Topic 3

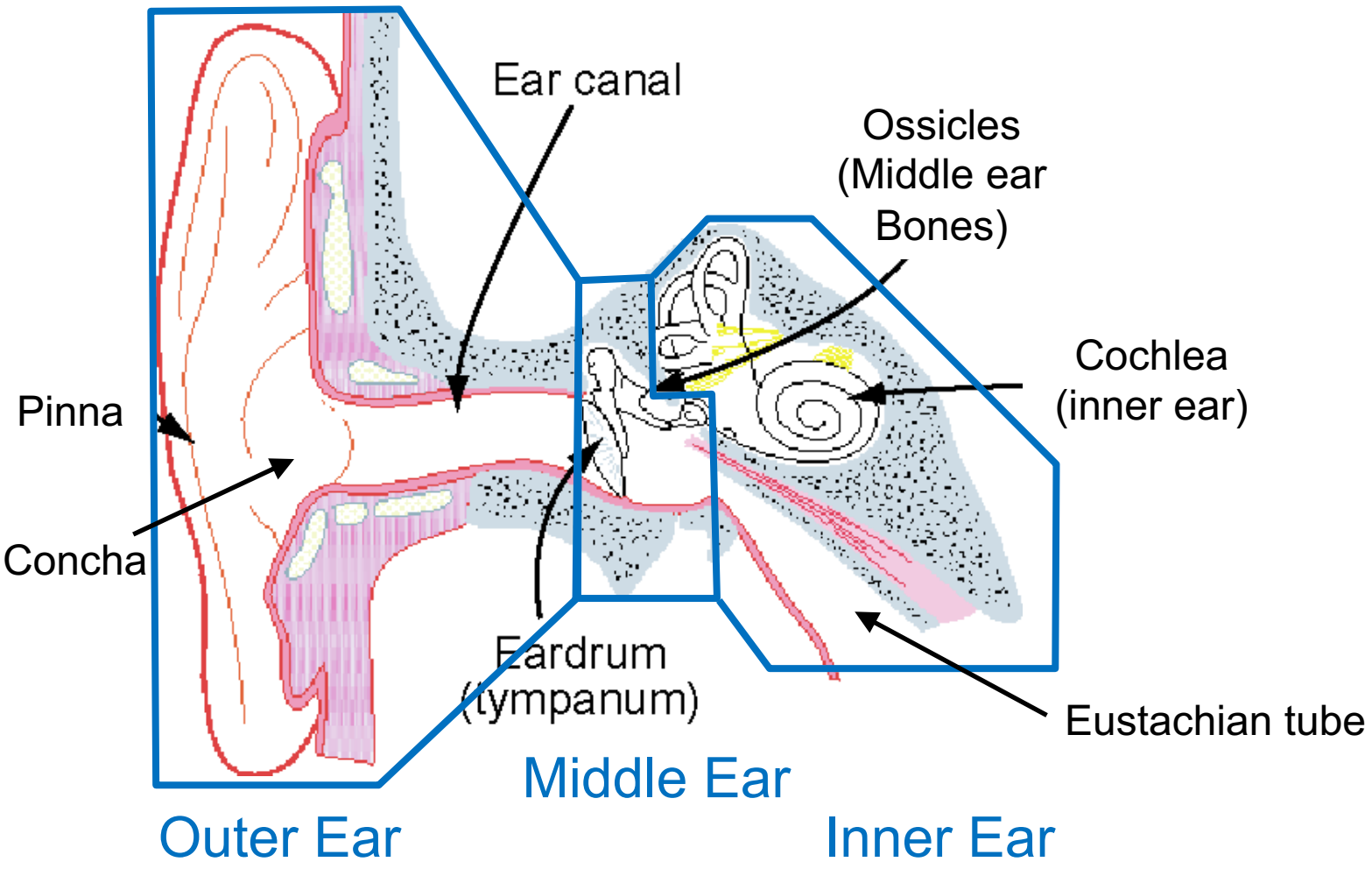
Loudness & Human Audition

(Some slides are adapted from Zhiyao Duan's course slides on Computer Audition and Its Applications in Music)

Why look at human audition?

