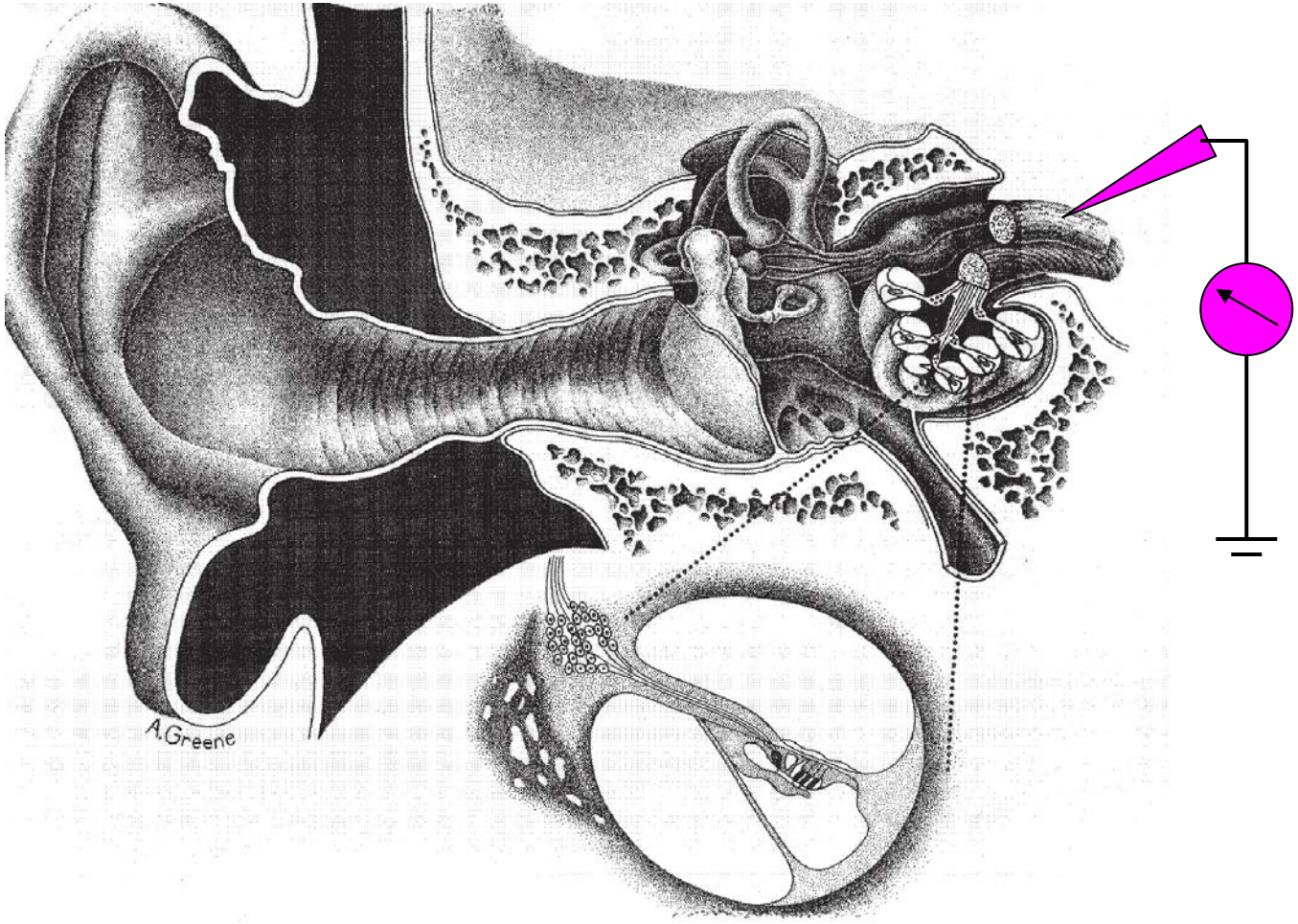
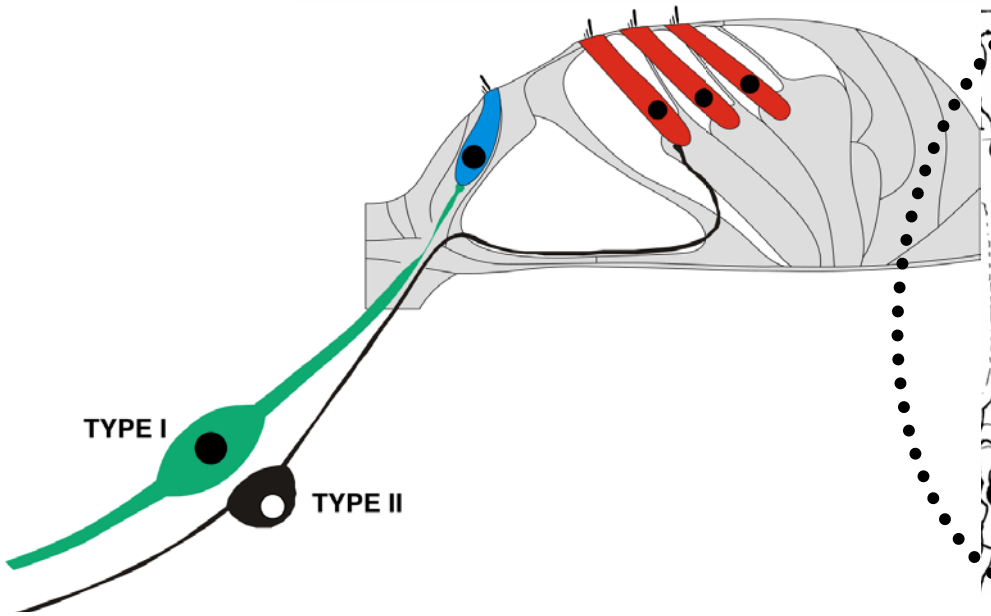
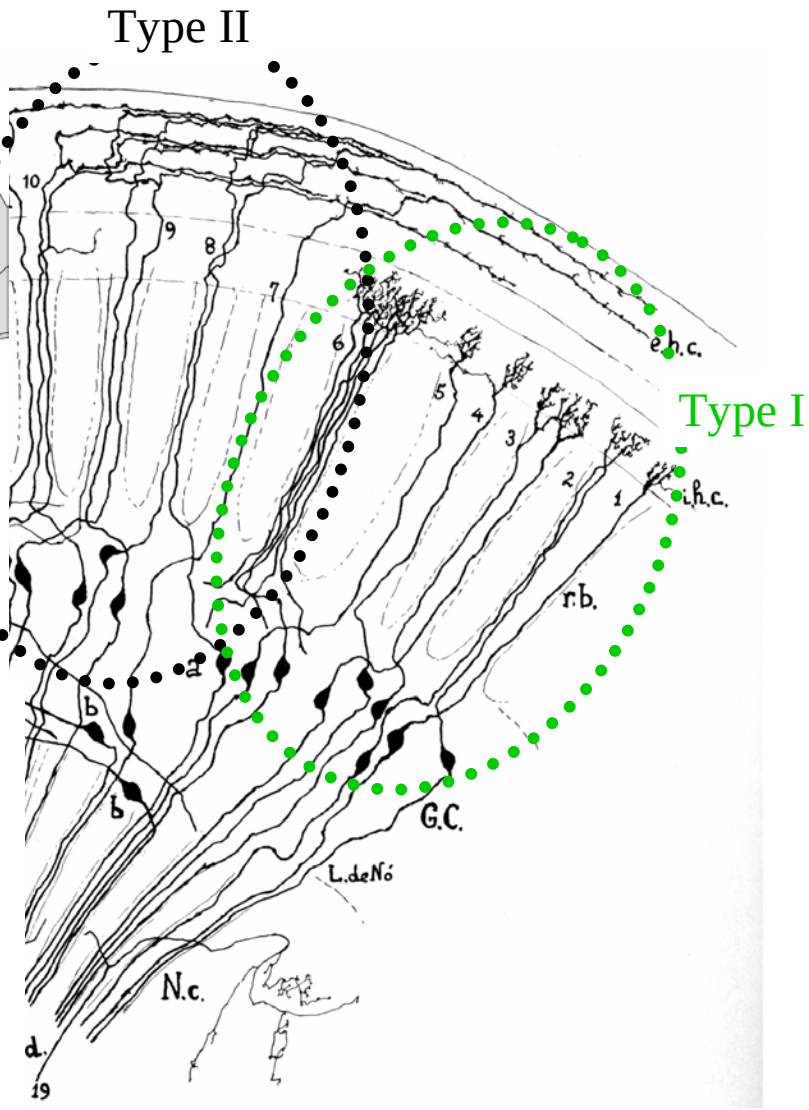
HST 721 Auditory Nerve Lecture

