Topic 4

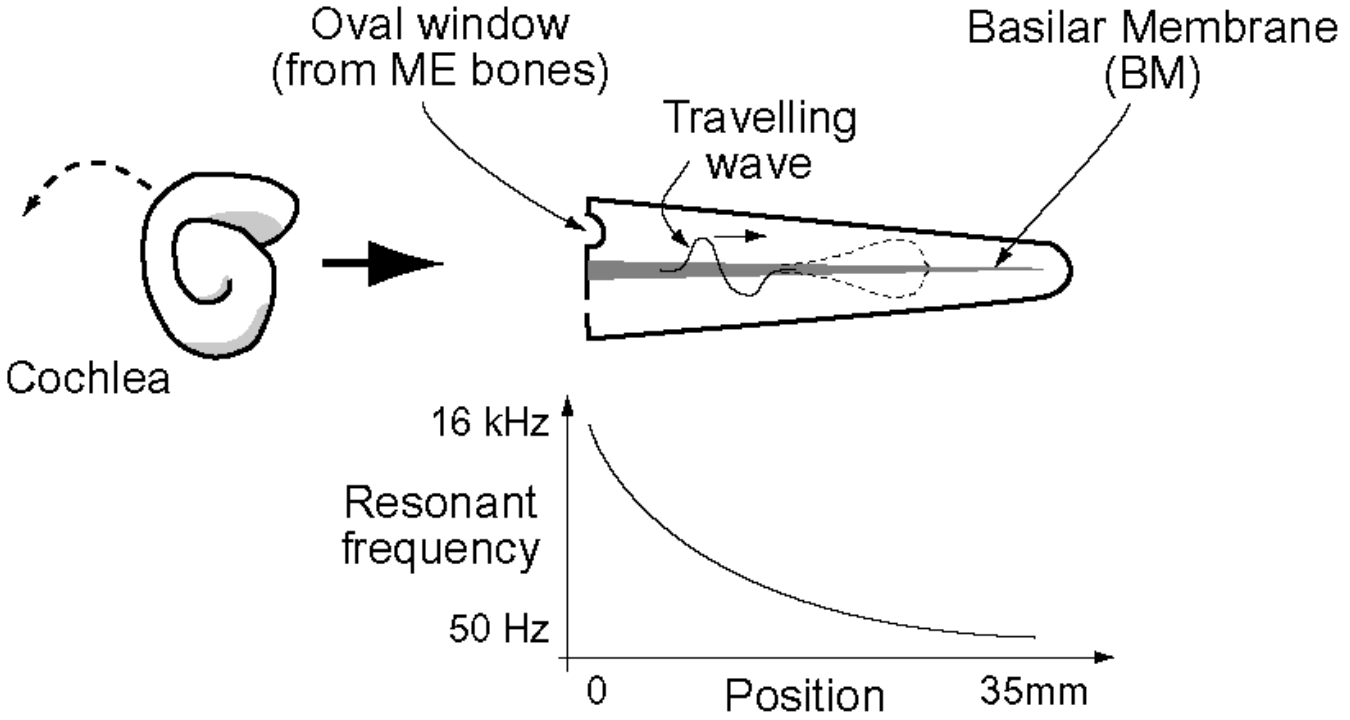
Pitch & Frequency

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

A musical interlude

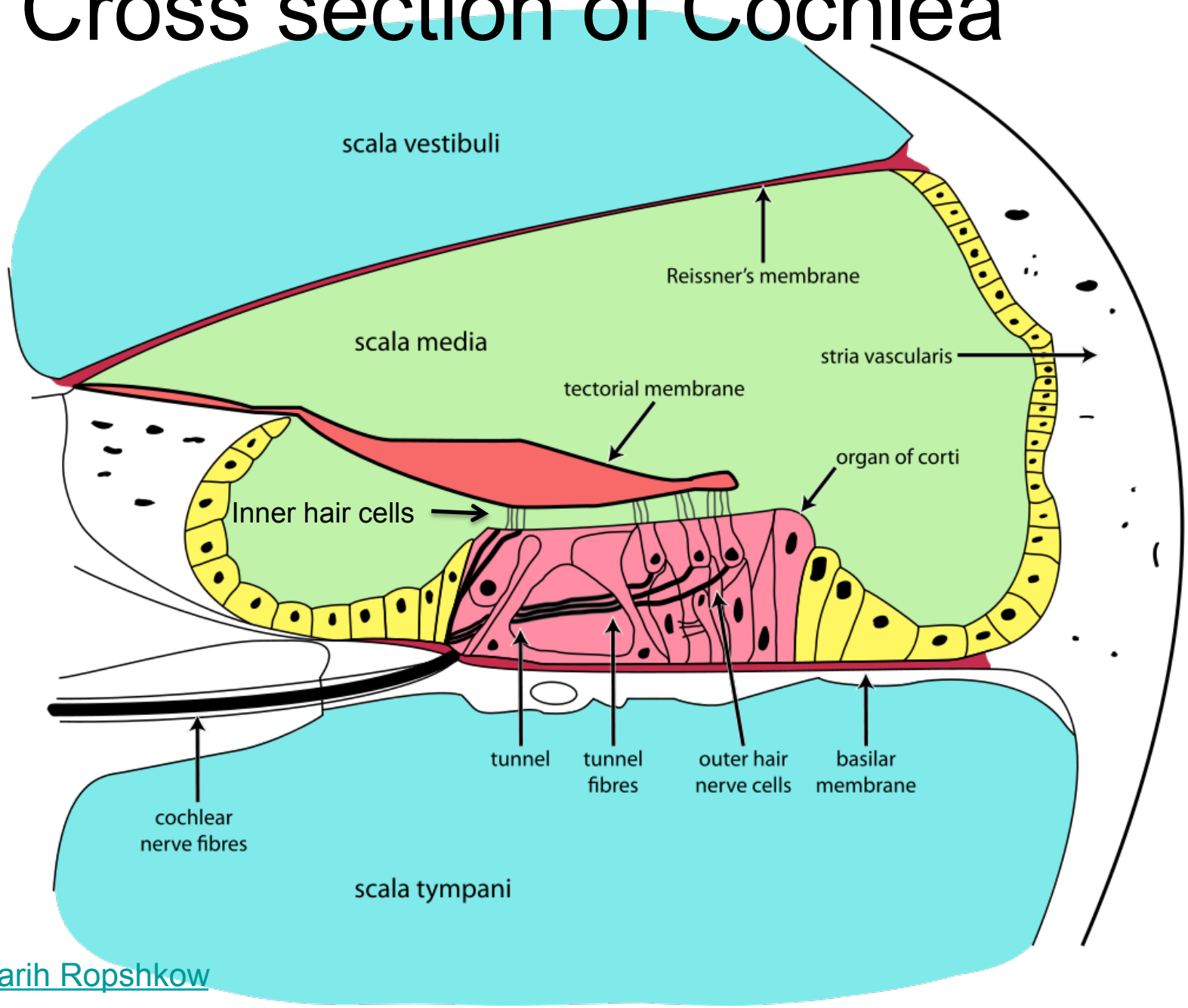
- **KOMBU** 
  - This solo by Kaigal-ool of Huun-Huur-Tu (accompanying himself on doshpuluur) demonstrates perfectly the characteristic sound of the Xorekteer voice
  - An example of Tuvan throat-singing, or Khoomei

