Computational Perception

15-485/785

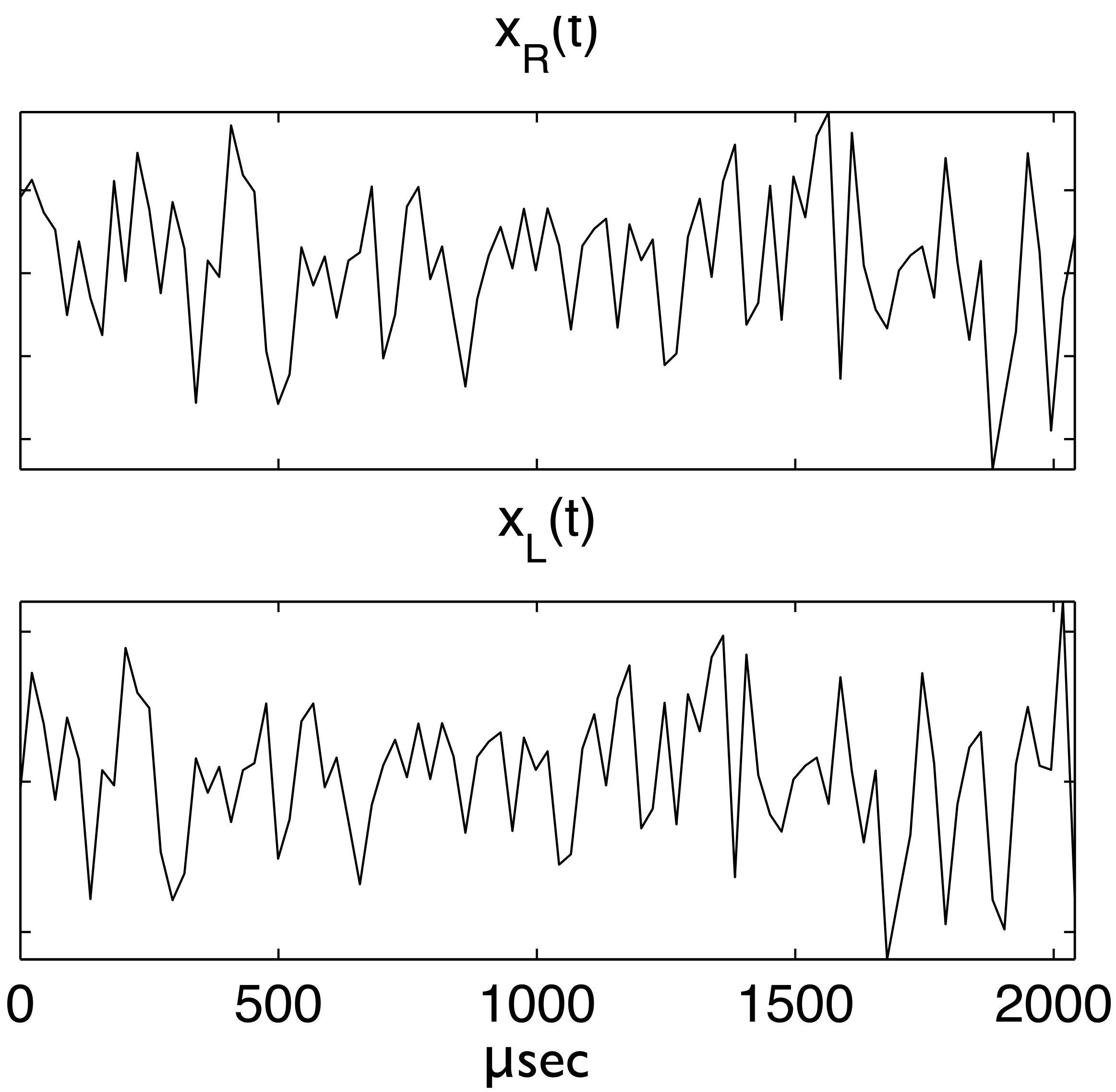
January 22, 2008

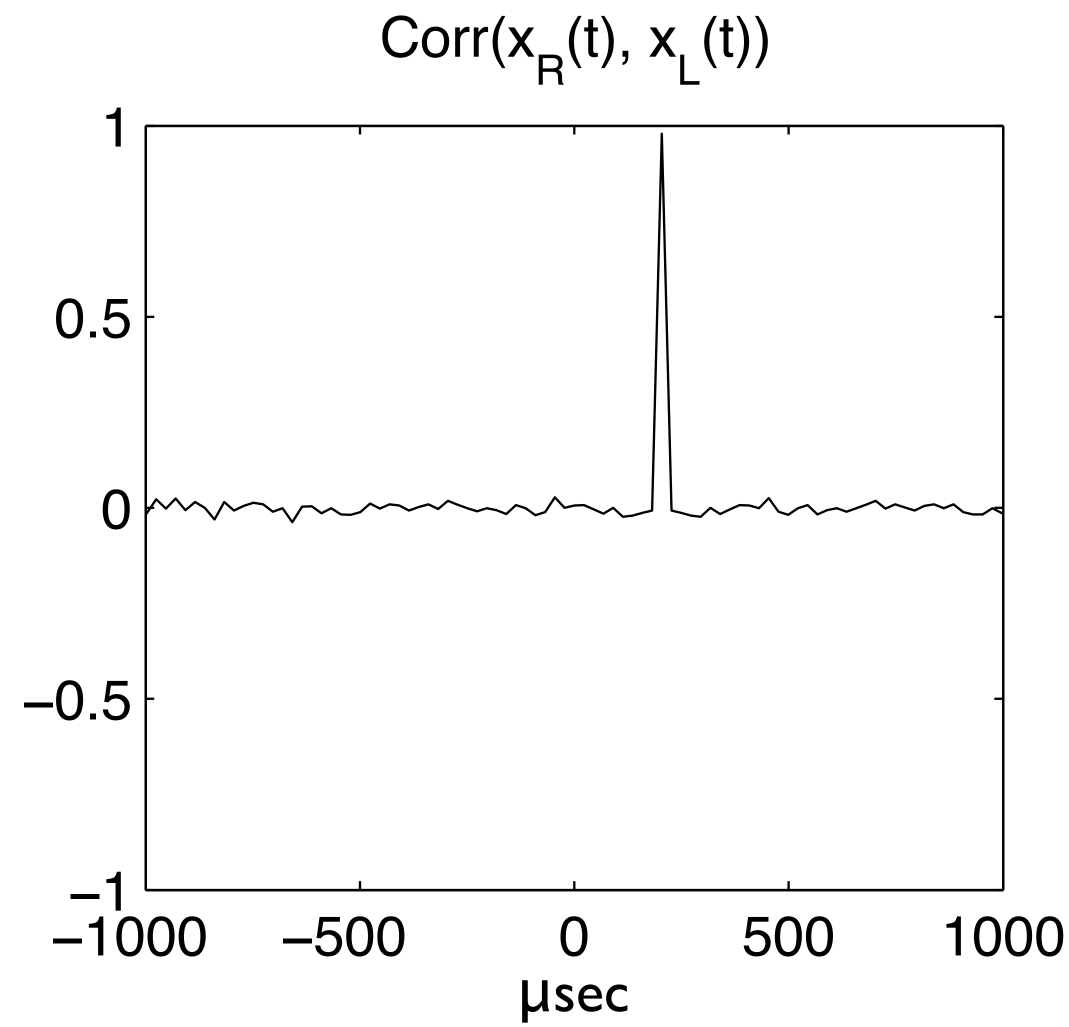
Sound localization 2

Last lecture

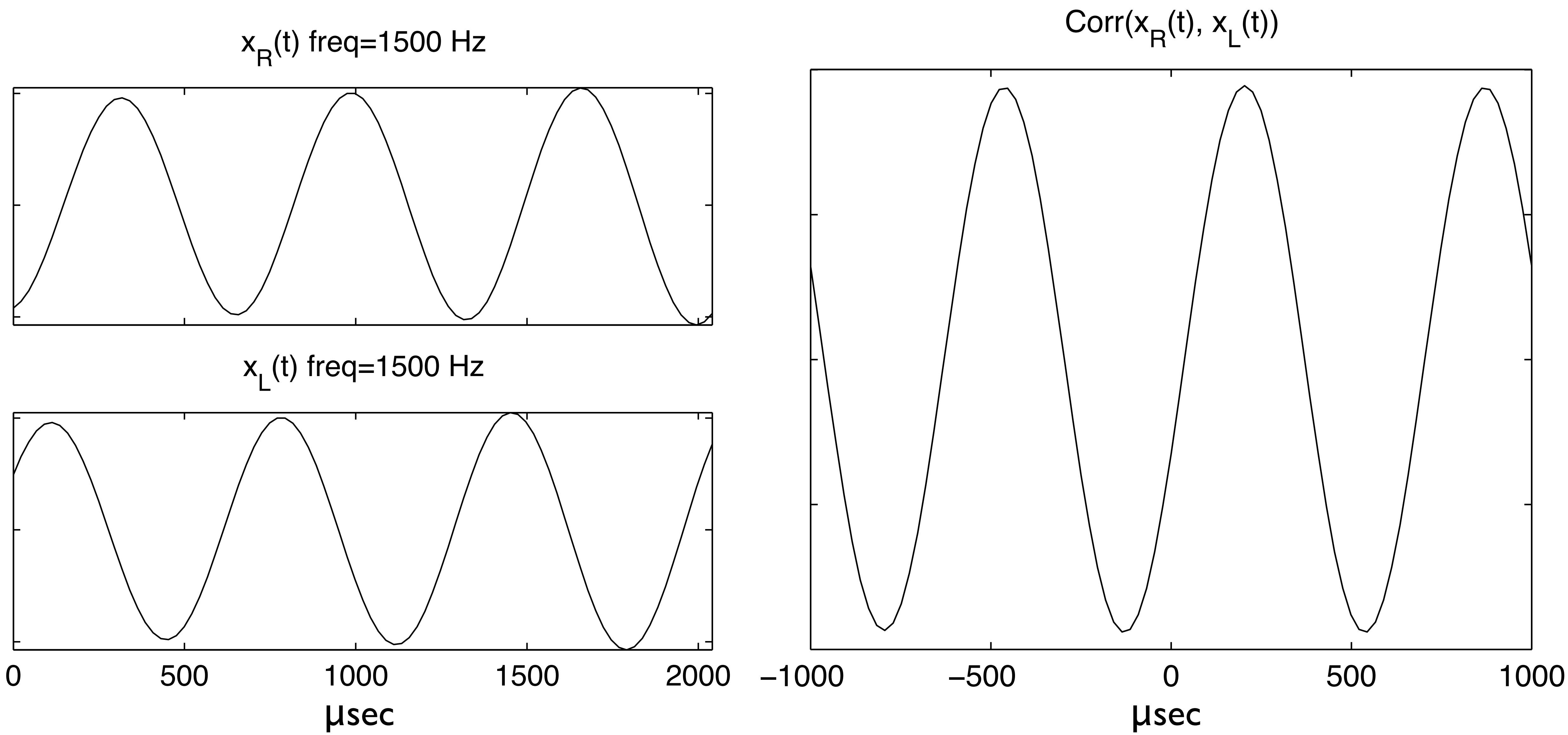
- sound propagation: reflection, diffraction, shadowing
- sound intensity (dB)
- defining computational problems
- sound lateralization
- ITD and IIDs
- duplex theory
- localization acuity, minimum audible angle
- estimating ITD, cross correlation

Cross correlation of white noise





Cross correlation of a high frequency tone



This is called *phase ambiguity* because there are multiple peaks within the natural range of ±690 μsecs.