October, 2004



Hair Cell Afferent Innervation

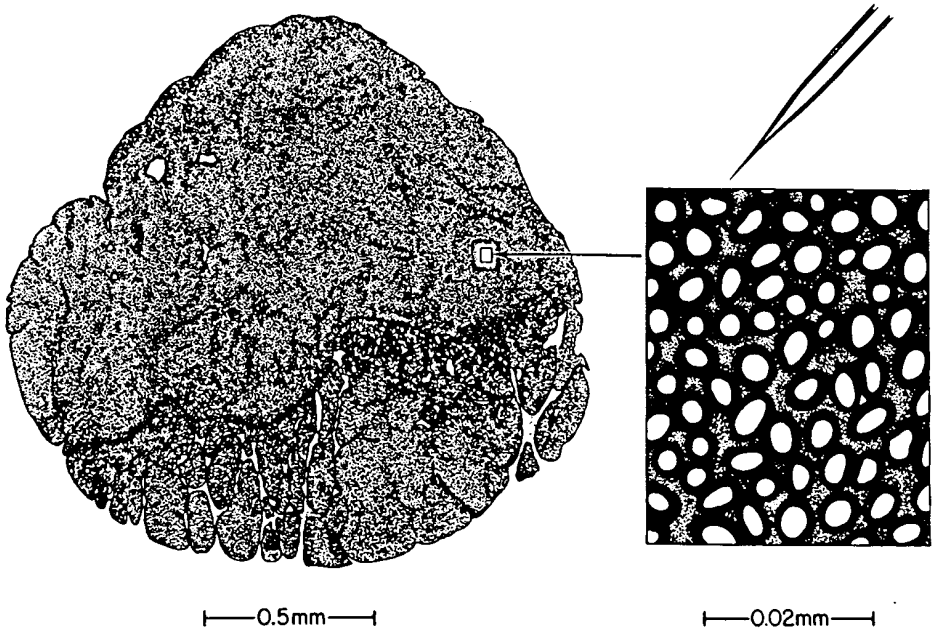


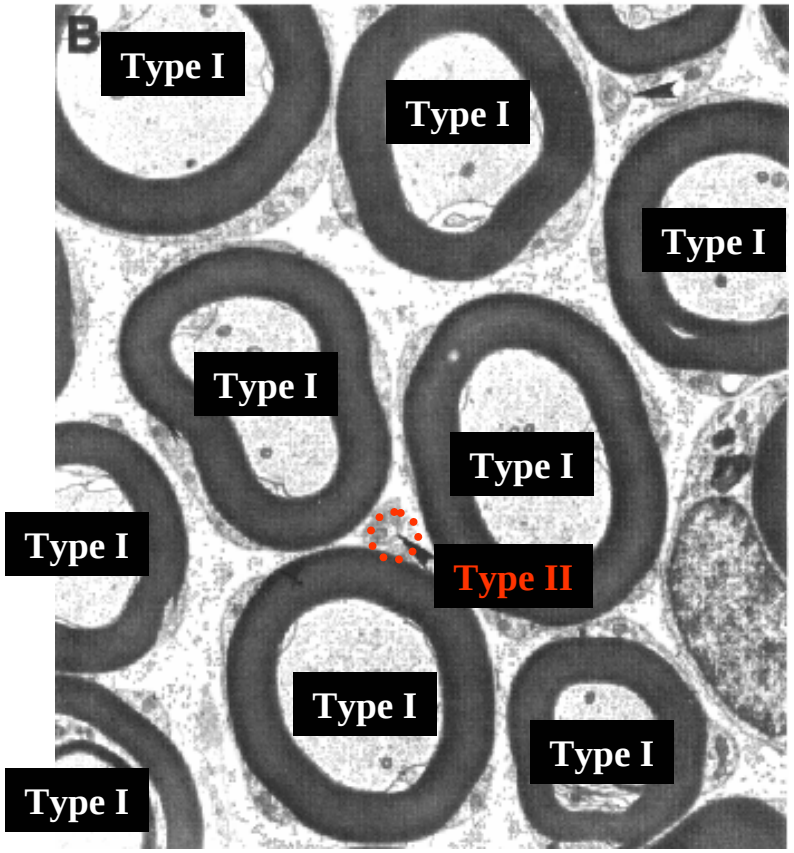


Type I: peripheral axon takes radial course to IHCs
each contacts only 1-2 IHC
95% of ANFs
myelinated axons

Type II: peripheral axon spirals basalwards among OHCs
each contacts 10-100 OHCs
5% of ANFs
unmyelinated axons

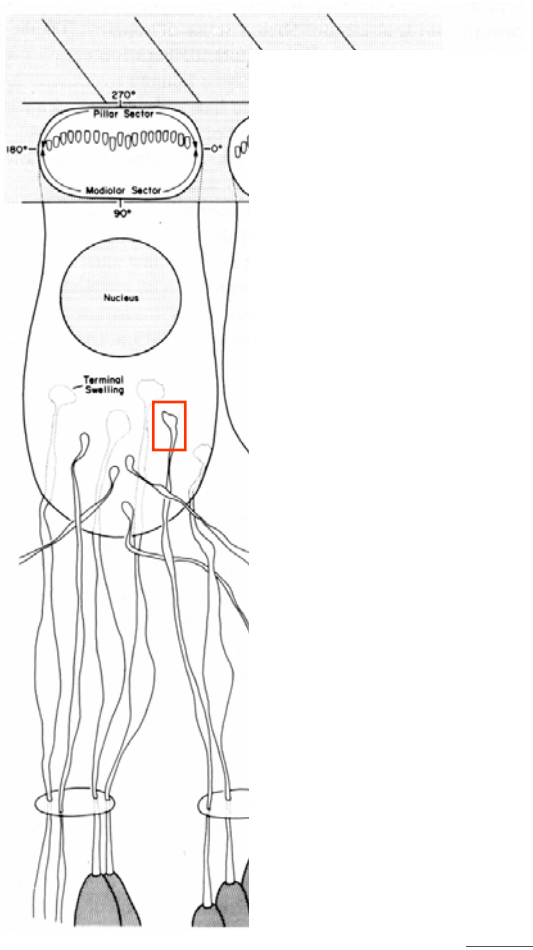
Hair Cell Afferent Innervation



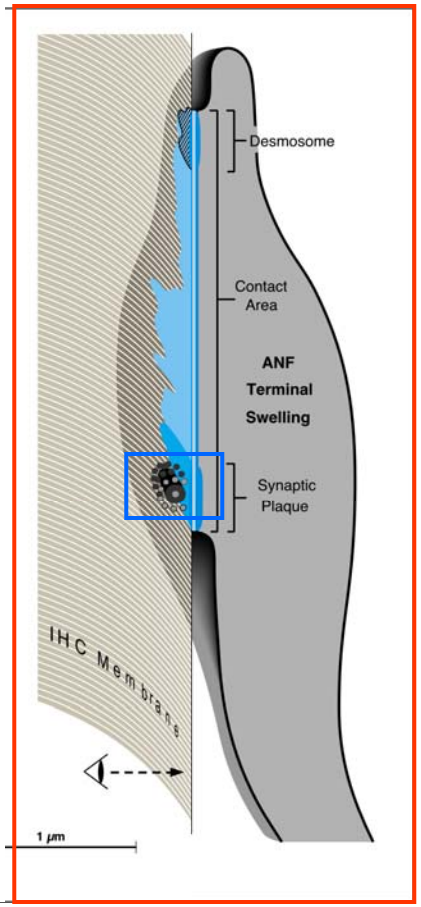


- Unmyelinated type-II axons are too small to record from
- All ANF data are from Type-I / radial fibers innervating IHCs

