Institute of Acoustics
9th INTERNATIONAL CONFERENCE ON Auditorium Acoustics

BREKKE ⁝⁝⁝ STRAND

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Link to online paper

CAN SPACIOUSNESS BE MEASURED DURING A CONCERT?

IOA Auditorium Acoustics, Saturday 31st October 2015

Pursuing the Spaciousness-Meter

Can Source Broadening (ASW) and Listener Envelopment (LEV) be measured directly from a music performance in a concert hall?

Approach: To test Binaural metrics that are sensitive to room acoustical properties that are known to influence on perception of Spaciousness

Pursuing the Spaciousness-Meter

Listeners Perceptual Aspect	Measure from IR	Measure from Music?
Listener Envelopment LEV	LLG or 1-IACCL and G_{late}	Easy?
Source Broadening ASW	LF or 1-IACCE	Difficult??

Concept: If we can hear it, we can measure it

Correlation and Lateral Energy can be measured as functions of time, with integration time T, e.g.

$$LF(T,t) \quad \text{and} \quad IACC(T,t)$$

Measurement equipment

Maybe not

Measurement equipment

Yes, the Hair-Do is on the equipment list
Better not draw any attention

Live data aquired so far

- NY, Avery Fisher Hall
- Berlin, Philharmonie
- Helsinki, Music Centre
- Boston, Symphony Hall
- Chicago, Orchestra Hall
- Norway:
  - Oslo, Kristiansand, Stavanger, Bergen

Including some recordings with same music in different halls

Well-worn devices

Long time utilized in Broadcasting, sound recording and -reproduction

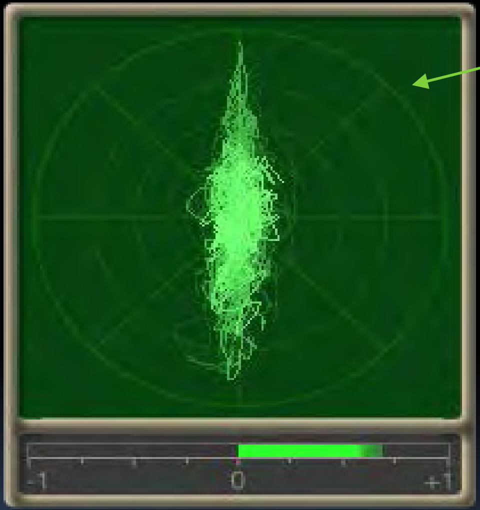
Goniometer

It’s basically an x-y scope turned 45 degrees

Correlation (r) meter

r = +1	means	L = R	«no stereo»	«no lateral energy»
r = 0	means	L ≠ R	«no mono, pure stereo»	«pure lateral energy»
r = -1	means	L = -R	«L and R in oposite phase»	«standing wave at 1kHz?»

Well-worn devices



«vertical» patterns indicate high correlation (r=0.5-1.0)

«round» patterns indicate low correlation (r=0.0-0.5)

Spaciousness - Lateral Energy - Correlation

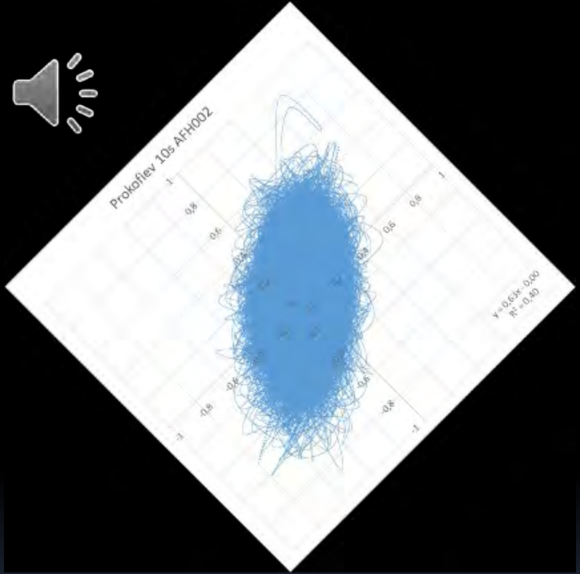
Spaciousness	Lateral Energy	L-R correlation
Little	Small fraction	High (0.5-1.0)
Much	Big fraction	Low (0.0-0.5)

Correlation and Lateral Energy Fraction is basically

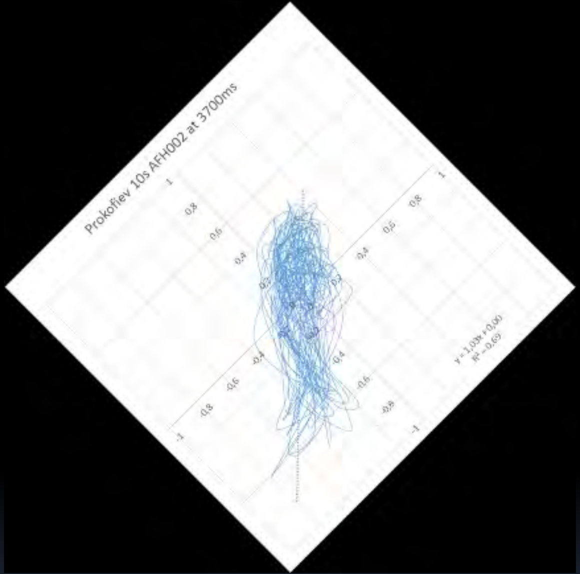
Lateral Energy normalized to Total Energy

Lateral Energy is the energy of the difference signal L(t)-R(t)