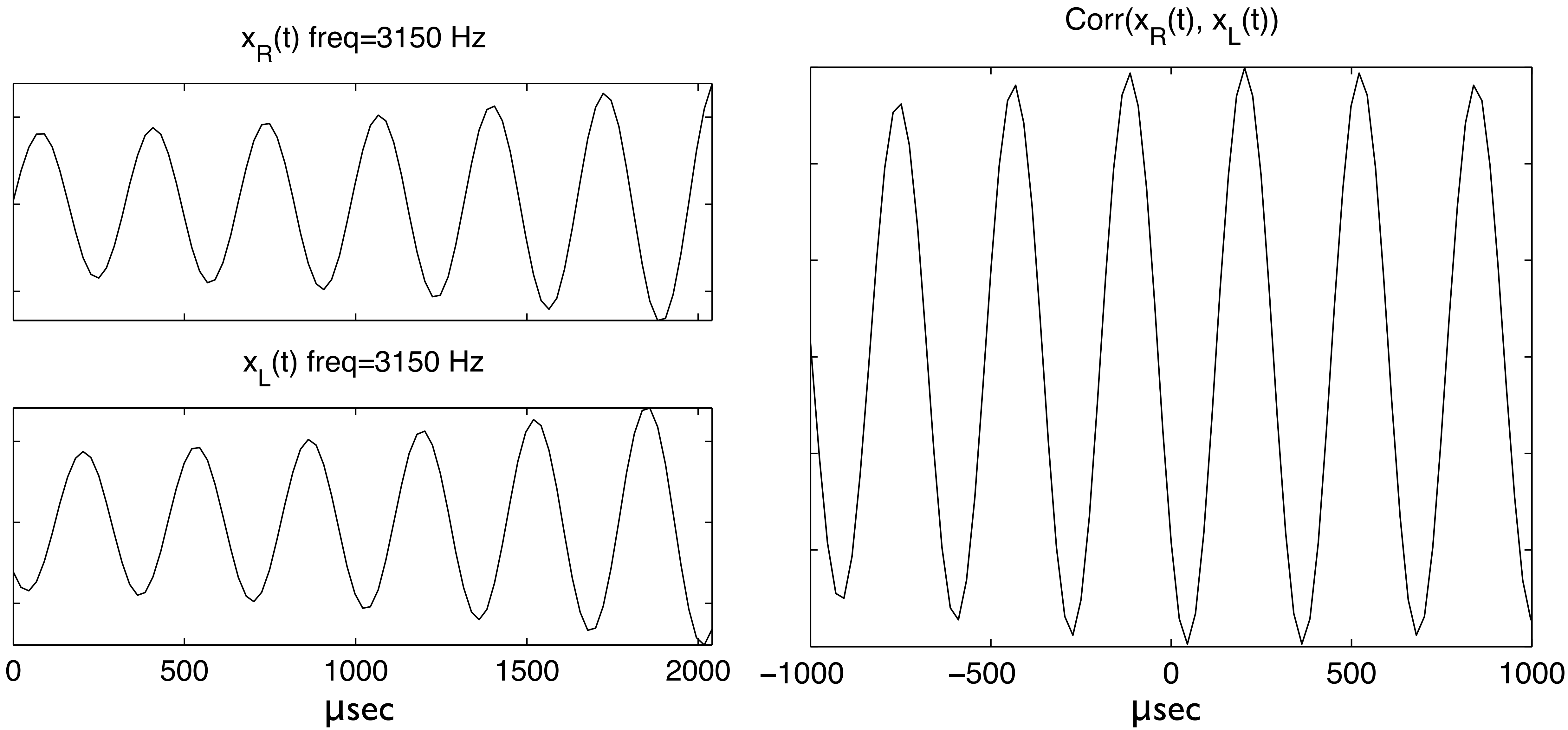
Testing the duplex theory

- Pure tones are ineffective for lateralization > 1500 Hz.
  - *Does this mean all sounds are?*

- Consider bandpass noise: 3000-3300 Hz
  - *How would you perceive this sound?*

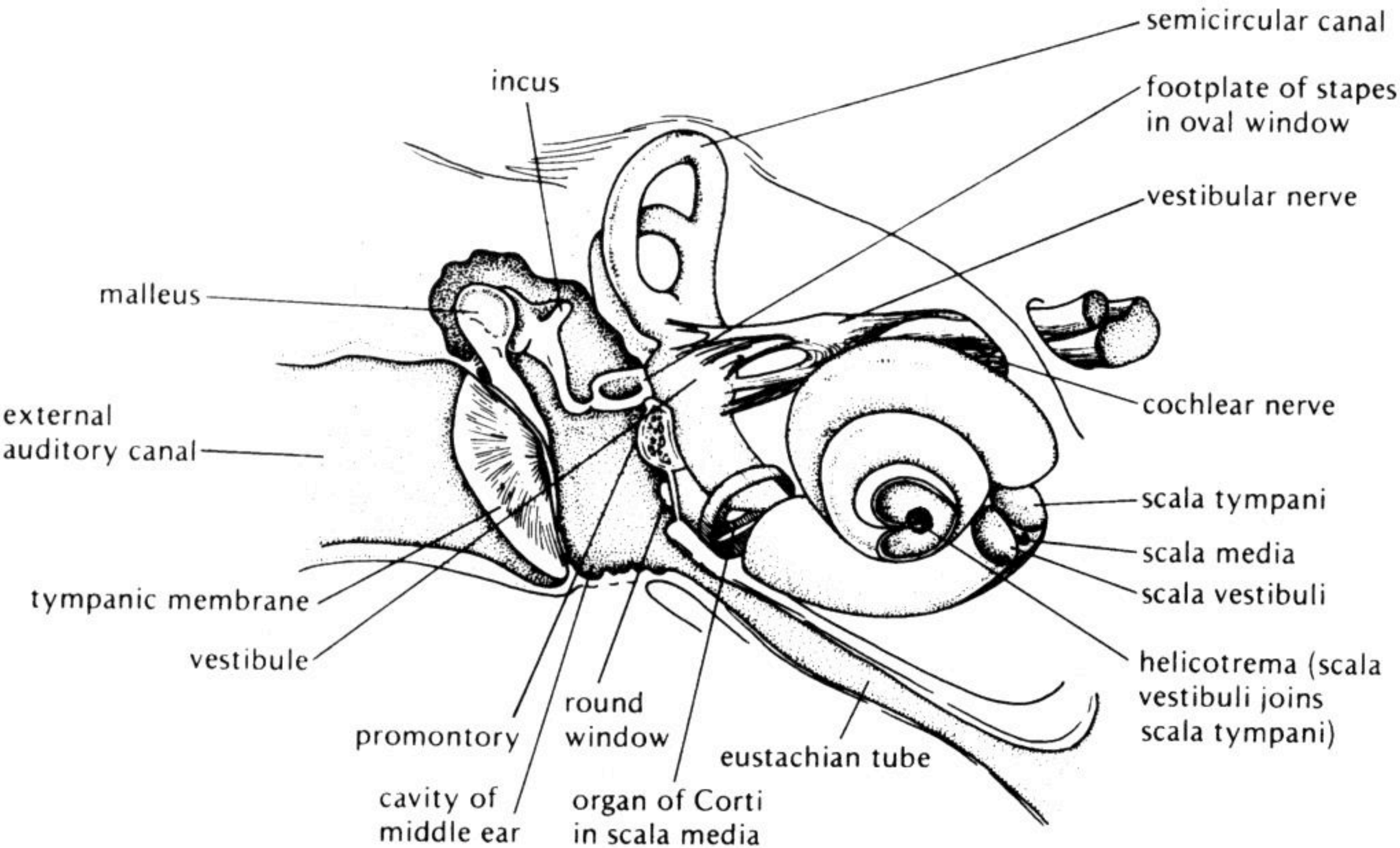
- Sound is correctly localized, but with greater error (60 μsecs vs 10).

Cross correlation of a high frequency tone



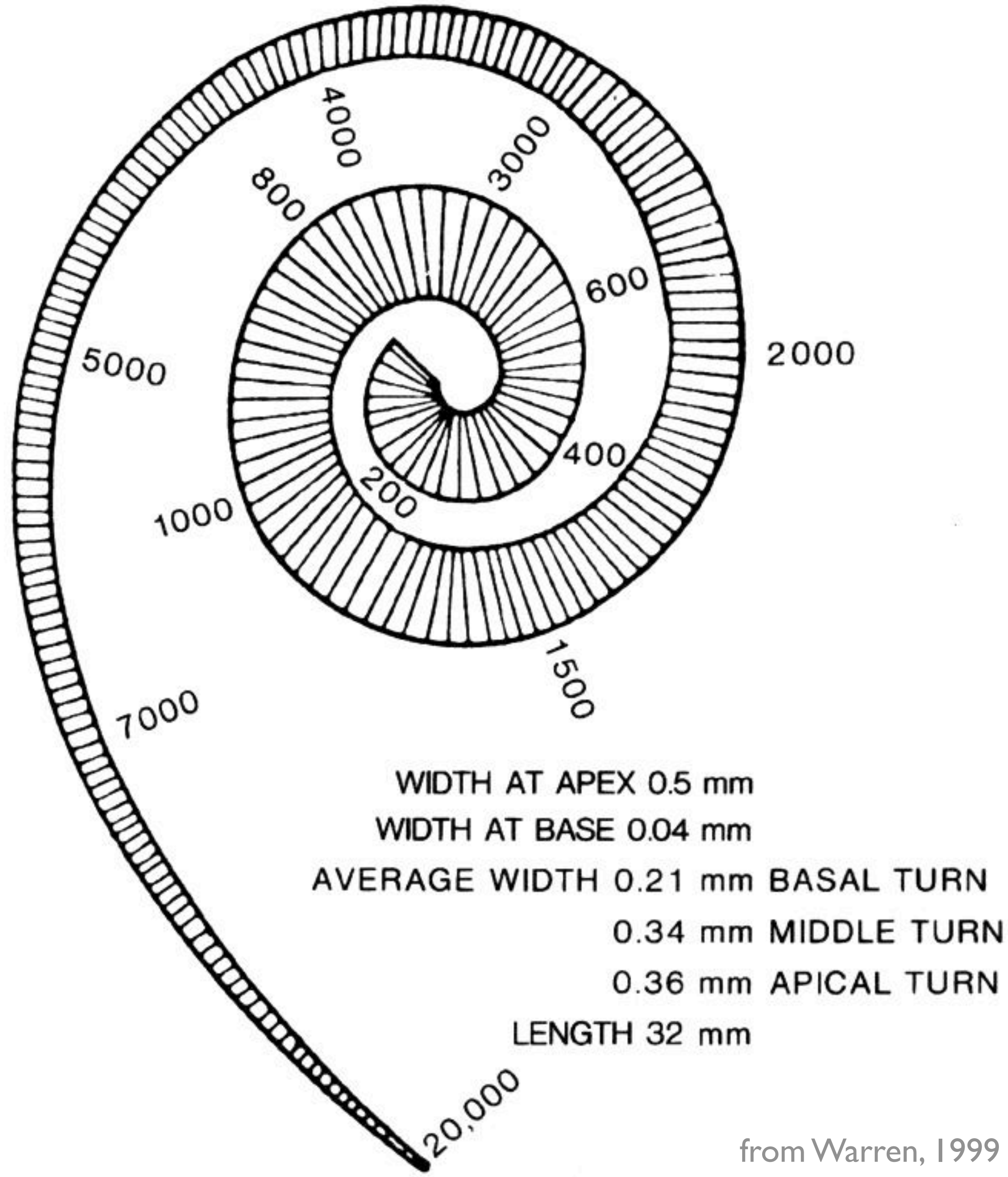
Why might this sound not be correctly localized?

