L. Magistrale in IA (ML&BD)

Scientific Computing (part 2 – 6 credits)

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Contents

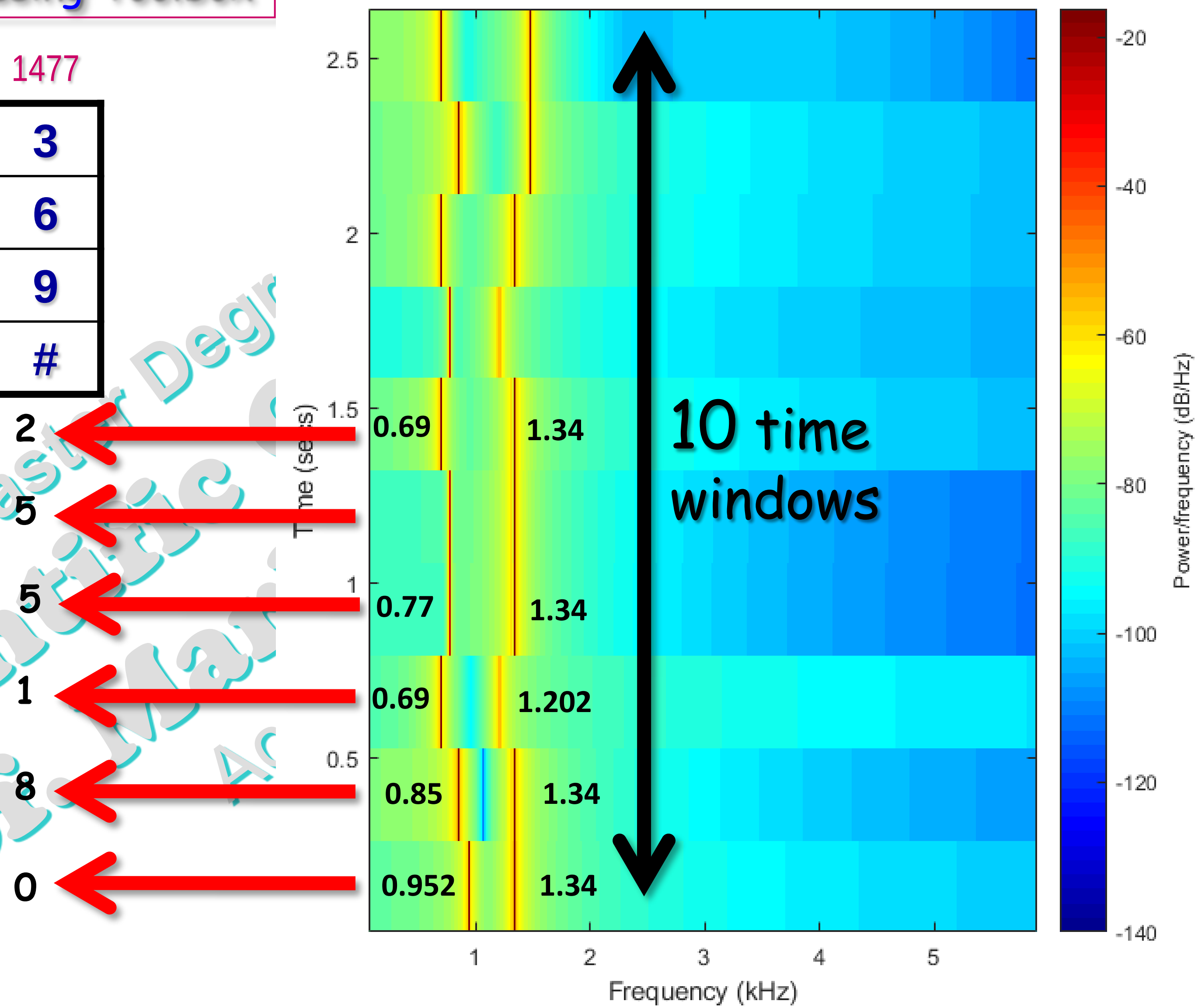
- Short Time Fourier Transform (STFT).
- Some applications to sounds of Fourier Transform.

STFT in MATLAB

```
[y,fs]=audioread('PhoneNumber.wav');
M=fix(numel(y)/10);
spectrogram(y,M,0,[ ],fs); colormap('jet')
```