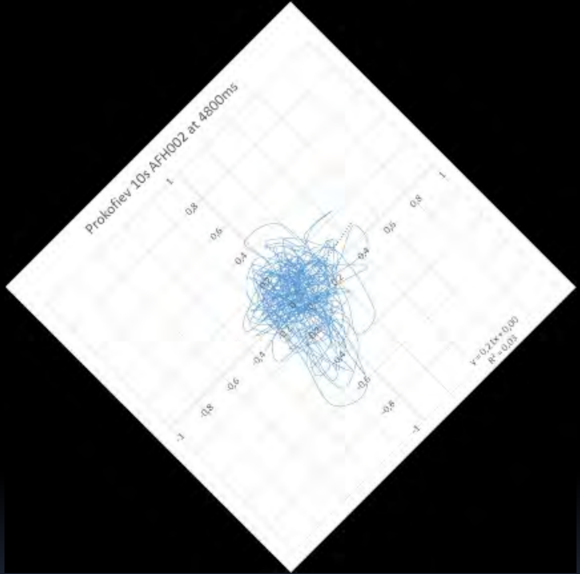
Prokofiev in NY



Goniometer, integrated 10s
Binaural Lateral Fraction =0.39
R^2 = 0.40

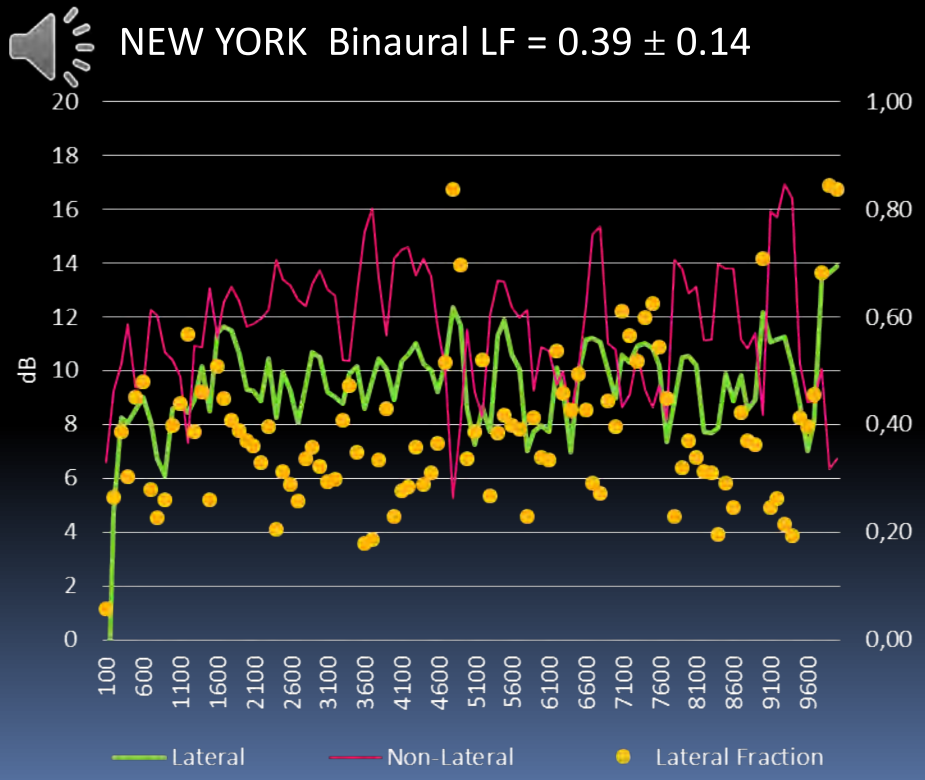


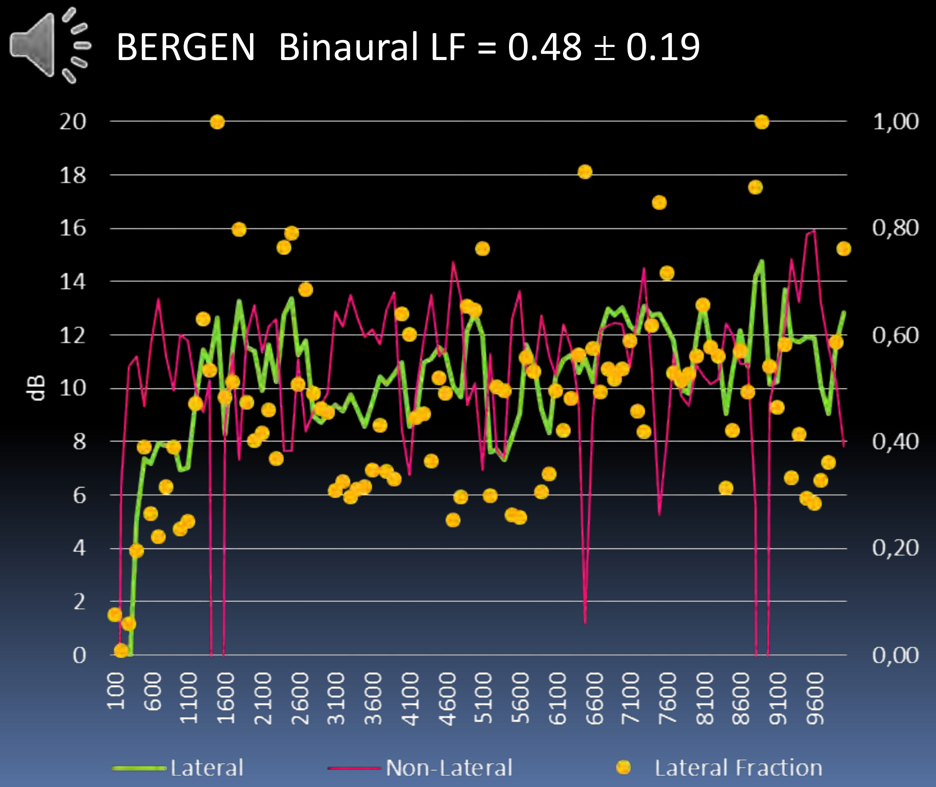
100ms frame at 3.7s,
Binaural Lateral Fraction =0.18
R^2 = 0.69



