PHOnA: A Public Dataset of Measured Headphone Transfer Functions

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PRINCETON UNIVERSITY

Headphone equalization

- Diffuse-field or free-field
- Binaural requires transparency

In theory

Y_1 = (Speaker Sig.) X (HRTF) X (Mic Response)

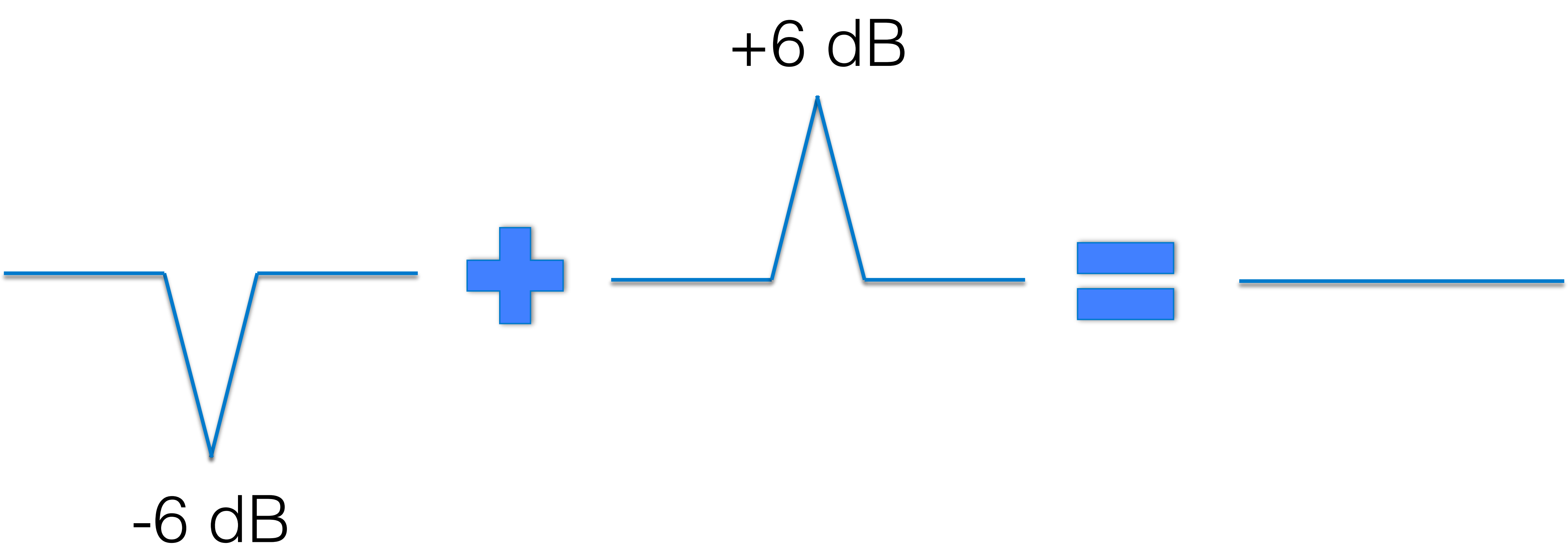
Y_2 = (Headphone Sig.) X (HpTF) X (Mic Response)

So if

(Headphone Sig.) = (Speaker Sig.) X (HRTF/HpTF)