in Signal Processing Toolbox

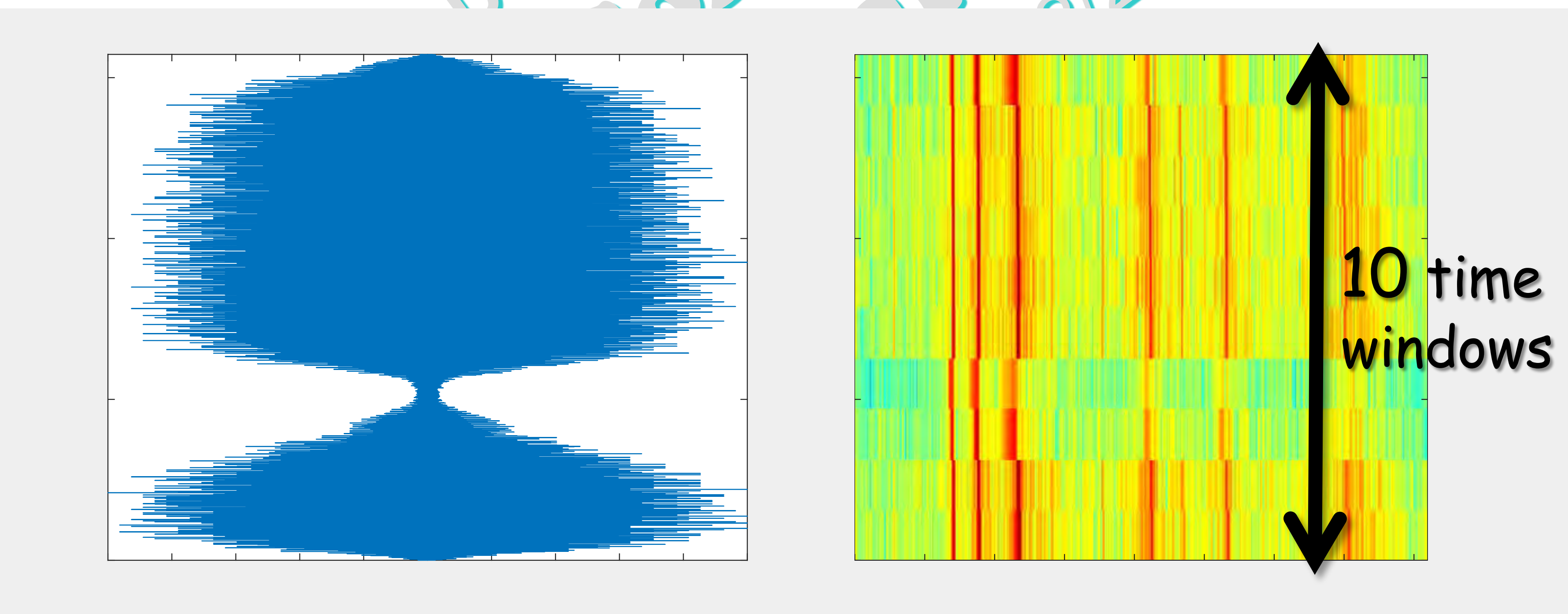
Hz	1209	1336	1477
697	1	2	3
770	4	5	6
852	7	8	9
941	*	0	#



STFT in MATLAB

```
load train; sound(y,Fs) % [y: samples, Fs: sample rate]
Dt=1/Fs  % Period = 1/circ.frequency
Duration=Dt*numel(y); tj=linspace(0,Duration,numel(y))';
plot(y,tj); axis tight; ylabel('time (sec)')
M=fix(numel(y)/10); spectrogram(y,M,0,[ ],Fs); colormap('jet')
```

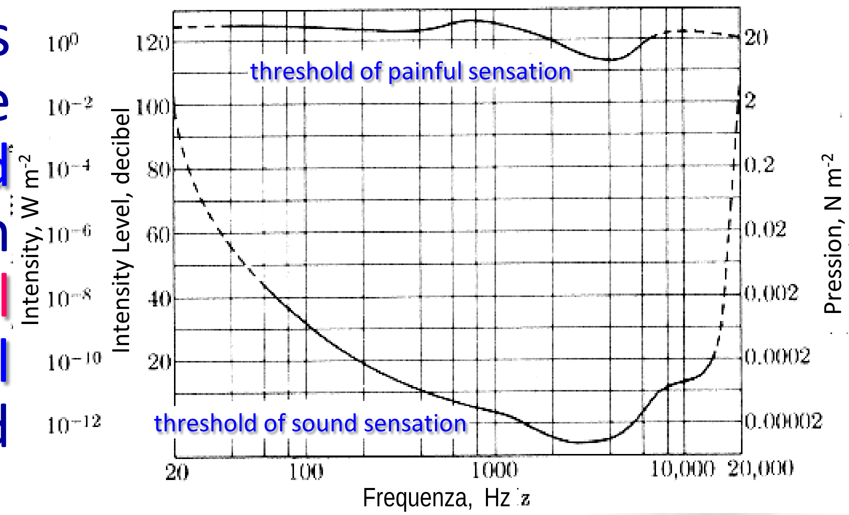
Compare with frequency table in the file: **Musical_Note_Frequencies.pdf**



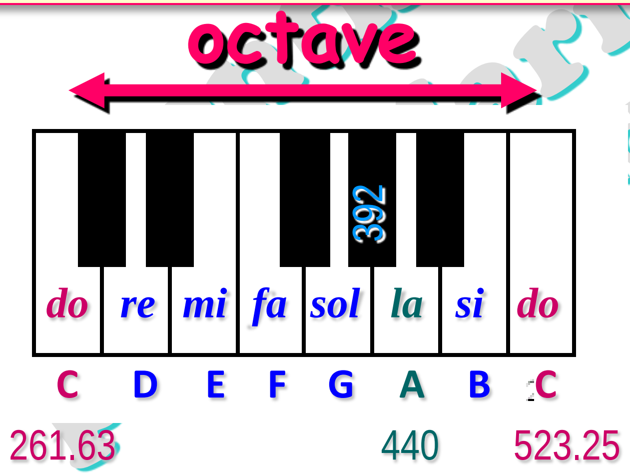
Example 4

Application to music

The sensitivity of human ears is such that for each frequency there is a minimal intensity, or threshold of sound sensation, below which sound is inaudible, and a maximal intensity, or threshold of painful sensation, above which sound produces discomfort or pain.