The Cochlea



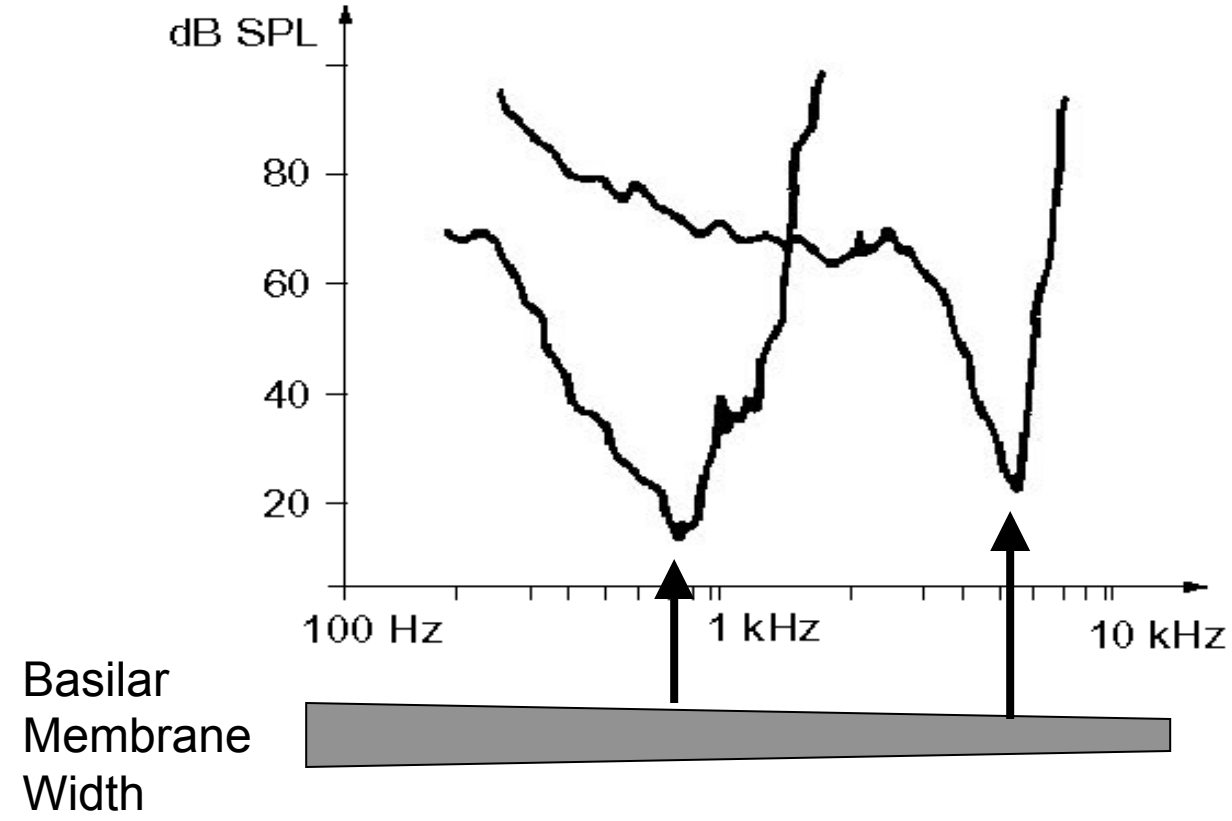
- Each point on the Basilar membrane resonates to a particular frequency
- At the resonance point, the membrane moves