100ms frame at 4.8s,
Binaural Lateral Fraction =0.84
R^2 = 0.03

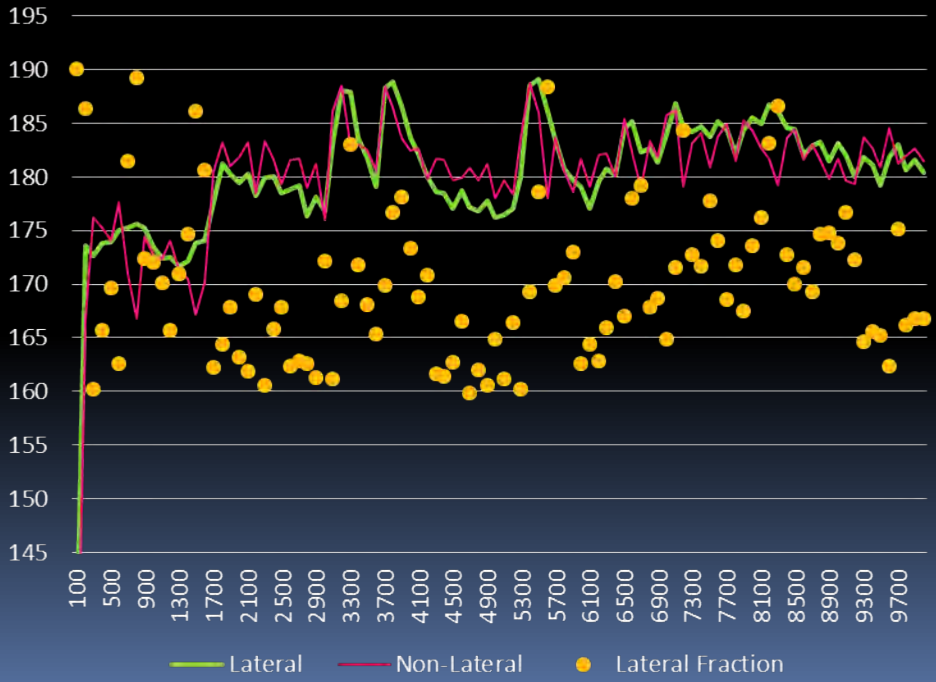
Prokofiev Dance of the Knights



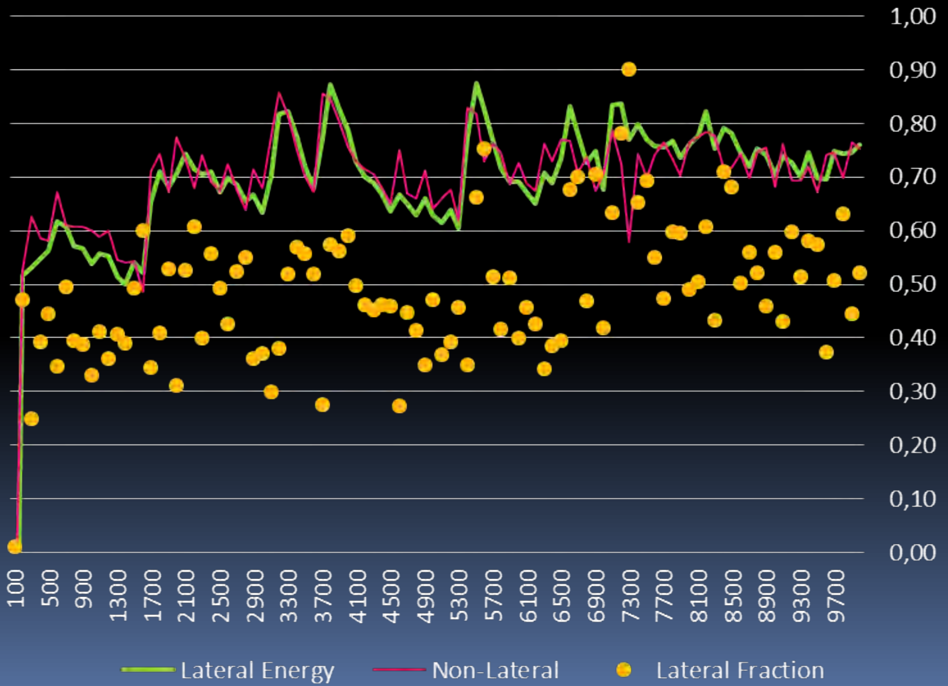


Stravinsky Rite of Spring

Binaural Lateral Fraction = 0.50 ± 0.14



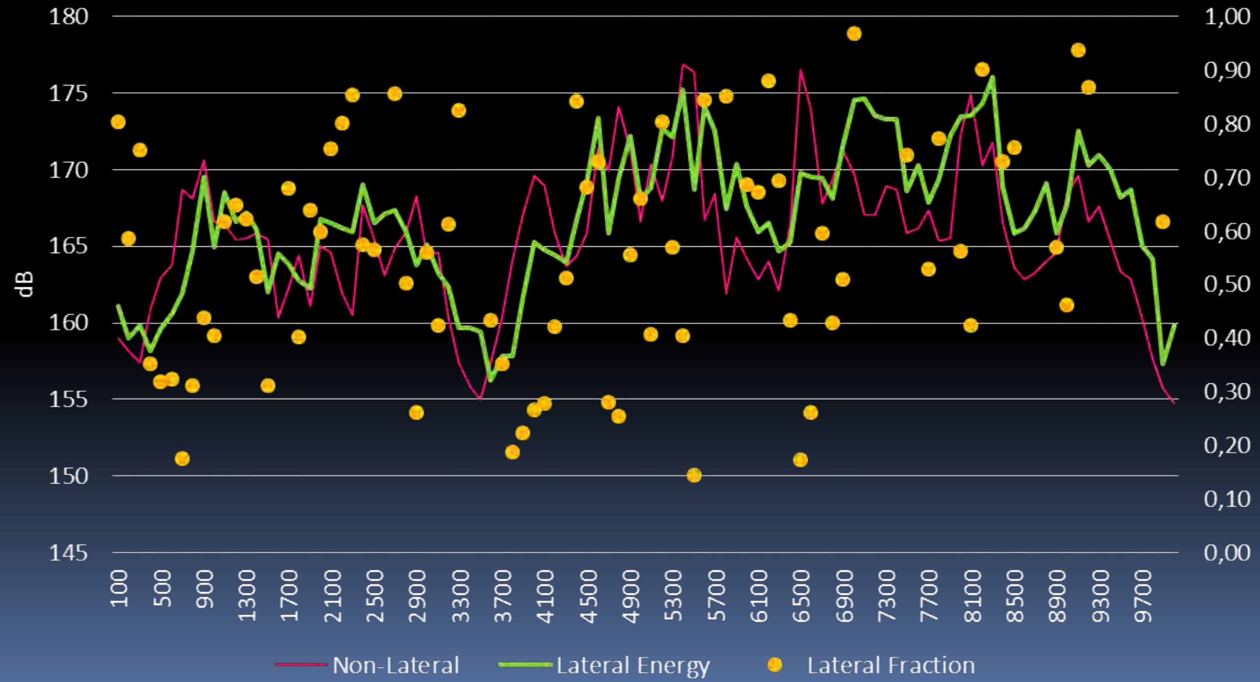
