Magne Skålevik:

# Tonal response in rooms

Microstructure of room acoustical frequency response (FR)

NAS, Trondheim, 17/10-2009

Extended English version 20/10-2009

Background: M Schröder

Frequency range of interest

L(dB)

$\Delta f_{mode} = 2.2/T$

> 3x modal overlap

$\Delta f_{max} = 4/T$

Modal density increase as f^2

$f_c = 2000(T/V)^{0.5}$

f (Hz)
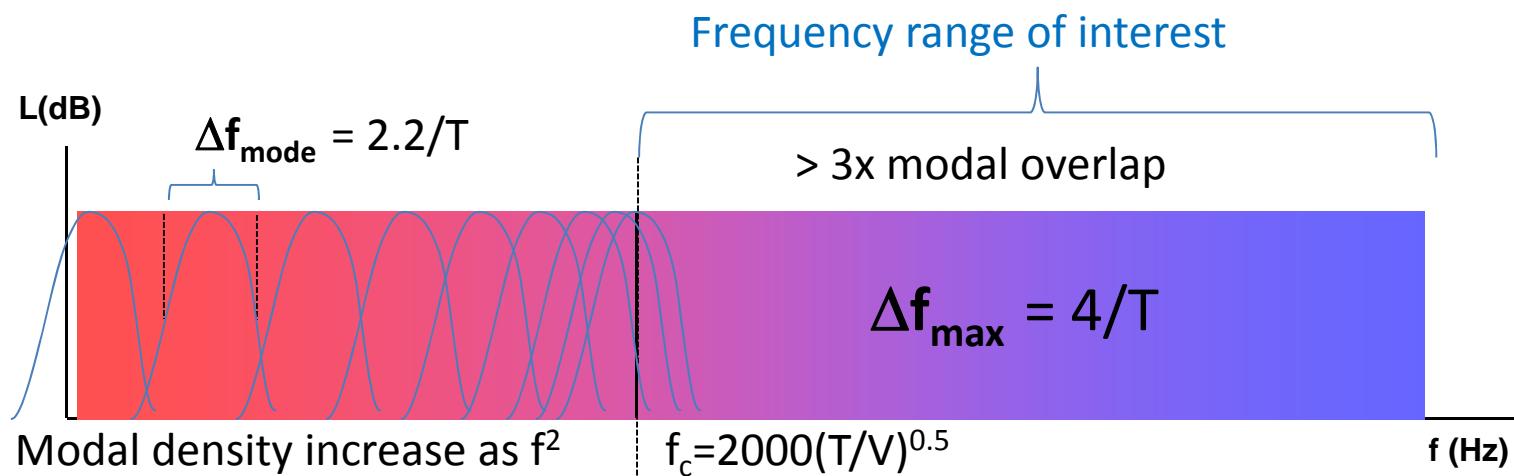
Concert hall 16000m^3 T=2.0s => f_c =22Hz

Δf_{max} = Average spacing between level maxima

dB

Δf_{max}

f (Hz)
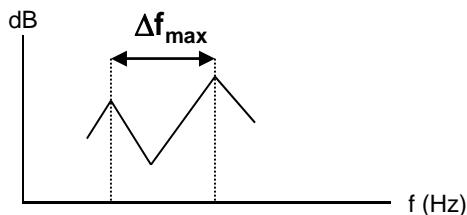
$\Delta t \cdot \Delta f$ =constant

$T \cdot \Delta f_{max}$ = 4

Big differences – Big similarities

Longer T implies more peaks and dips

But same distribution
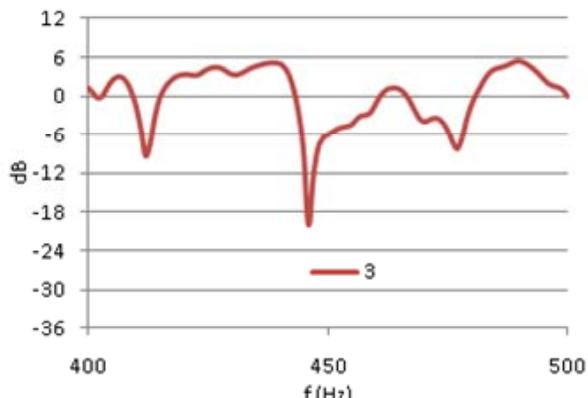
Listening room 50m3
T=0.4s f_c =180Hz
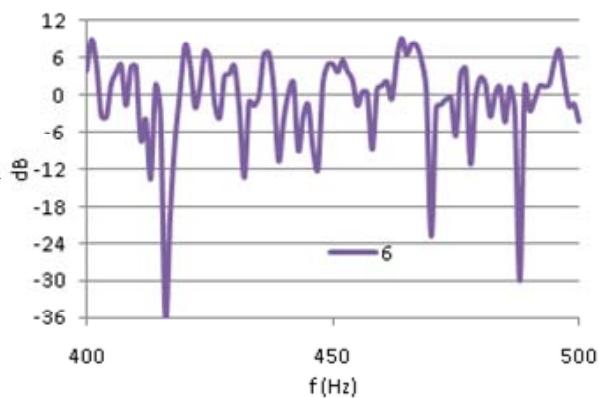
Opera hall 15000m3
T=2.0s f_c =23Hz
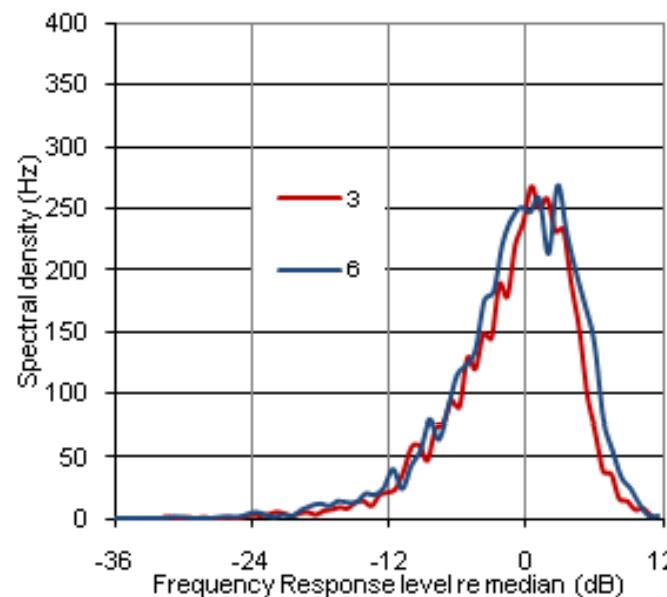
Which one is simulated?