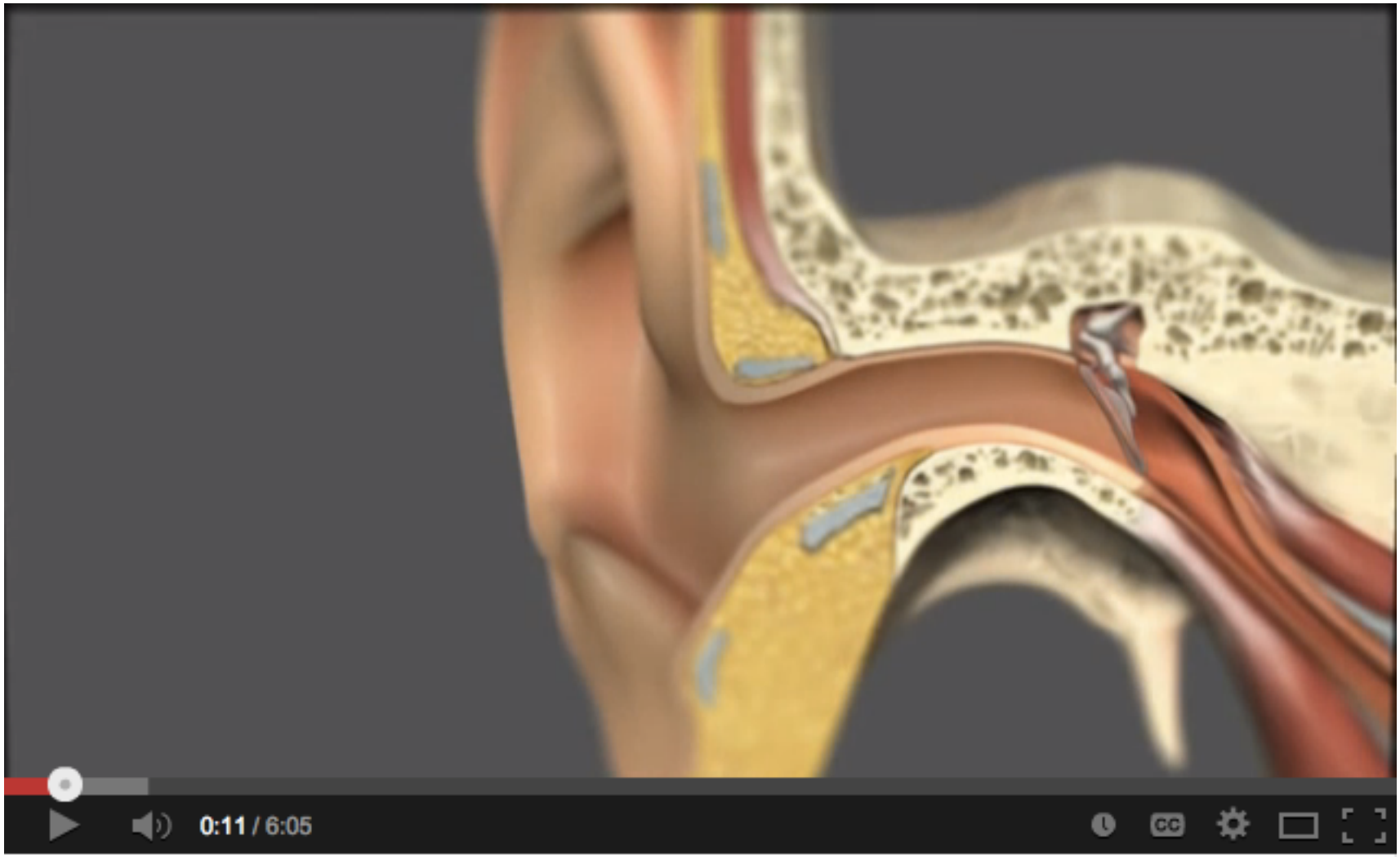
- Humans are the final judge for…
  - What is salient information
  - How good things sound
- Music is designed for human consumption
  - Takes advantage of how we hear/process
- Human audition gives us hints about how to build systems