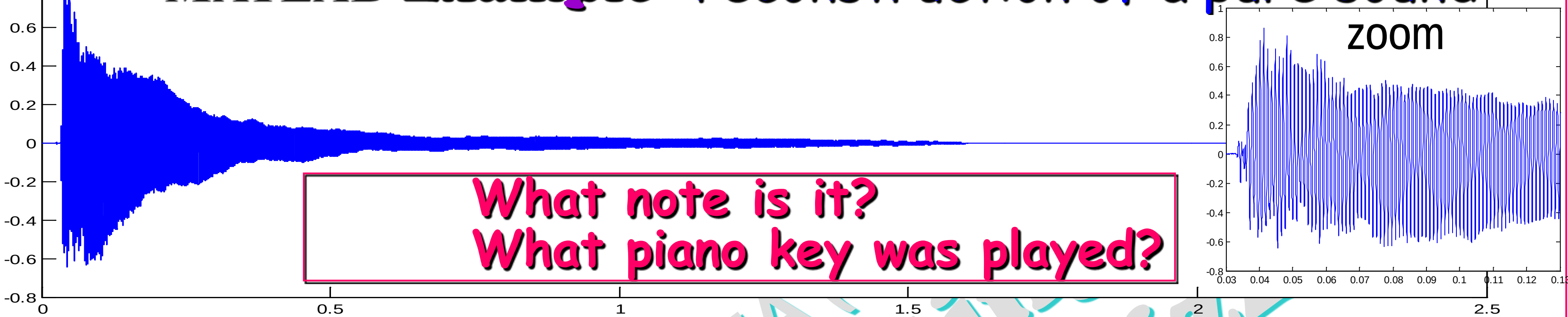


> "The sensation of **musical sound** is given by rapid, periodic vibrations; that of **noise** by non-periodic vibrations"
>
> *Sensations of Tone*, **Hermann von Helmholtz (1821-1894)**
>
> (German physician)



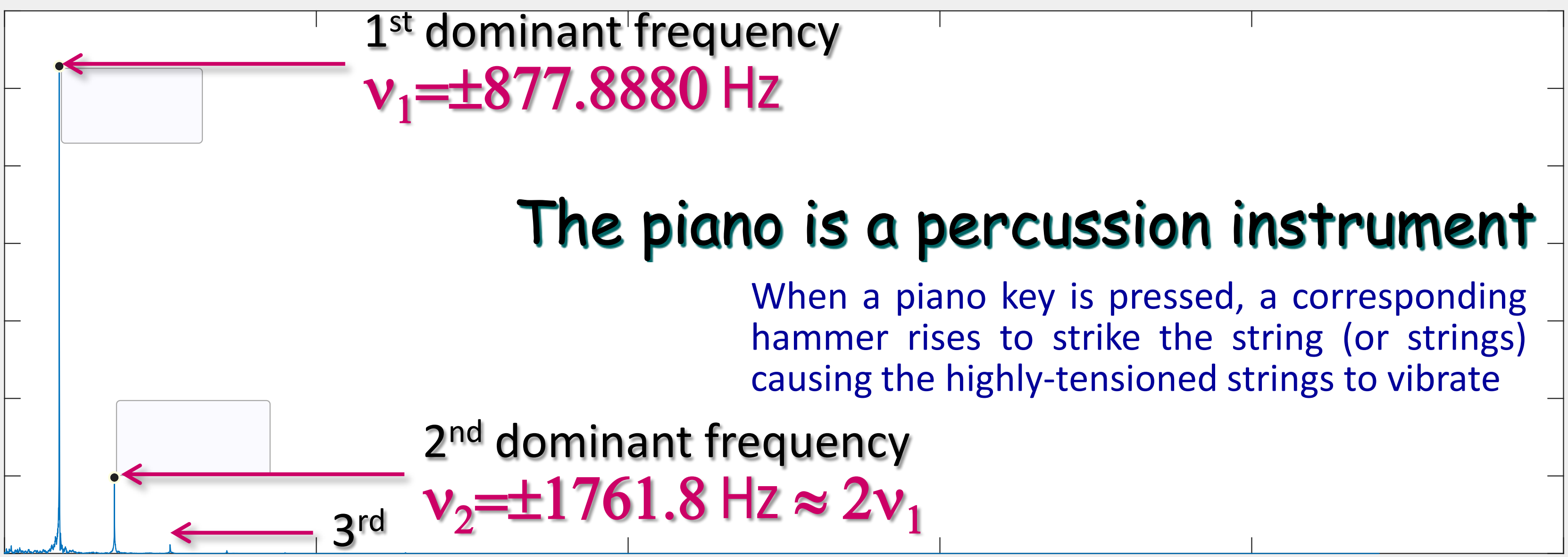
sound	frequency
lowest note of a piano	27.187
higher note of a piano	4180
Middle C of the piano	261.63
A above middle C	440