⇨ $Y_2 = Y_1$

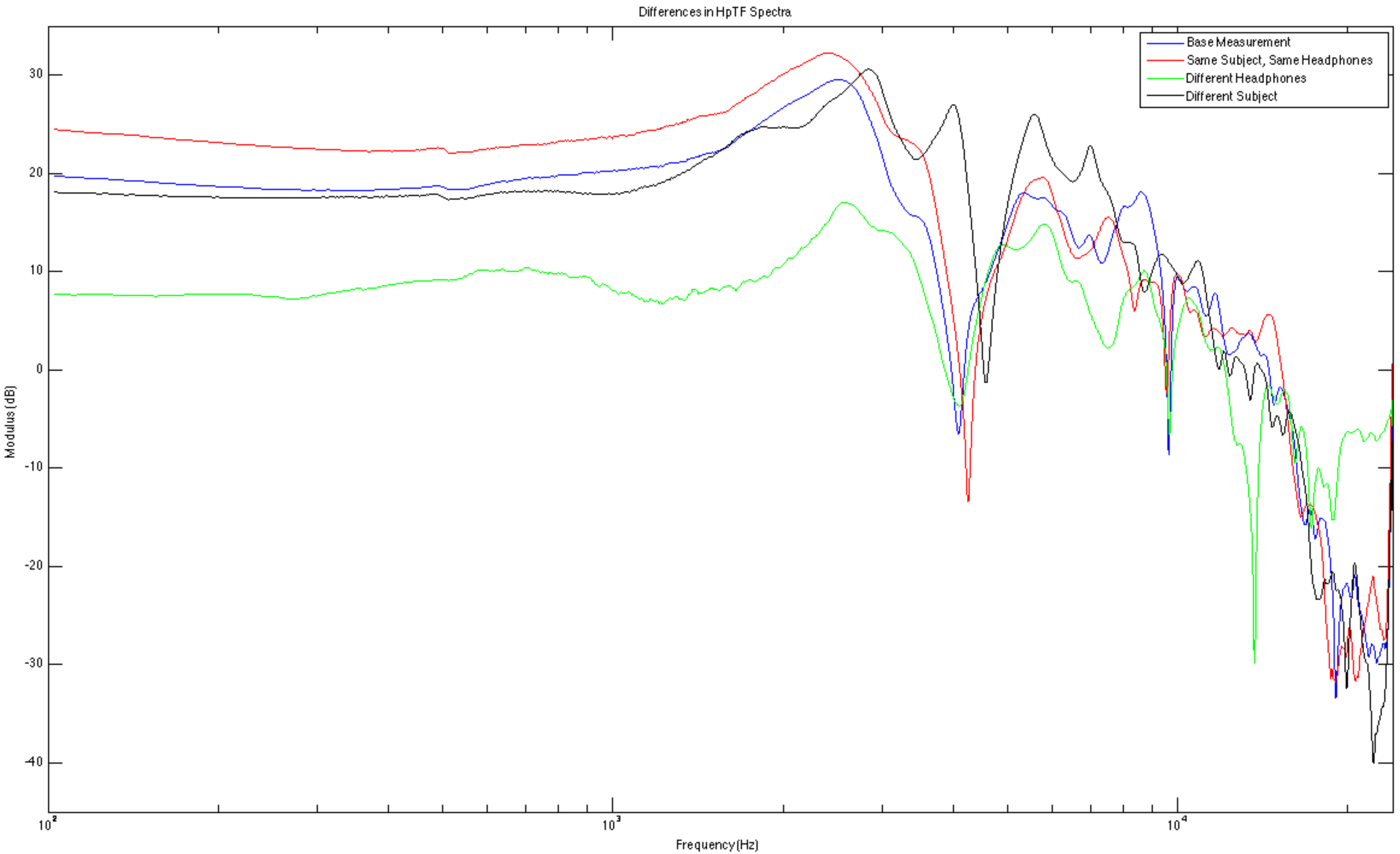
Ideal inverse filtering



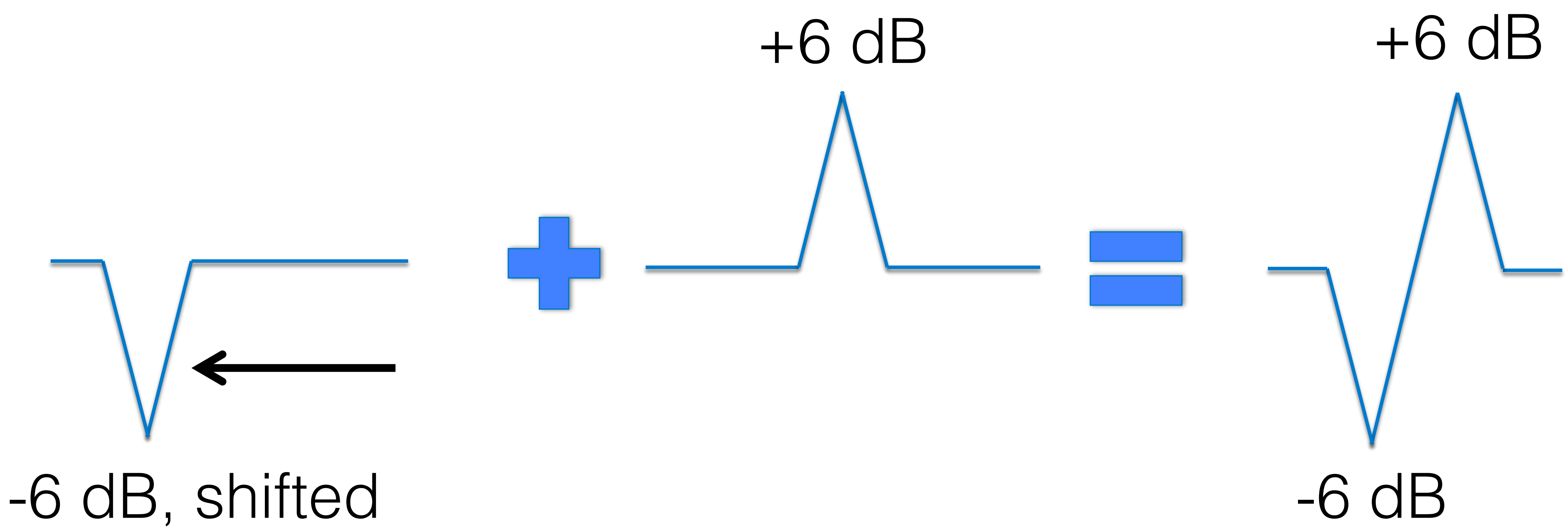
In practice

Spectrum changes with

- Different headphones (inter-headphone variation)
- Different subjects (inter-subject variation)
- Different fittings (intra-subject variation)


Differences in HpTF Spectra
Base Measurement
Same Subject, Same Headphones
Different Headphones
Different Subject
30
20
10
0
-10
-20
-30
-40
Modulus (dB)
10^2
10^3
10^4
Frequency (Hz)