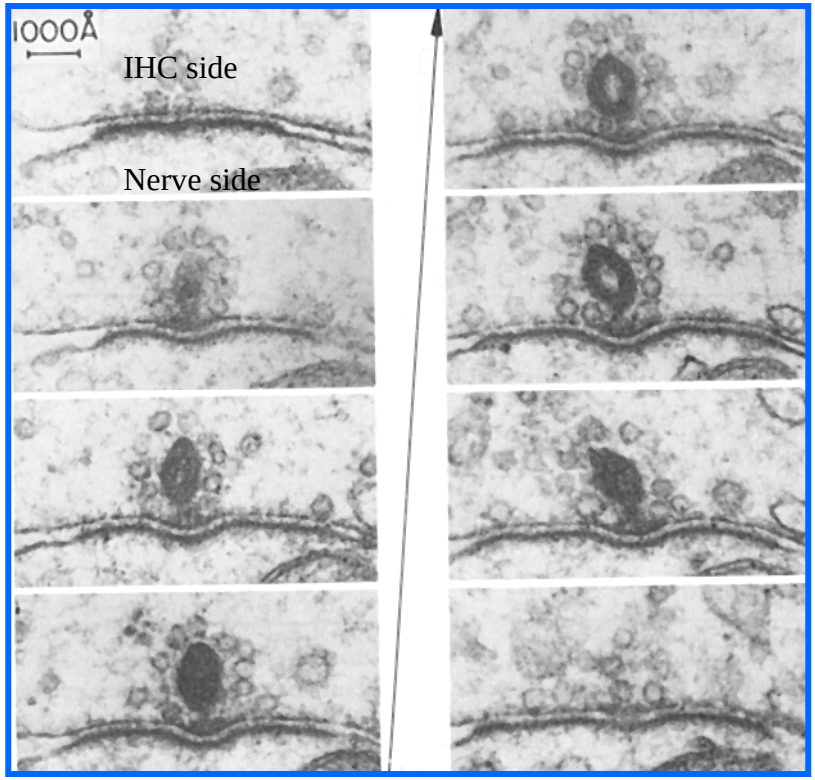
IHC Afferent Innervation



Each radial fiber (RF) contacts a single IHC by a single terminal swelling

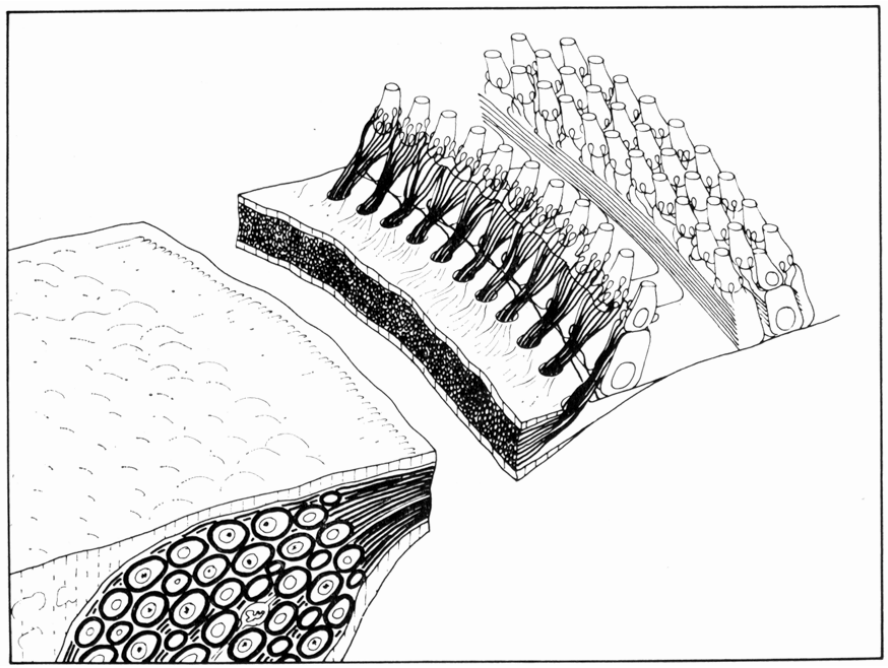


Each terminal swelling consists of a single synaptic plaque

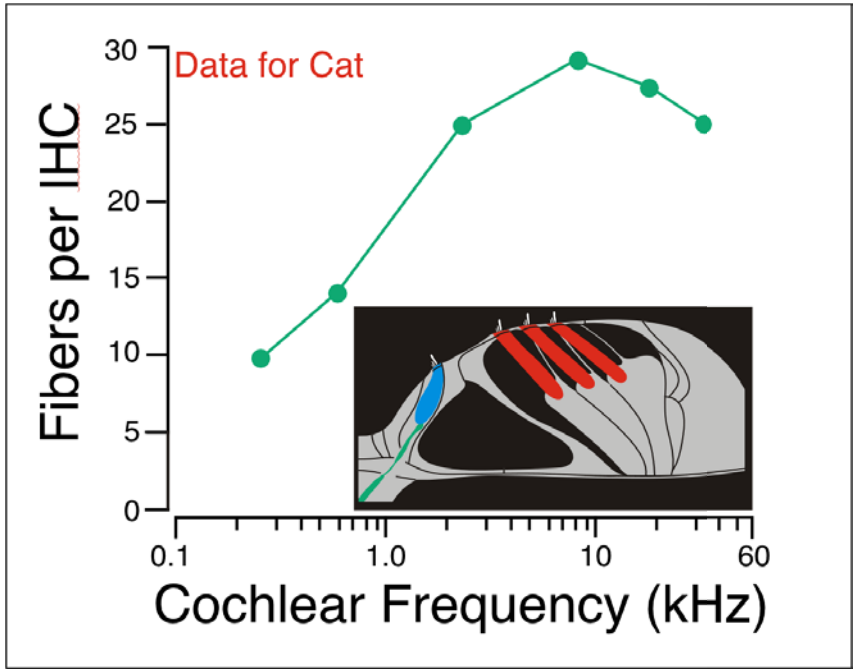


Each synaptic plaque is continuous sheet of specialized (thickened) membrane pre- and post-synaptically, with a synaptic ribbon and associated halo of vesicles