MATLAB **Example**: reconstruction of a pure sound



What note is it?
What piano key was played?

```
[y,fs]=audioread('PIANO.wav'); sound(y,fs)
N=numel(y); Dt=1/fs; tj=Dt*(1:N)'; T=N*Dt; Dnu=1/T;
figure(1); plot(tj,y); xlabel('Time (sec)')
Y=fftshift(fft(y));   Y=[Y;Y(1)]*T/N;   nu=(-N/2:N/2)'/T;
figure(2); plot(1e-3*nu,abs(Y)) % KHz
xlabel('frequency (KHz)'); title('Fourier Spectrum')
```



The piano is a percussion instrument

When a piano key is pressed, a corresponding hammer rises to strike the string (or strings) causing the highly-tensioned strings to vibrate

frequencies and musical notes

DO5	C5	523 Hz
DO#5	C#5	554 Hz
RE5	D5	587 Hz
RE#5	D#5	622 Hz
MI5	E5	659 Hz
FA5	F5	698 Hz
FA#5	F#5	740 Hz
SOL5	G5	784 Hz
SOL#5	G#5	831 Hz
LA5	A5	880 Hz
LA#5	A#5	932 Hz
SI5	B5	988 Hz
DO6	C6	1046 Hz
DO#6	C#6	1109 Hz
RE6	D6	1175 Hz
RE#6	D#6	1245 Hz
MI6	E6	1319 Hz
FA6	F6	1397 Hz
FA#6	F#6	1480 Hz
SOL6	G6	1568 Hz
SOL#6	G#6	1661 Hz
LA6	A6	1760 Hz
LA#6	A#6	1865 Hz
SI6	B6	1976 Hz

$\nu=877.8880$ Hz

≈ 880 Hz

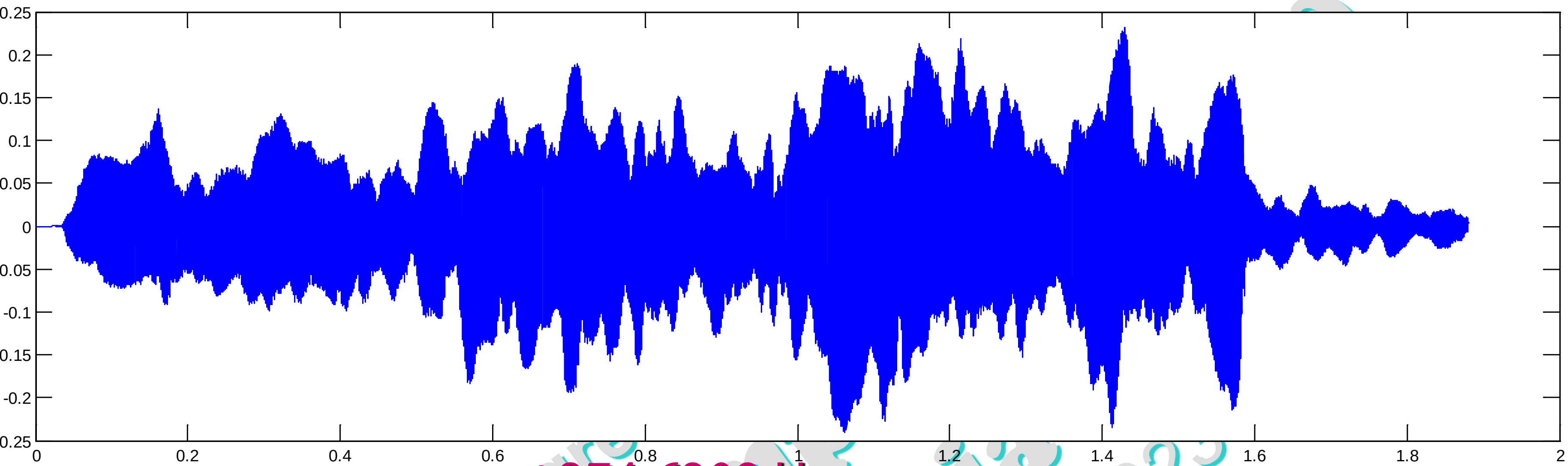
1 octave

$\approx 1760 = 2\times 880$

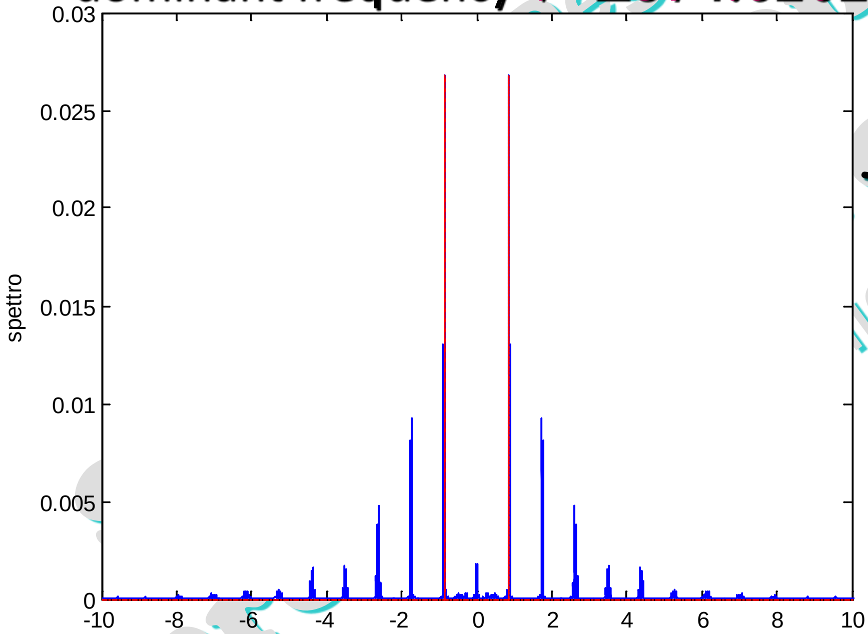
$\nu=1761$ Hz

(prof. M. Rizzardi)