Cross section of Cochlea



Thanks to Oarih Ropshkow

Frequency Sensitivity

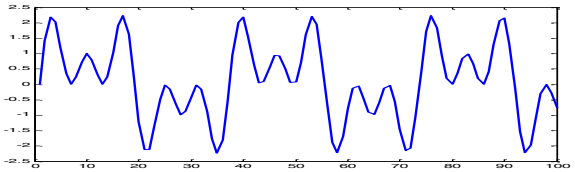


- single nerve measurements

We decompose sounds into sines

Output: sine waves

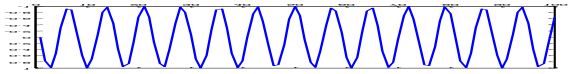
Input: complex sound



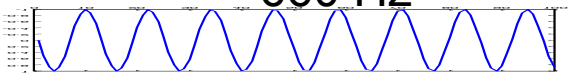
Peripheral
Auditory system

Cochlea,
Auditory nerve

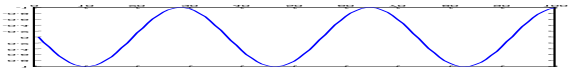
1100 Hz



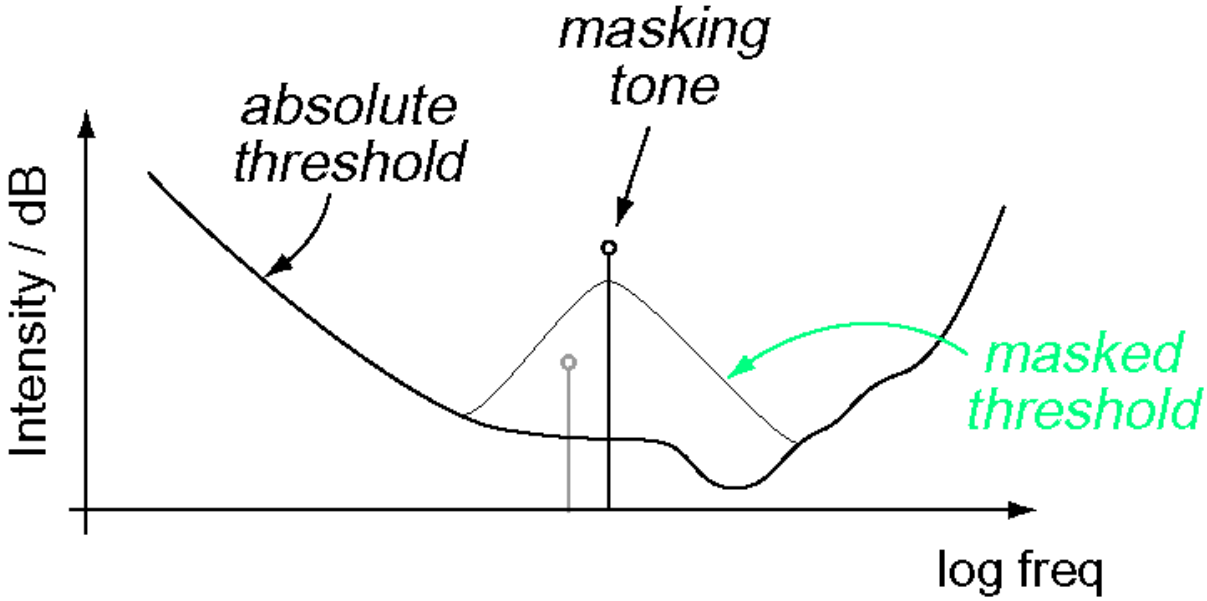
660 Hz



220 Hz



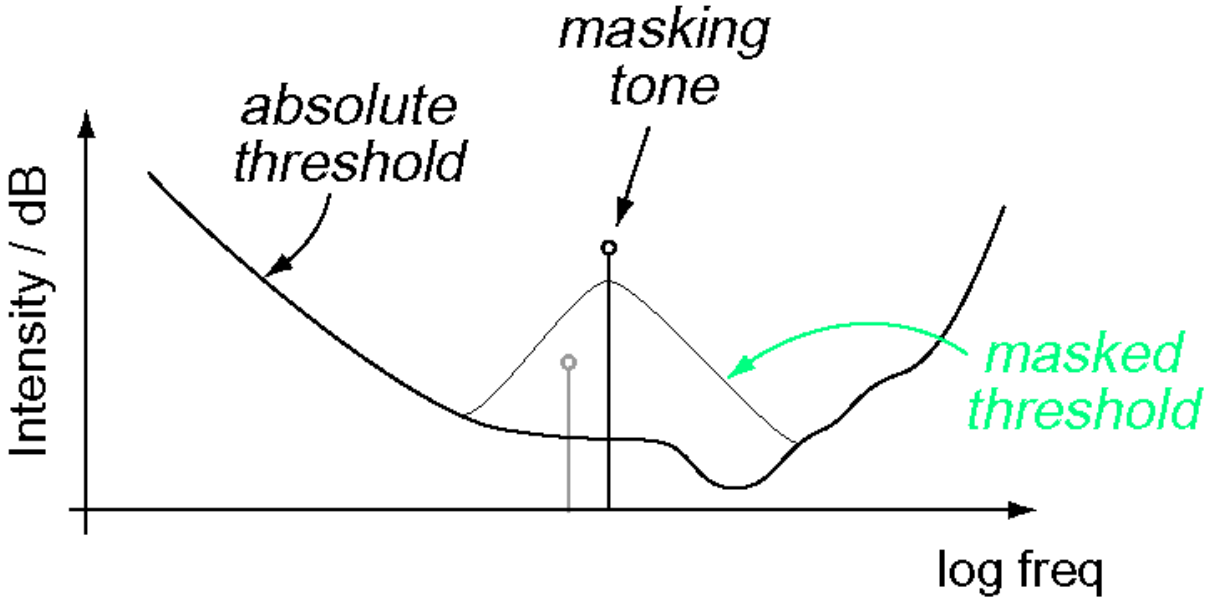
Masking



- A loud tone masks perception of tones at nearby frequencies

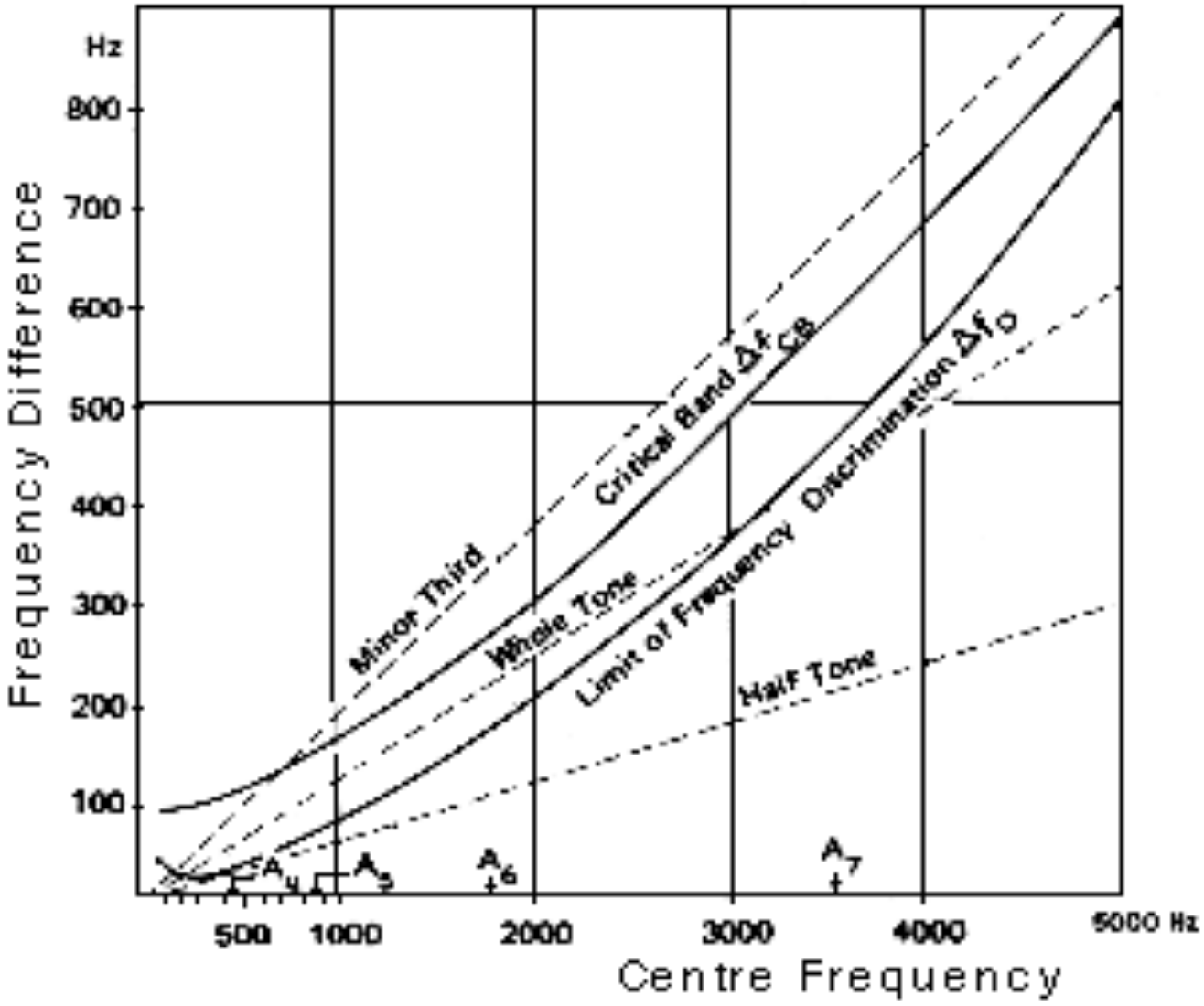
1000 Hz 1000_975_20dB 1000_975_6dB 1000_475_20dB

Critical Band



- Critical band – the frequency range over which a pure tone interferes with perception of other pure tones
- Critical bands get wider as frequency increases

More Critical Bands



Coding frequency information (a simplified story)

- Frequencies under 5 kHz
  - Individual harmonics are resolved by the cochlea
  - Coded by *place* (which nerve bundles along the cochlea are firing)
  - Coded by *time* (nerves fire in synchrony to harmonics)
- Frequencies over 5 kHz
  - Individual harmonics can't be resolved by the inner ear and the frequency is revealed by temporal modulations of the waveform amplitude (resulting in synched neuron activity)

Pitch (ANSI 1994 Definition)

- That attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high. Pitch **depends mainly on the frequency** content of the sound stimulus, but **also depends on the sound pressure and waveform** of the stimulus.