The Ear

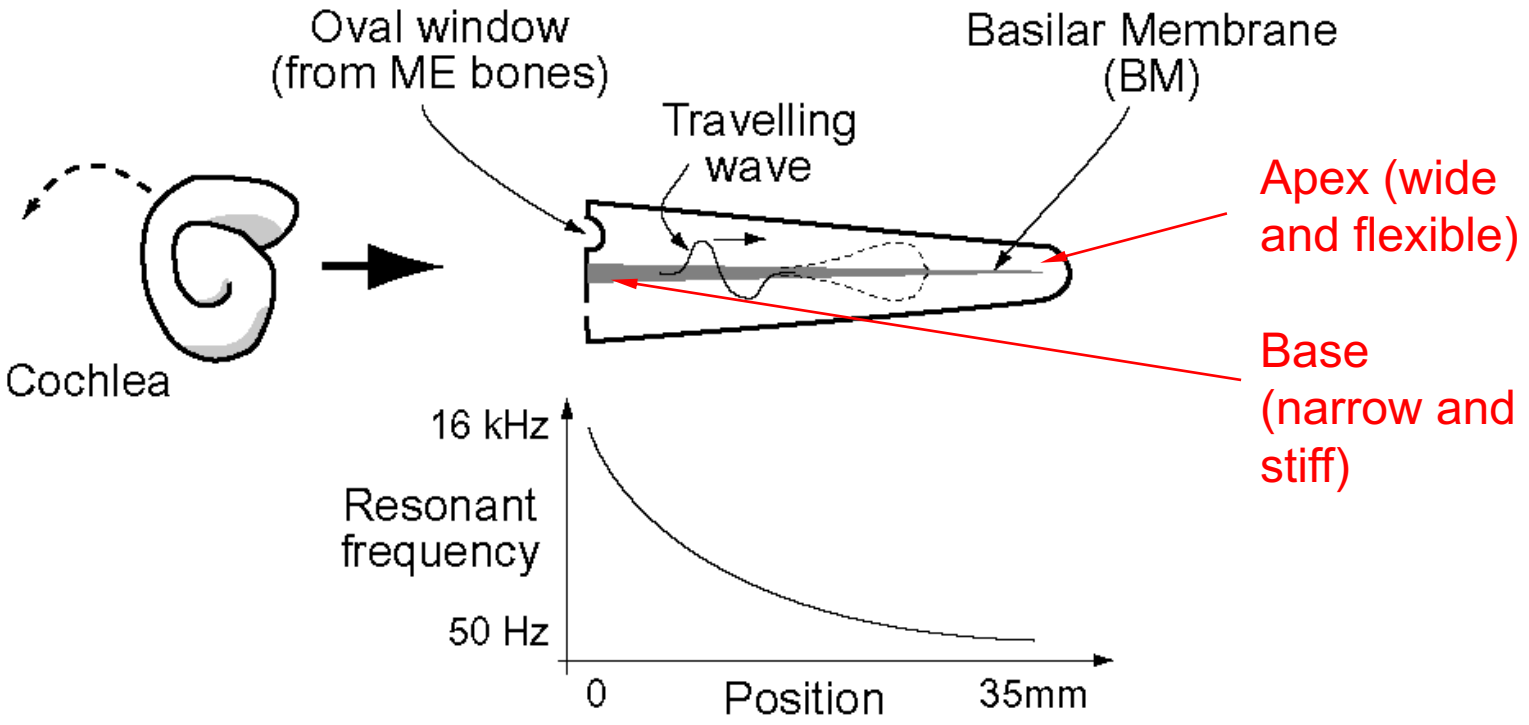

Ear canal
Ossicles
(Middle ear
Bones)
Cochlea
(inner ear)
Pinna
Concha
Eardrum
(tympanum)
Eustachian tube
Middle Ear
Outer Ear
Inner Ear

Let’s watch a movie!

(thanks to Carlos Gonzales and Genevra Garrett)