If we repeat the experiment with a violin ... (file "VIOLIN.wav")



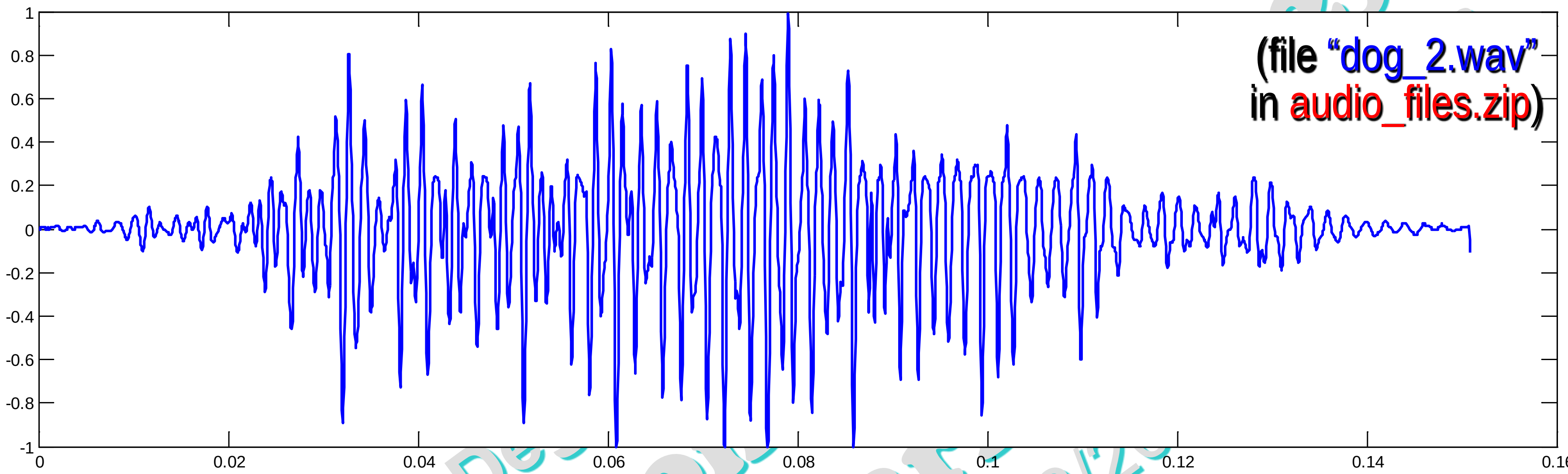
dominant frequency $\nu = \pm 874.6202$ **Hz**

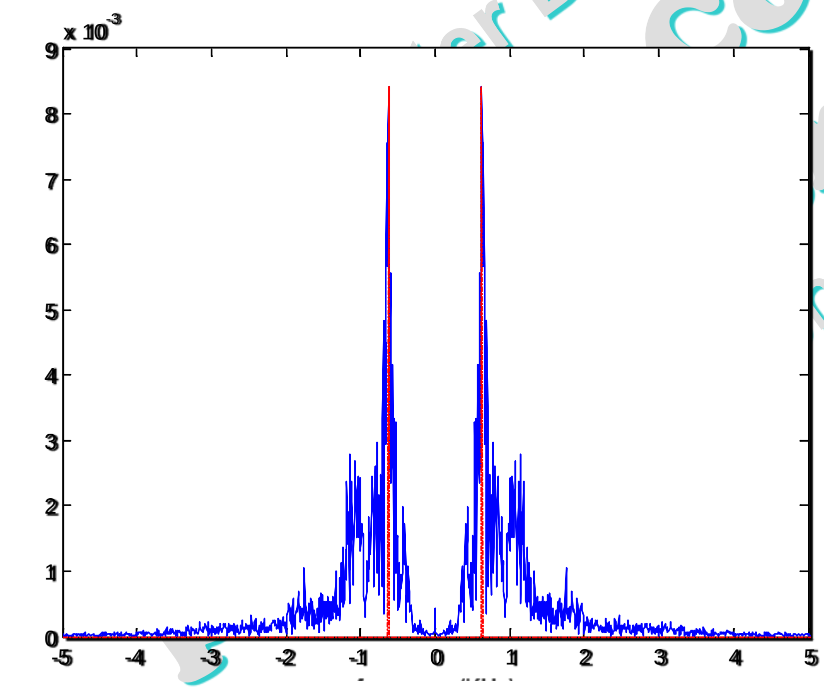


The violin is a string instrument

a given note on a violin will have several frequencies vibrating at once, since the violin bow touches the chords