Realistic inverse filtering



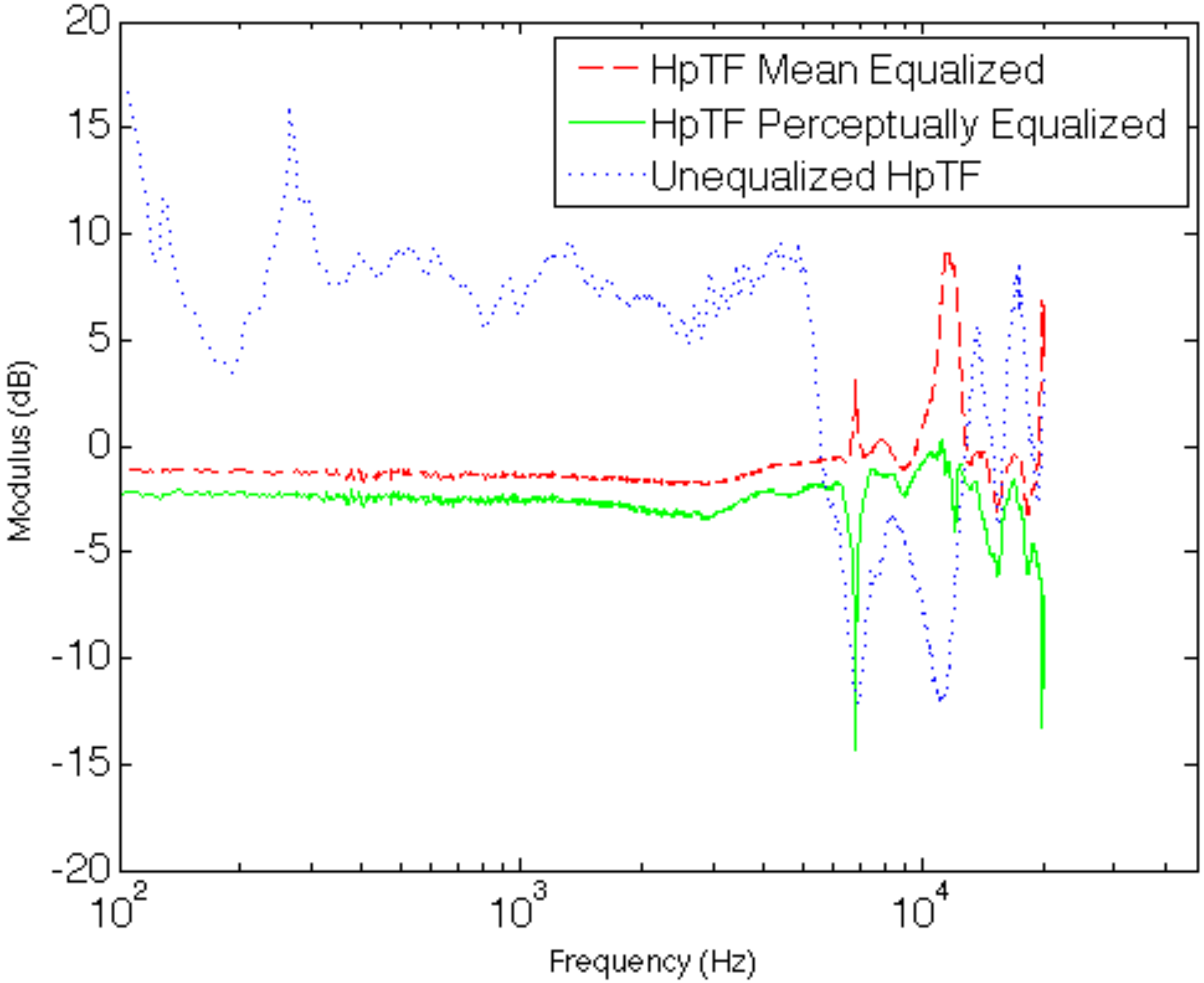
Practical headphone EQ

- Remove mic responses
- Account for variations
- Reduce peaks (‘ringing’) in inverse filter

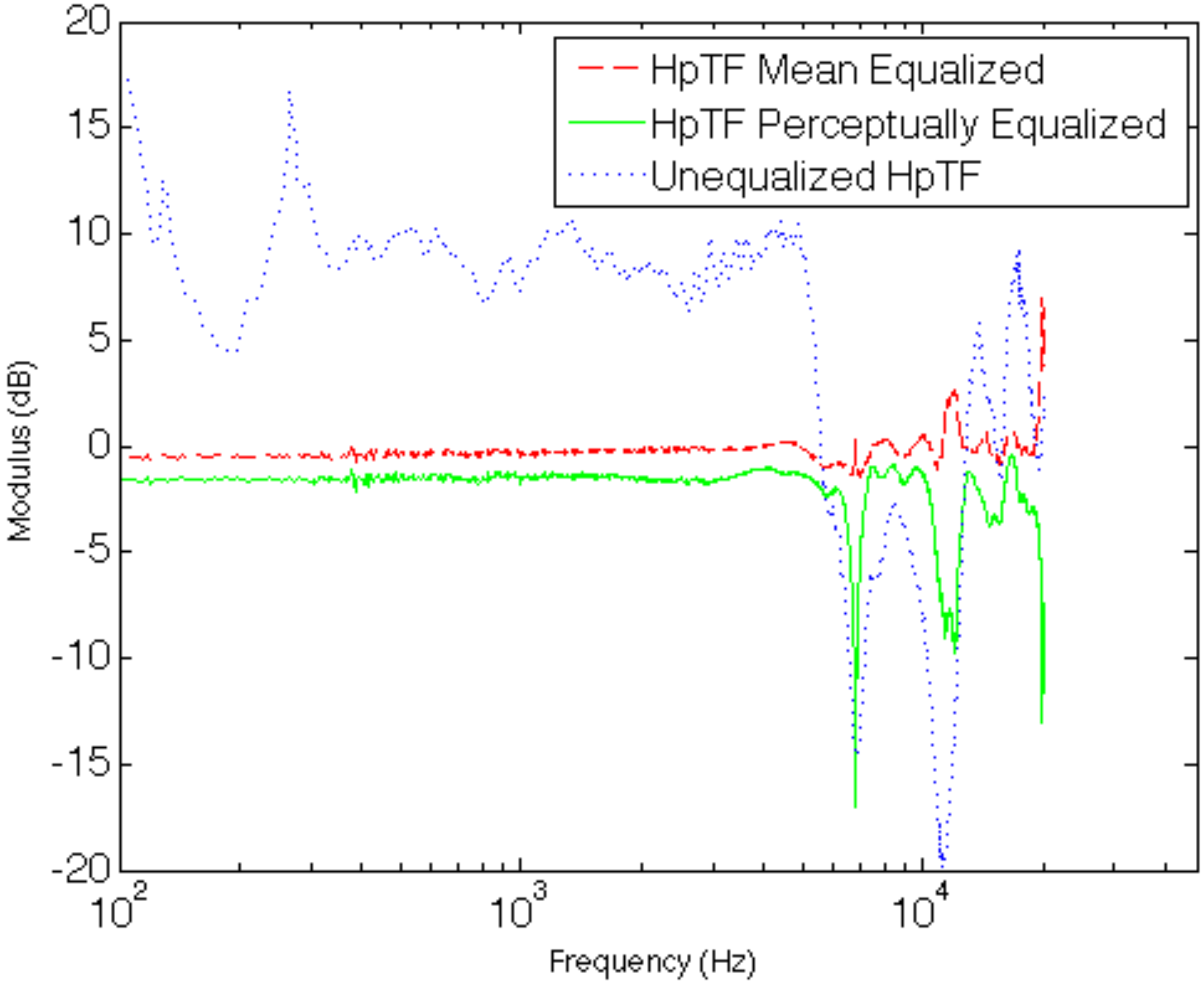
Existing EQ algorithms

- Mean response of many measurements
- Peak compression (Hiekkanen et al, 2009)
- Perceptual inversion (Masiero et al, 2011)
- Regularization techniques (Lindau et al, 2012)