What does the auditory system do?



from Yost, 2000

Frequency mapping of the basilar membrane



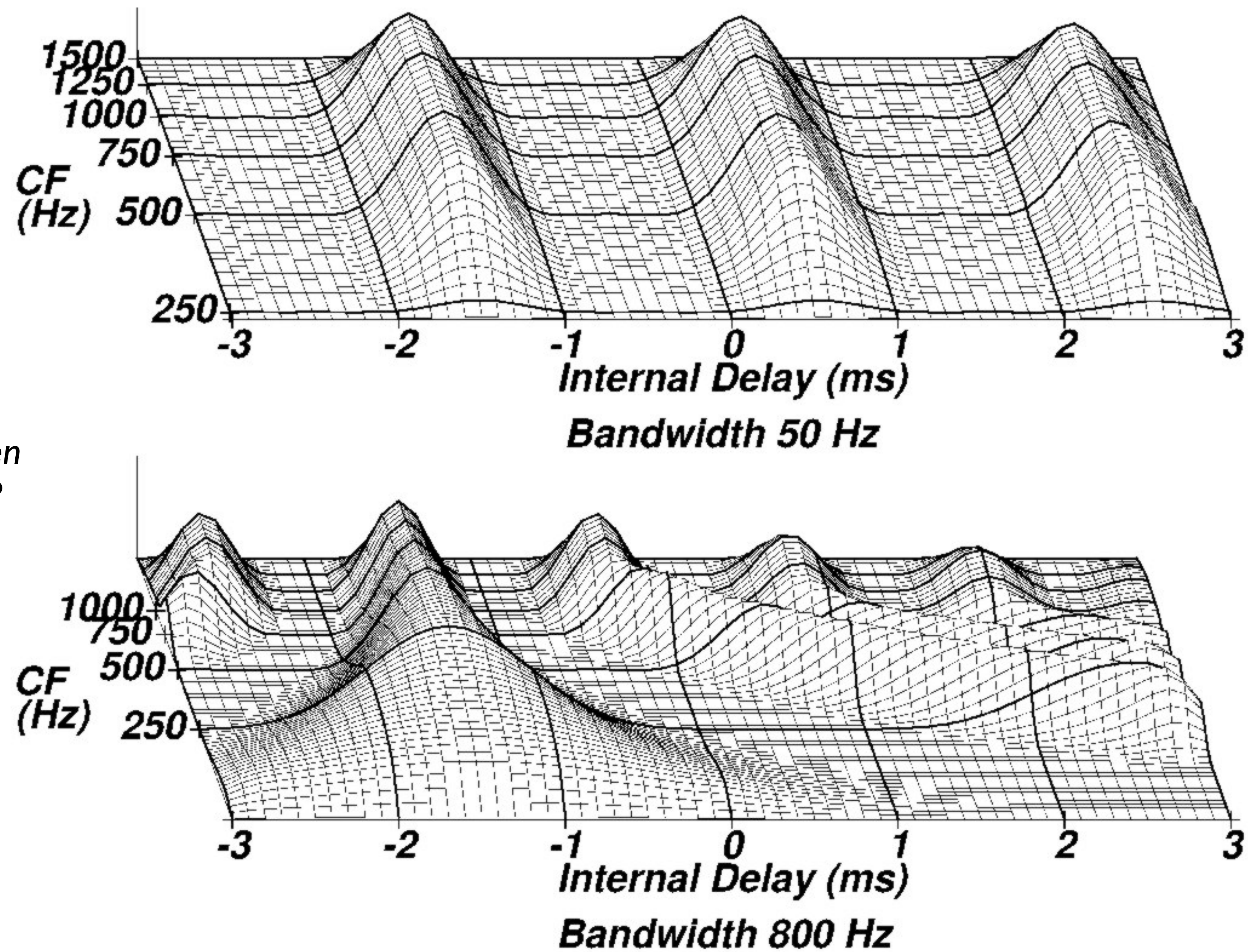
from Warren, 1999

How do we lateralize narrowband sounds if the ear decomposes sound in terms of frequency?

filtering and frequency space (on board)

Integrating across frequency: psychophysical models

Ensembles of coincidence-counting units (Stern and Trahiotis, 1995)



How is sound localized when the bandwidth is increased?

Note: the sound is still lateralized correctly even though ITD is far outside it's natural range.

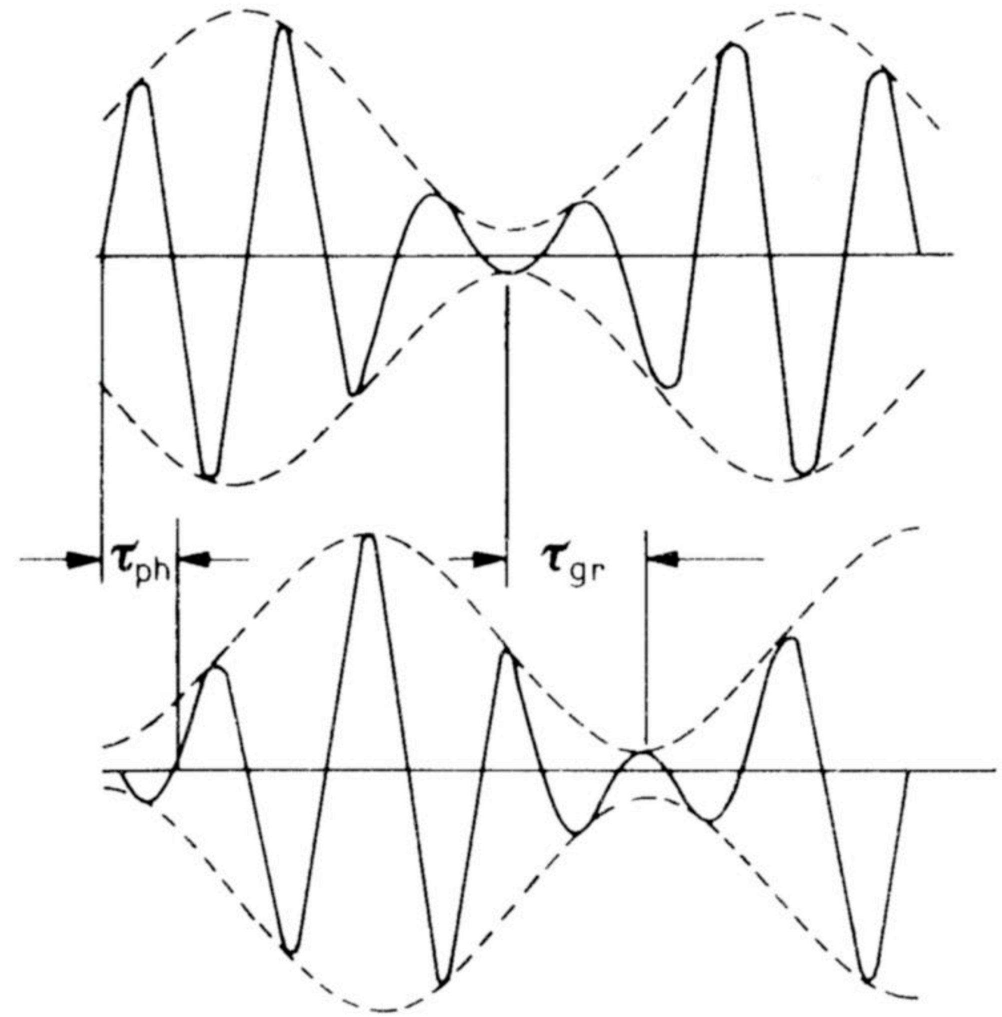
Narrow band sound lateralized to the right, broadband to left.

Things are not as simple as the might seem

- Delay a 3900 Hz tone modulated at 300 Hz.
- *Can this ITD be detected?*
- *Could ITD of low frequencies explain this?*
- *No*: Beat frequency is 300 Hz

  ⇒ spectrum is 3900 and 3900±300 Hz.

- Time delay of envelope predicts lateralization.