Binaural Lateral Fraction = 0.49 ± 0.13

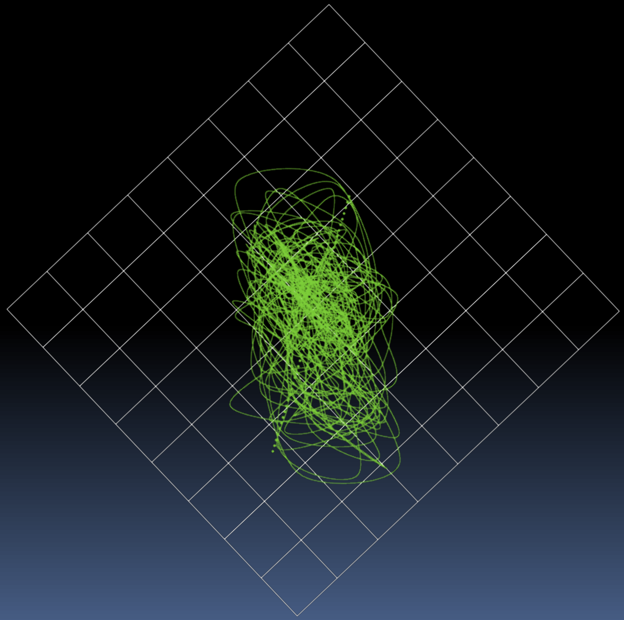


Solo play in Paris Philharmonie

From IR, stage to K-03:
1-IACCe = 0.51 ± 0.15
1-IACCL = 0.88 ± 0.02

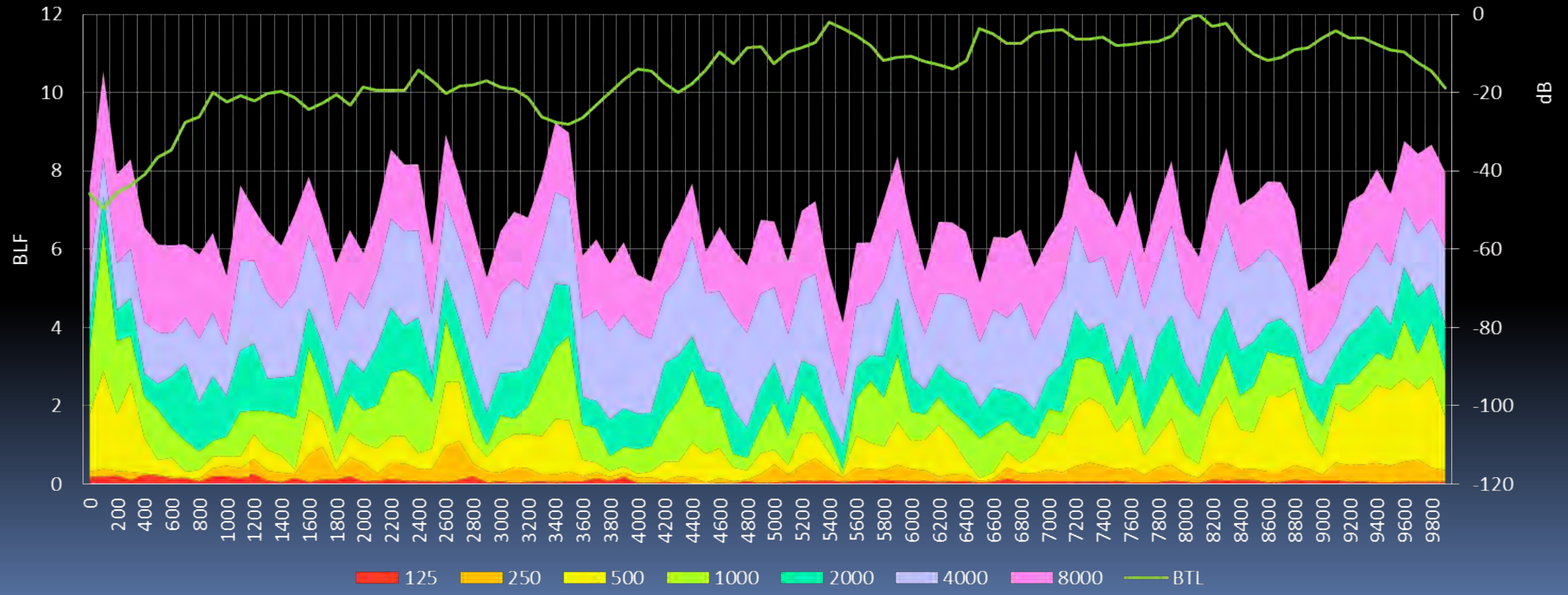
Stalls Row K seat 03
Binaural Lateral Fraction = 0.70 ± 0.33