Peaks vs. notches



Peaks vs. notches



The last 20 years

Many labs have studied HpTF variance

- Measured a database
- Proposed an algorithm
- Drawn (different) conclusions

Moving forward

Goals:

- Universal HpTF format
- Assemble HpTF database
- Compare algorithms

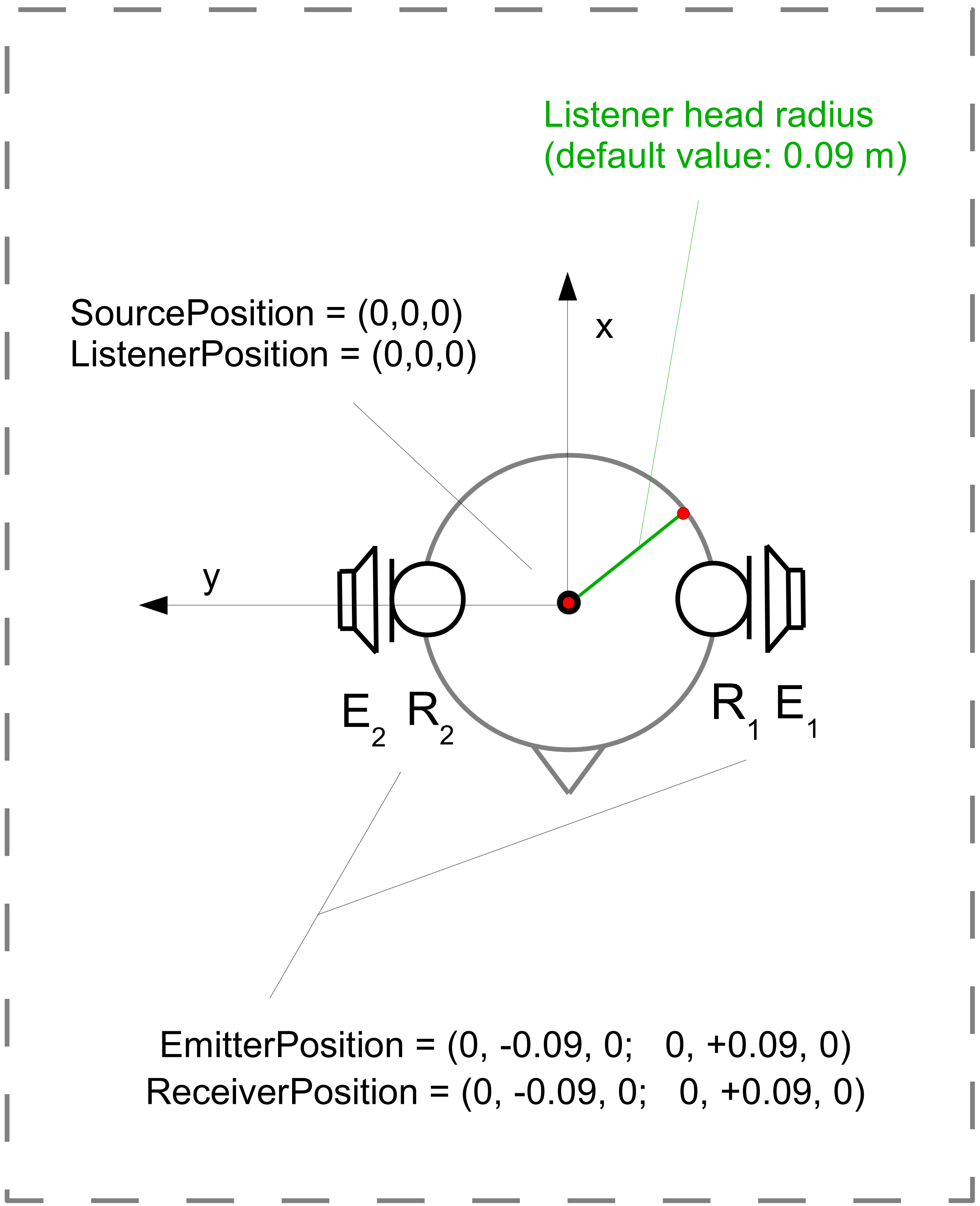
Data format

Different HRTF formats led to SOFA (Majdak et al, 2013)