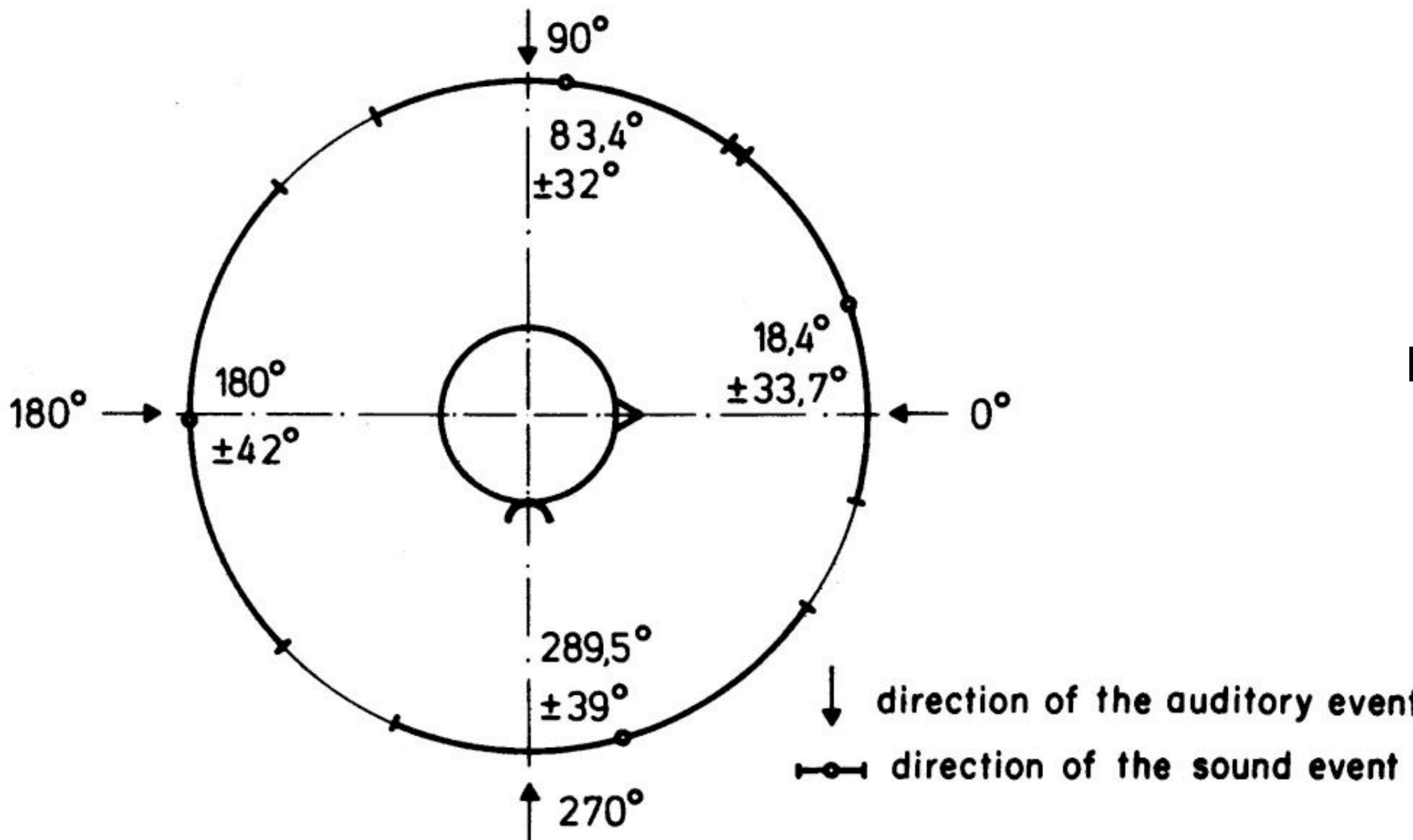
from Blauert, 1997

Limitations of the Duplex Theory

- limited to lateralization
- doesn’t do front-back discrimination
- doesn’t explain why are sounds are outside your head

Can sound be localized with one ear?

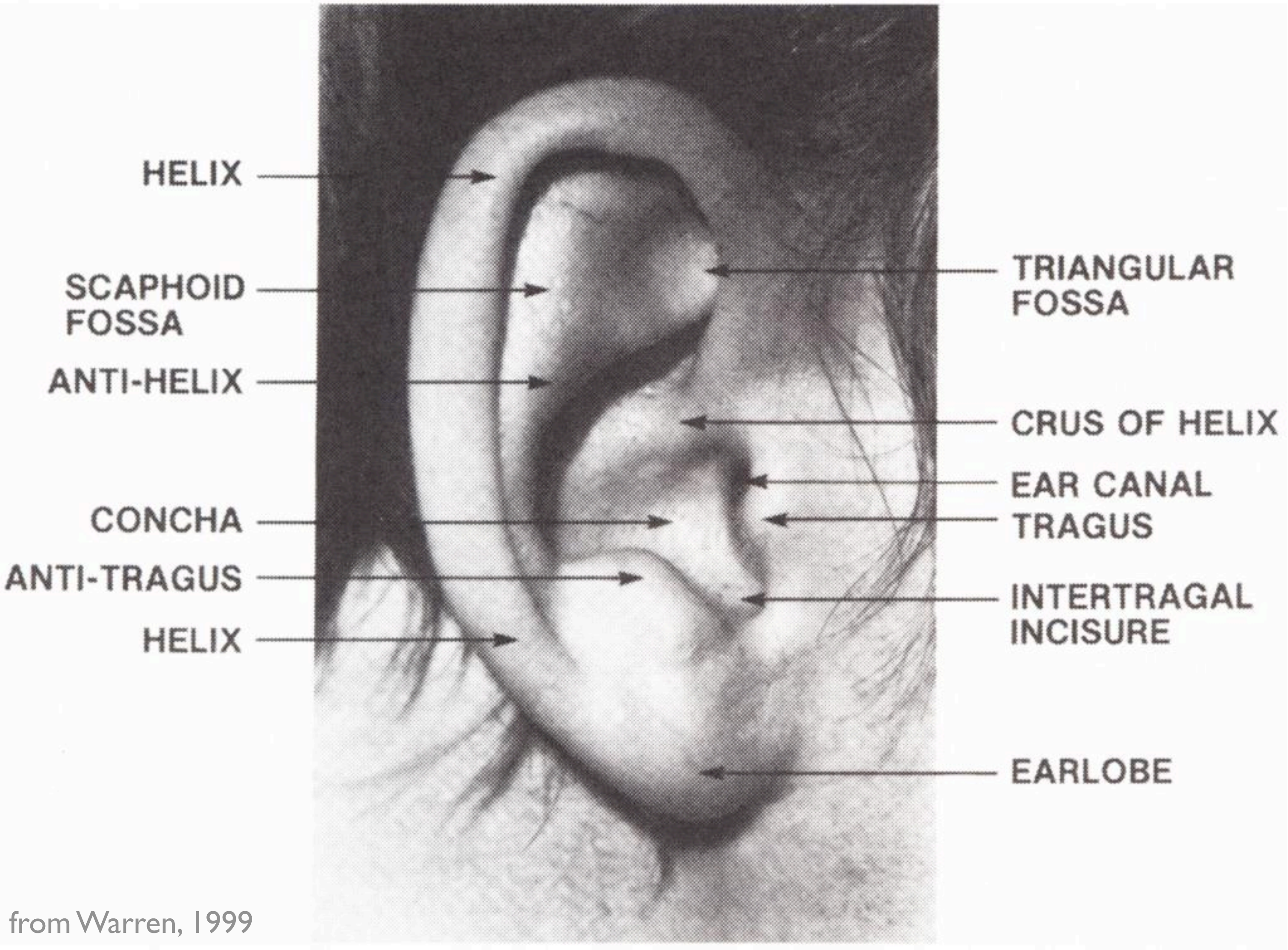
- total deafness in left ear, normal in right
- 100 ms white noise pulses.
- head immobilized



from Blauert, 1997

Localization ability improves with experience.

The Function of the Pinna



from Warren, 1999

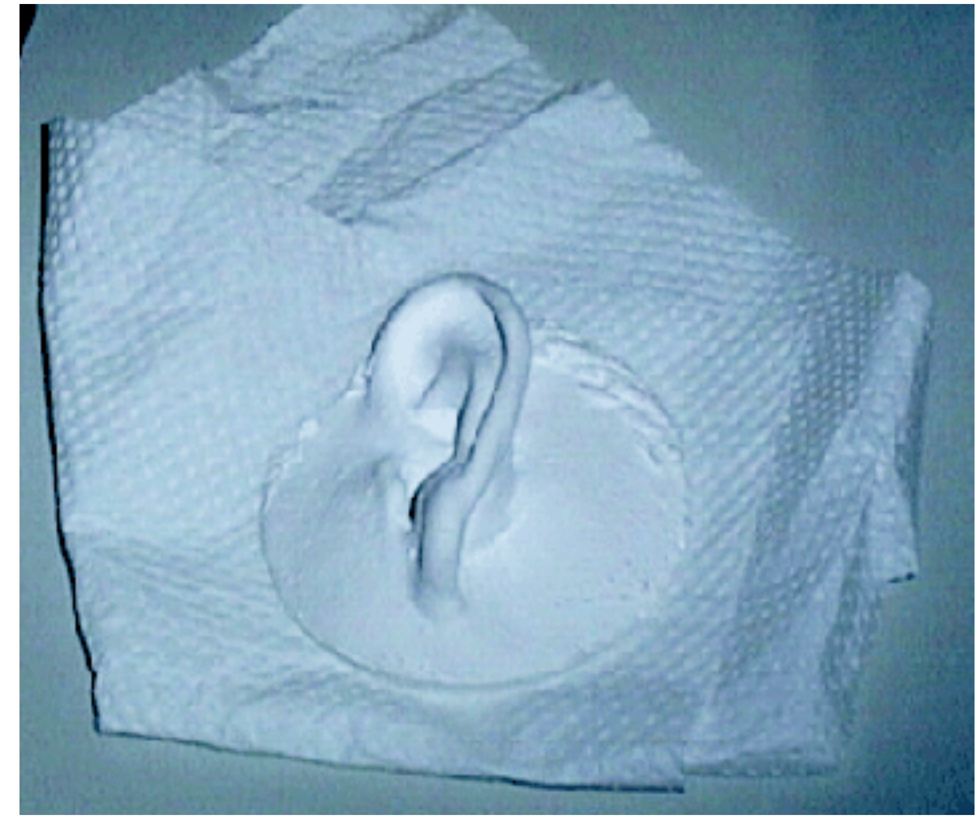
Older theories:

- sound gathering (1600s - even today)
- Darwin (1800s): vestigial form of animal ear, no role in sound localization
- Lord Rayleigh (1907): distinguish between front and back

Batteau's theory (1967, 1968)

- Echos produced by pinnae provide lateralization and elevation cues.
- used microphones in pinna casts
- measured delays for azimuths and elevations:
  - azimuths: 2 to 80 µsec
  - elevations: 100 to 300 µsec
- then the key experiment:

  listening through casts caused externalization
- also observed that animals have pinnae of similar shapes



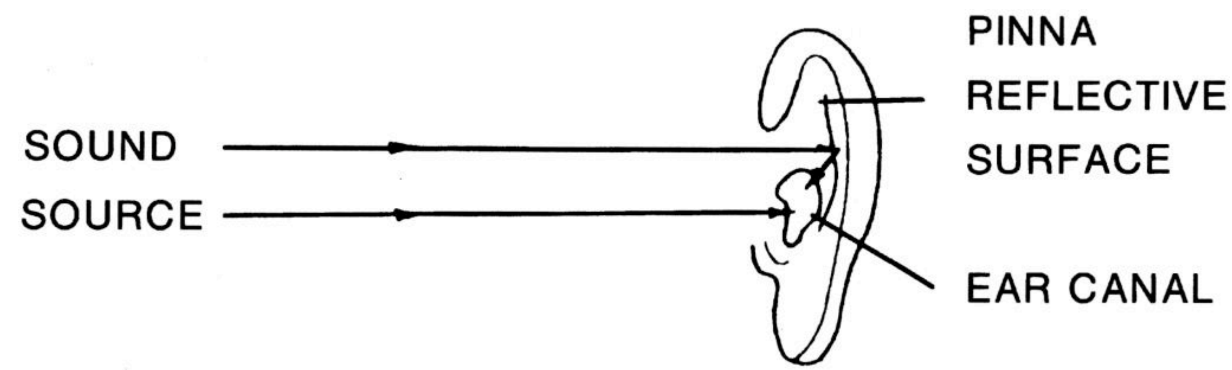
Timmear

Freedman and Fisher (1968):