L(f)=20*log(sum of 5 complex numbers of equal size but random individual phase
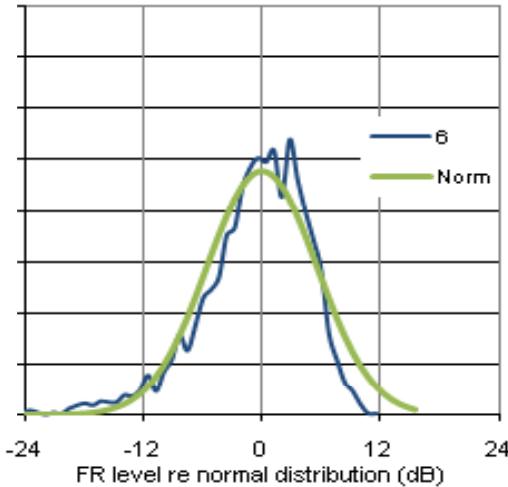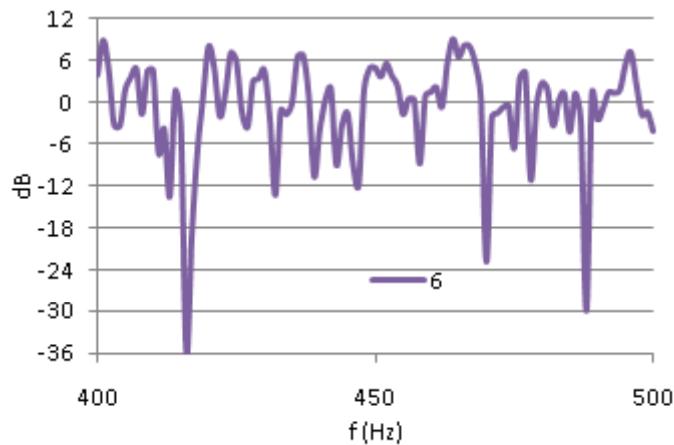

ST DEV = 5.6dB
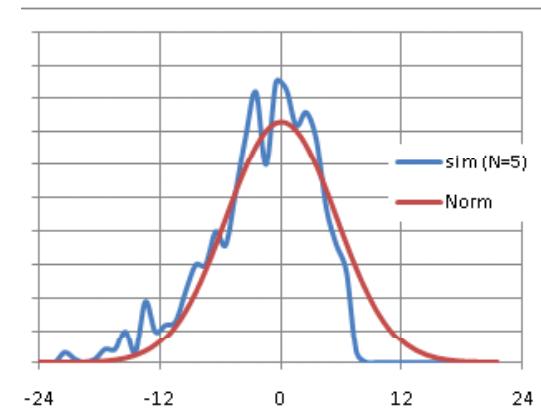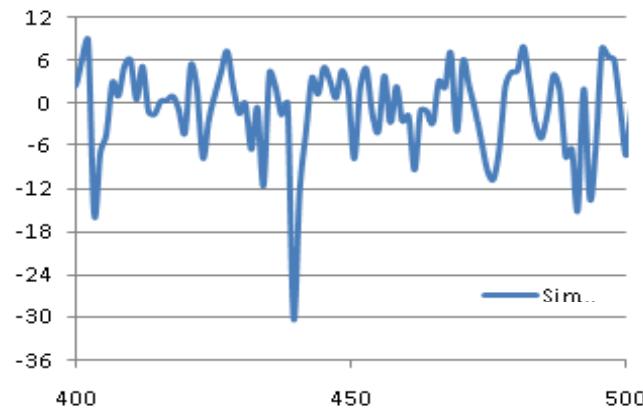
ST DEV = 5.5dB

So far

- Peaks seen in FR are not single modes
- Dips seen in FR are not absence of modes
- FR can not be predicted in detail
- Levels are pure lottery outcomes – stochastic prosess
- Statistical properties of "lottery" (FR-distribution):
  - Standard deviation ~ 5.5dB
  - 55% of levels exceed +/-3dB (usually means spectral distortion in 55% of frequencies)
  - 94% of levels within 20dB interval
  - Peak-peak and dip-dip spacing typically 2Hz in concert hall

Transmission of 5 first harmonics of the tone "G", opera hall T=2.0s
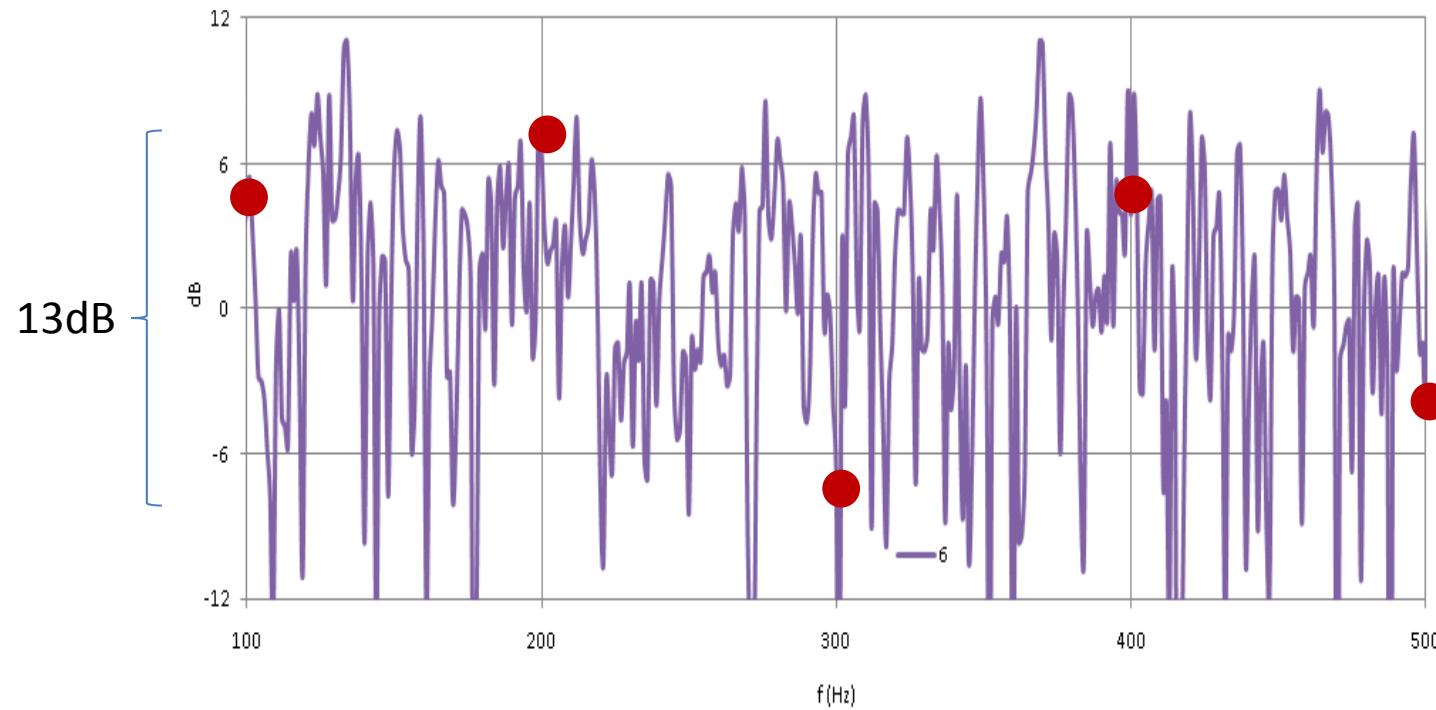
Level interval 13dB, mean value μ =1dB, standard deviation σ =5.8dB