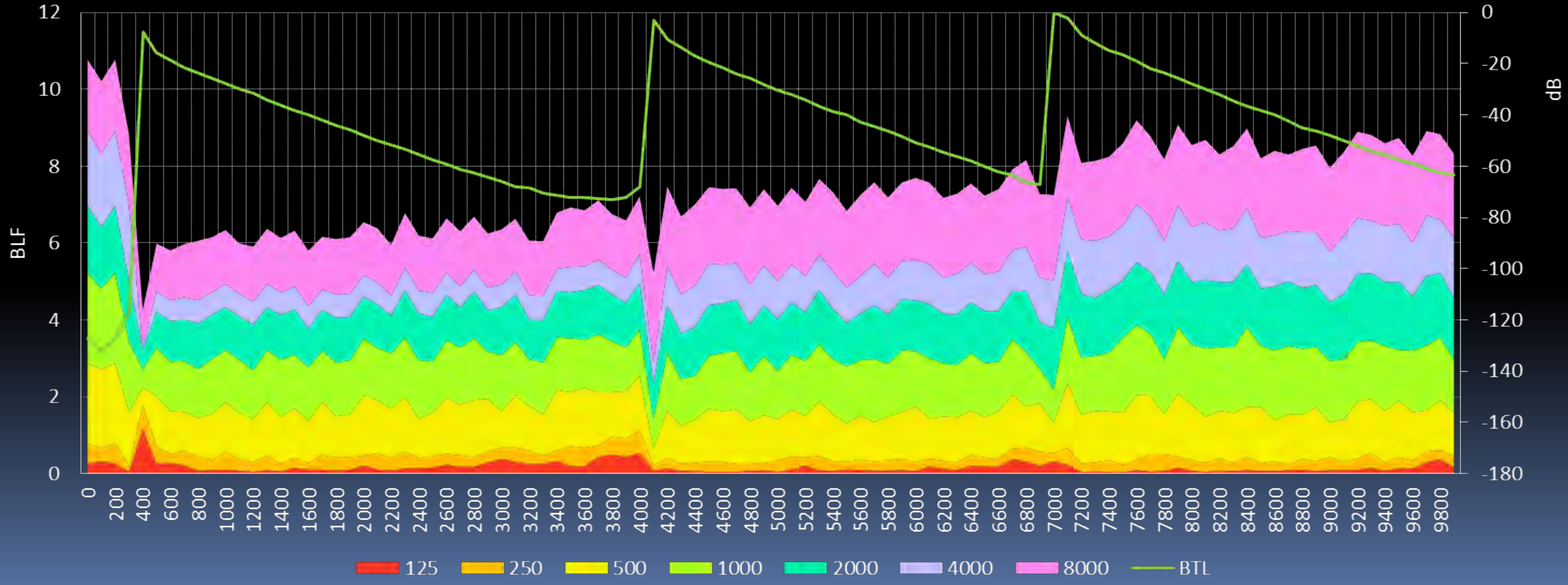
Testing sensitivity to transients

Echard plays in Philharmonie: Binaural Lateral Fractions stacked octave bands



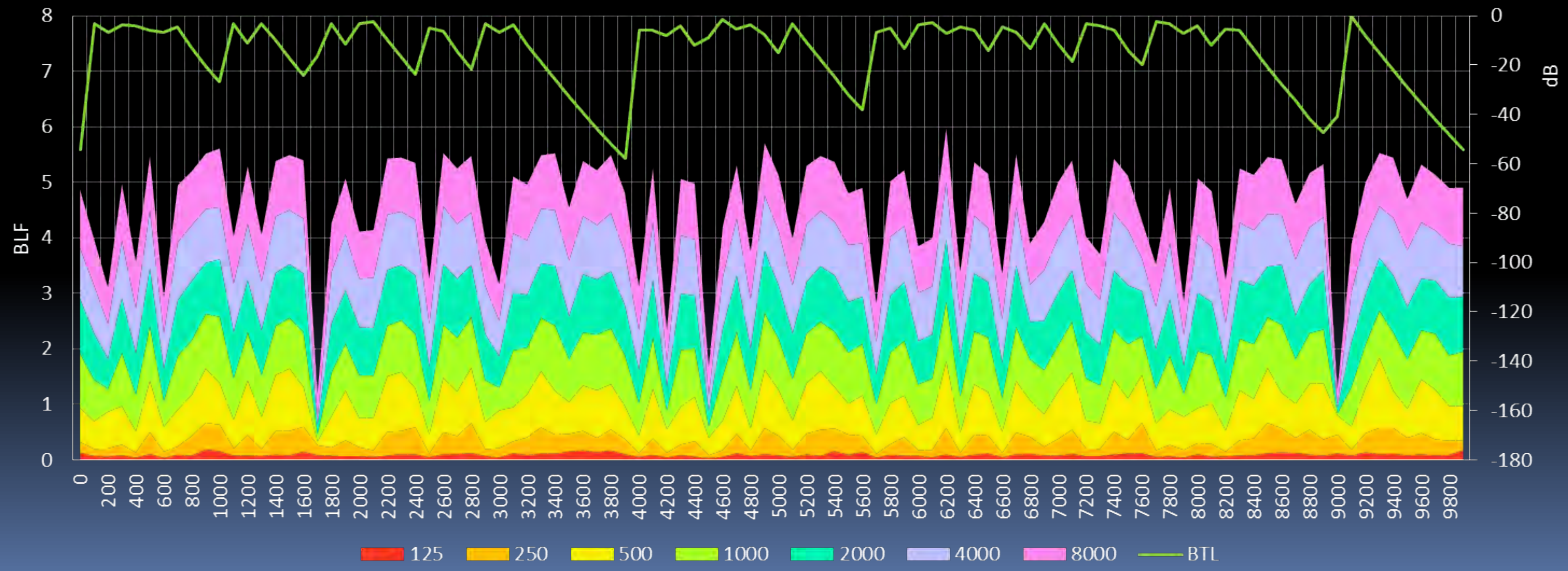
Testing sensitivity to transients

10s of 3 balloon bursts in Philharmonie: Binaural Lateral Fractions stacked octave bands



Testing sensitivity to transients

10s of 'Fireworks' in reverberant room: Binaural Lateral Fractions stacked octave bands



Doing the math

Given a sequence of n samples (1,2,..i,...,n) of a binaural signal pair from period T, sample rate n/T, and the i-th sample, pair is { L_i, R_i },

then the (normalized) Inter-Aural Cross-Correlation over a period T is

$$IACC = N/D \text{ , where}$$

$$N = \sum L_i \cdot R_i$$

$$D = \mathrm{sqrt}(\sum L_i^2 \cdot \sum R_i^2)$$

Note that D, the normalizer, is the product of the RMS of the L-signal and the RMS of the R-signal, over the period T