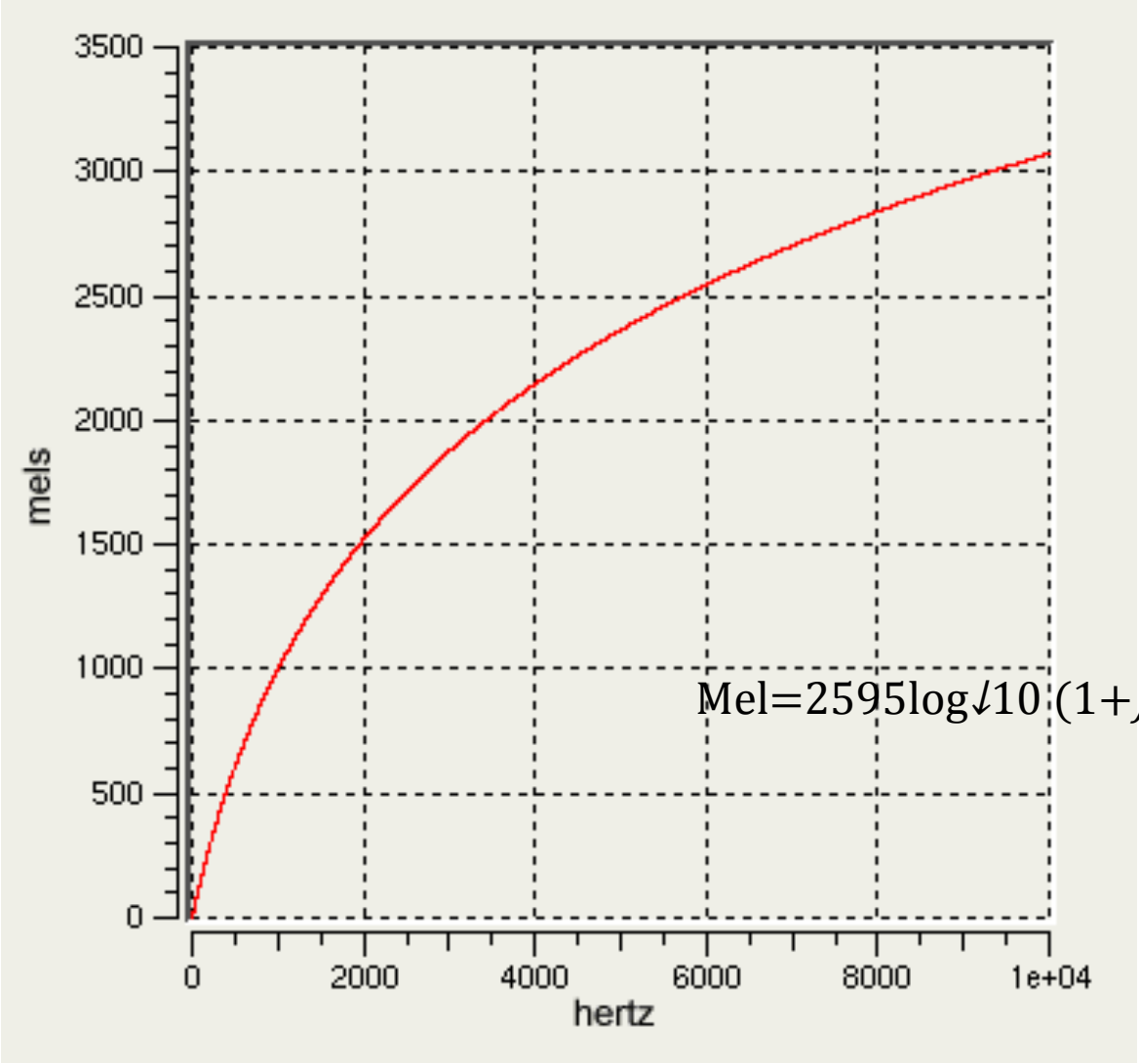
Pitch (Operational)

- A sound has a certain pitch if it can be reliably matched to a sine tone of a given frequency at 40 db SPL

Mel Scale

- A perceptual scale of pitches judged by listeners to be equal in distance from one another. The reference point between this scale and normal frequency measurement is defined by equating a 1000 Hz tone, 40 dB SPL, with a pitch of 1000 mels.

Mel Scale



$$\text{Mel} = 2595 \log_{10}(1 + f/700)$$

Mel Scale

- Above about 500 Hz, larger and larger intervals are judged by listeners to produce equal pitch increments.
- The name **mel** comes from the word **melody** to indicate that the scale is based on pitch comparisons.
- proposed by Stevens, Volkman and Newman (Journal of the Acoustic Society of America 8(3), pp 185-190, 1937)

Ear Craziness

- Binaural Diplacusis
  - Left ear hears a different pitch from the right.
  - Can be up to 4% difference in perceived pitch
- Otoacoustic Emissions
  - Ears sometimes *make* noise.
  - Thought to be a by-product of the sound amplification system in the inner ear.
  - Caused by activity of the outer hair cells in the cochlea.

Harmonic Sound

- A complex sound with strong sinusoid components at integer multiples of a fundamental frequency. These components are called **harmonics** or **overtones** or **partials**

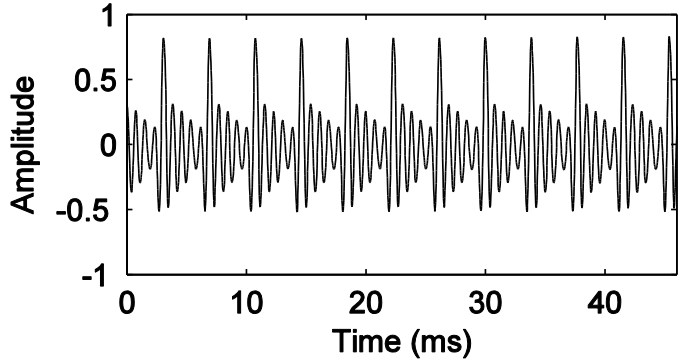
- Sine waves and harmonic sounds are the sounds that may give a perception of "pitch"

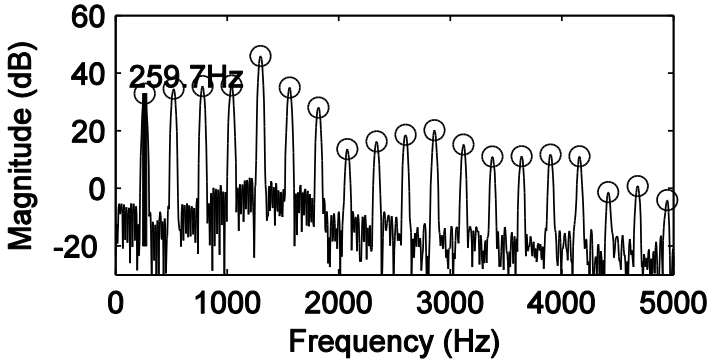
Continuity of Sounds

- Sine wave
- Strongly harmonic (Flute)
- Somewhat harmonic (Me)
- Not very harmonic (Vacuum cleaner)
- Absolutely not harmonic (White noise)