Levels of 5 harmonics in one symbol
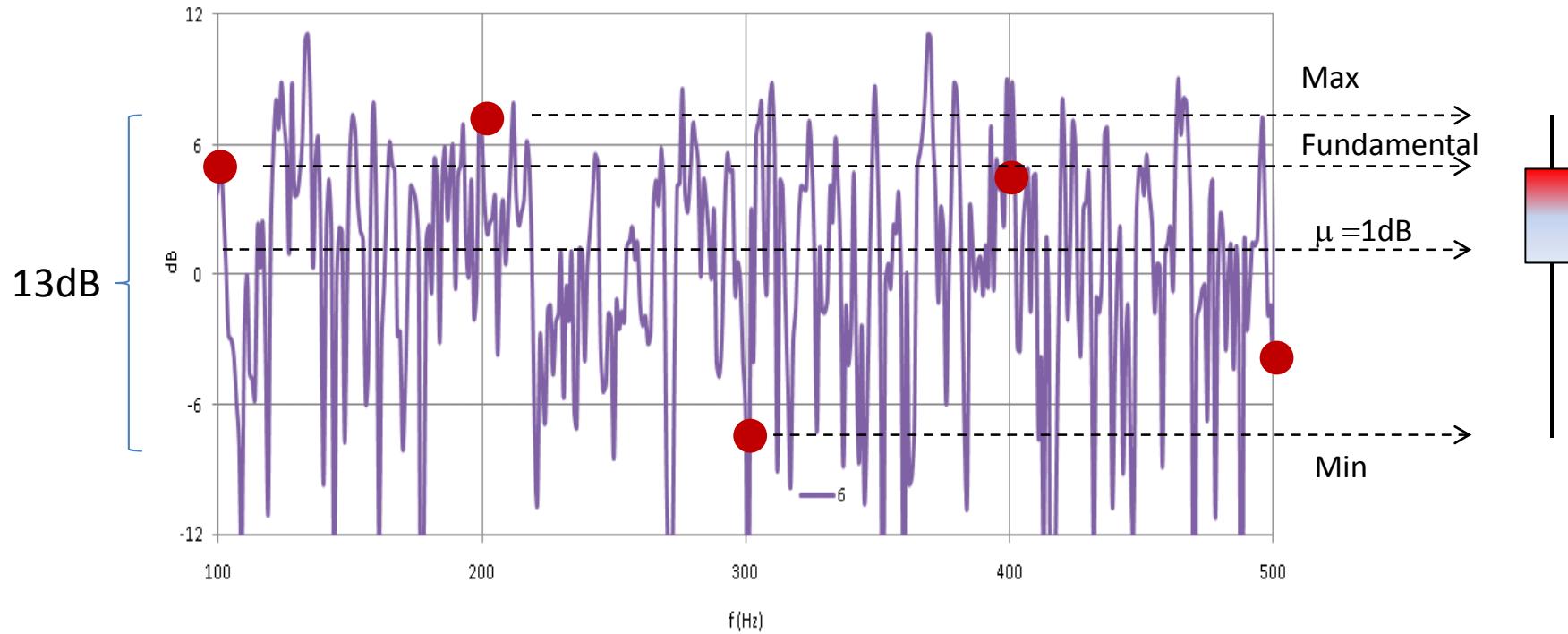
Q: Why just study up to 5th harmonic?
A: Because higher order harmonics will not be perceived separately when intervals between neighboring harmonics are smaller than the critical bands

FR of preferred acoustics

# Dummy head in Vienna – Right ear

Semi-tone scale from G til a'

Left ear

Semi-tone scale from G til a'

Sum loudness level L+R

Semi-tone scale from G til a'