- Not necessary to use subject's own pinnae
- subjects can localize with other pinnae, but with less accuracy
- Only a single pinna (monaural) is needed for localization

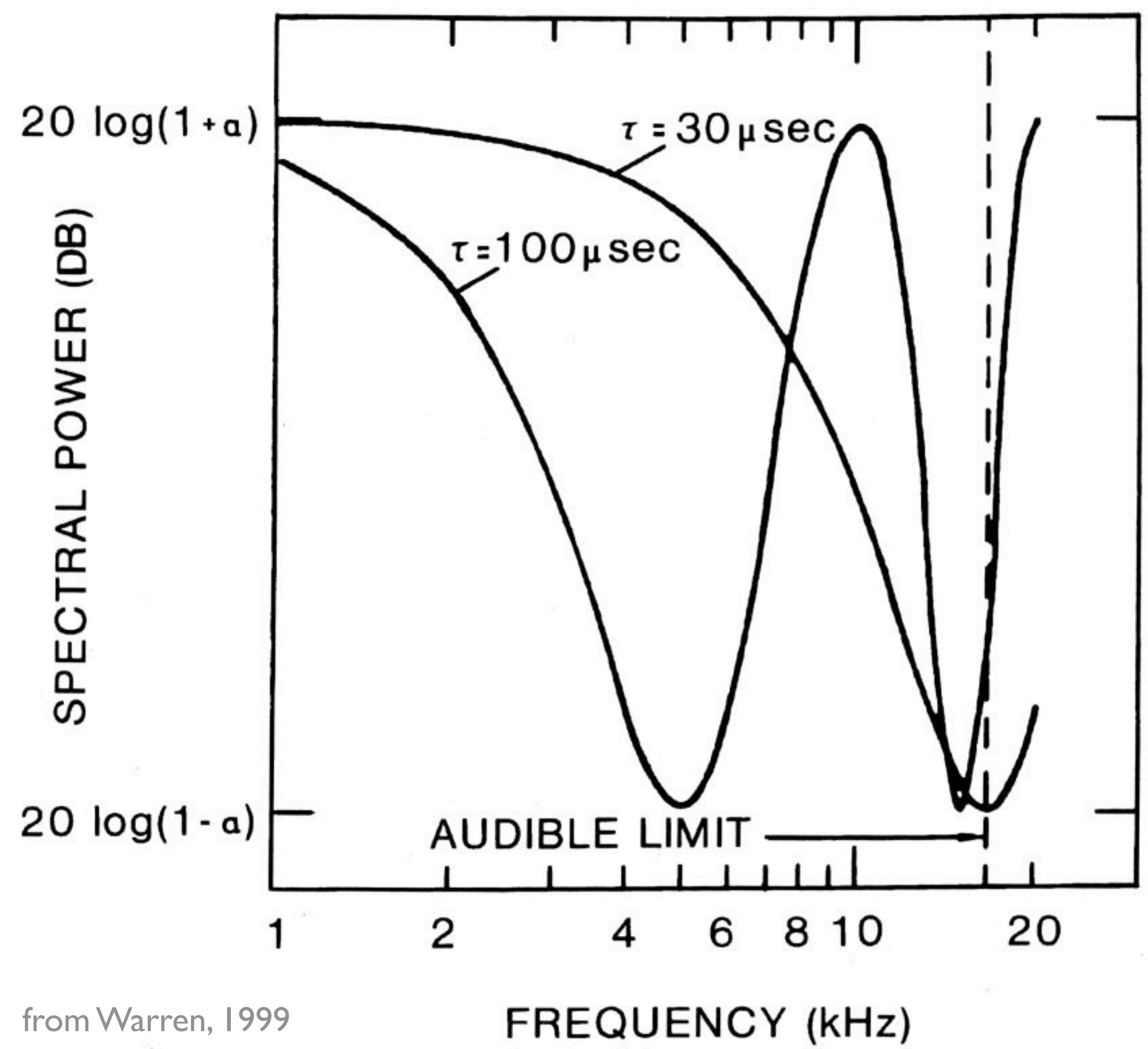
Testing Batteau's theory

- Do we perceive monaural echos?



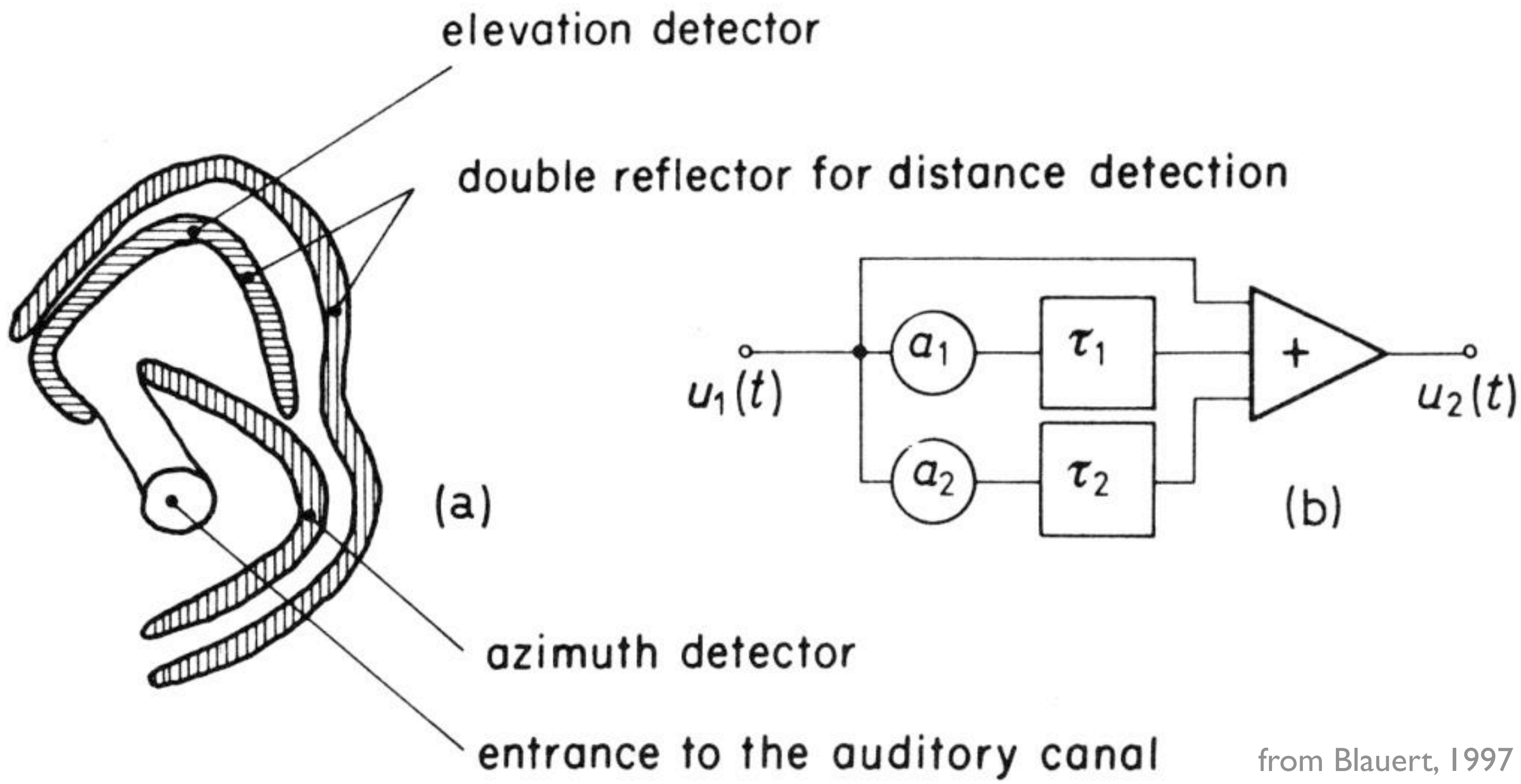
from Warren, 1999

- Combining noise with a delay of itself results in spectral filtering



from Warren, 1999

Model proposed by Blauert to explain the effect of the pinna as a reflector.

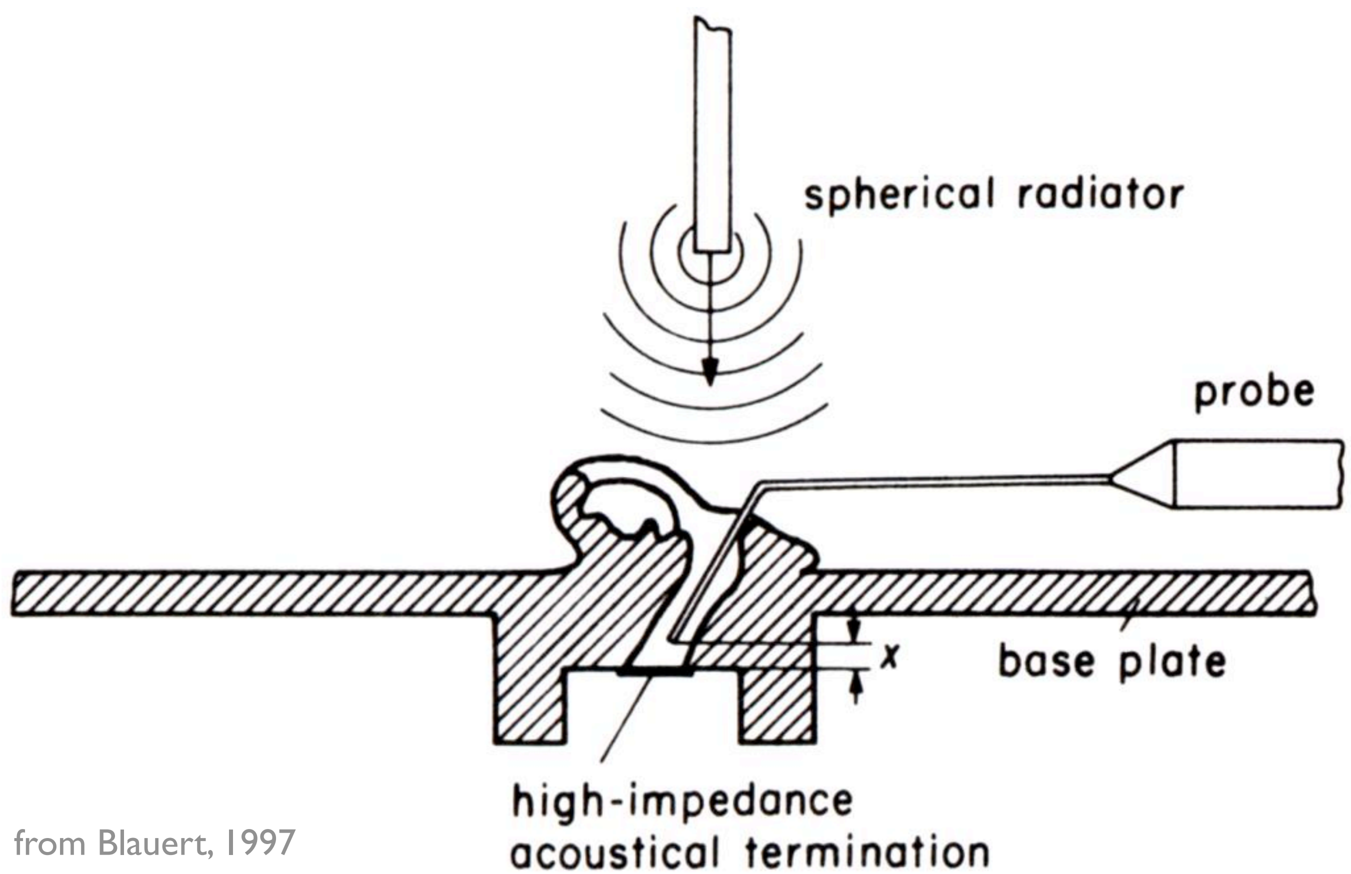


from Blauert, 1997

An improved analysis

Shaw and Teranishi (1968):