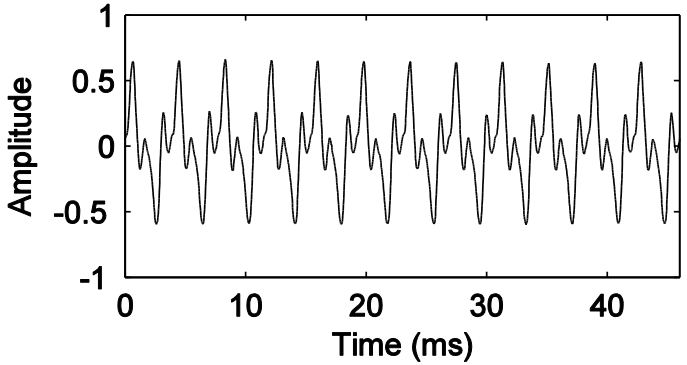
Classify Sounds by Harmonicity

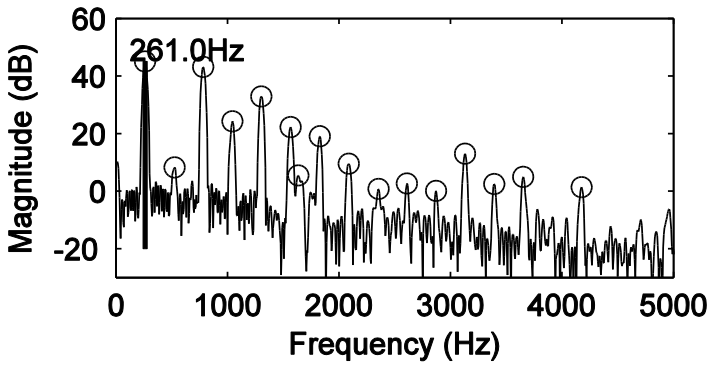
- Sine wave
- Strongly harmonic





Oboe

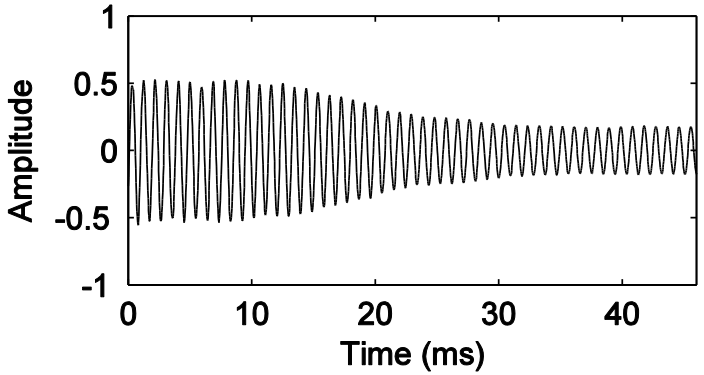


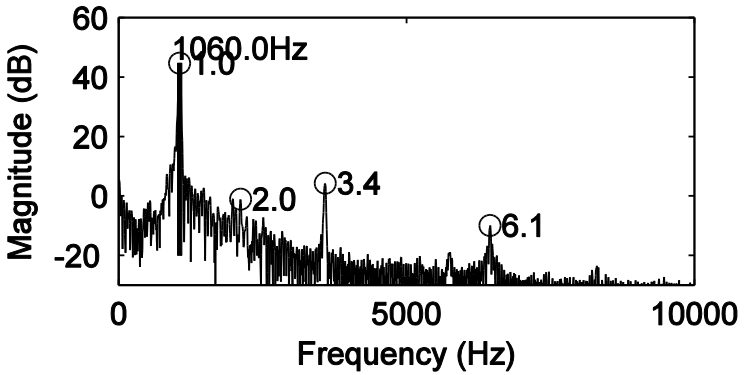


Clarinet

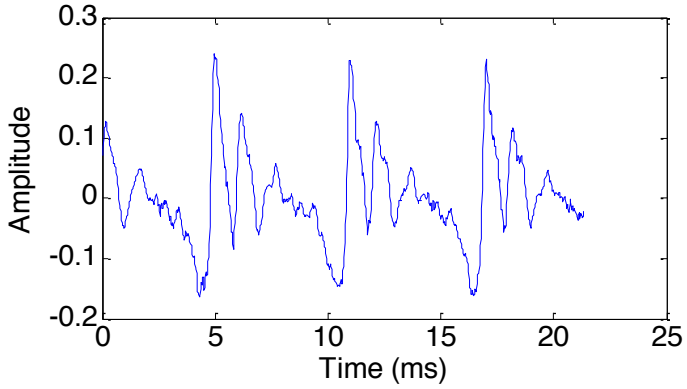
Classify Sounds by Harmonicity

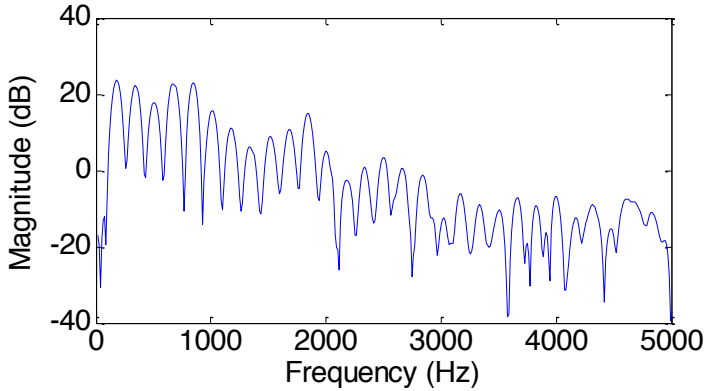
- Somewhat harmonic (quasi-harmonic)