- Interchangeability
- Efficient metadata storage
- Objects *listener* and *source*

Data format

- Use SOFA for HpIRs
- Prototype HpIR convention, *HeadphoneIR* now available with SOFA v. 0.4.3
- *SimpleHeadphoneIR* under development


Listener head radius
(default value: 0.09 m)
SourcePosition = (0,0,0)
ListenerPosition = (0,0,0)
x
y
E2 R2
R1 E1
EmitterPosition = (0, -0.09, 0; 0, +0.09, 0)
ReceiverPosition = (0, -0.09, 0; 0, +0.09, 0)

Princeton Headphone Open Archive (PHOnA*)

- HpTFs from 6 institutions
  - 226 subjects
  - 1-3 headphones per subject
  - 5-20 fittings per subject

* available at www.princeton.edu/3D3A/Phona.html

PHOnA databases

Institution	Subjects	Headphones	Fittings per subject
ARI Austria	120	1	5
DSTO Australia	3	1	20
ITA Aachen	15	2	8*
Princeton 3D3A	4	1	20
TU Berlin	66	1	10
University of Padova	18	3	10

*4 normal measurements, and 4 extreme measurements

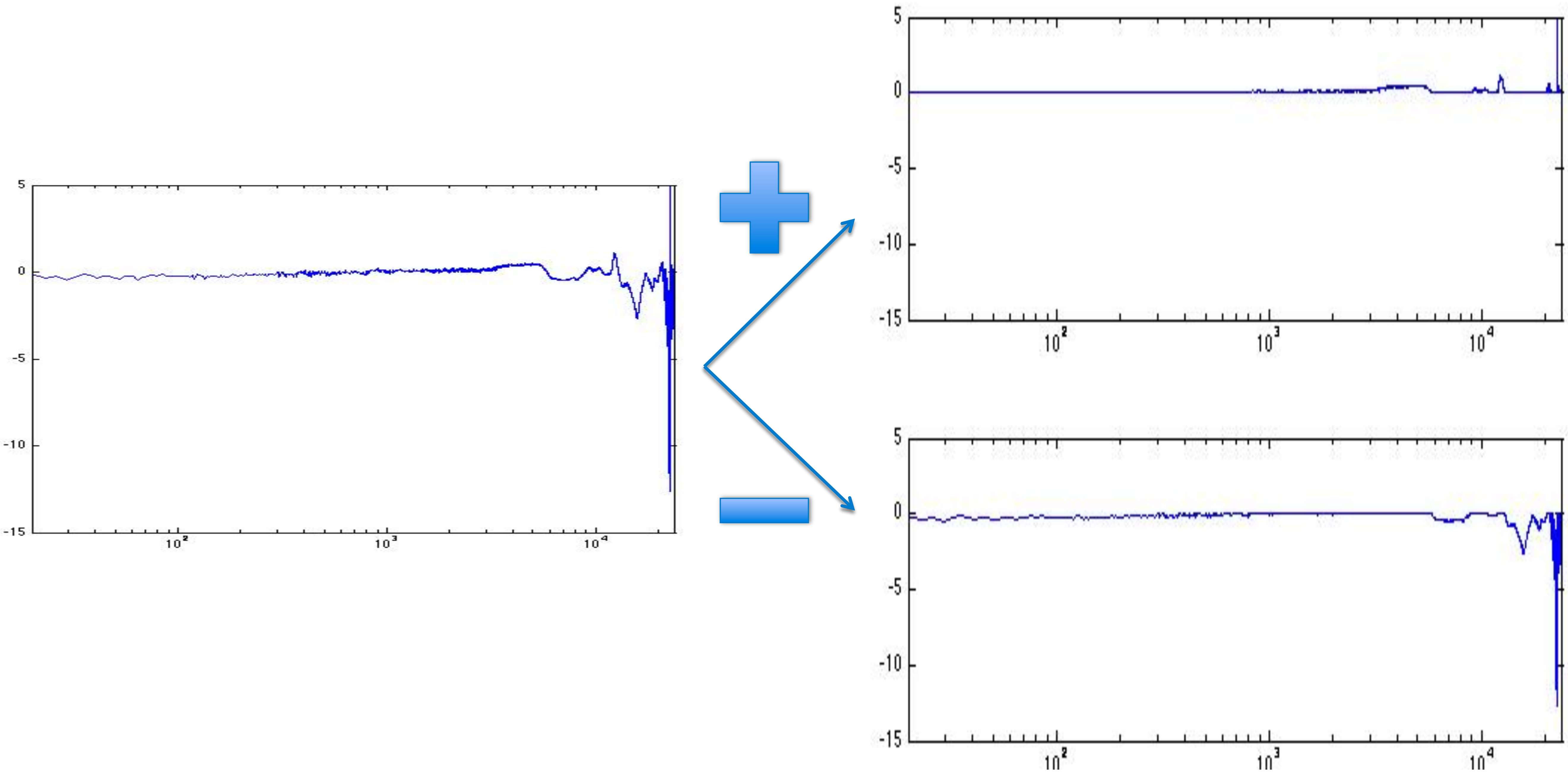
PHOnA features

- Mic-compensated and raw HpIRs
- *HeadphoneIR* SOFA format
- MATLAB code for searching by database, headphone, and ear condition (blocked/open)

Metric for EQ performance

- Peaks worse than notches
- Wider is more noticeable
- Quantify post-EQ spectral coloration

Coloration index C



Coloration index C

Starting with power spectrum H,

$$H_+ = \max(H, 0),$$
$$H_- = \text{abs}(\min(H, 0))$$

$$C_{-/+} = \sum_{f=20}^{20000} \left(\frac{H_{-/+}(f) + H_{-/+}(f + \Delta f)}{2} \right) \log_{10} \left(\frac{f + \Delta f}{f} \right)$$