- Investigate pinna behavior in frequency domain using external ear model:

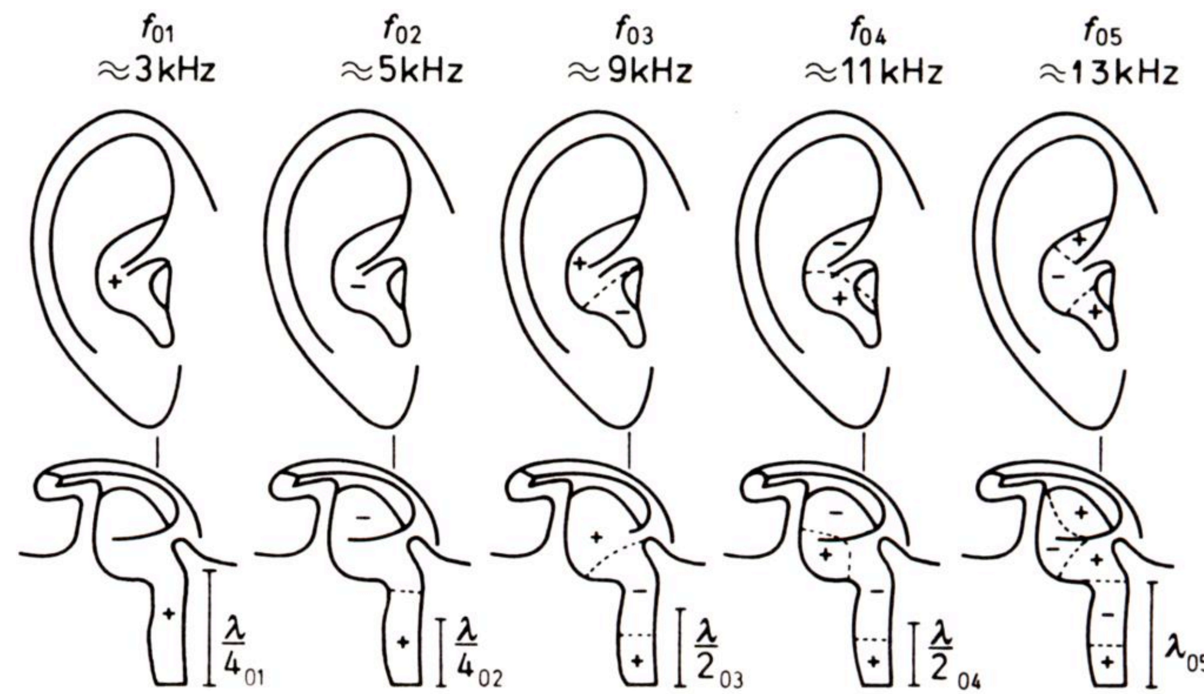


from Blauert, 1997

Acoustic resonance in the outer ear

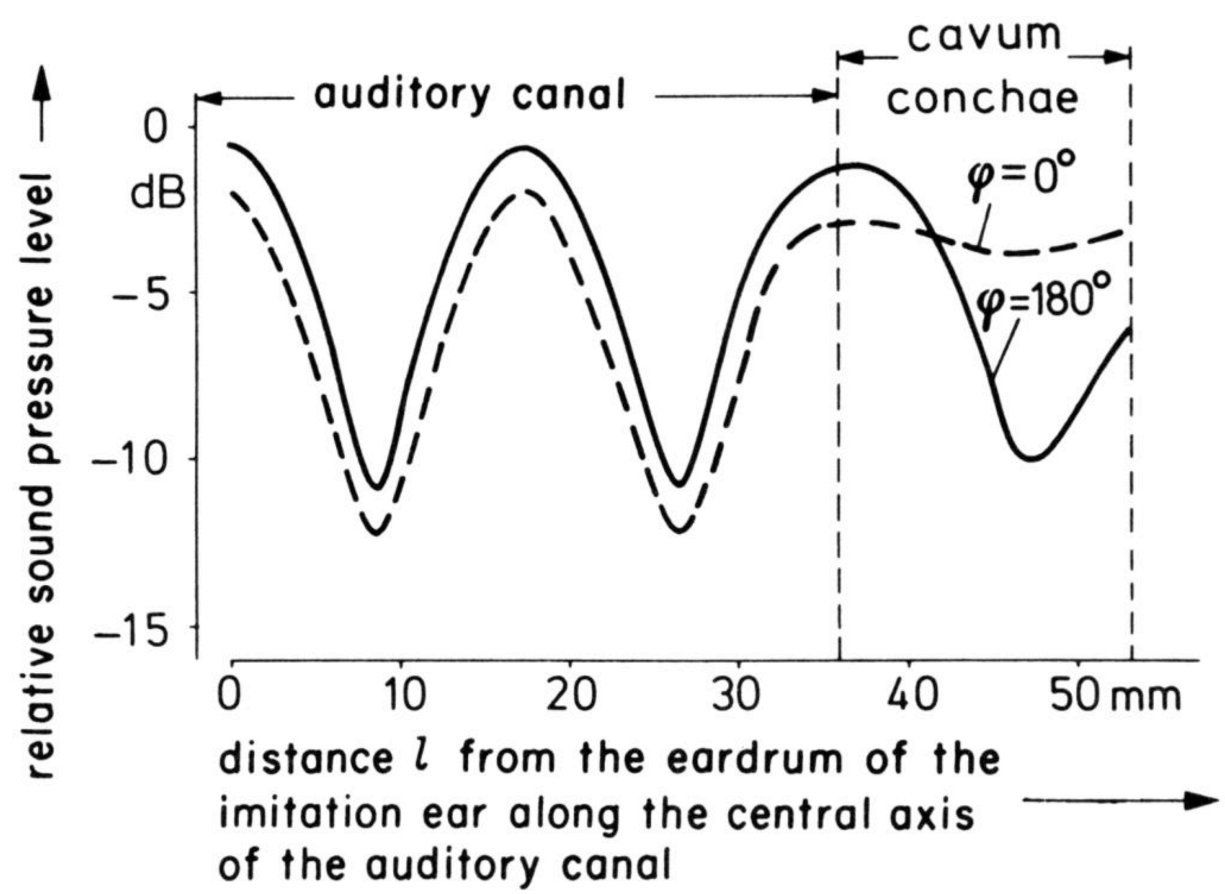
Distribution of sound pressure for several natural resonances:

- confirmed first two resonances in natural ear
- others combine into a broad resonance



Distribution of sound pressure along model ear canal for 10 kHz:

- resonances are direction dependent.
- *pinna and ear canal form a system of acoustical resonators.*



from Blauert, 1997

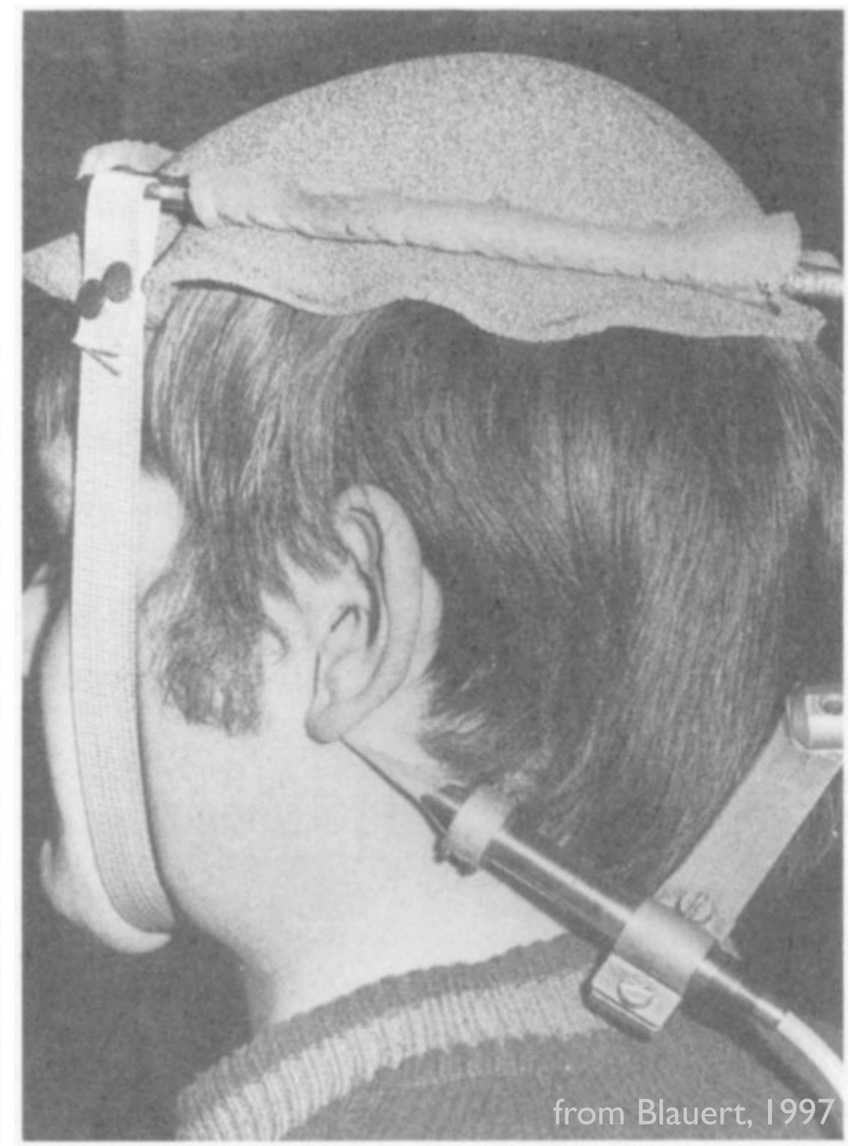
The general case

- What limitations do the pinnae measurements have?
  - Do not take into account the effect of the head and body.
- How to characterize the filtering?
  - Measure the transfer function: ratio of pressure at sound source to pressure of (ideally) sound reaching eardrum
  - this is called the *head-related transfer function* (HRTF)