1-IACC relates to LF

The nominator $\sum L_i \cdot R_i$ can be obtained in different ways, e.g

$$L_i \cdot R_i = ¼ \cdot [(L_i + R_i)^2 - (L_i - R_i)^2]$$

or

$$L_i \cdot R_i = ½ \cdot [L_i^2 + R_i^2 - (L_i - R_i)^2]$$

If L and R are picked up by two closely spaced omni-mics, then

$(L_i - R_i)^2$ would be the figure-8-mic energy the Nominator of LF, and

$½ \cdot [L_i^2 + R_i^2]$ would be the omni-mic energy of the Denominator of LF

1-IACC relates to LF

For closely spaced pick-up of L and R,

$$L_i^{\,2} = R_i^{\,2}$$

and

$$sqrt(\sum L_i^2 \cdot \sum R_i^2) = \sum L_i^2$$

thus

$$\sum L_i{\cdot}R_i = \sum \tfrac{1}{2} \cdot [L_i^{\,2} + R_i^{\,2} - (L_i - R_i)^2] = \sum L_i^{\,2} - \tfrac{1}{2} \cdot \sum (L_i - R_i)^2$$

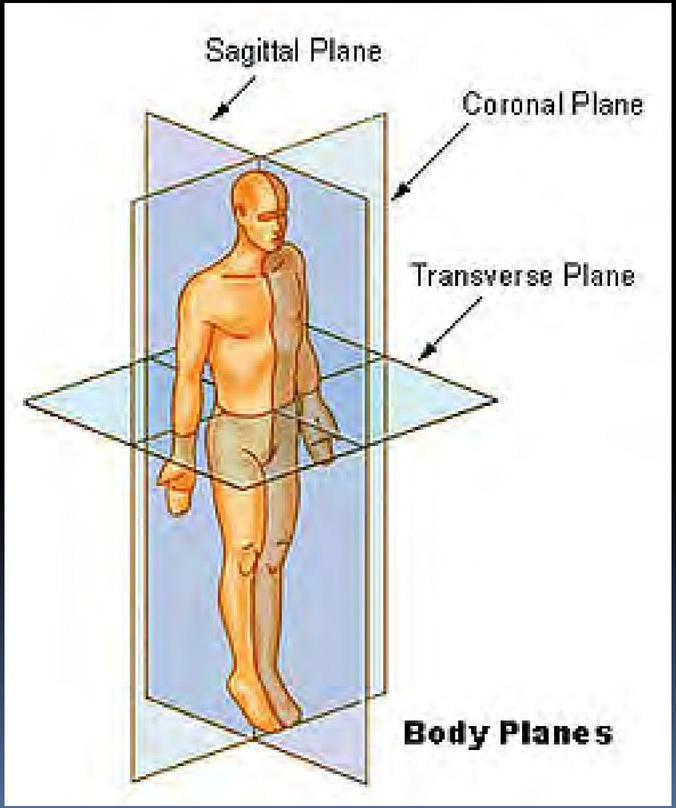
dividing by $\sum L_i^{\,2}$, rearranging and arriving at

$$\sum L_i{\cdot}R_i \;/ \sum L_i^{\,2} = 1 - \tfrac{1}{2} \cdot \sum (L_i - R_i)^2 / \sum L_i^{\,2}$$