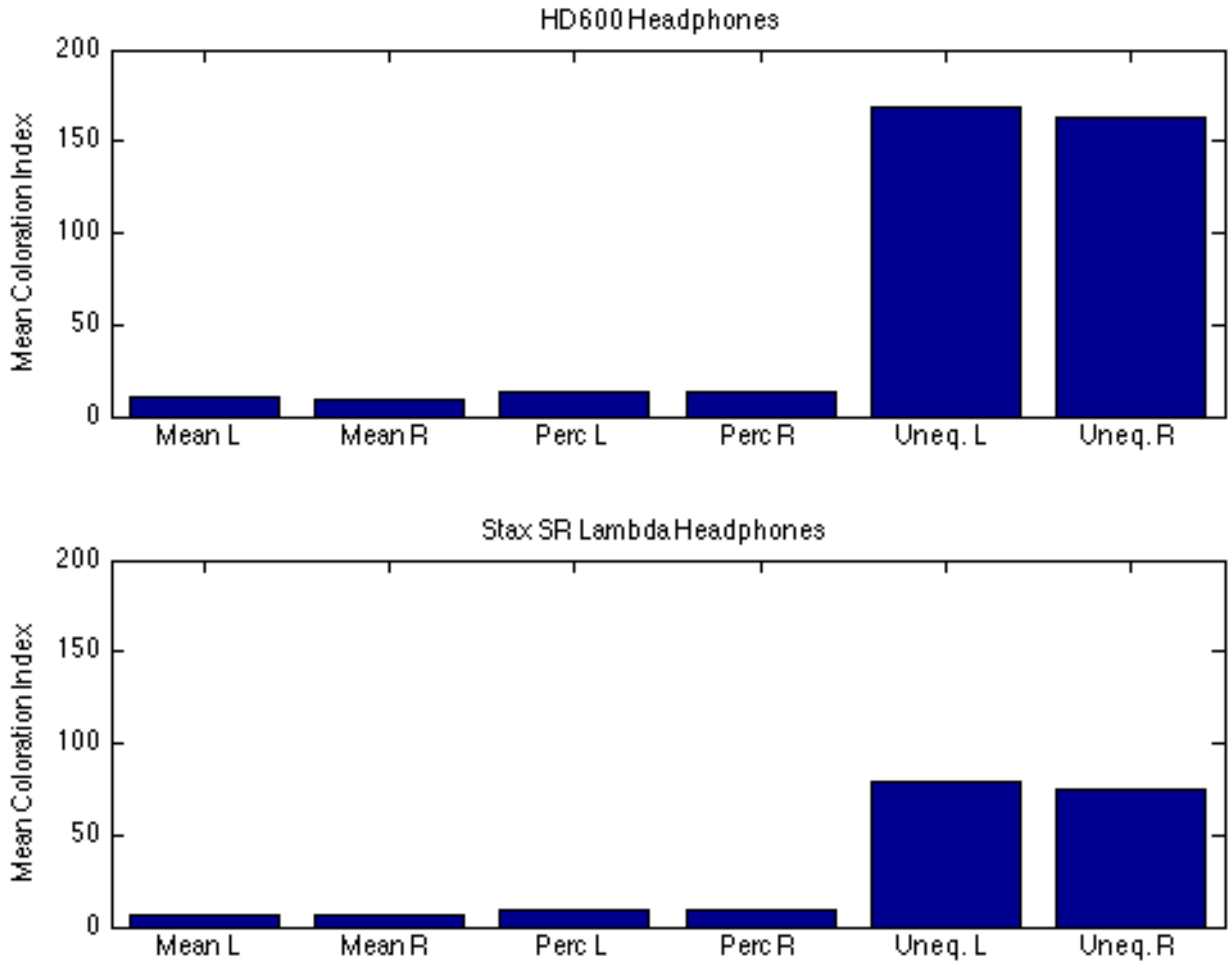
$$C = C_- + 3C_+$$

EQ Comparison

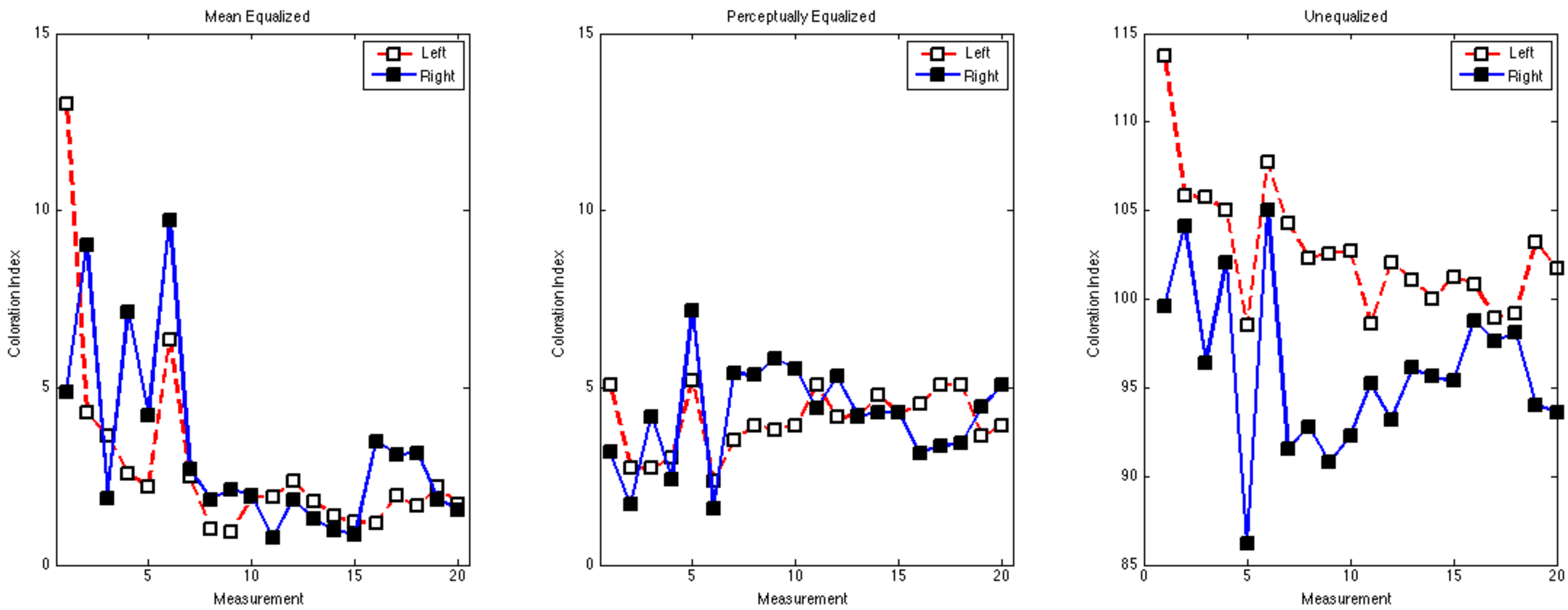
Examined

- Mean inverse filter (L&R)
- Masiero's perceptual inverse filter (L&R)
- No equalization (L&R)

Coloration by headphones



Robustness of EQ



Preliminary Findings

- Mean filters: lower average coloration
- Perceptual filters: lower coloration variance

Future work

- Developing an auditory filter model of coloration
- Large-scale comparison of current algorithms
- Apply machine learning to optimizing
    - Headphone-specific filters
    - Listener-specific filters

Acknowledgements

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Questions?