Marimba

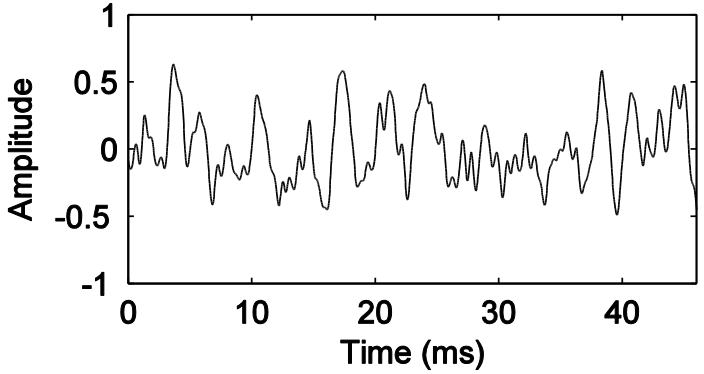


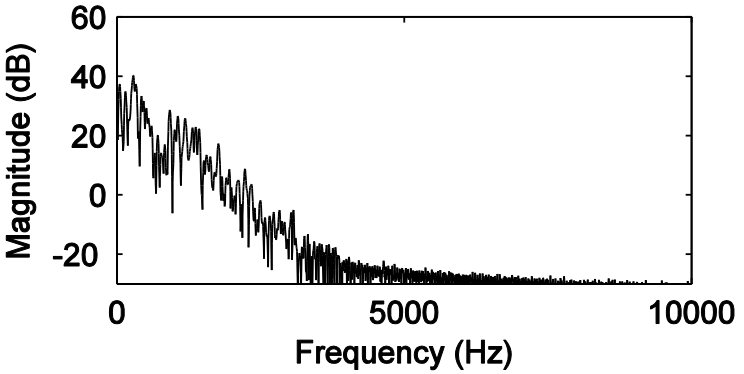


Human voice

Classify Sounds by Harmonicity

- Inharmonic





Gong

Sounds	Instrument family	Instruments
Harmonic	Woodwind	Piccolo, flute, oboe, clarinet, bassoon, saxophone
	Brass	Trumpet, horn, euphonium, trombone, tuba
	Arco string	Violin, viola, cello, double bass
	Pluck string	Piano, guitar, harp, celesta
	Vocal	Voiced phonemes
Quasi-harmonic	Pitched percussive	Timpani, marimba, vibraphone, xylophone
Inharmonic	Non-pitched percussive	Drums, cymbal, gong, tambourine

Frequency (often) equals pitch

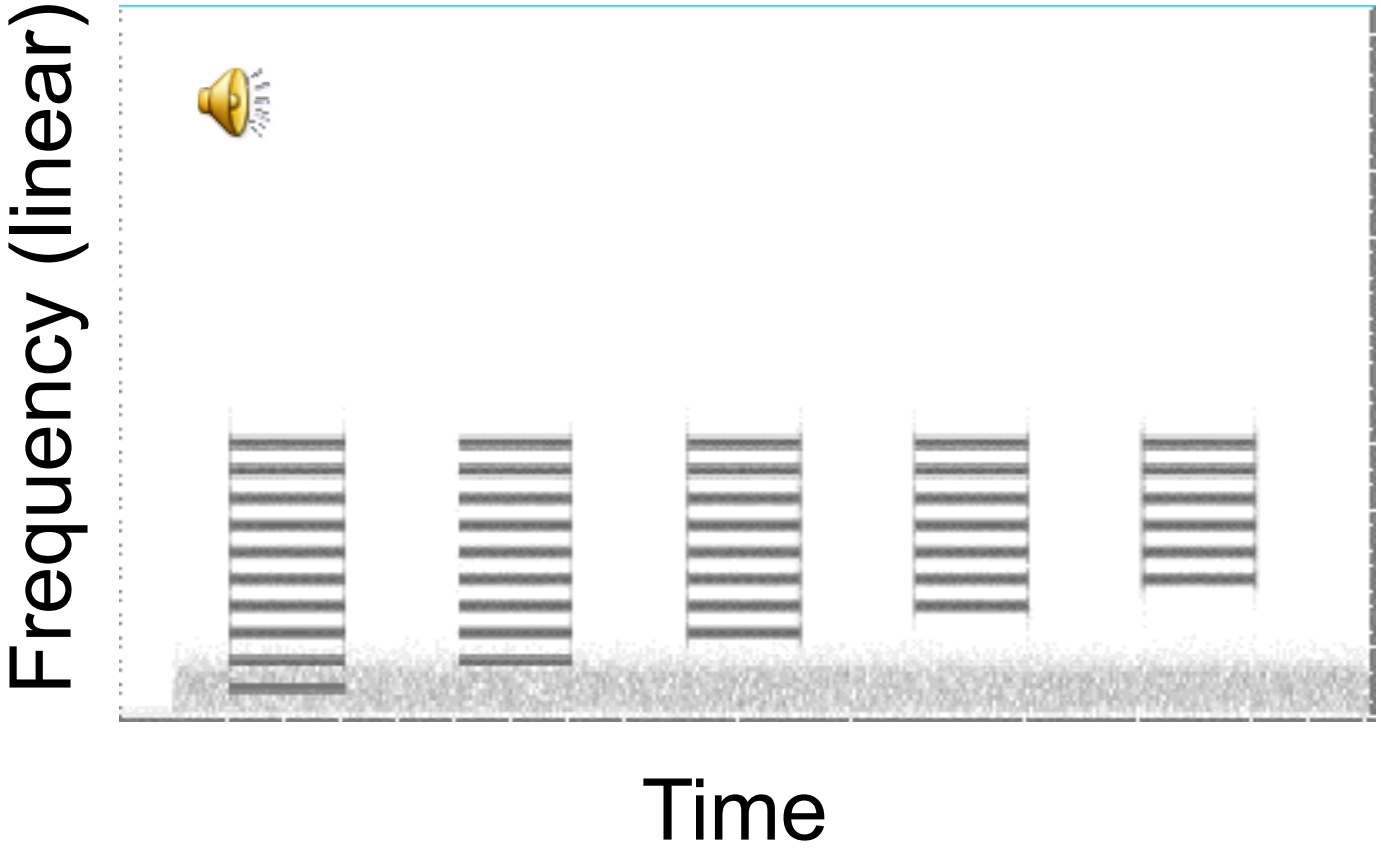
- Complex tones
  - Strongest frequency?
  - Lowest frequency?
  - Something else?