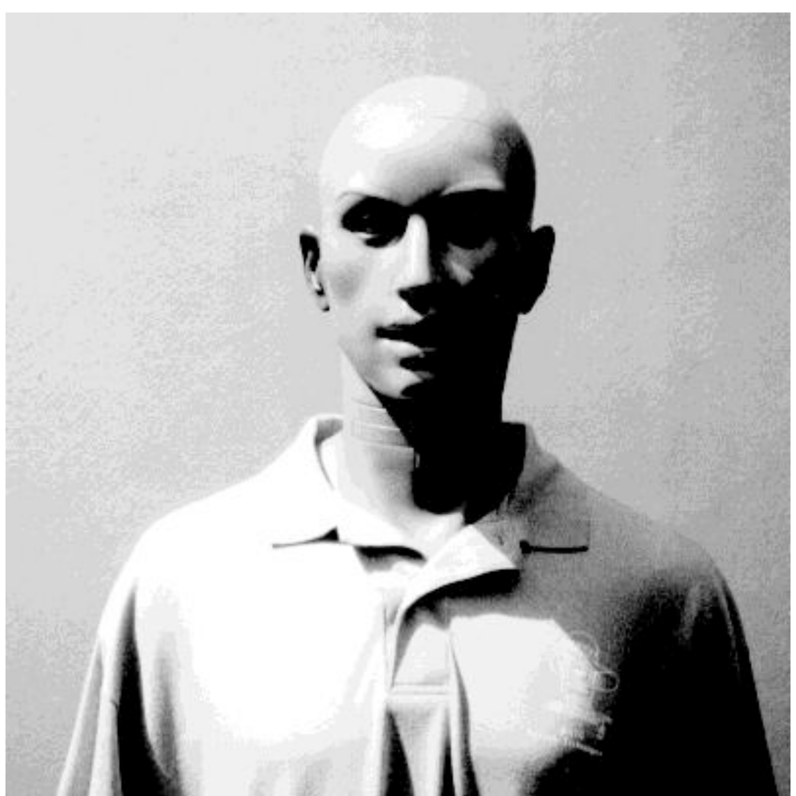
Measuring HRTFs

- Different types of HRTFs
  - monaural: pressure at source vs ear drum
  - binaural: pressure difference for two corresponding points in the ear canal

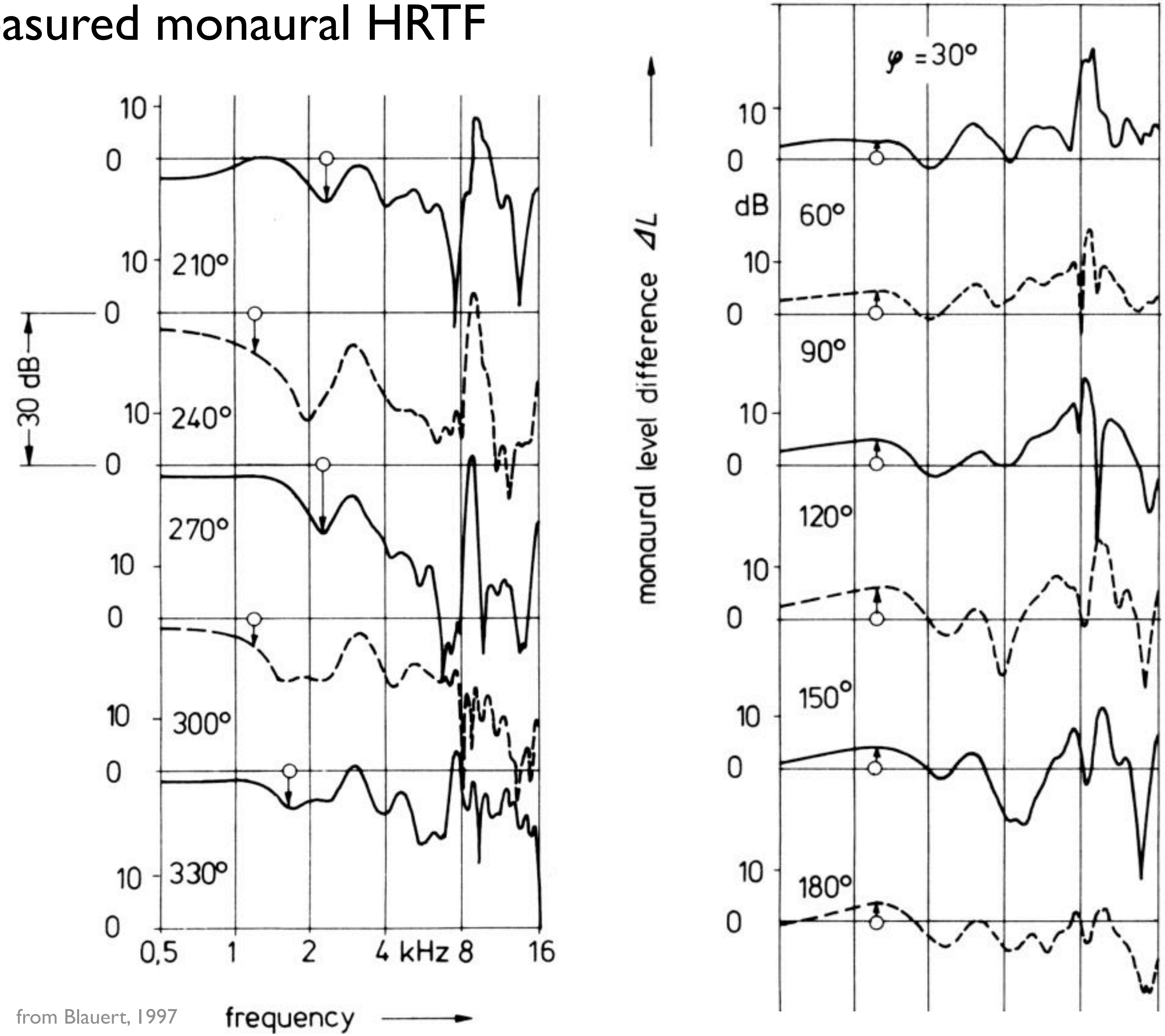
Subject with probe mics



Kemar the sound dummy



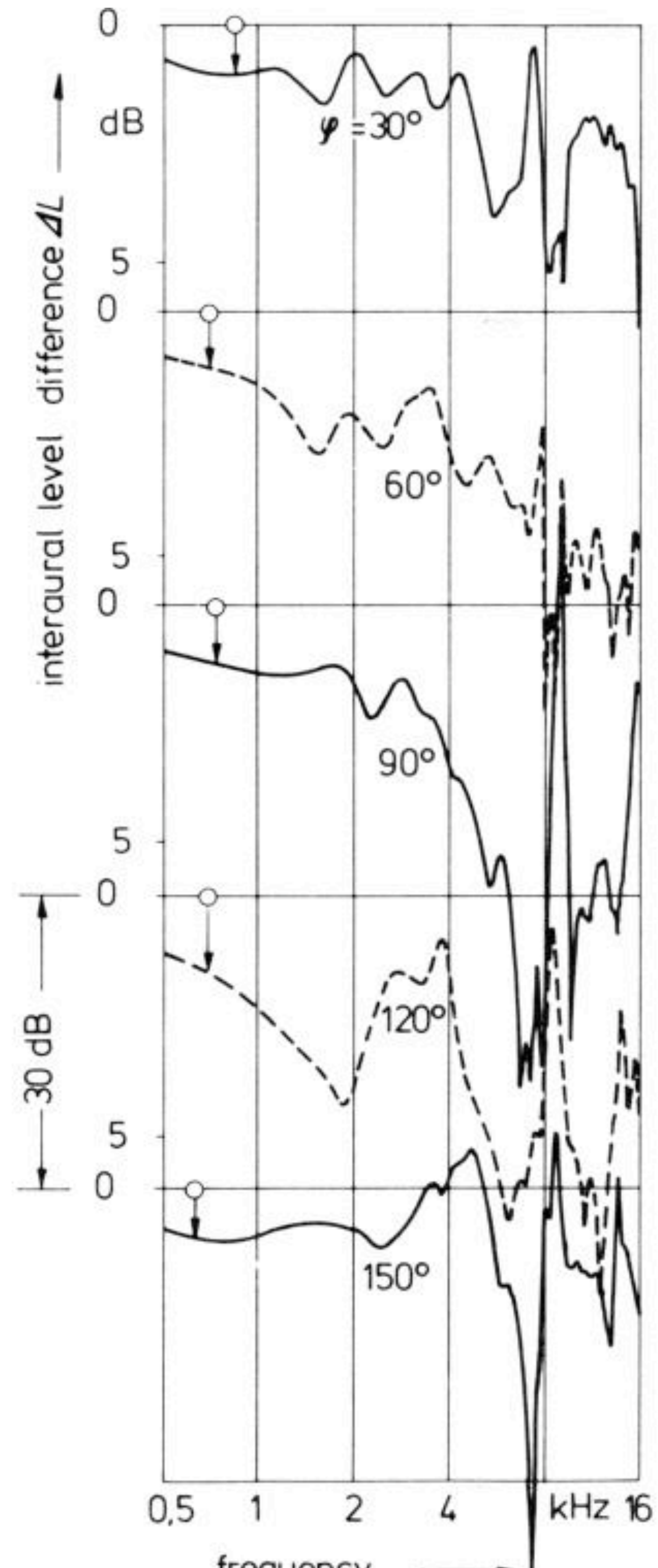
Measured monaural HRTF



from Blauert, 1997

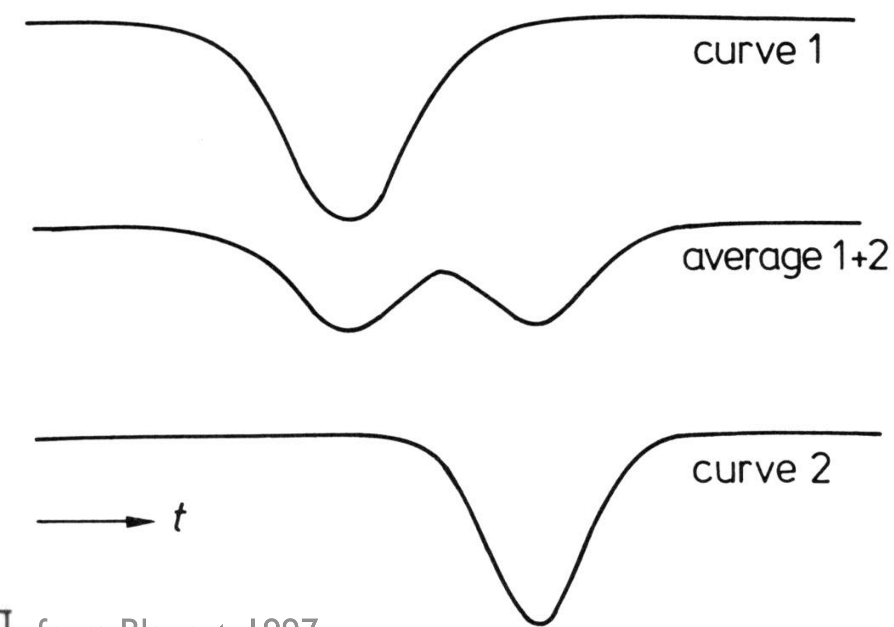
Measured binaural HRTF

from Blauert, 1997



Problems in using HRTFs

- HRTFs vary across subjects
- can't easily get an "average"
- but can do "structural averaging"