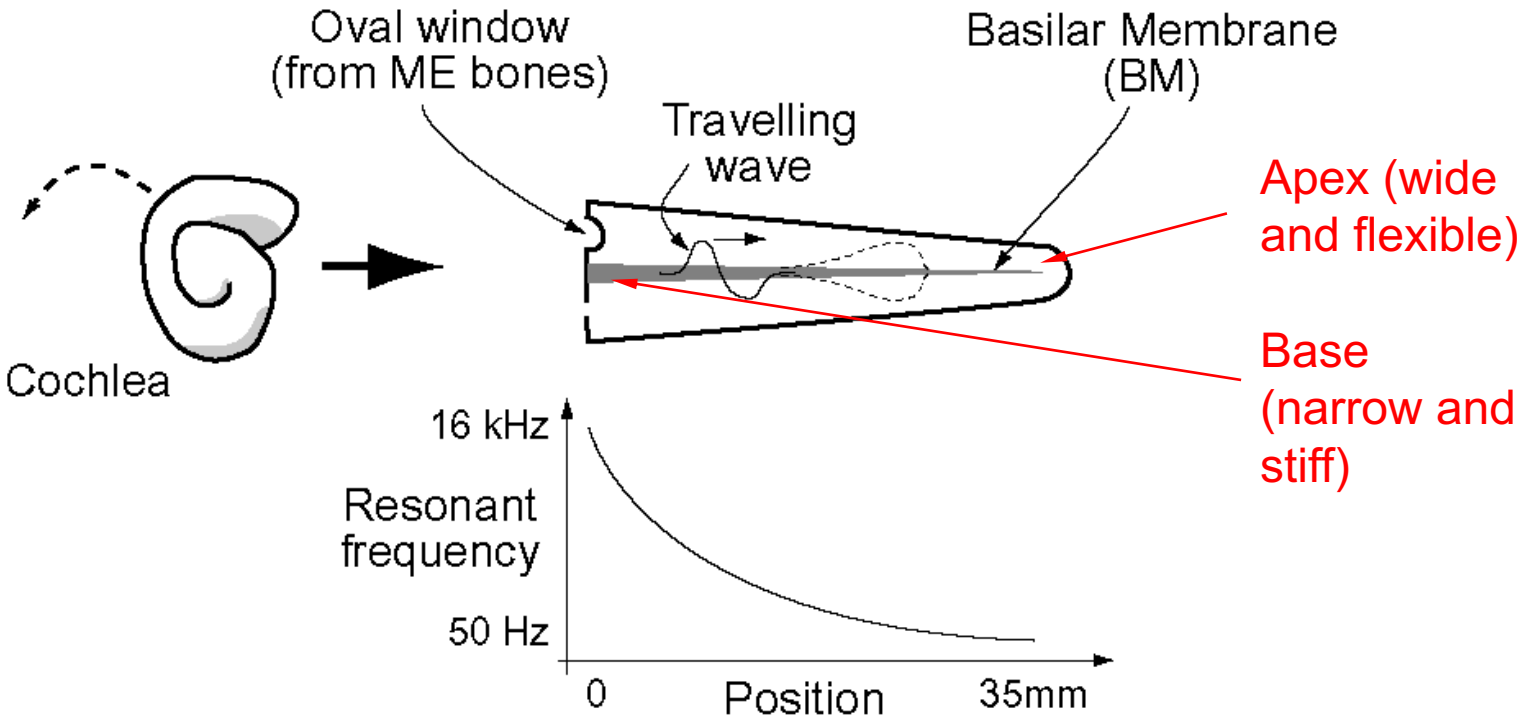


The Cochlea



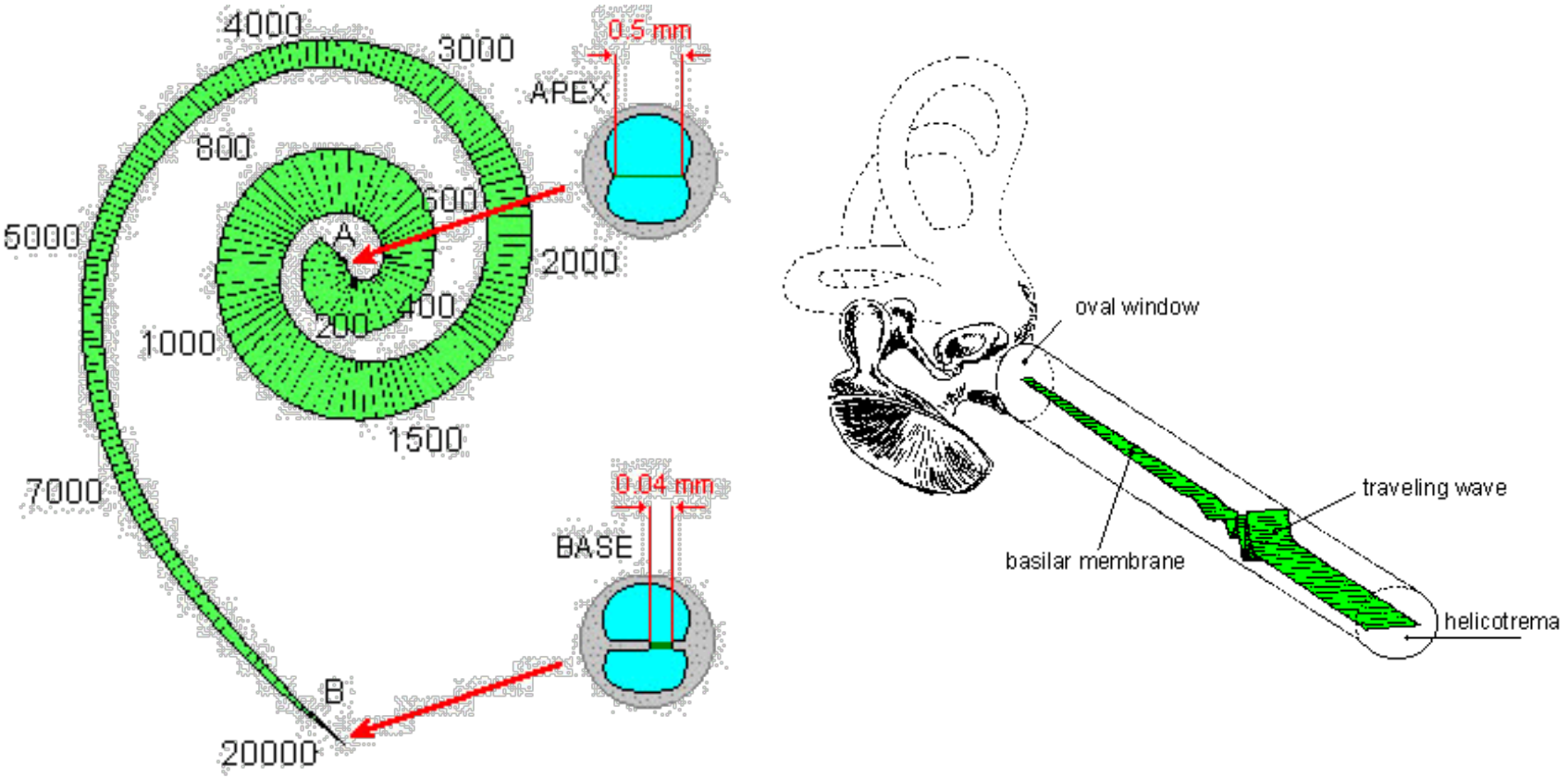
- Each point on the Basilar membrane resonates to a particular frequency
- At the resonance point, the membrane moves