Compared

H

V

H+V

σ=5.8dB

σ=4.0dB
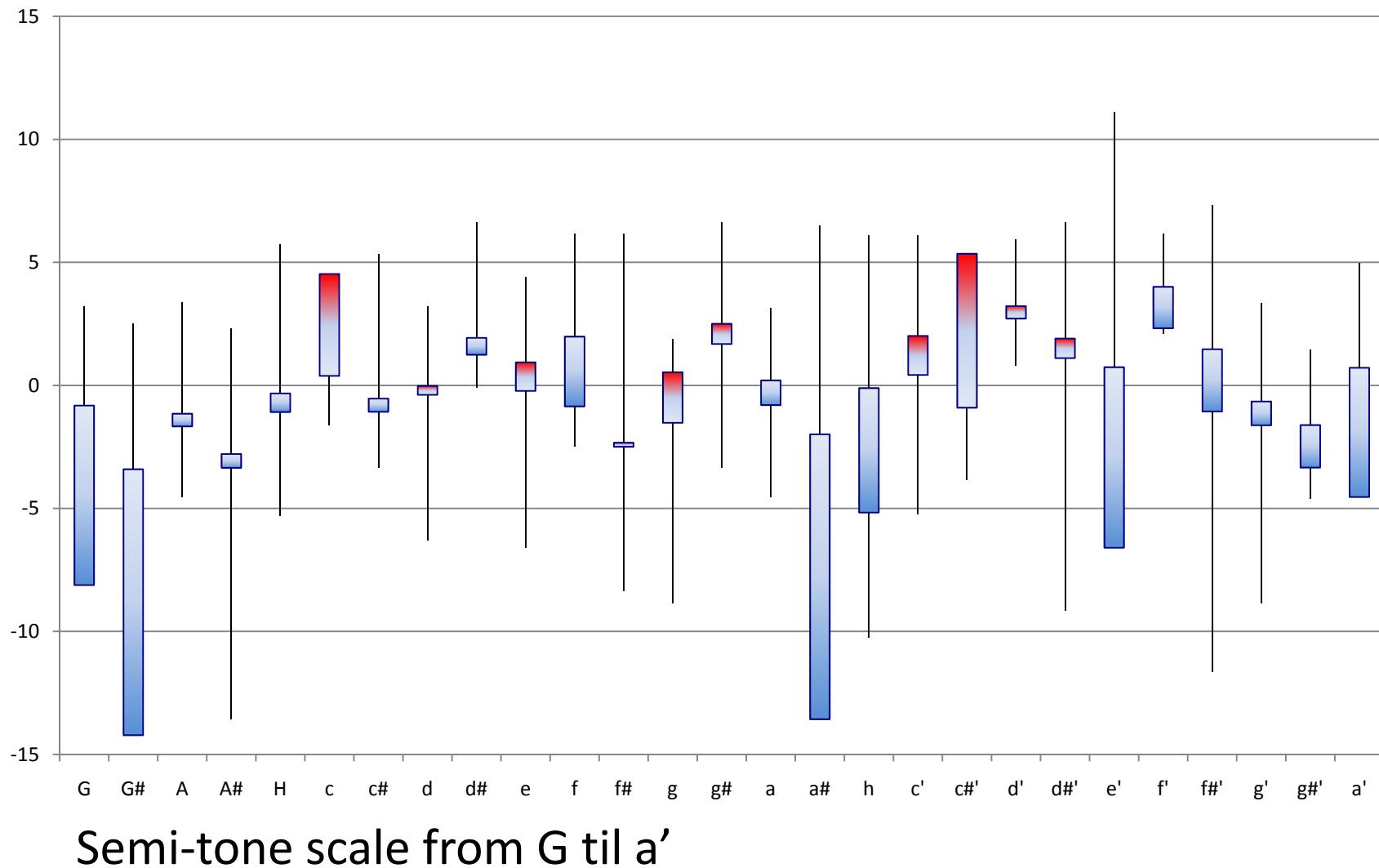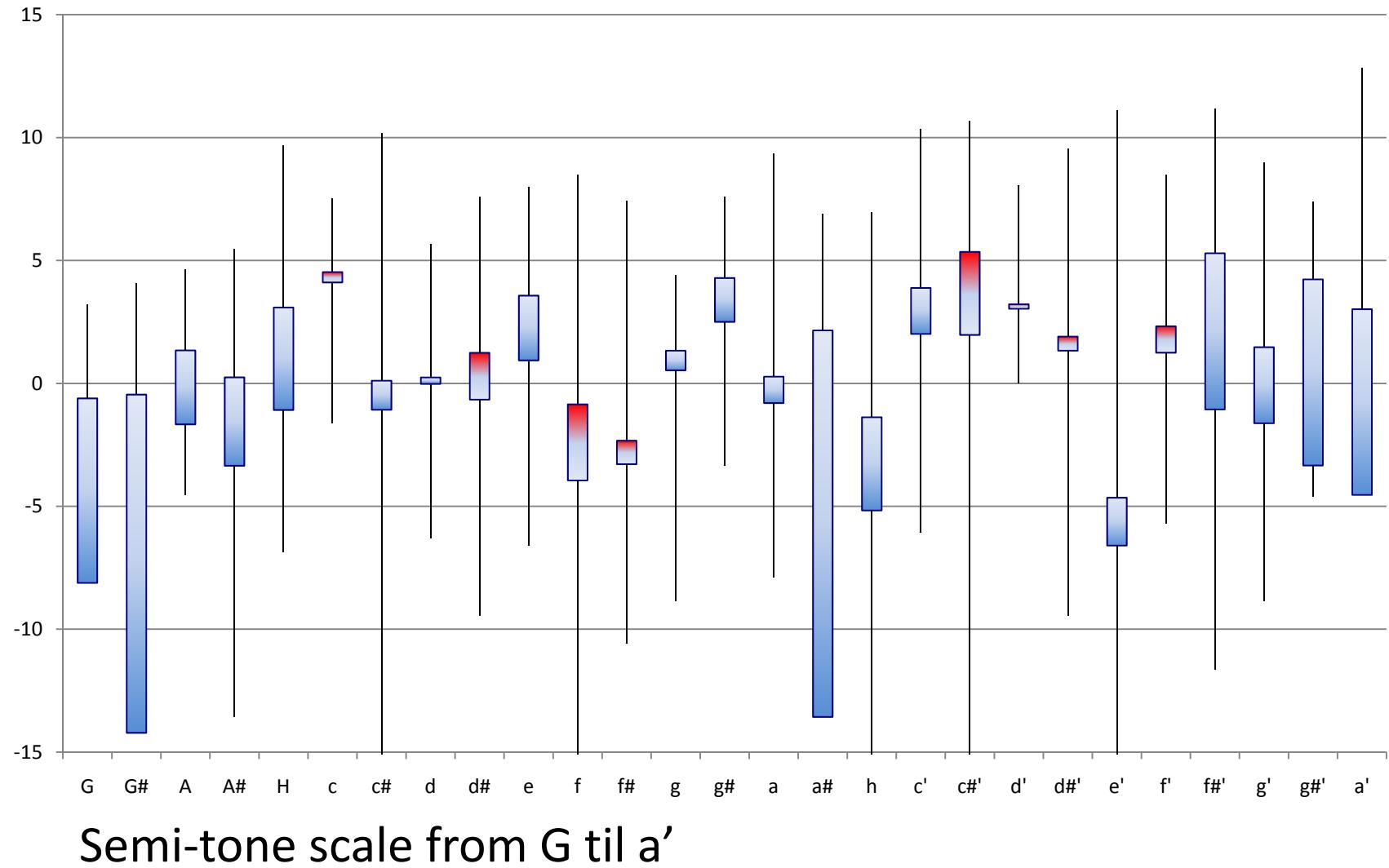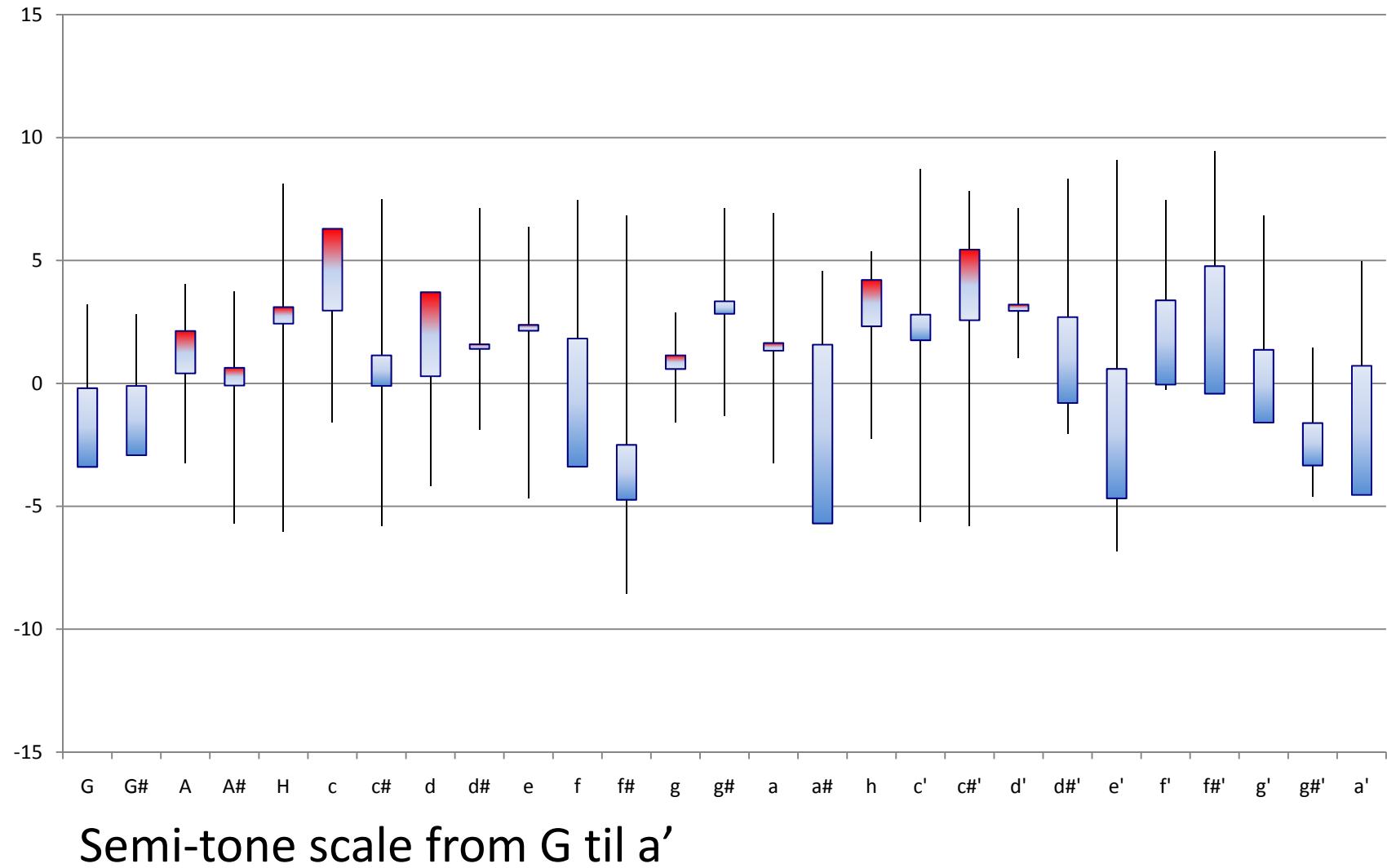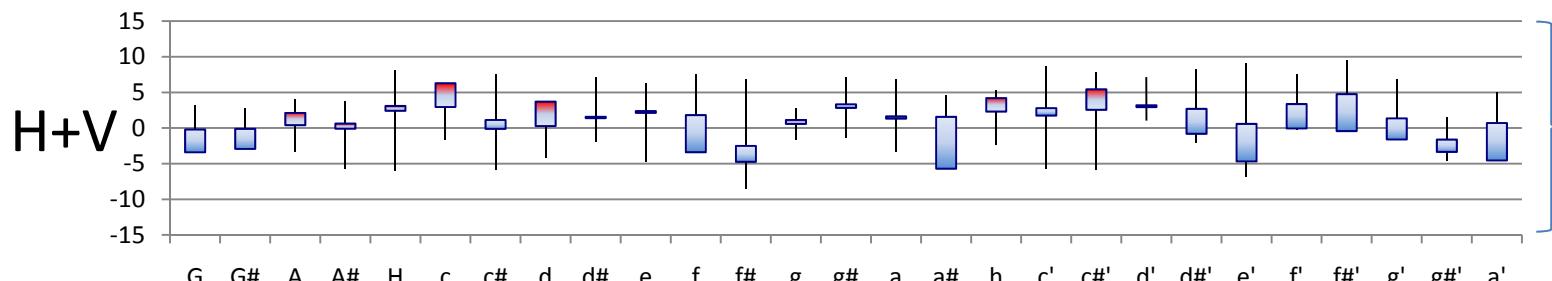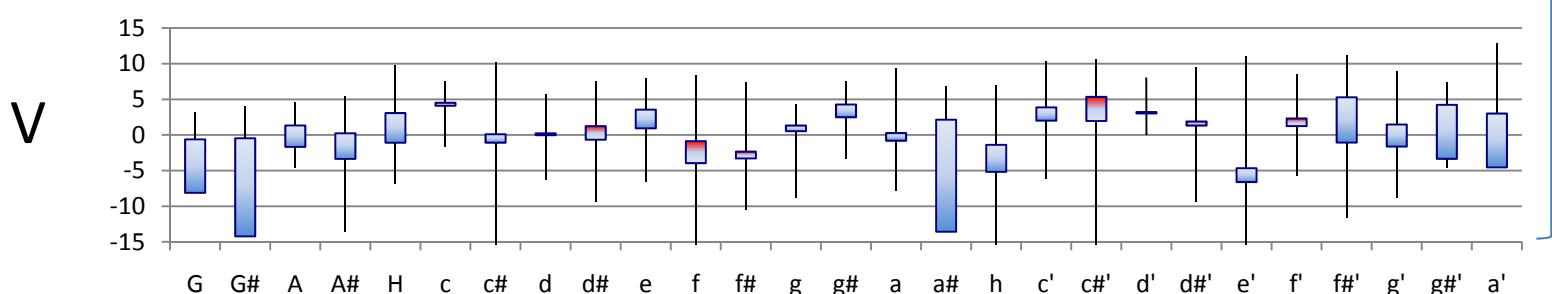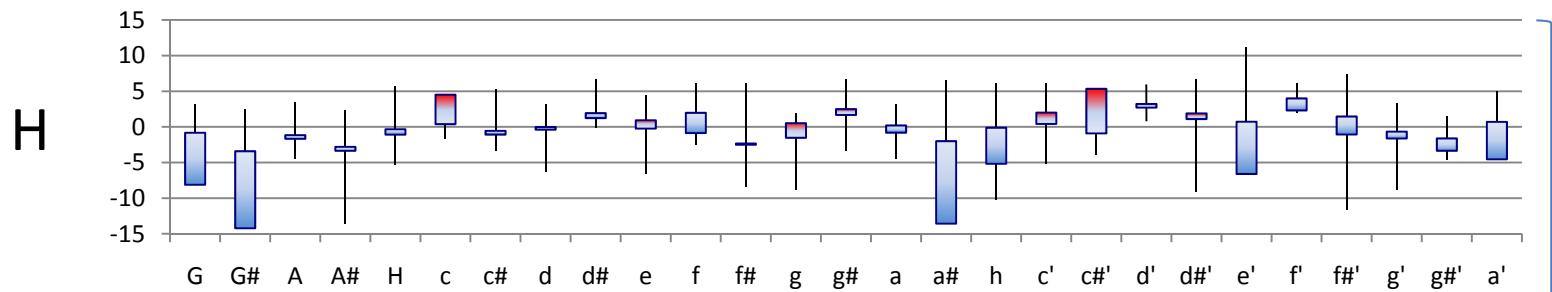
Semi-tone scale from G til a'

