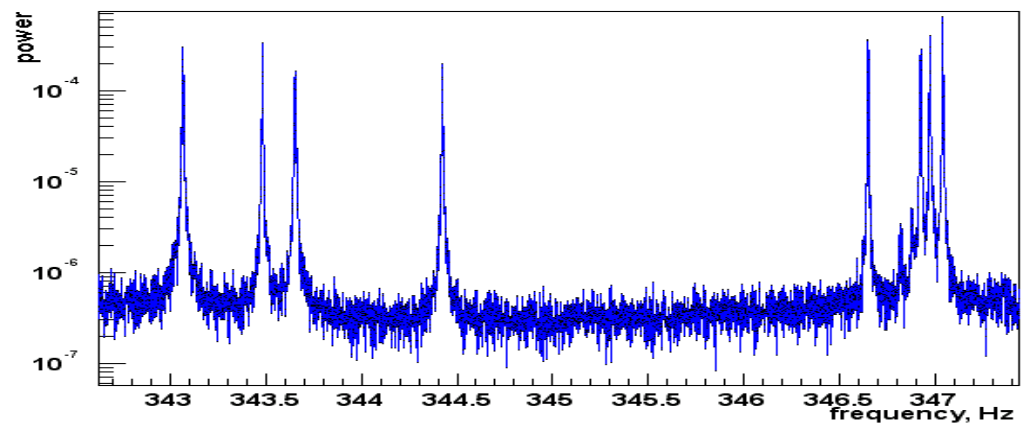
Table 1. Measured frequency and width of the violin peaks.



H1



H2



L1

Figure 1. Violin resonances in the S1 data.

The typical width of the violin resonances is 3-5 mHz (see Figure 2).

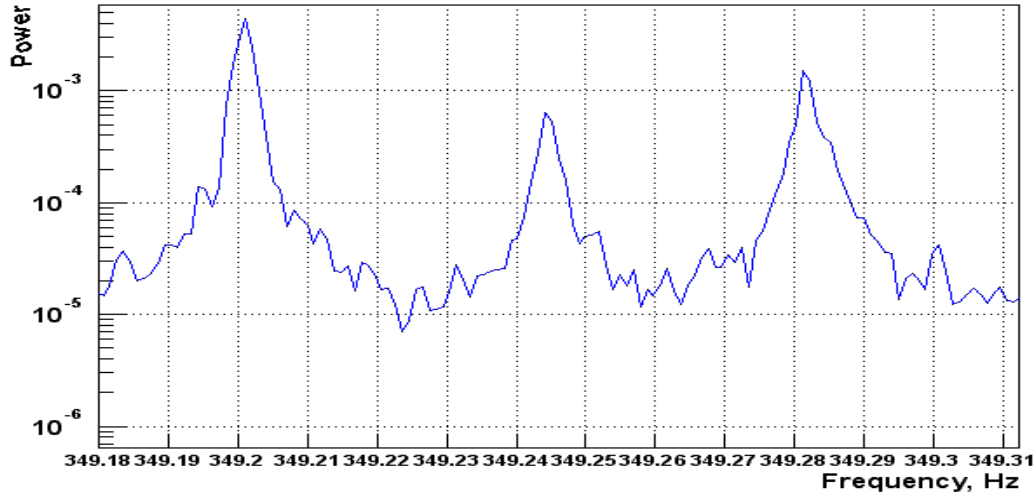


Figure 2. Width of the H2 violin modes.

We also measured the frequencies of some second harmonics. If we divide the frequency of the second harmonics by two, the resulted frequency doesn't match precisely any of the first harmonics. Typically they are 10-50 mHz higher. One possible explanation is the frequency shift due to the oscillation dumping

$$\omega = \sqrt{\omega_0^2 - \lambda^2},$$

where ω_0 is the violin angular frequency and λ is the dumping coefficient ($1/\lambda$ is the decay time). The difference between the second harmonic frequency divided by 2 and the first harmonic frequency is approximately

$$\Delta\omega \approx \frac{3}{8}\omega_0\lambda^2,$$

which could be 5-20 mHz for the decay time 185-60 sec respectively. In principle by measuring the frequencies of two first harmonics one can measure the dumping coefficient of the suspension wires, it's hard to estimate the systematic errors of this measurement.