The Cochlea



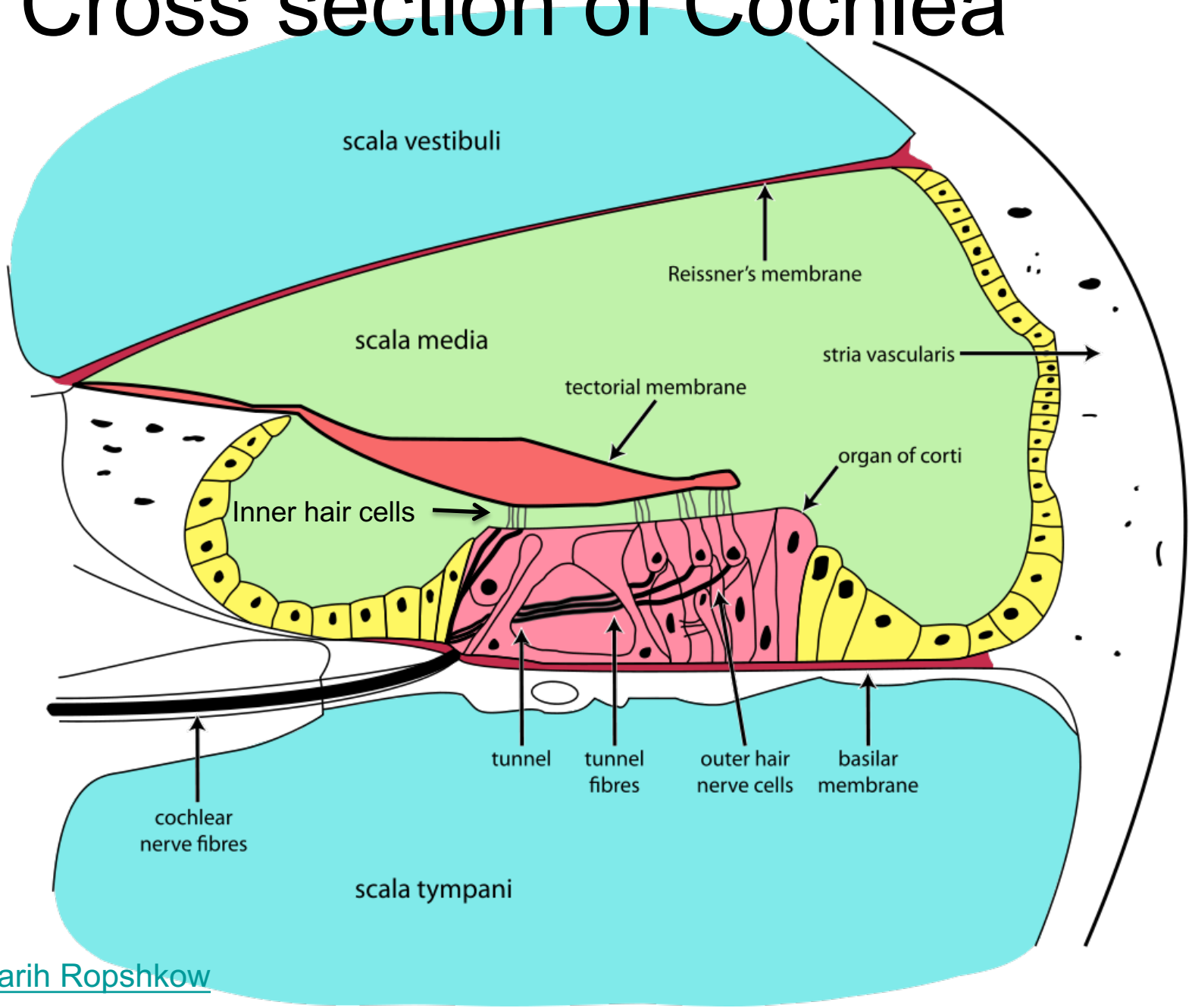
- When the membrane moves, it moves hairs.
- When hairs move, they fire nerve impulses
- These impulses tell us we're hearing sound