L-R balance
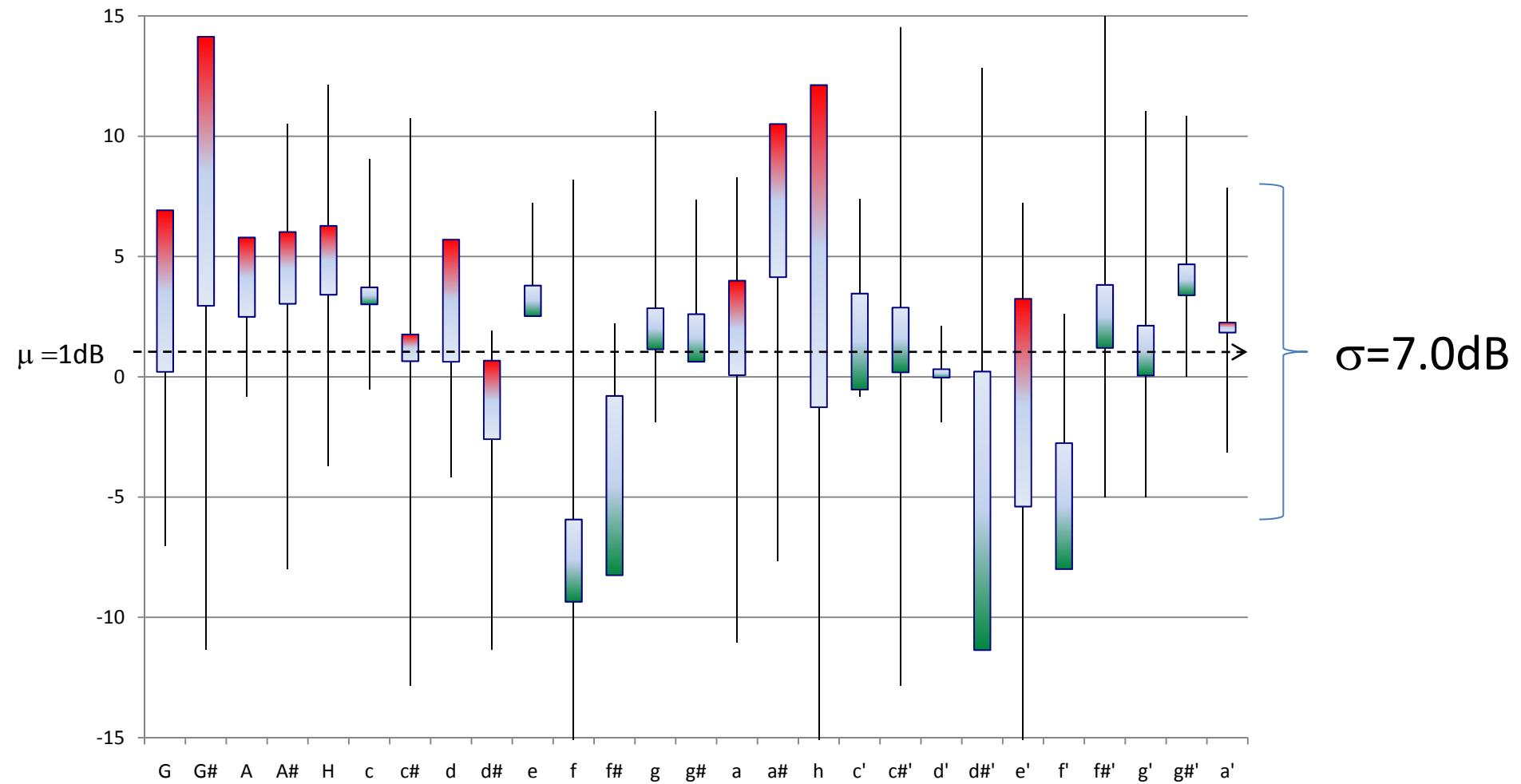
Vibrato, frequency modulation, A ±1%