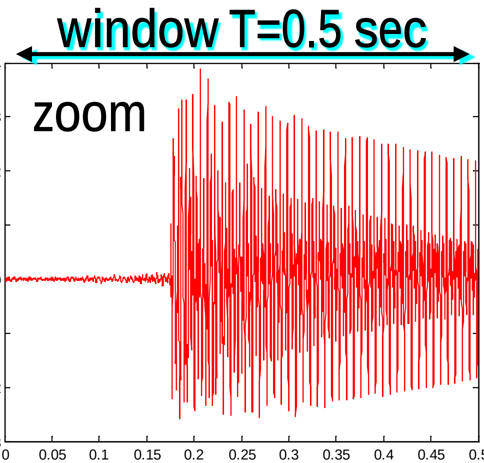
If we repeat the experiment with a non-periodic sound (noise)

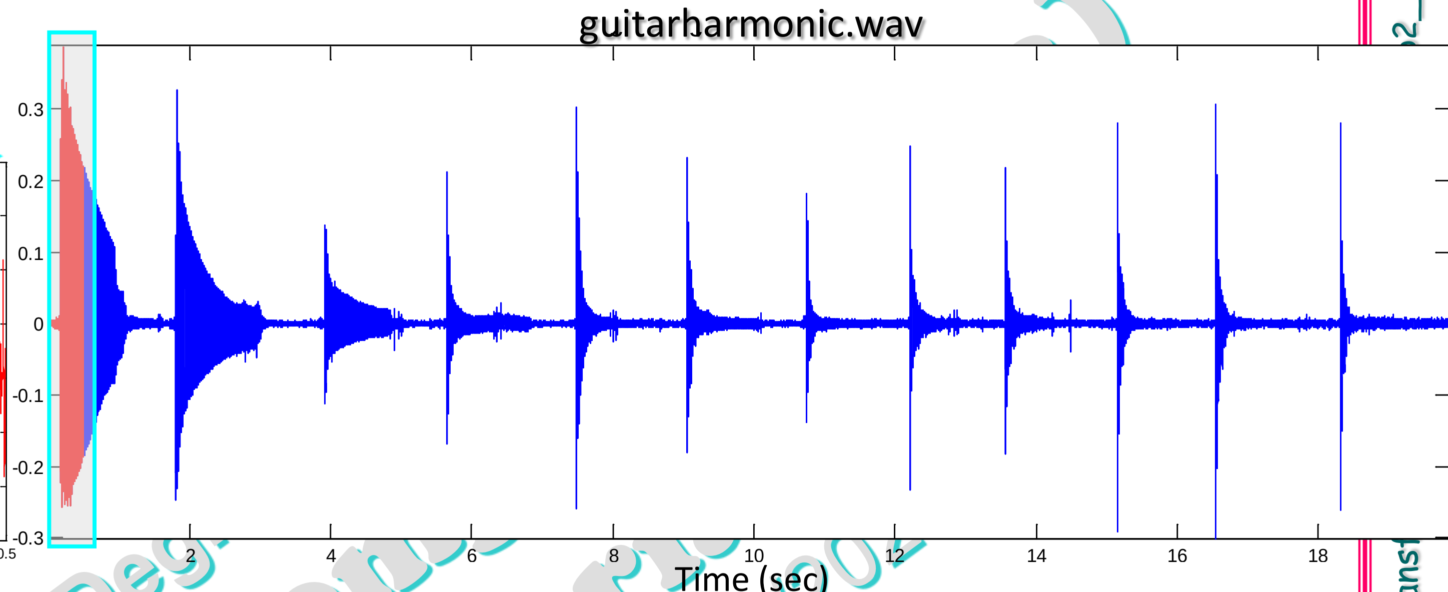


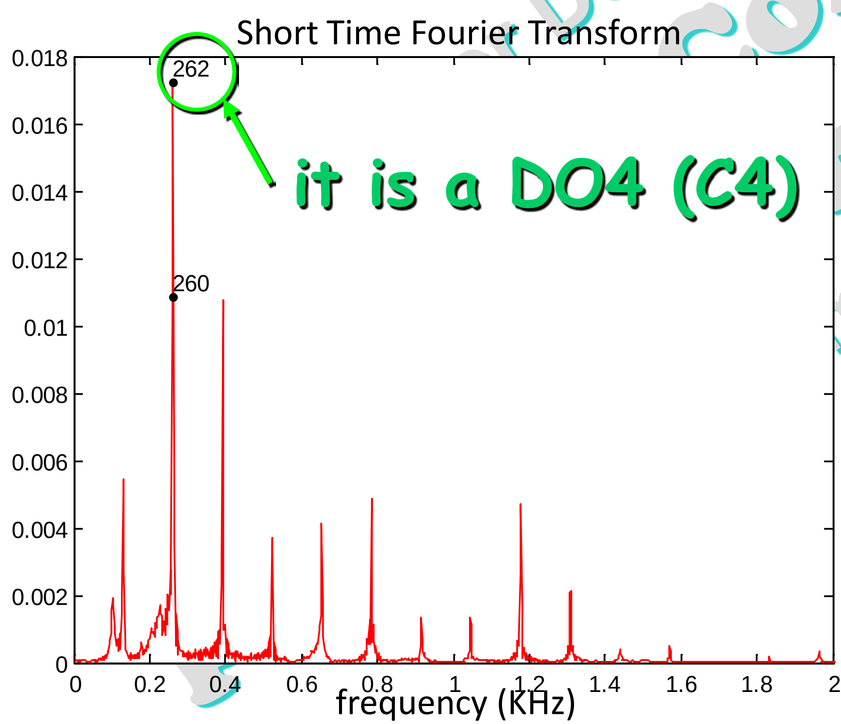