IHC Afferent Innervation

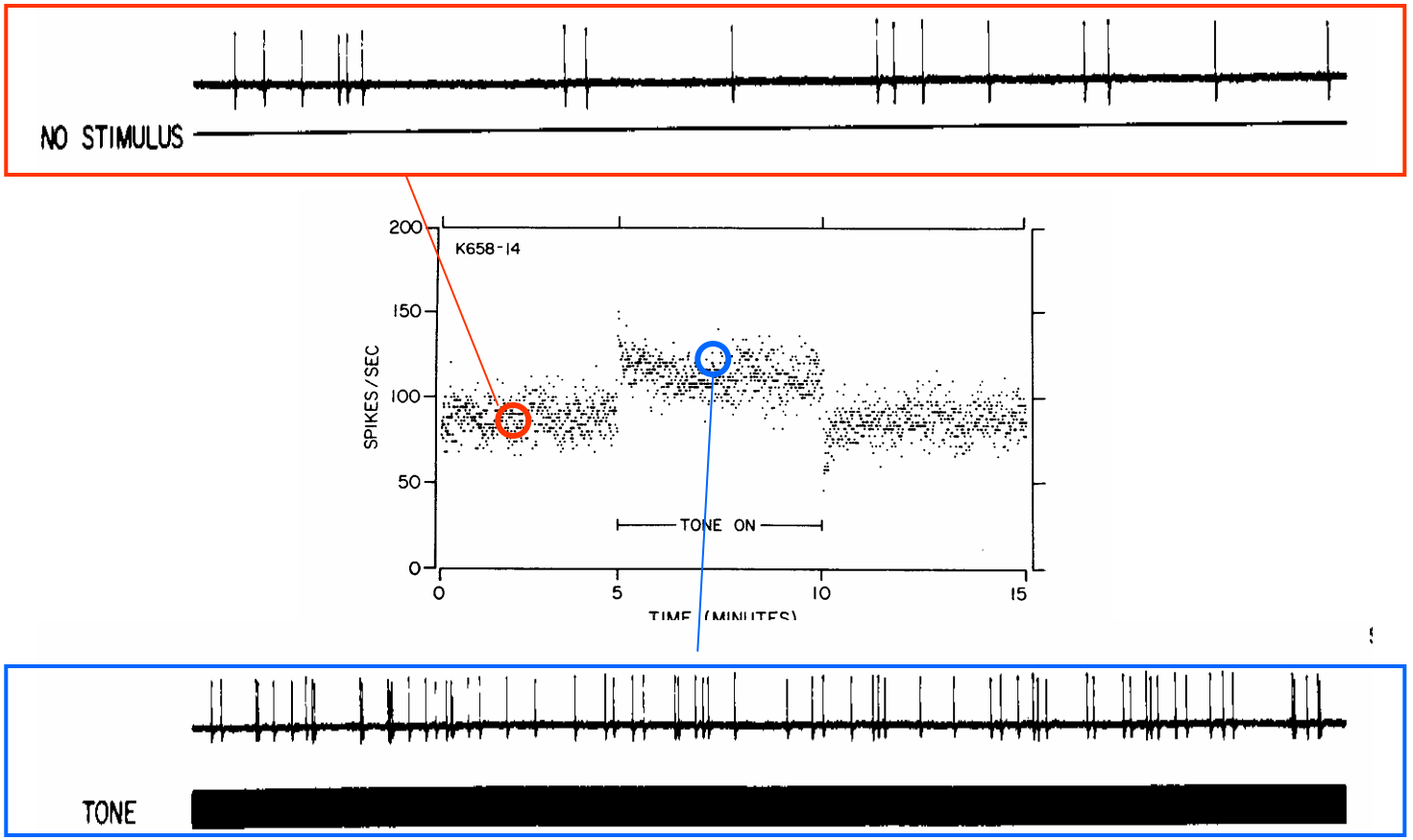


Each IHC is contacted by 10 to 30 radial fibers



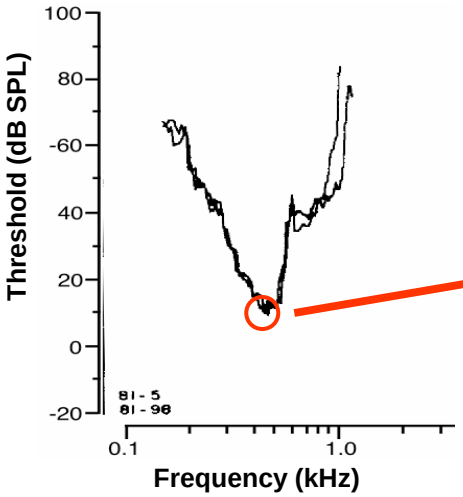
Fibers/IHC varies from base to apex

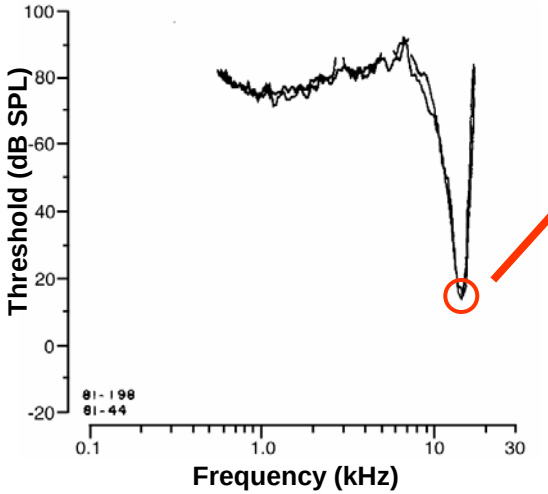
Rate Coding in the Auditory Nerve



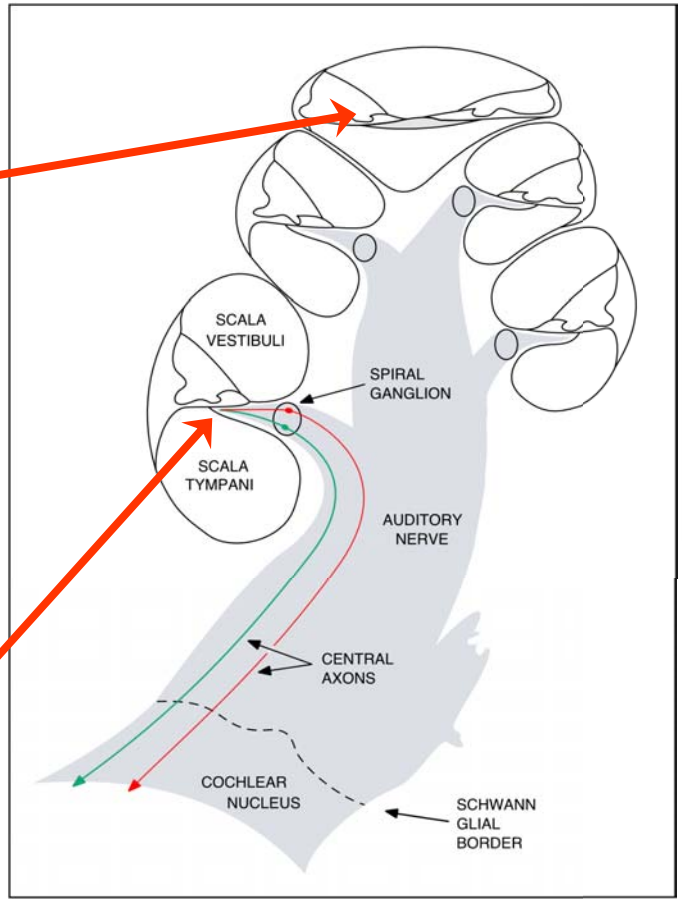
- ANFs fire without acoustic stimulation: spontaneous rate (SR) varies from 0 -120 sp/sec
- With tones at some frequency-intensity combos, ANFs increase average rate
- Although there is post-onset adaptation, response continues as long as tone continues
- Response is probabilistic: tone-off rate sometimes exceeds tone-on rate

Tuning curves, CF and the cochlear frequency map

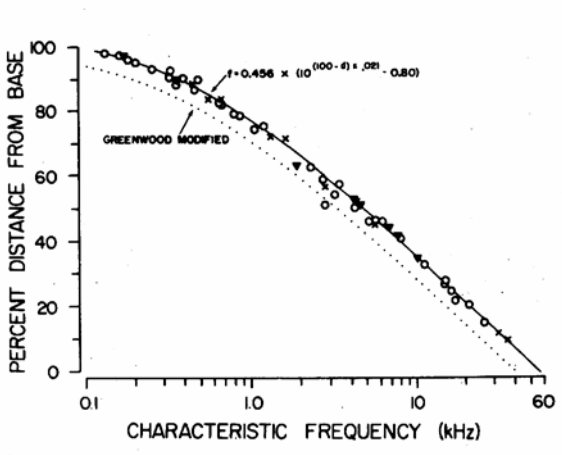




Tuning curve defines iso-response contour: frequencies-intensities within curve evoke rate increase.

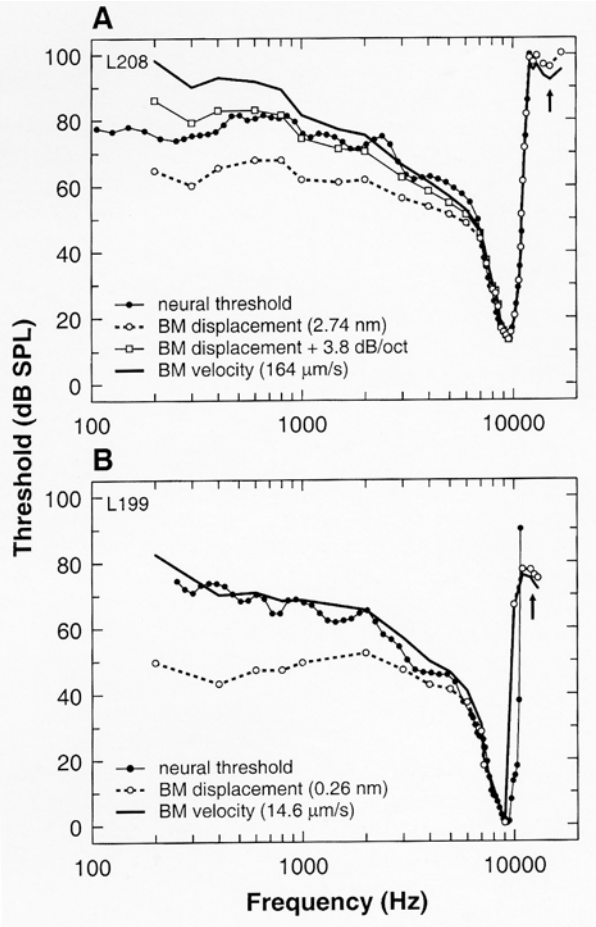


Characteristic Frequency (CF) defines where along cochlear spiral each radial fiber originates



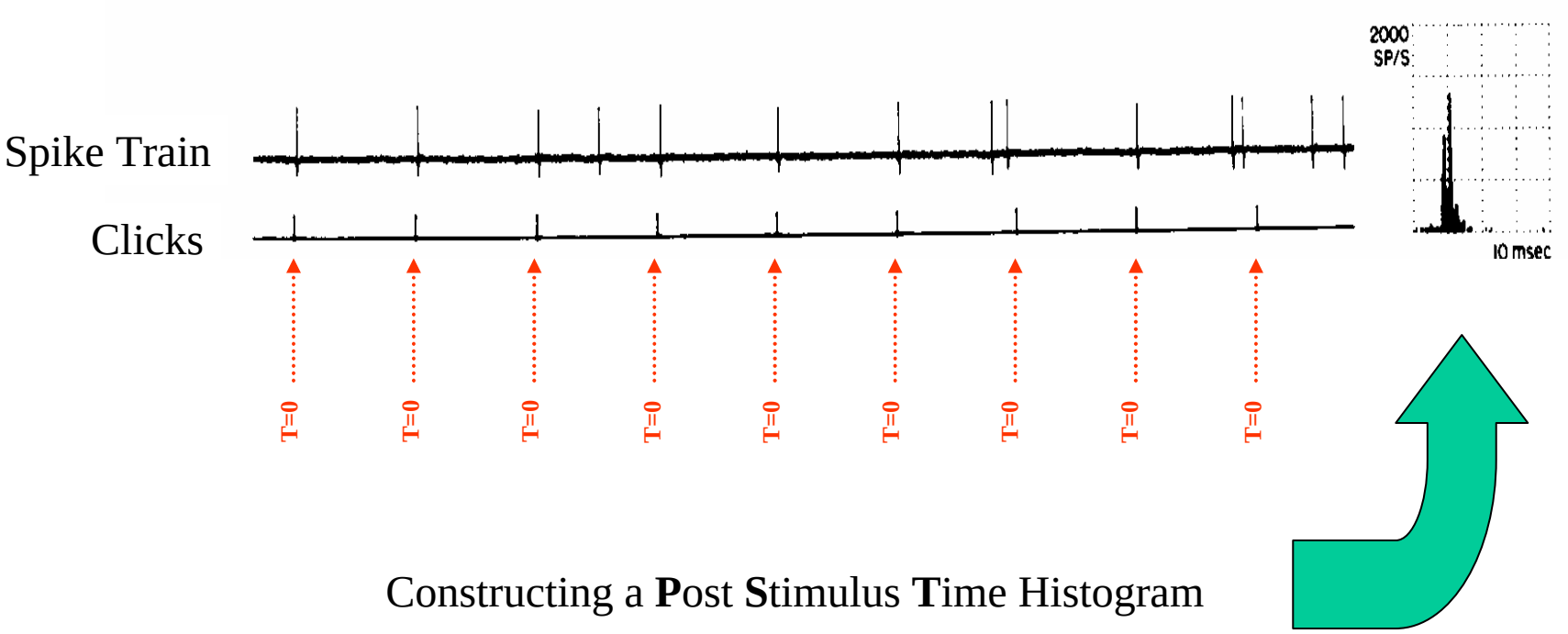
Intracellular labeling reveals cochlear frequency map: linear distance to log frequency