Opera hall T=2.0s
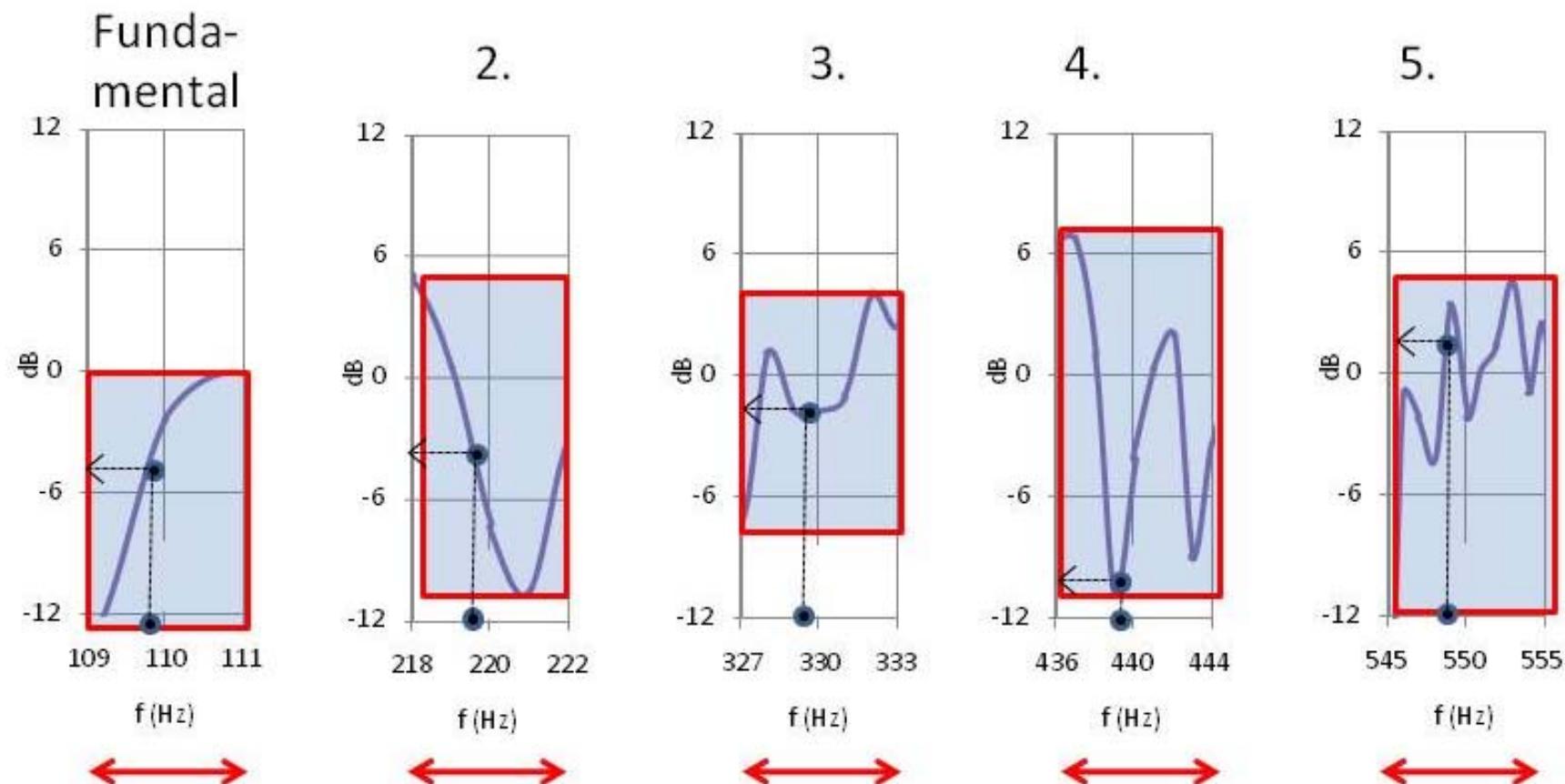
L(t)   Level varies with frequency which varies with time, disallowing the distortion (the uneven transfer function) to become static