Recognizing the correlation *r* on the left side

$$1 - r = \tfrac{1}{2} \cdot \sum (L_i - R_i)^2 / \sum L_i^{\,2}$$

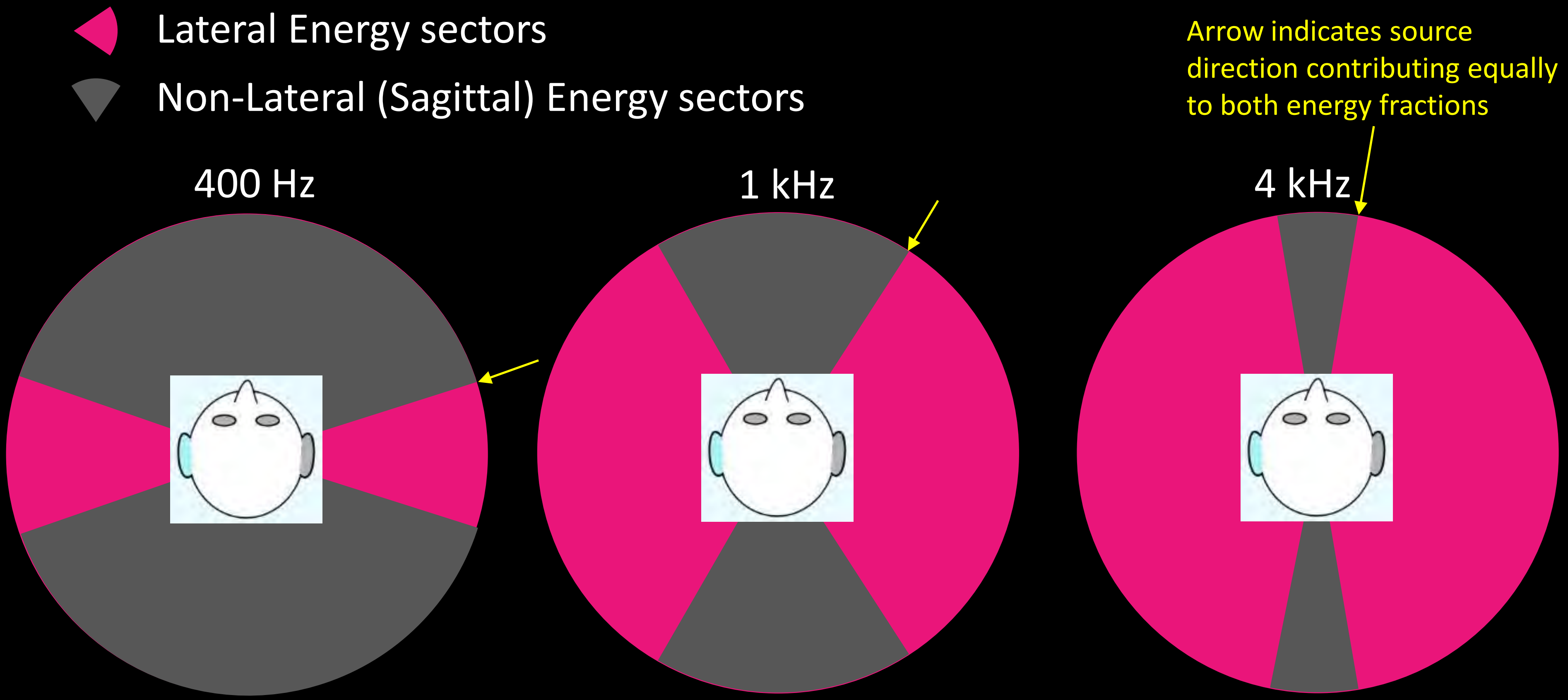
The Sagittal Plane



Non-Lateral Energy travels and arrives in or near the Sagittal Plane

Sagittal Energy = Non-Lateral Energy

Lateral Energy vs Non-Lateral Energy

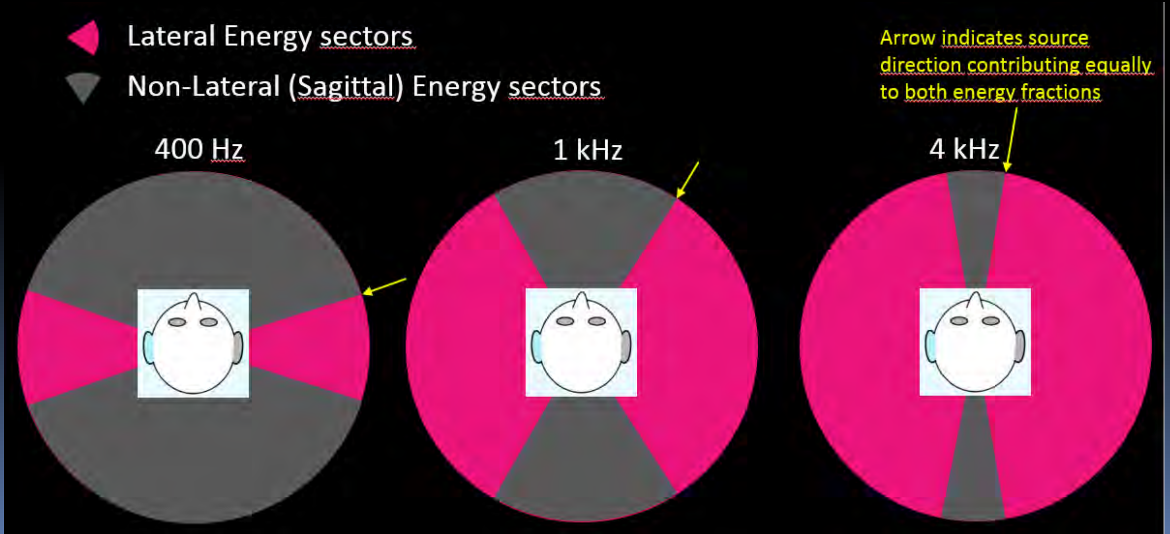


Lateral Energy vs Non-Lateral Energy

NOTE 1: Correlation and Lateral Energy Fraction in Mid-Frequencies is relevant to Spaciousness

NOTE 2: Low Frequency sounds «surround» the listener and would contribute to Spaciousness regardless of direction

NOTE 3: Above ca 1.5kHz our hearing change startegy to use ITD envelope ques and ILD (or IID) ques



Relevant spaciousness measures

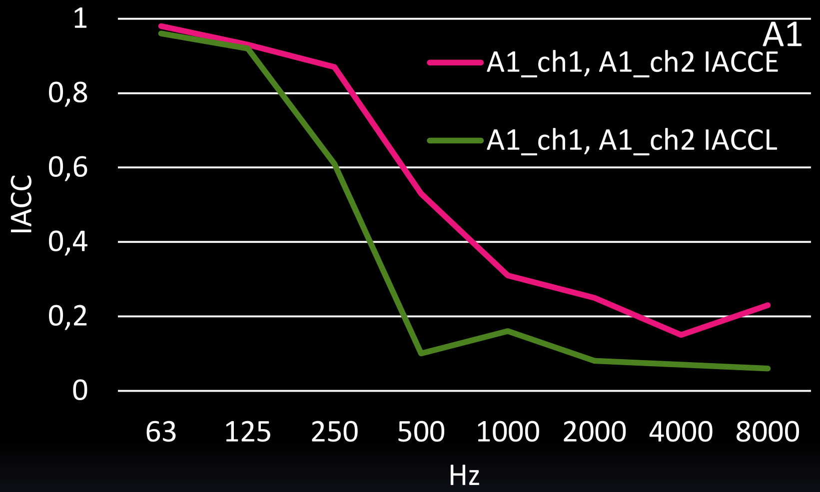
1-IACC and LF ≈ Lateral Energy normalized to Total Energy

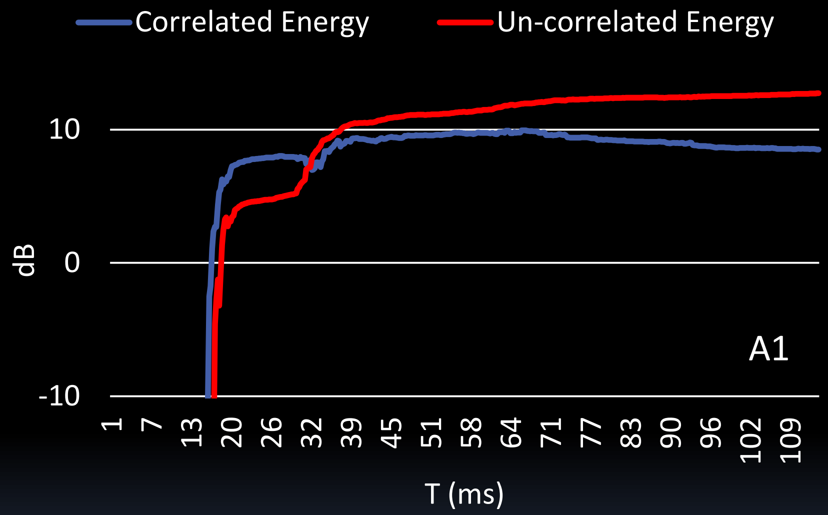
Measures defined for the purpose of the investigation:

Quantity	Notation [unit]	Formula
Binaural Total Energy Level	BTL (T,t) [dB]	$10 \lg [L^2 + R^2]$
Binaural Lateral Energy Level	BLL (T,t) [dB]	$10 \lg [(L - R)^2]$
Binaural Sagittal Energy Level*	BSL (T,t) [dB]	$10 \lg [L^2 + R^2 - (L - R)^2]$
Binaural Lateral Energy Fraction	BLF (T,t) [1]	$(L - R)^2 / (L^2 + R^2)$

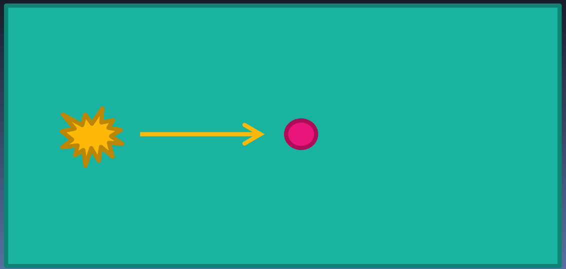
*Sagittal Energy = Total Energy – Lateral Energy

BRIR: IACC and buildup of Lateral and Non-Lateral Energies

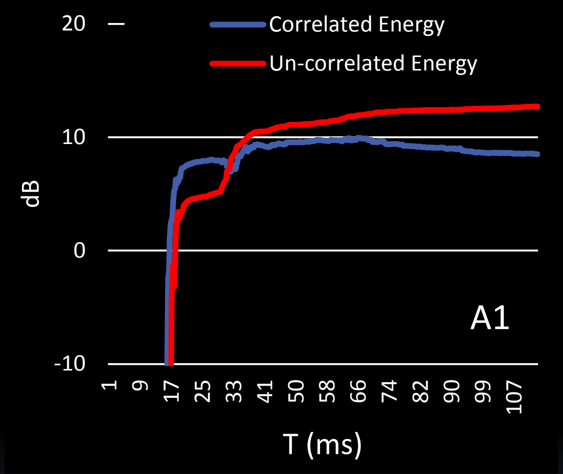


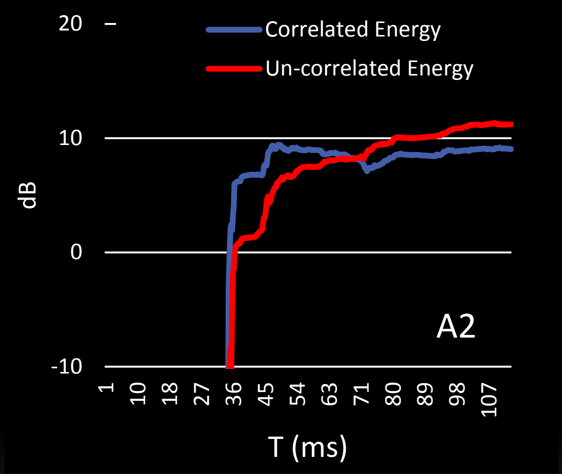


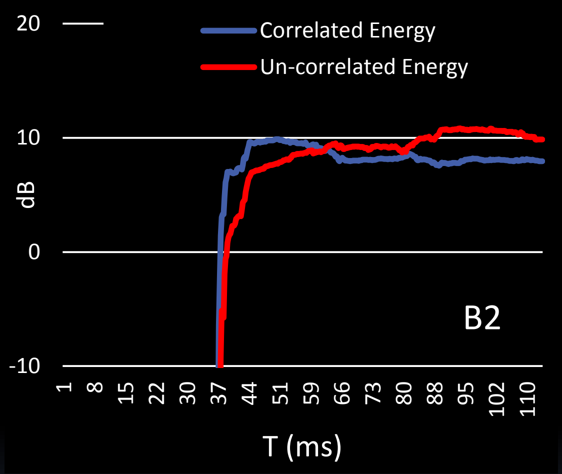
IACCE = 0.36
IACCL = 0.11

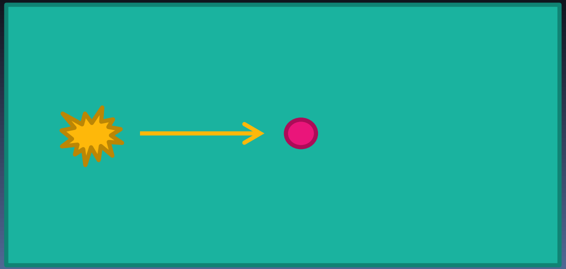


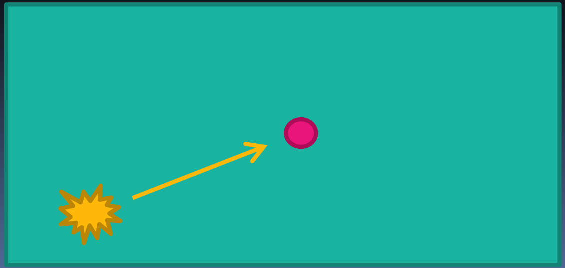
BRIR Buildup of Lateral and Non-Lateral energies

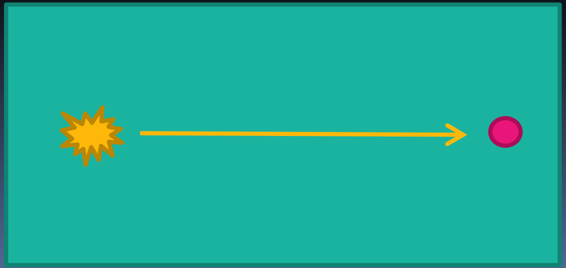












Further work

- Determine optimum T: 33ms, 50ms, 80ms, 100ms?
- Searching for ques of Source Broadening
- Data collection
- More testing of Spaciousness-relevant measures
- Goal: To arrive at a technique that measures significant differences between rooms that we know have significantly different Spaciousness parameter values according to ISO-3382-1

Link to online paper

Thank you

More info?

The www center for search, research and open sources in acoustics

www.akutek.info

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