The Cochlea



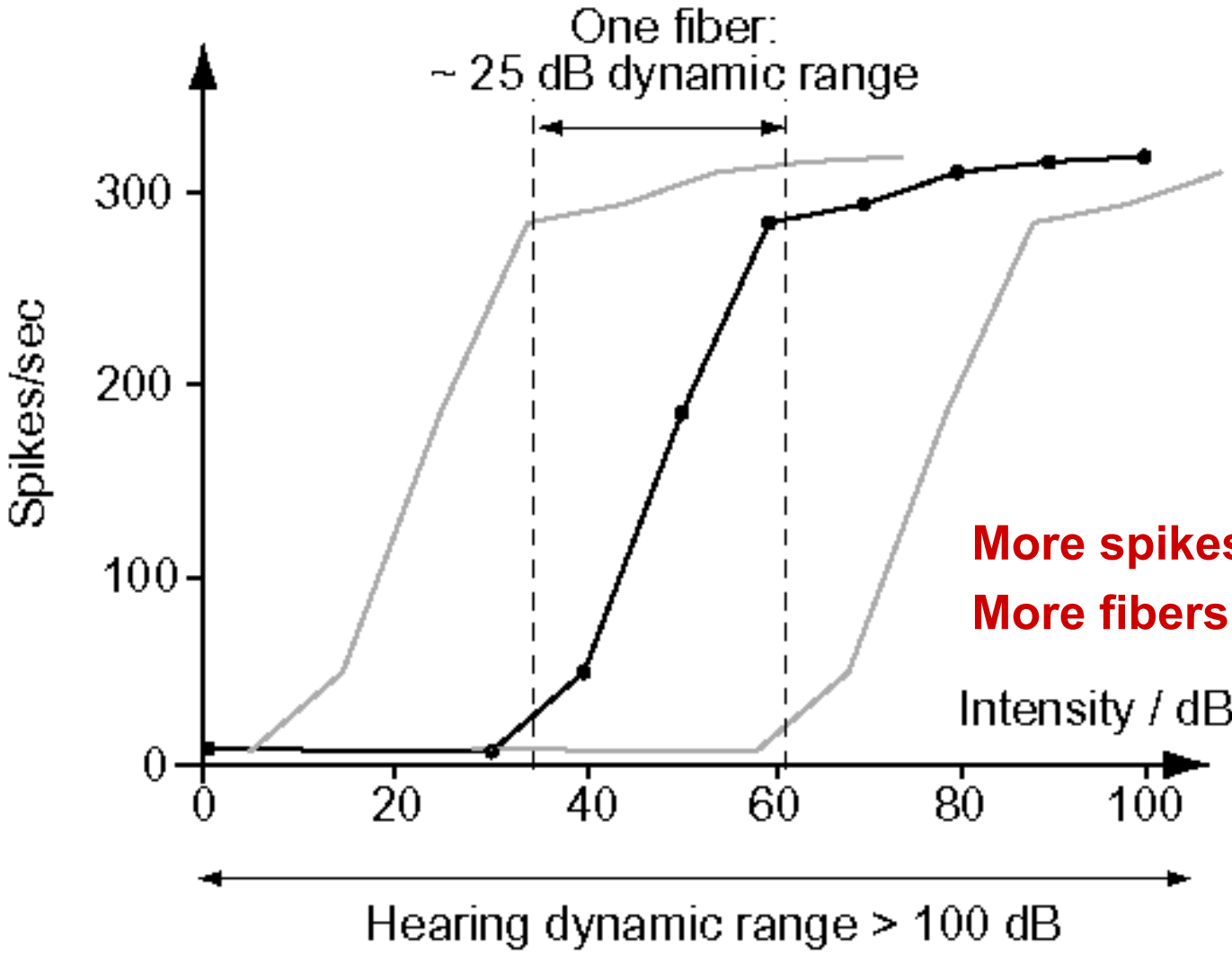
(image thanks to Mammano and Nibili)