Introducing vibrato (bottom)

L+R

no vibrato

σ=4.0dB

w vibrato

σ=2.7dB
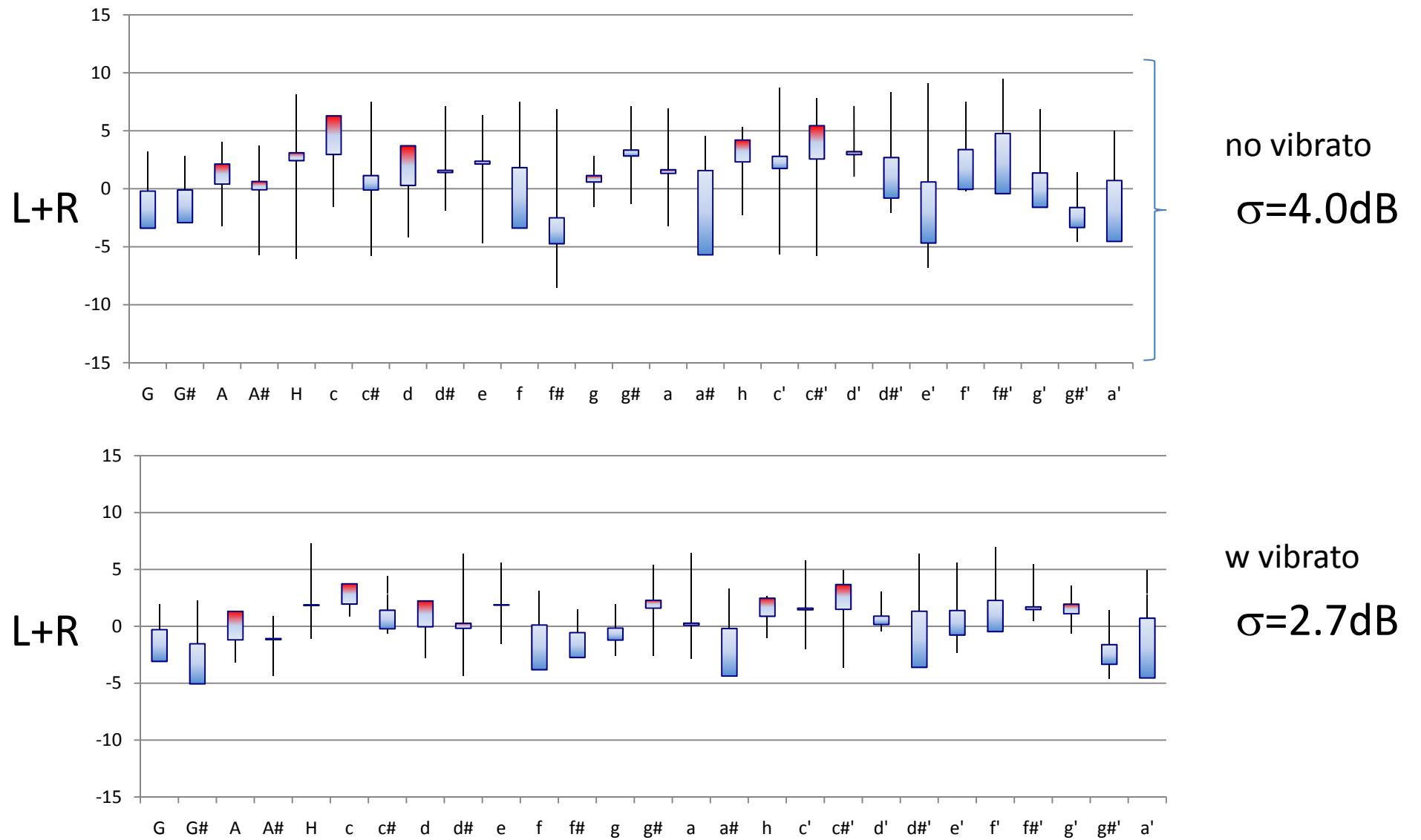
Spacing between maxima decreasing toward 4/T with tone duration ->T
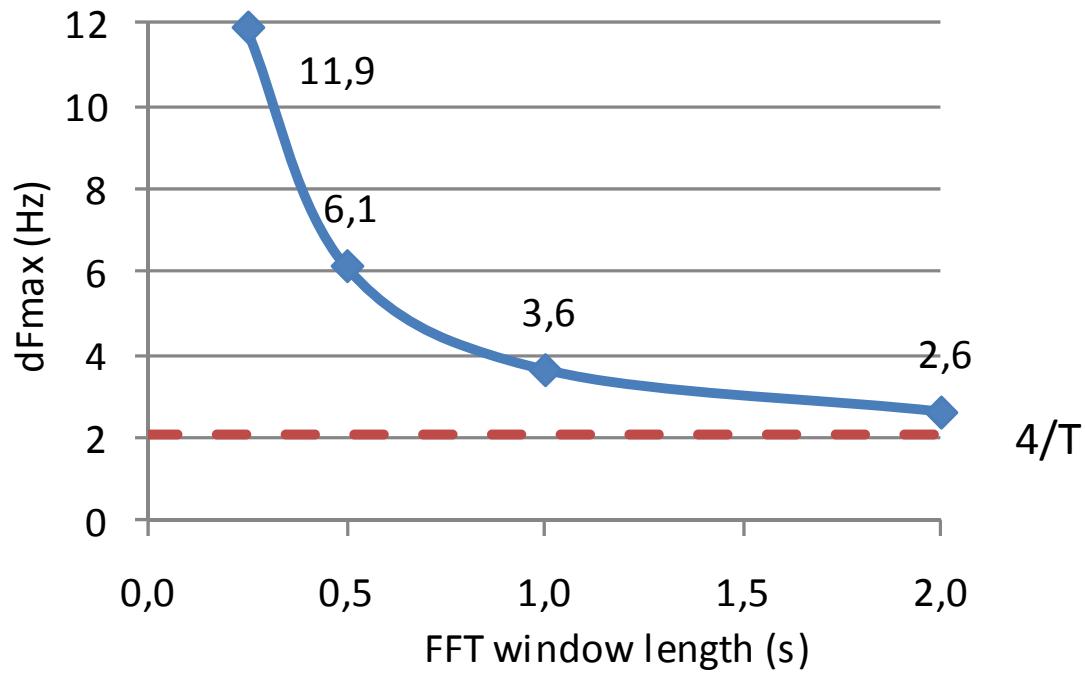
Does duration affect standard dev σ?
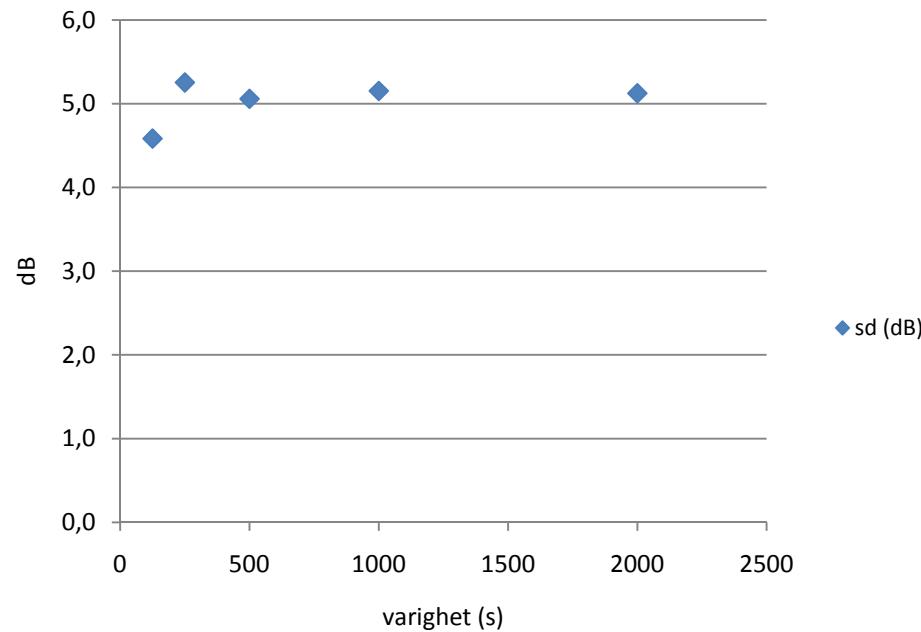
14 FR's from rooms of 50-19000m³
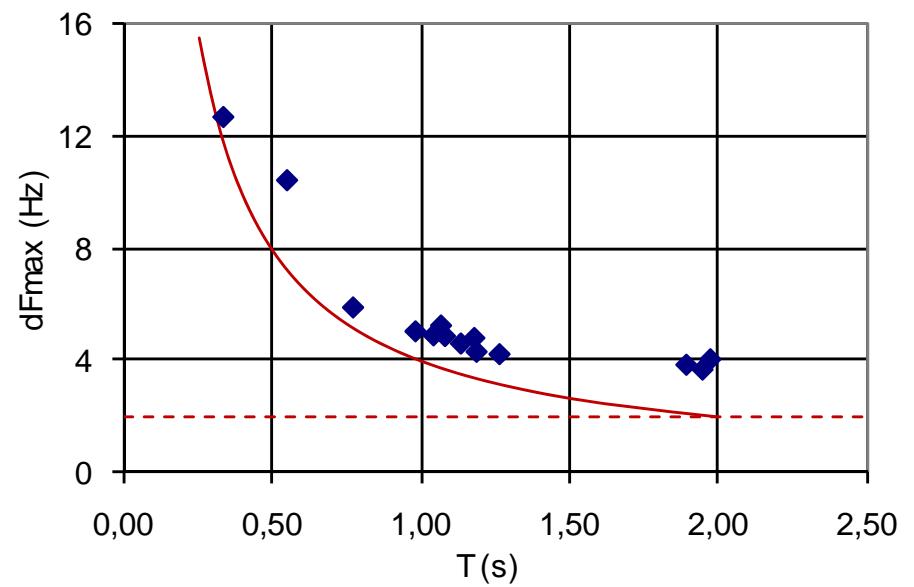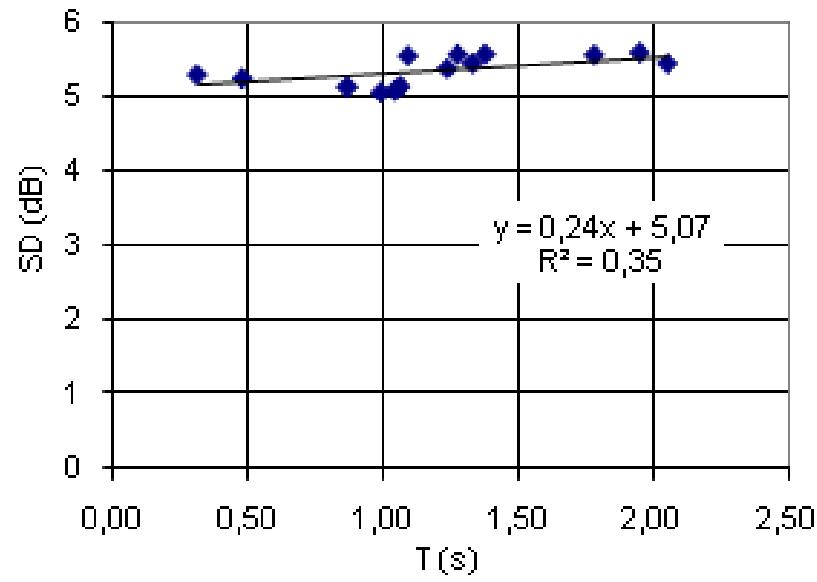
Conclusion