Tuning curves, CF and the cochlear frequency map



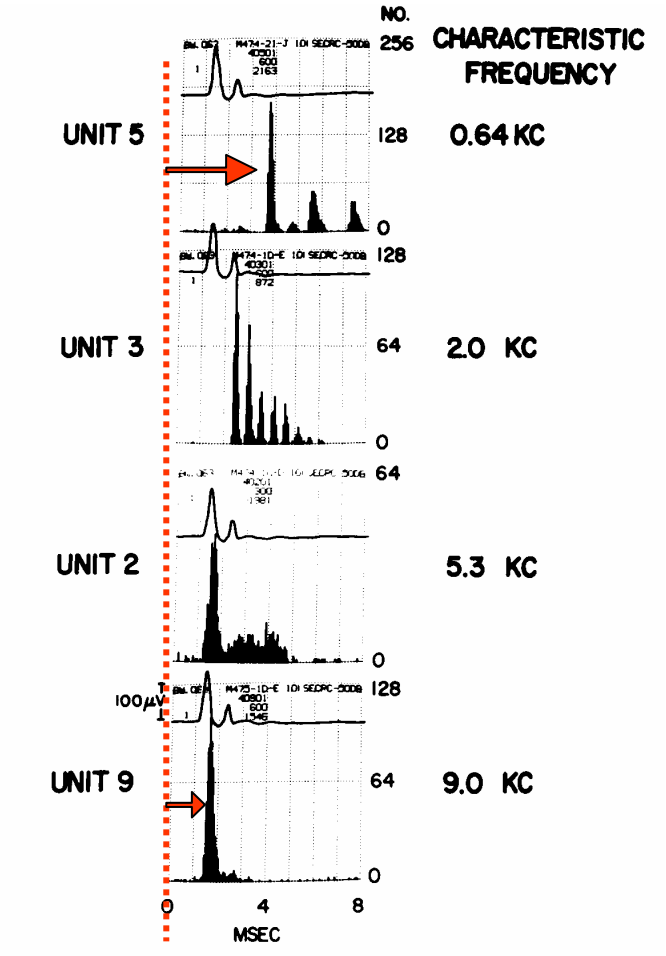
- Tuning characteristics arise largely in the cochlear mechanics stage
- BM iso-response contours show similar tuning to ANF isoresponse tuning curves.

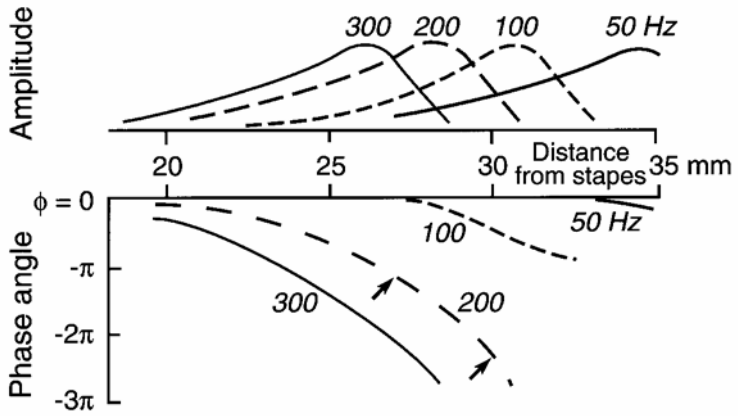
Click Response, Latency and BM traveling waves

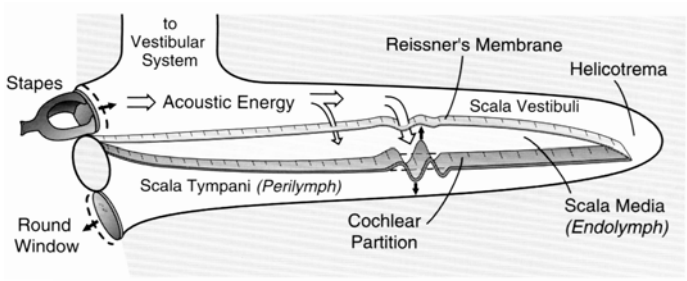


Constructing a **P**ost **S**timulus **T**ime Histogram

Click Response, Latency and BM traveling waves



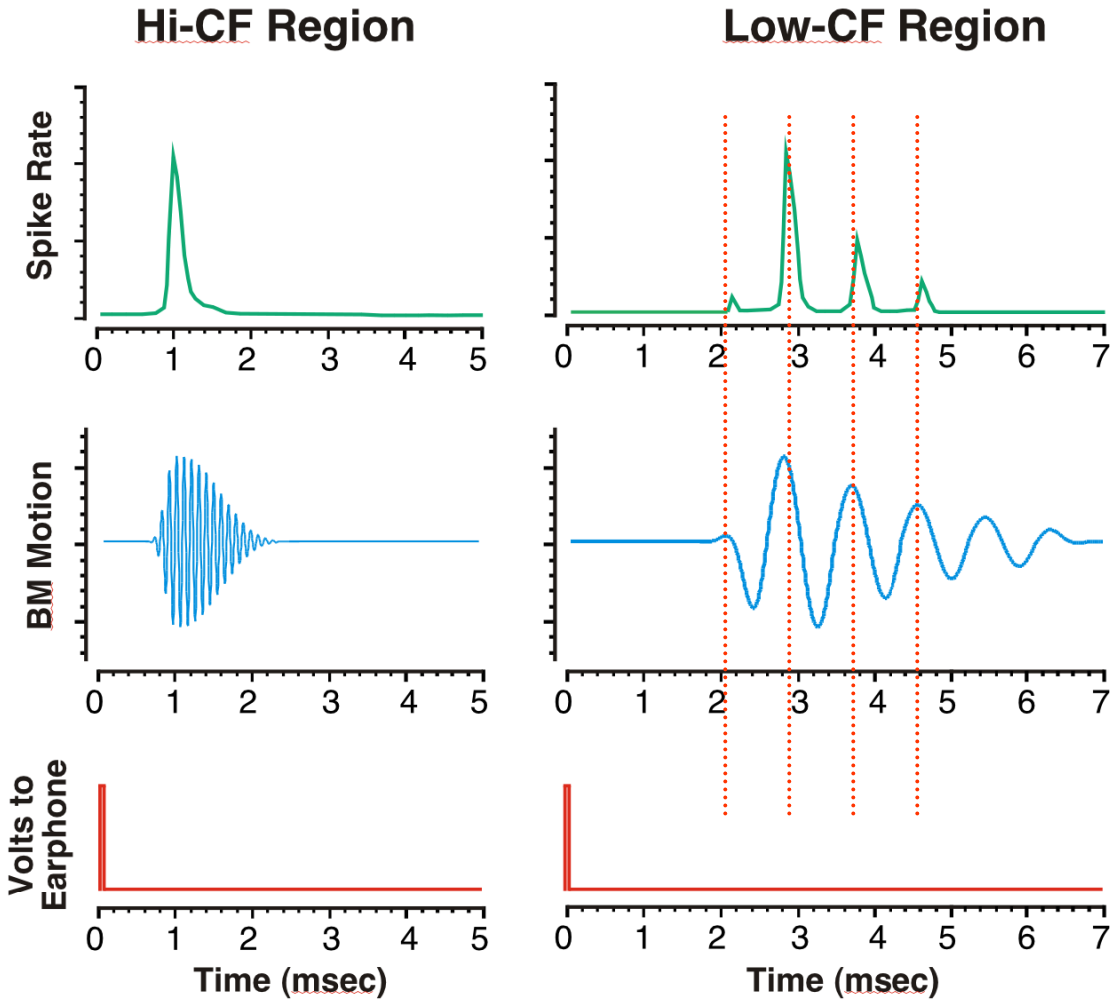




- Increasing "latency" with decreasing CF reflects BM traveling wave delay
- Interpeak time in PST for low-CF fibers = 1/CF

- Increasing phase delays in mechanical measurements of basilar membrane motion showed traveling wave delays