Cross section of Cochlea



Thanks to Oarih Ropshkow

Encoding Loudness



More spikes/second = louder

More fibers firing = louder

Loudness

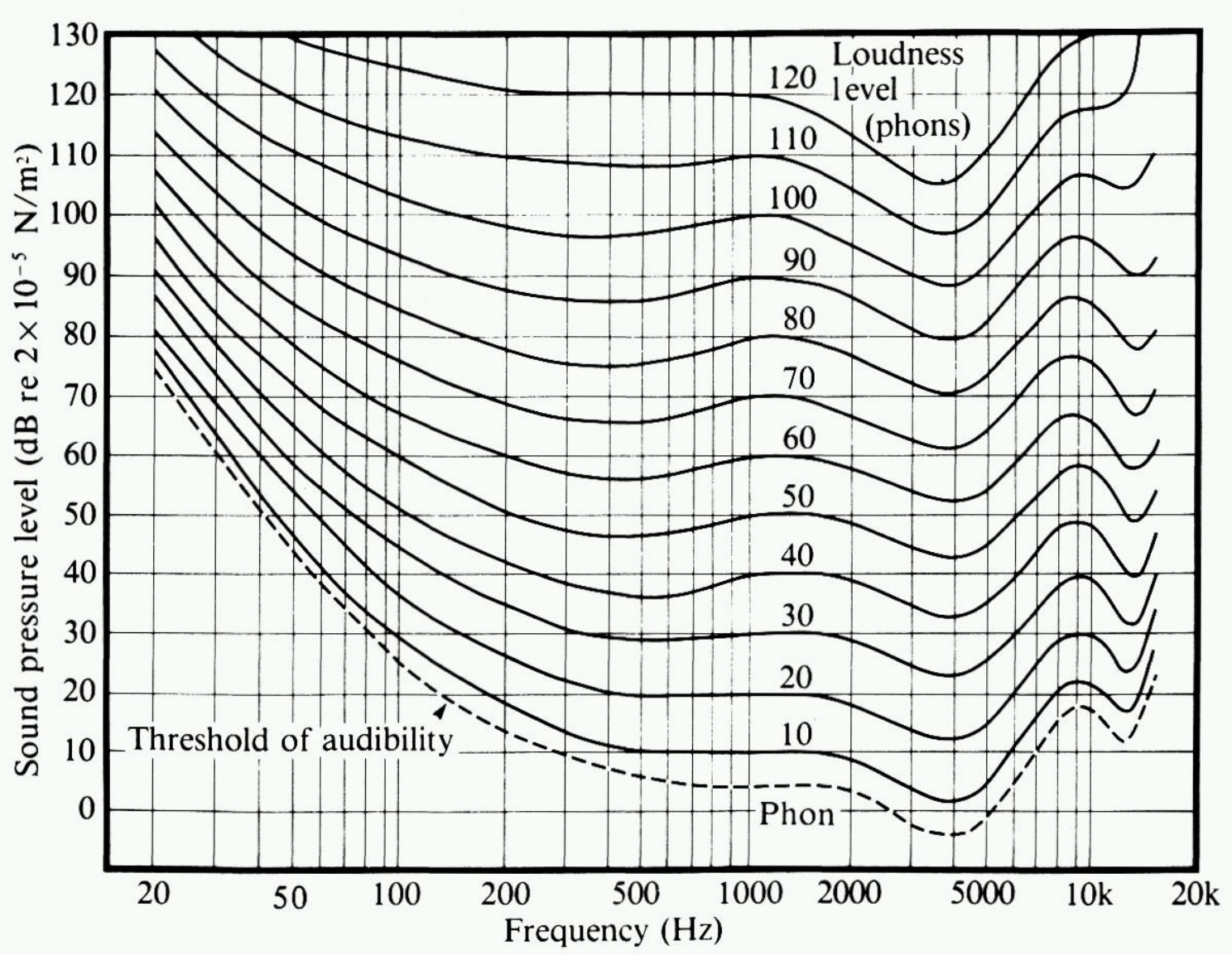
Loudness is a subjective measure of sound pressure (or intensity).

- How does the intensity of a sound relate to its perceived loudness?
  - Does frequency matter?
  - Is broadband noise different from narrow band?
  - How can we find out?

Measuring Frequency's Effect

- Pick a reference frequency (like 1000Hz)
- Play a sine wave of a defined intensity at that frequency (say, 30 dB SPL)
- Pick another frequency (any one)
- Play a sine wave at the new frequency, *f*
- Adjust the intensity of the sine at *f* until its loudness equals the reference