- Tonal response in rooms is random and uneven over frequency and space
- Level distribution is ca σ=5.5dB independent of T
  - Reduced (example σ=4.0dB) by equal binaural hearing
  - Reduced further to σ=2.7dB by 0.8% frequency-modulation (vibrato)
- Vibrato (frequency modulation) will create individual amplitude modulations in each harmonic, making a single source act like multiple incoherent sources - > ensemble effect
  - [sound engineers have traditionally used such complex modulation techniques to create spaciousness]
  - It dissallows spectral distortion of FR to become static
- Spacing between maxima -> 4/T as tone duration ->T
- Random unevenness, tonal spaciousness and virtual ensemble are three different features of the same physical conditions
  - Creates richness
  - Adds life to the tone, by supressing static ness
  - Peaks in single harmonics makes reverberance more audible than if FR was FR
  - In contrast to the unevenness of comb-filters, which is not random, and not pleasant

Further work

- Further work will include
  - Effect of source directivity
  - Effect of small changes in source and receiver position
  - Study effect of tremolo vs vibrato (amplitude modulation vs frequency modulation)
  - Study effects of musicians' typically delay in modulation onset
    - In particular the effect of non-vibrato tonal bandwidth narrowing with time
  - Compare variance in room FR levels with variance in source spectrum level (the chain of transfer functions - room considered an extended body of musical instrument or voice)
  - Review the crossover frequency, suggesting the criteria "average modal spacing = 4/T" (see discussion on http://akutek.info/articles_files/stochastics.htm)

Thank you

More info:

www.akutek.info

http://akutek.info/articles_files/stochastics.htm

http://akutek.info/articles_files/stochastics_2.htm