Click Response, Latency and BM traveling waves



ANF PST Histograms

BM Motion

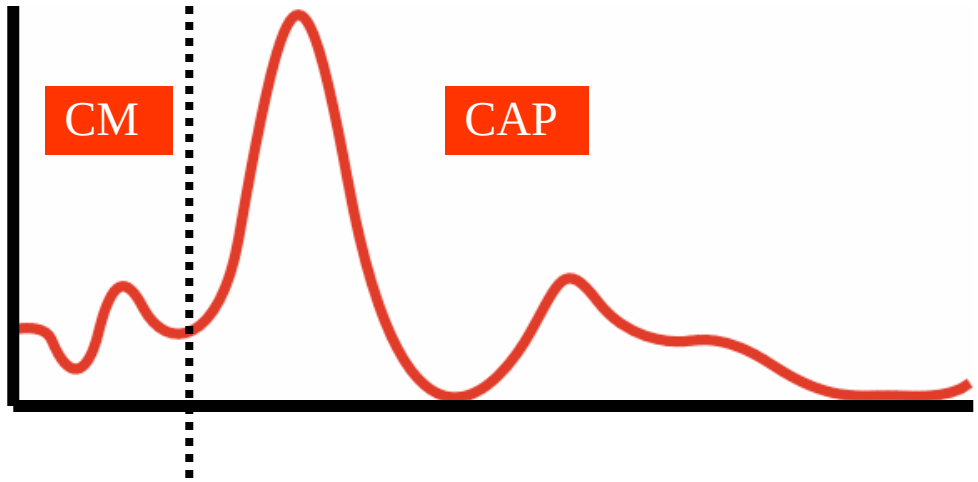
Click Stimuli

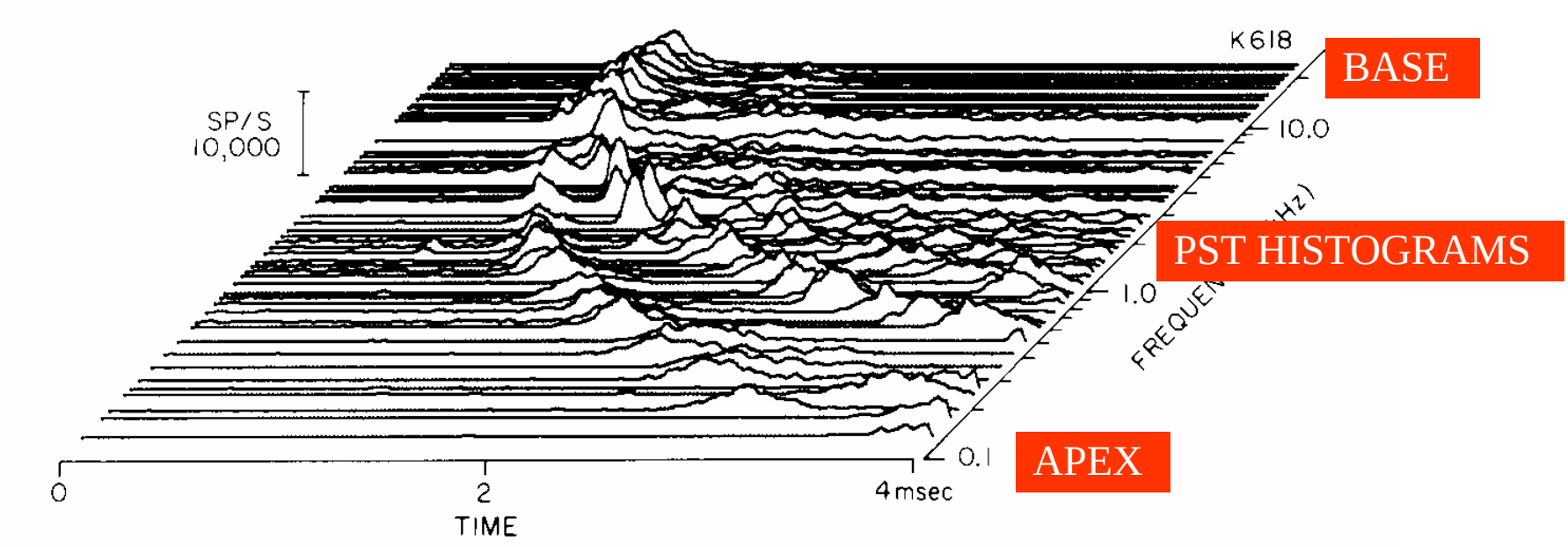
- At low CFs (< 4 kHz), PST peaks mirror peaks in BM motion
- At high CFs (> 4 kHz), ANF cannot follow individual cycles of BM motion

Click Response: the CAP

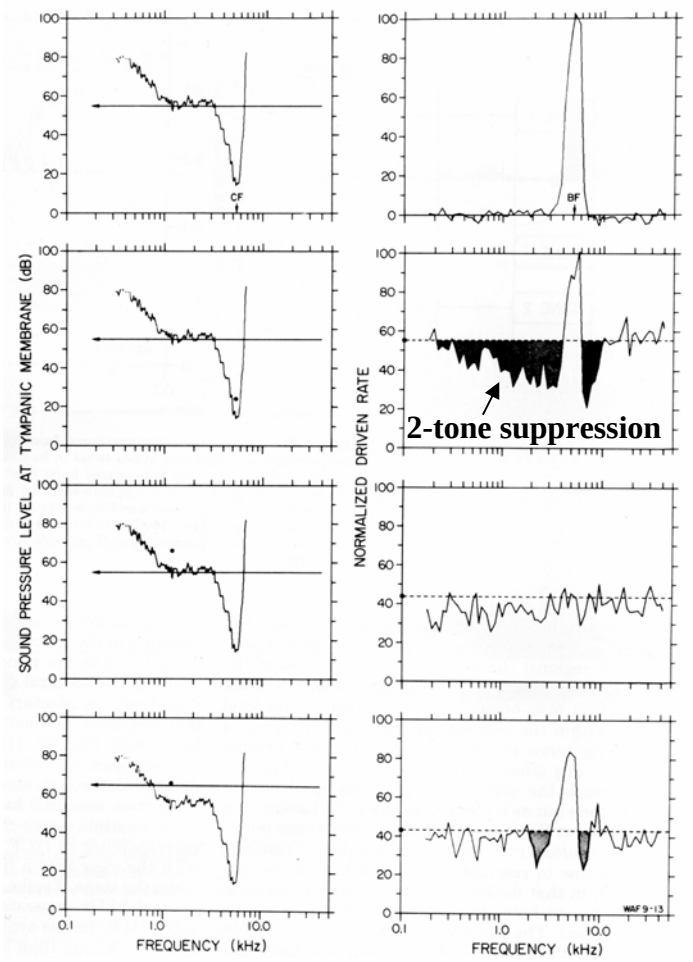
- **C**ompound **A**ction **P**otential, recorded from round window