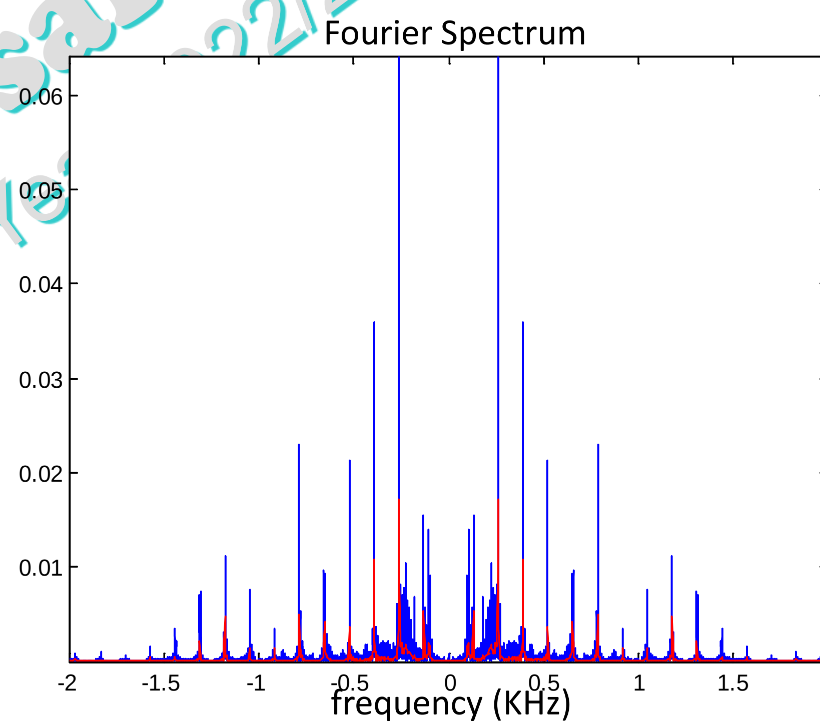
infinitely many frequencies
for a non-periodic sound

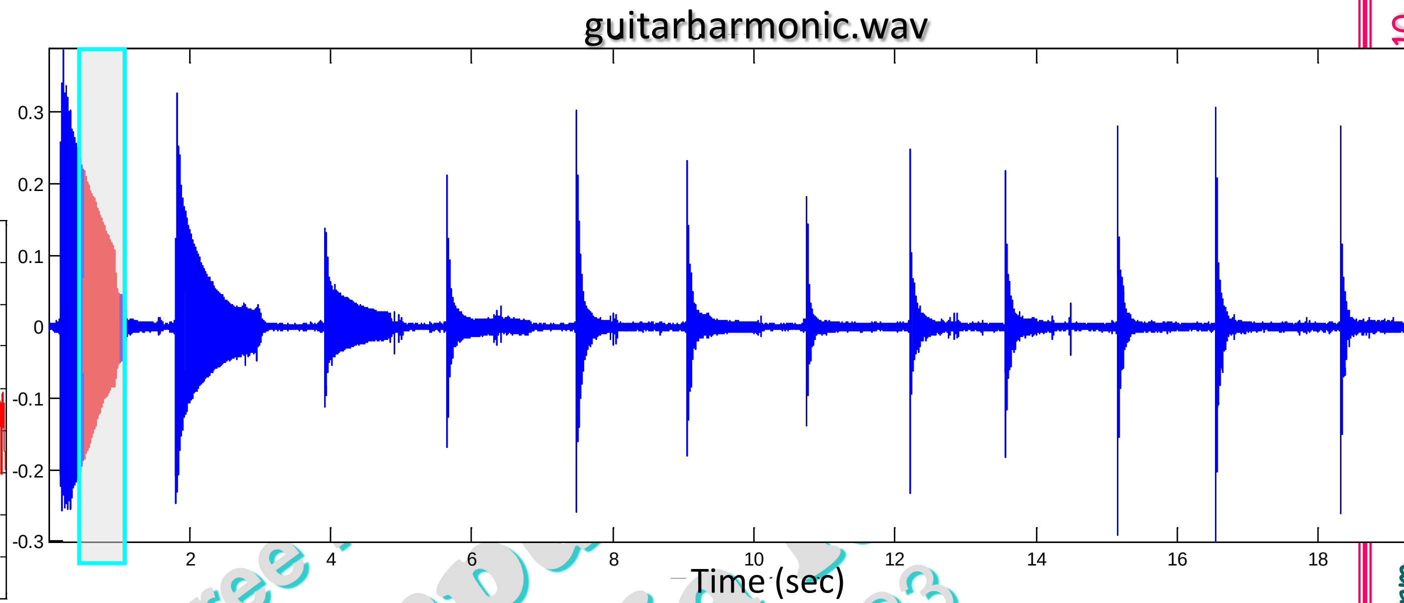
by means of Short Time Fourier Transform ...