2. Comparison with the previous measurements.

During the E7 and S1 runs we measured the frequencies and decay time of the L1 violin lines listed in Table 2.

E7		S1	
frequency, Hz	decay time, sec	frequency, Hz	decay time, sec
343.056	58	343.063	65
343.665	185, 140	343.652	48
346.932	64	346.926	61

Table 2. Comparison of frequencies and decay time for violin resonances measured during E7 and S1 runs.

There is the order of 10 mHz difference between the S1 and E7 measurements, and we believe these are the same lines. In both cases the measurement accuracy was ~ 1 mHz. From here we may conclude that the violin frequency varies with time, which could be due to the temperature variation. Of course it could be due to some unaccounted systematic errors in the frequency measurement as well.

Table 2 shows also the comparison of the decay time measured for three violin lines for E7 and S1 data. During the E7 run we measured the decay time directly by tracking the amplitude of the resonances as a function of time (see Figure 2). For the S1 run the decay time was estimated from the line width.

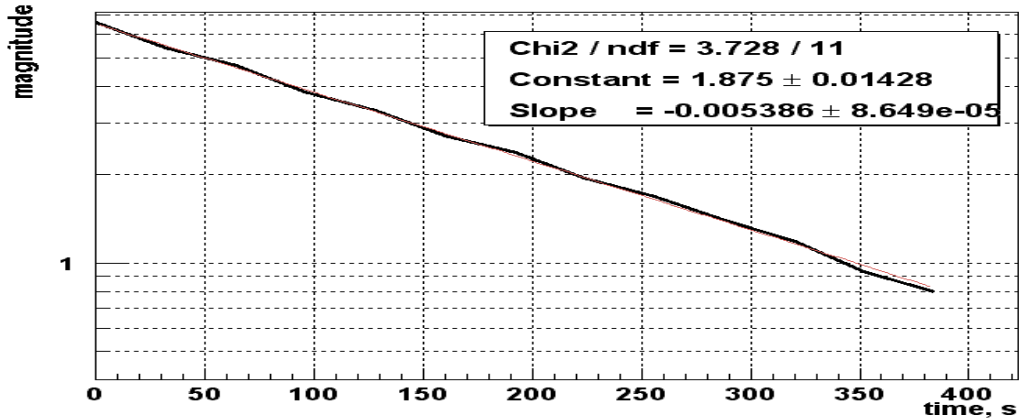


Figure 2. The decay of the 343.665 Hz line with decay time of 185 sec.

There is a reasonable agreement between the decay time of two lines at the frequencies 343.065 Hz and 346.932 Hz. However there is a considerable disagreement for the 343.665 Hz line. One possible explanation is that the 343.665 Hz line in fact consists of two (or more) modes. Figure 3 shows the frequency distribution measured with the LineMonitor during E7 run. There are three lines, which may correspond to different modes. The lines at the 343.665 Hz and the 343.668 Hz have systematically different decay time 140 sec and 185 sec respectively. Figure 3 shows the amplitude variation as a function of time for the 343.668 Hz line.