- Click-evoked CAP dominated by basal ANFs





Tuning and Non-linearities: two-tone suppression

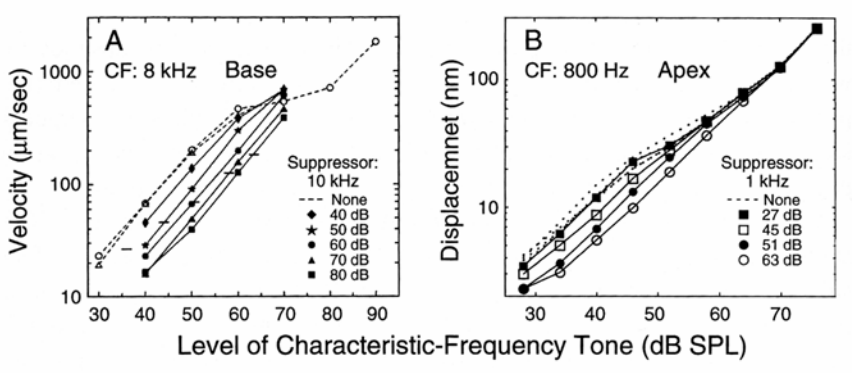


1-tone sweep

CF tone + 1-tone sweep

Off-CF tone + 1-tone sweep

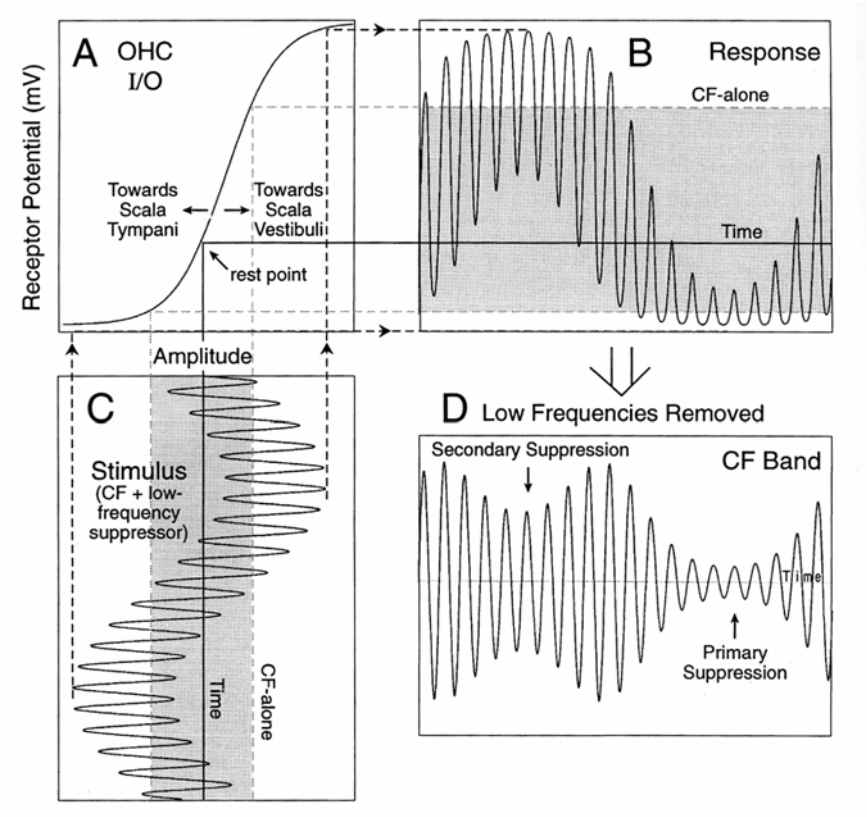
Off-CF tone + 1-tone sweep

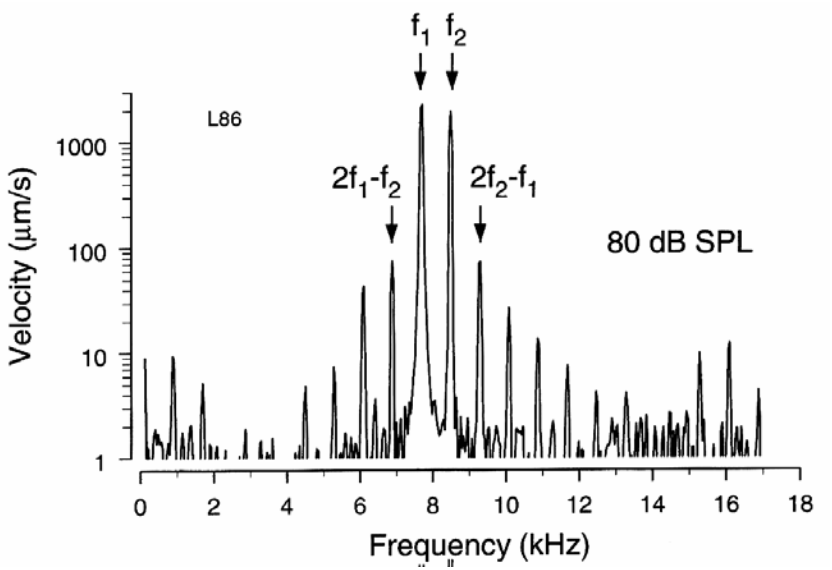


- Two-tone suppression is seen in BM response

- Single tone is always excitatory
- With a fixed CF tone, 2nd tone above or below CF will suppress

Tuning and Non-linearities: two-tone suppression



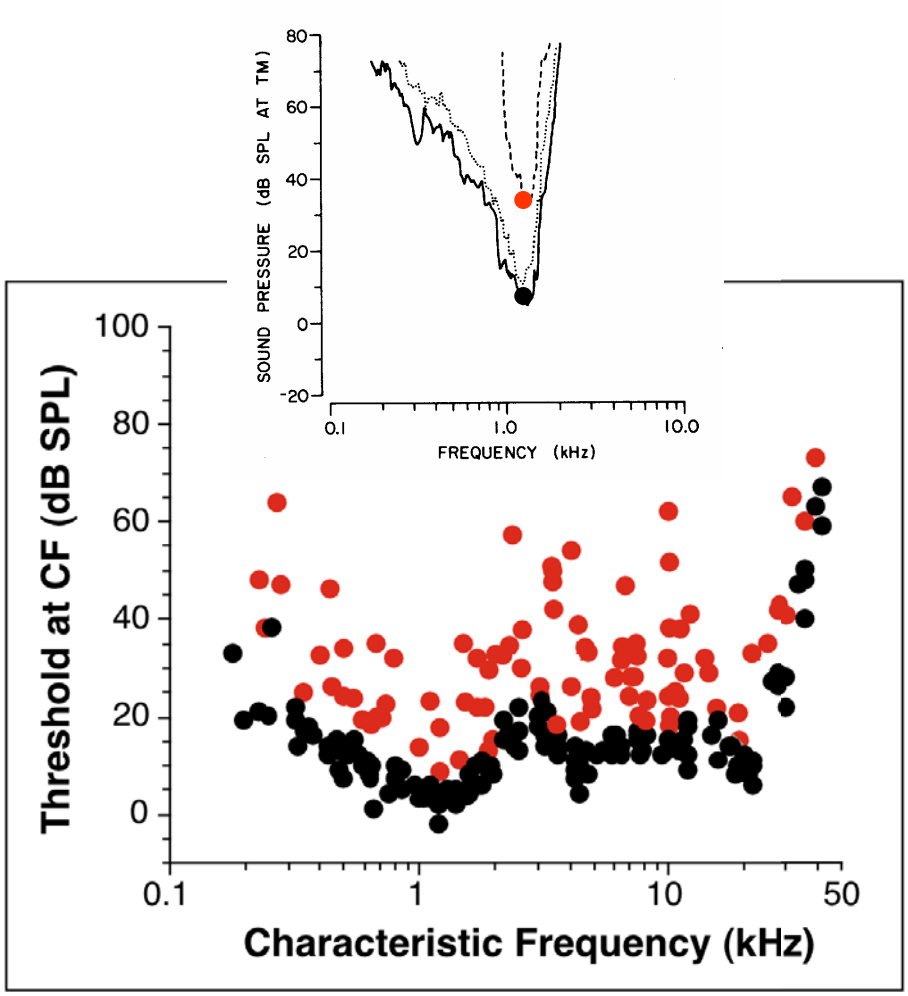


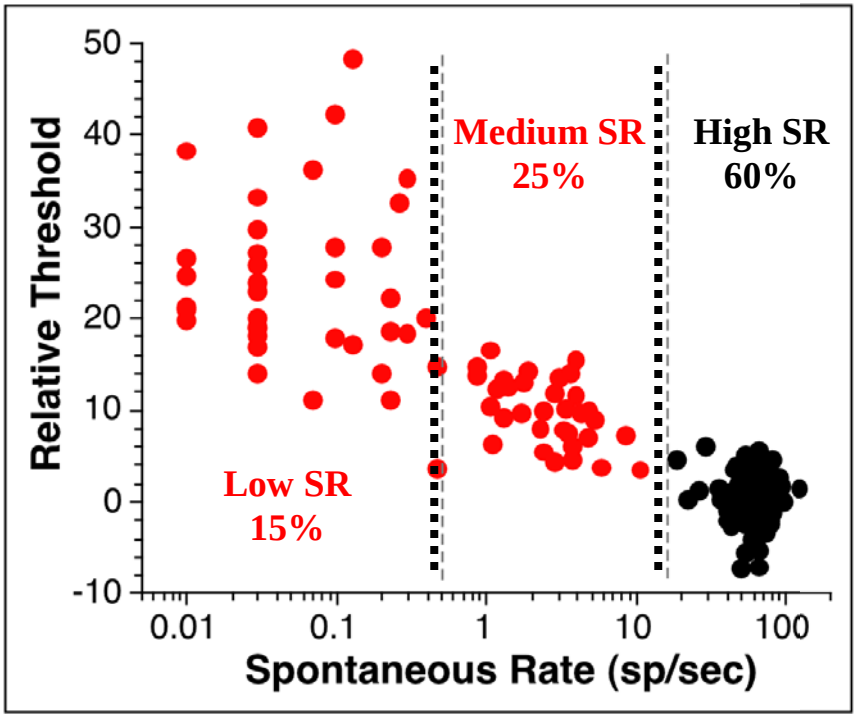
- A simple scheme to explain how transducer nonlinearity produces two-tone suppression

- Visual Basic Distortion Simulator:
- http://oto.wustl.edu/cochlea/

- Same scheme produces distortion products (DPs), e.g. 2f1-f2, when driven with two tones f1 and f2
- DPs are seen in BM motion, ANF response and ear canal sound pressure