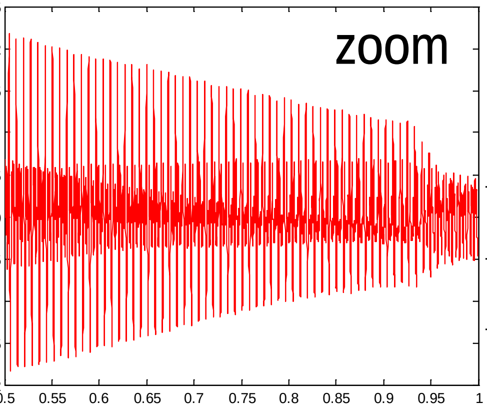


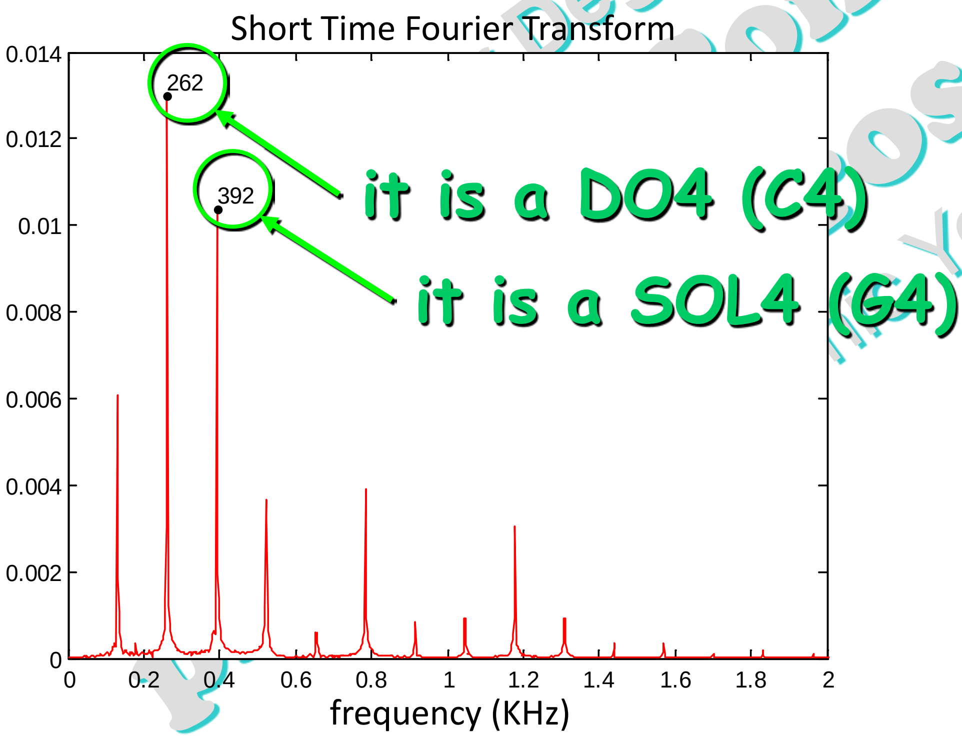


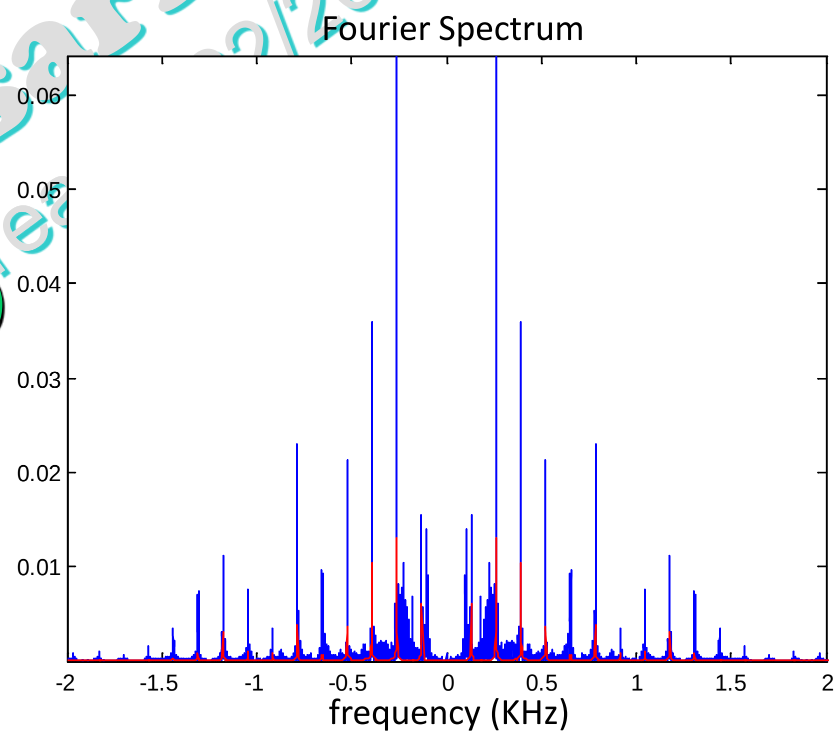





guitarbarmonic.wav
Time (sec)


zoom


Short Time Fourier Transform
262
392
it is a DO4 (C4)
it is a SOL4 (G4)
frequency (KHz)


Fourier Spectrum
frequency (KHz)