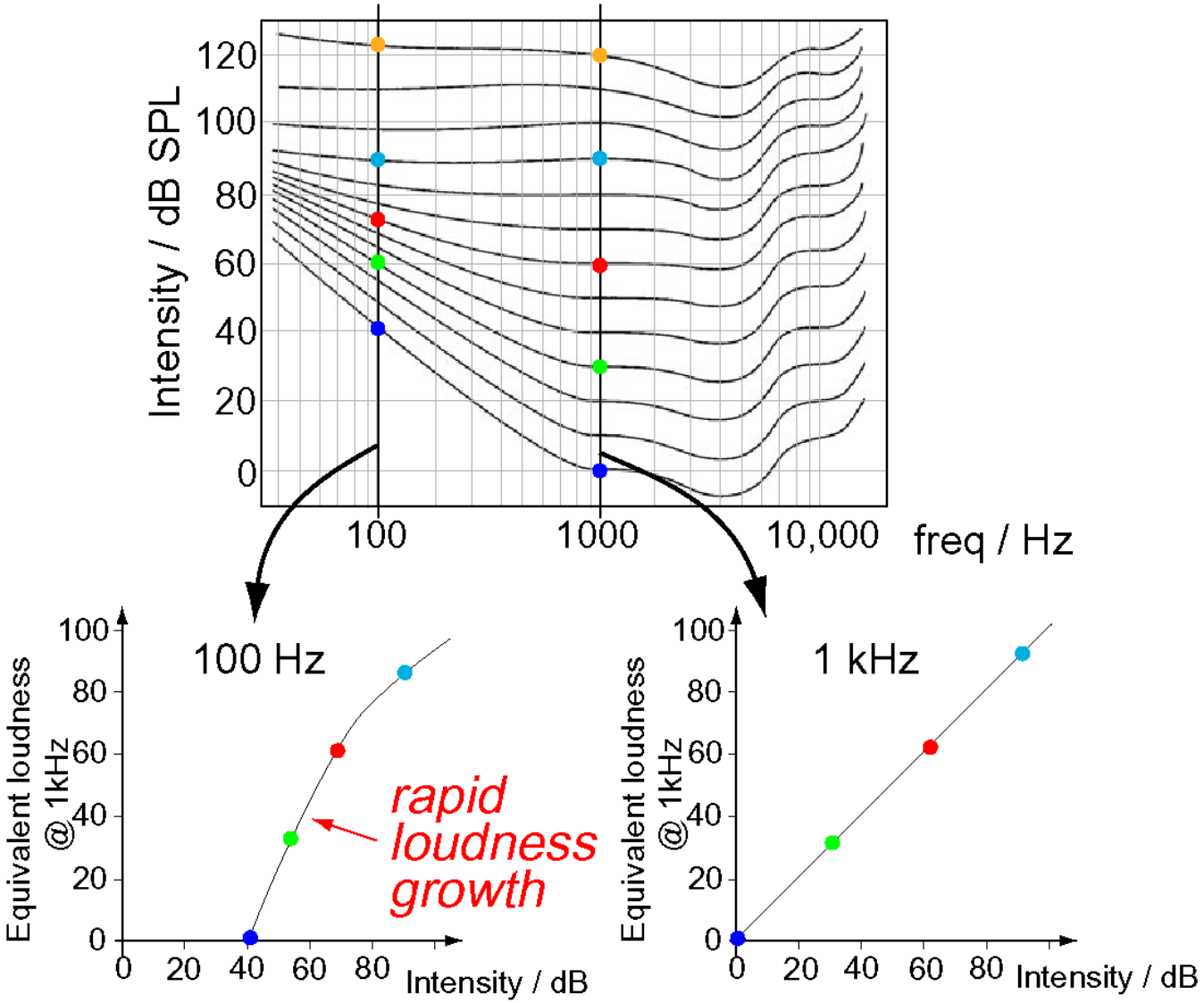
Fletcher-Munson Equal Loudness Curves



Phons (“Phones”)

The **phon** is a unit of perceived loudness for pure tones. The purpose of the phon scale is to compensate for the effect of frequency on the perceived loudness of tones. By definition, 1 phon is equal to 1 db SPL at a frequency of 1000 Hz.

Sensitivity to Loudness



JND

The **just noticeable difference** (JND) is the smallest difference in sensory input that is detectable by a human being. It is also known as the **difference limen** (DL)

Weber's Law

Weber's Law (named after Ernst Heinrich Weber, 1795-1878) attempts to describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli.

$$DL \propto \frac{\Delta I}{I}$$

Difference Limen

The Sone

The **sone** is a unit of perceived loudness, based on a 1936 proposal by S. Stevens.

- At 1kHz, 1 sone = 40 phons = 40 db SPL

$$\Psi = \frac{1}{15.849}\left(\frac{I}{I_{ref}}\right)^{0.3}$$

Loudness in sones

10^{-12} watts/meter^2

The Sone

$$\Psi_{sone} = \frac{1}{15.849}\left(\frac{I}{I_{ref}}\right)^{0.3}$$

$$\log\left(\Psi_{sone}\right) = -\log(15.849) + 0.03 \times 10 \log\left(\frac{I}{I_{ref}}\right)$$

$$\log\left(\Psi_{sone}\right) = -1.2 + 0.03\Psi_{phon}$$

Really, it's is complicated…

- Frequency dependent audibility thresholds
- Frequency dependent growth rates of loudness
- Saturating 'auditory filters'
- Interactions of sinusoids in complex sounds
- Temporal effects:
  integration times, adaptation, fatigue
- Binaural loudness