- Let's listen and explore…

Hypothesis

- Pitch is determined by the lowest strong frequency component in a complex tone.

The Missing Fundamental



Hypothesis

- Pitch is determined by the lowest strong frequency component in a complex tone.
- The case of the missing fundamental proves that ain't always so.

Hypothesis

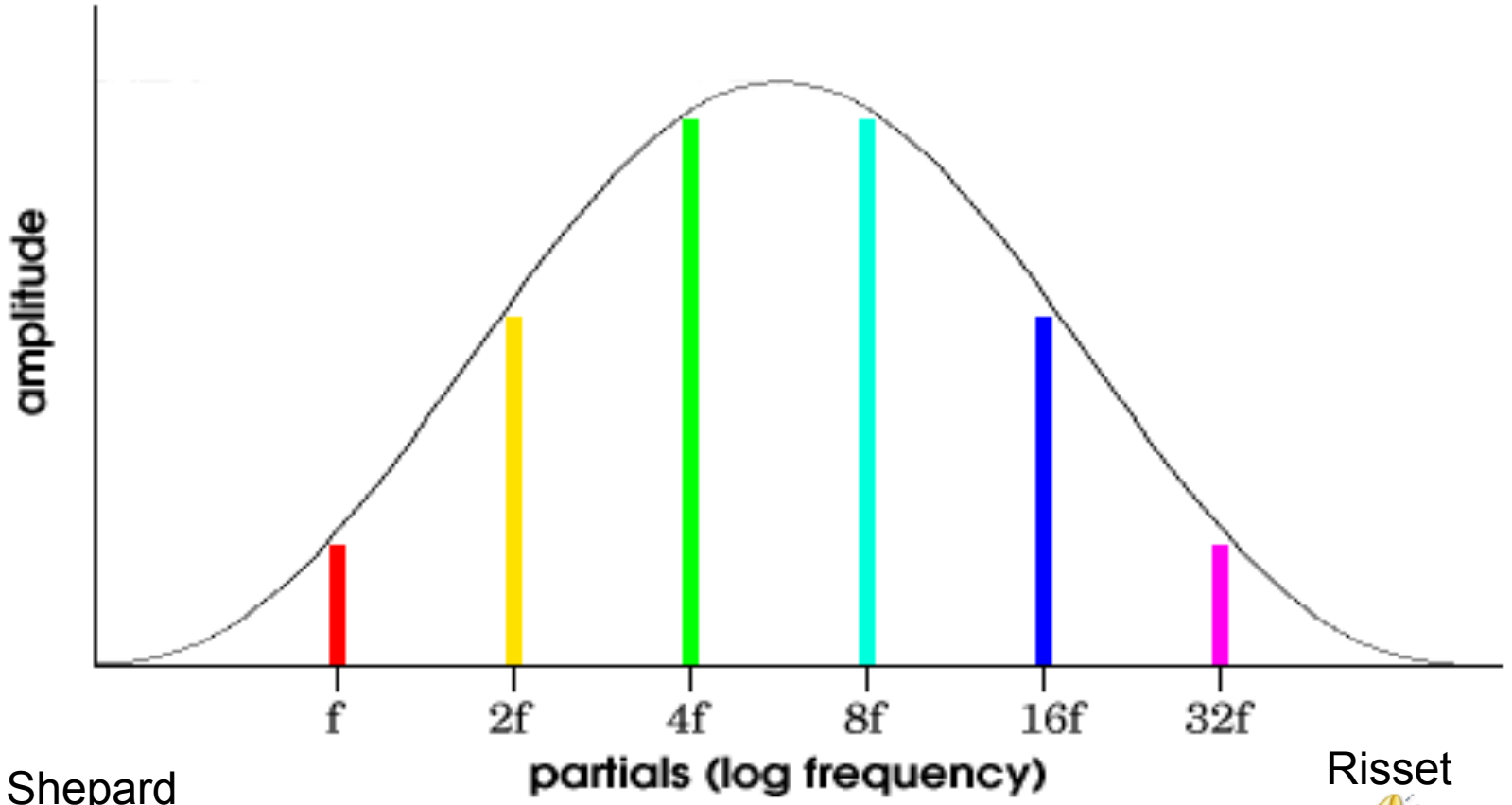
- Pitch is determined by the strongest frequency component in a harmonic tone.
- Tuvan throat singing seems to back this up.
- But what about that case of the missing fundamental?

Hypothesis – “It’s complicated”

- We hear which frequency components are loudest
- We decide if they all go together
  - Do they all start together?
  - Do they modulate together?
- We hear how they are spaced in frequency
  - Are they all spaced at intervals which are multiples of a common frequency?
  - Are their frequencies multiples of the same common frequency?
- We hear (or don’t hear) a pitch.

Shepard Tones

http://www.cs.ubc.ca/nest/imager/contributions/flinn/Illusions/ST/st.html



Shepard

Risset

Shepard tones

- Make a sound composed of sine waves spaced at octave intervals.
- Control their amplitudes by imposing a gaussian (or something like it) filter in the (log of the) frequency dimension
- Move all the sine waves up a musical ½ step.
- Wrap around in frequency.