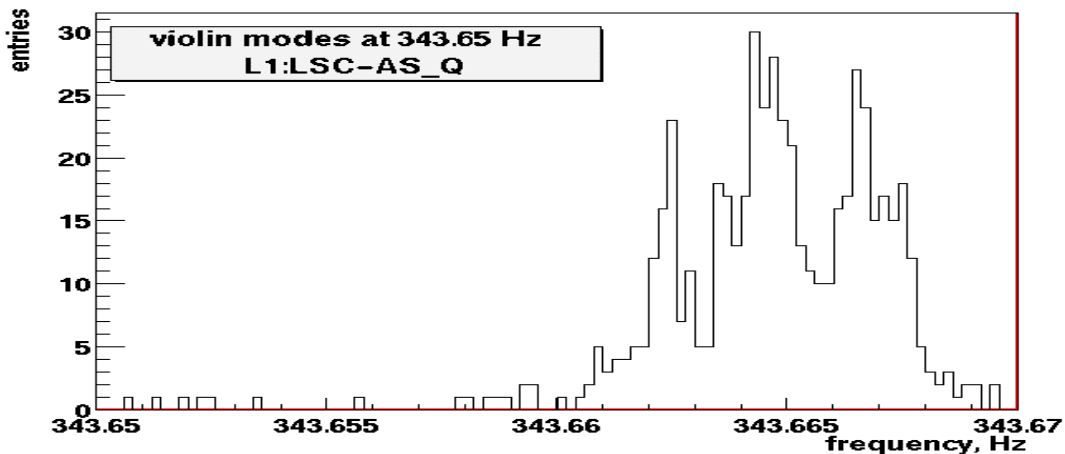


Figure 3. Frequency distribution measured by the LineMonitor for 343.665 Hz line during E7 run.

3. Tracking of the violin modes.

In the S1 data the amplitude of the violin resonances was very unstable. It was measured by the LineMonitor, which has the integration time of one minute. Sometimes the violin modes were excited in the beginning of the lock sections and usually they were barely seen by the LineMonitor when the detectors were in lock. Table 3 shows the frequency and duty cycle of the violin resonances, which can be seen by the LineMonitor.

f, Hz	f/2	duty, %	SNR	f, Hz	f/2	duty, %	SNR	f, Hz	f/2	duty, %	SNR
343.49		20.27	81.1	343.36		2.03	63.7	343.94		5.65	95.9
344.43		23.3	22.3	343.94		35.59	79.2	349.31		16.64	29.6
346.91		55.38	23.9	344.85		0.58	24.6	683.96	341.98	0.12	36.5
686.12	343.06	1.95	86.7	683.95	341.98	0.15	28.2	688.21	344.11	0.13	27.1
687.22	343.61	7.86	348.0	686.93	343.47	5.76	494.0				
688.91	344.46	2.79	92.4	688.18	344.09	12.71	386.0				
				689.67	344.84	0.53	68.9				

Table 3. Violin modes measured by the LineMonitor for the L1, H1, H2 interferometers.

The duty cycle was calculated as a fraction of the lock time when the violin amplitude exceeds the LineMonitor threshold. Also the table shows the average signal to noise ratio (SNR) for the data stretches when the modes are visible.

The average ratio of the violin signal PSD and the noise PSD (SNR), estimated from the FFT analysis, is approximately 3.5 for the LineMonitor integration time. Therefore an accurate tracking of the violin modes for S1 data with integration time of 1 minute is not possible.

4. Other questions related to the violin noise investigation

- Does the violin noise present any threat for the ongoing data analysis?
Violin modes give small contribution into the variance of the detector output signal. It's not likely that the violin modes are correlated between different interferometers, because violin frequencies are unique and the amplitudes are non-stationary. Therefore they should not be a problem for the stochastic searches. Besides they are located in the frequency band, which give small contribution to the cross-correlation. The violin noise doesn't seem to be a problem for inspiral (too different signature) or continues waves searches. The burst analysis may suffer from the violin noise, however at the moment there is no evidence that it's a dominant noise.
- Does the violin noise affect the detector operation?
- Do we need to track them during data taking? If yes, then how?
Perhaps we need to track large bursts of the violin noise associated with the external excitation. Then the LineMonitor is an adequate tool for the violin tracking.
- Is it important to know which mode is produced by which mirror?