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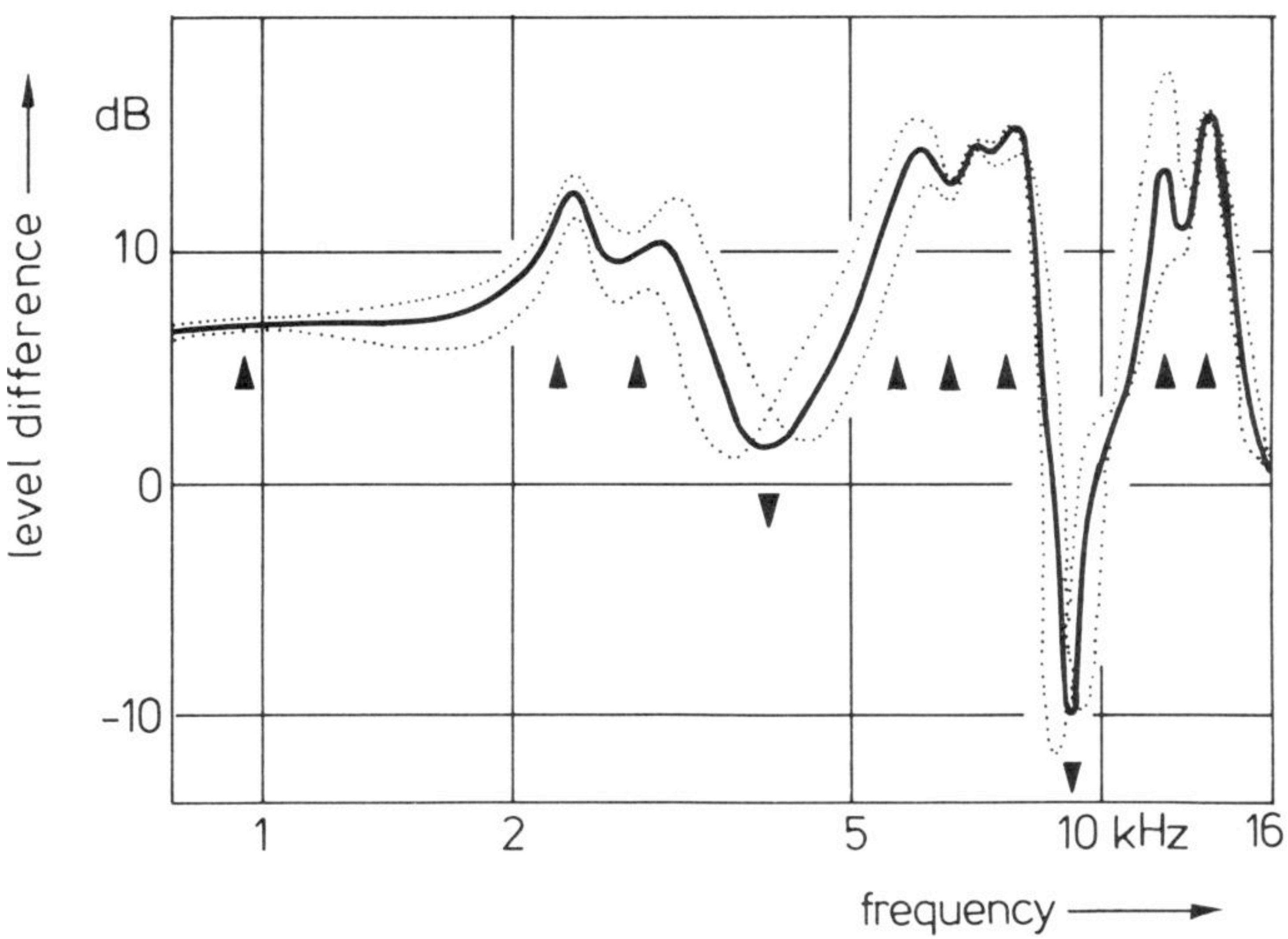
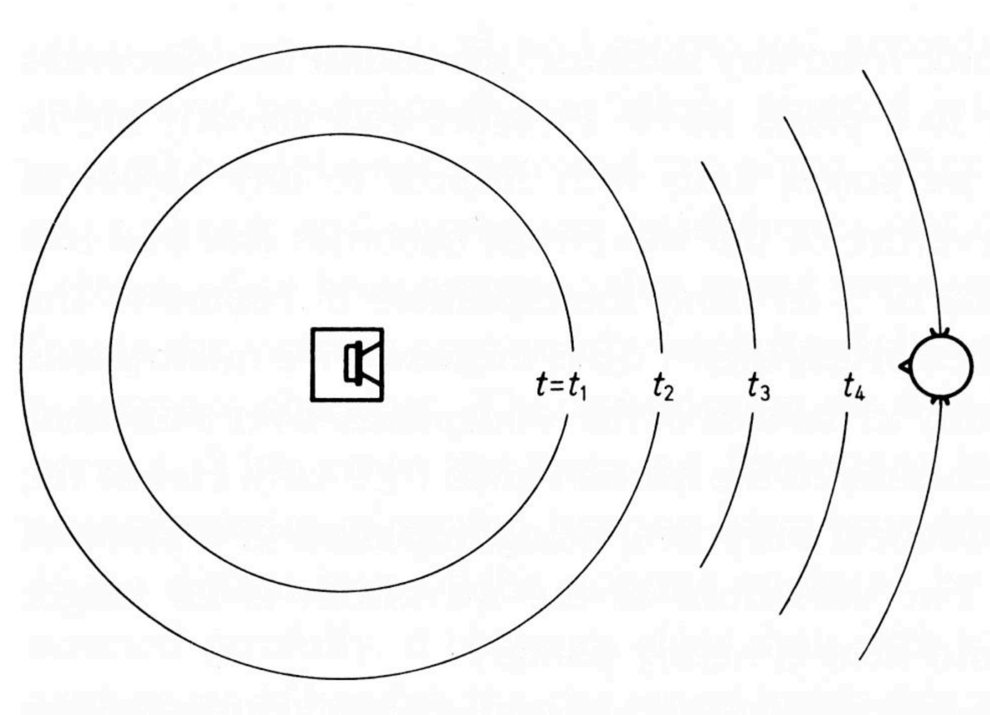


More than just direction: cues for sound distance

- Frequency independent 1/r
- pressure attenuation – works if you know some properties of sound source
- HRTF depends on distance
- freq. dependent attenuation (long distances)
- head movements (short distances)



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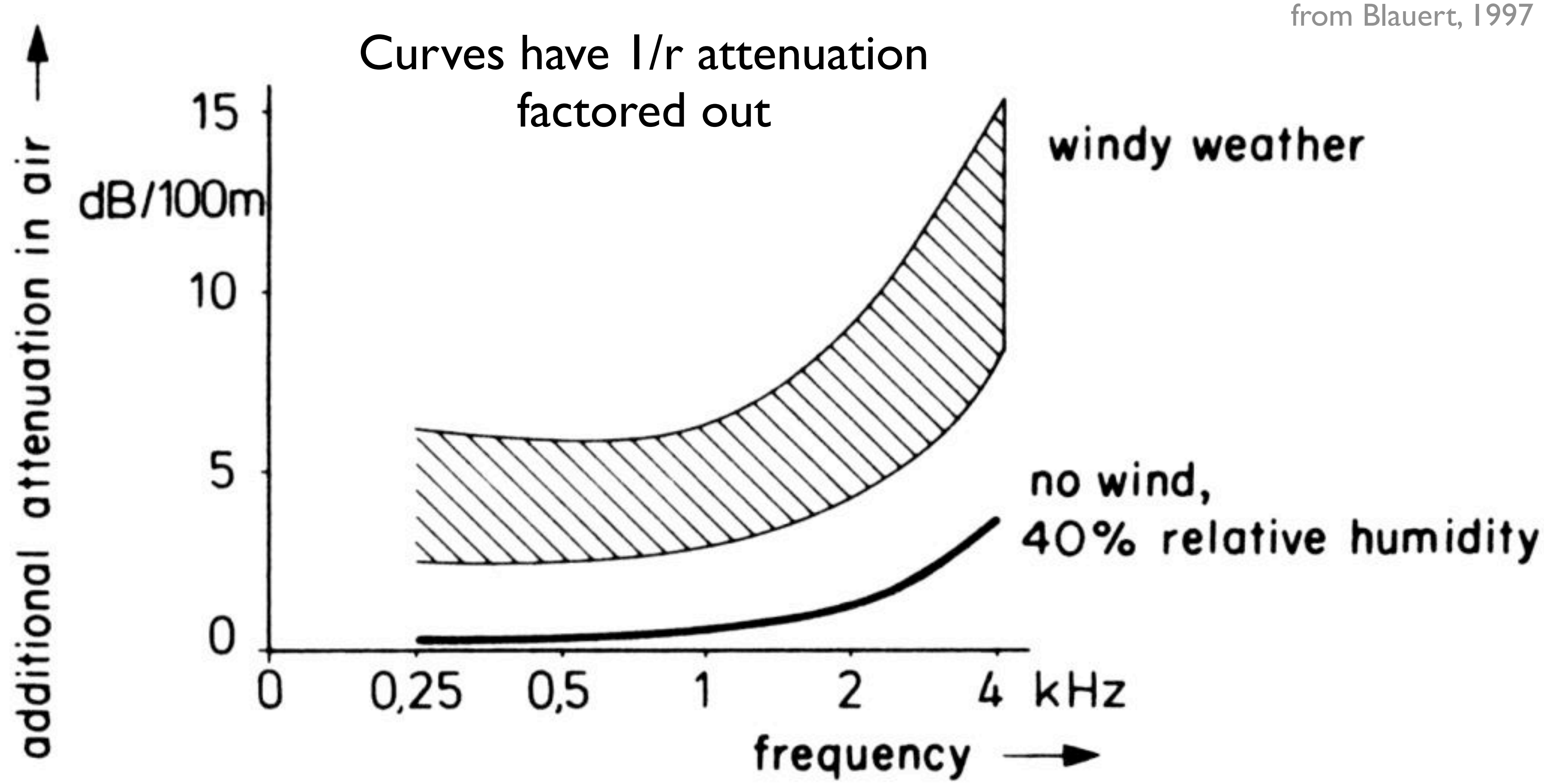

Next time: the computational problem

Misconceptions still persist today...