Tuning Curves, Threshold spread and SR groups

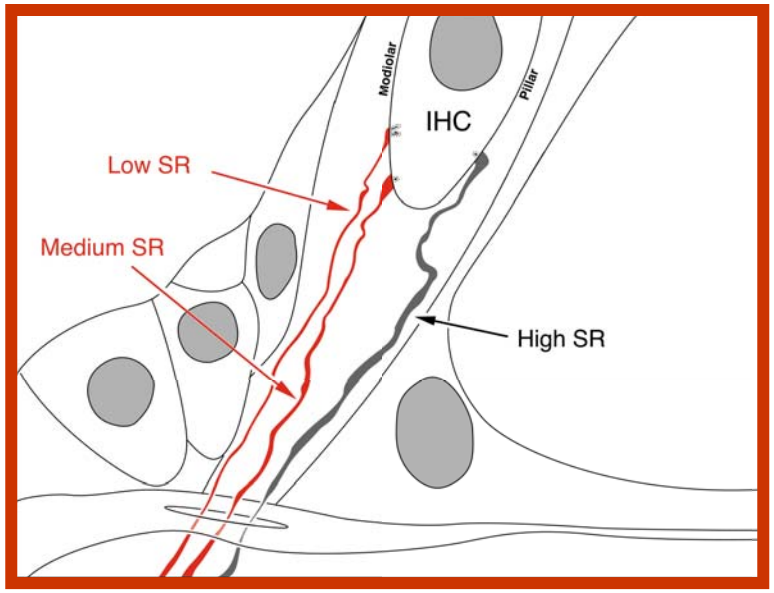




- Threshold at CF for ANFs from one animal:
- At each CF region, >60dB threshold spread

- Threshold difference is correlated with SR
- SR vs Threshold suggests three ANF subgroups

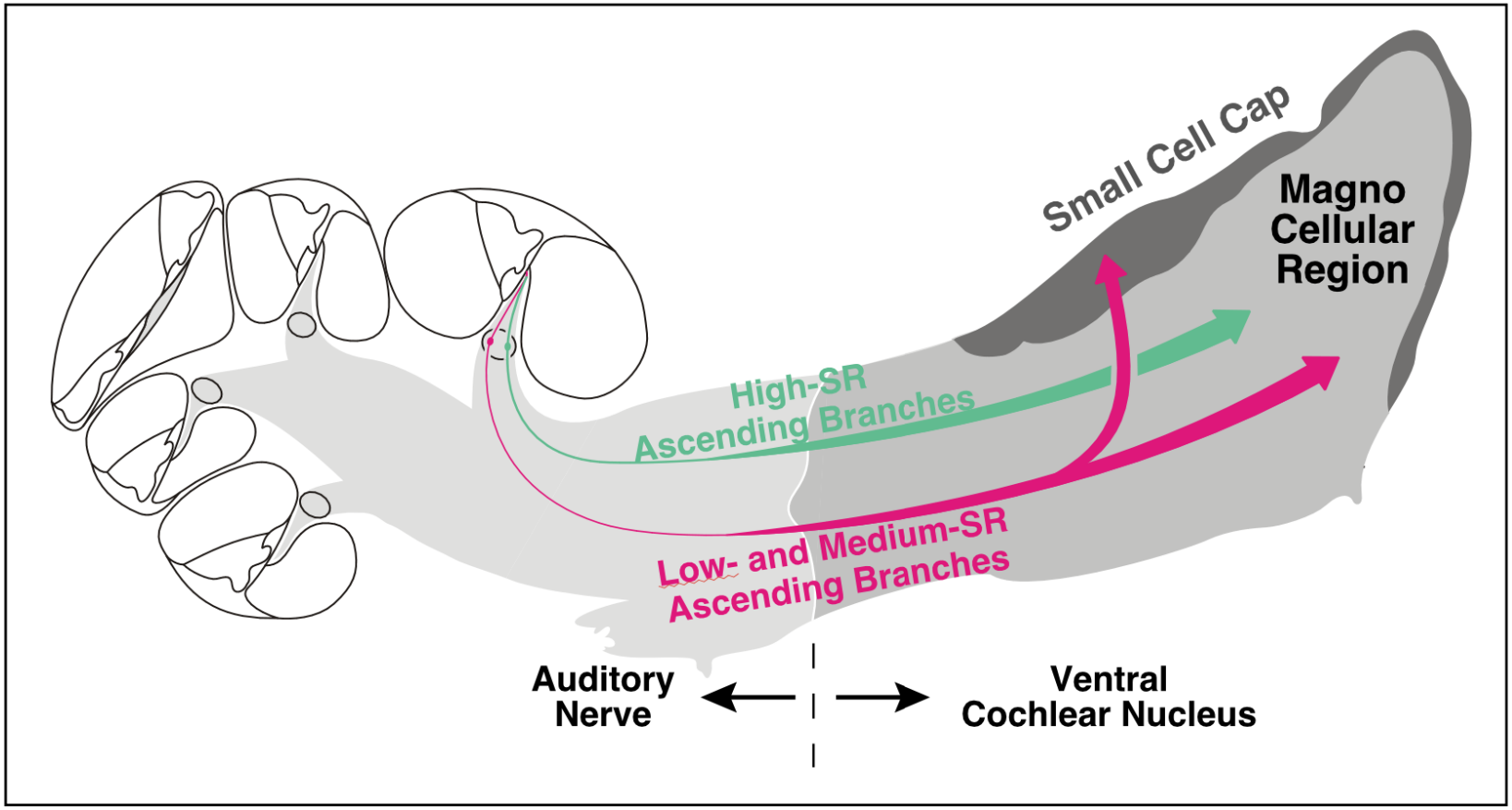
Tuning Curves, Threshold spread and SR groups



Intracellular labeling experiments show:

- high SR fibers are large, mitochondrion-rich fibers on pillar side
- low/medium SR fibers are small, mitochondrion-poor fibers on modiolar side of IHC

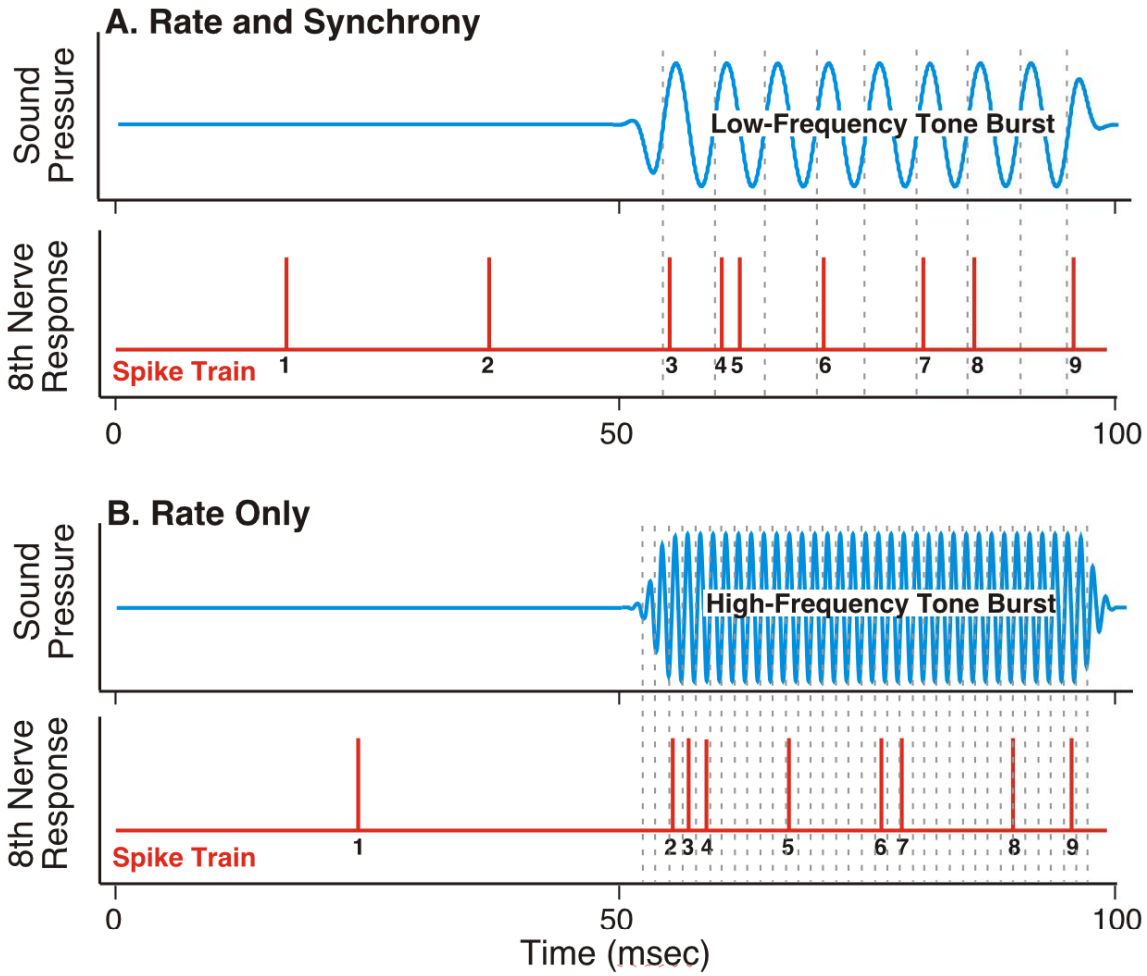
Tuning Curves, Threshold spread and SR groups



Central Projections:

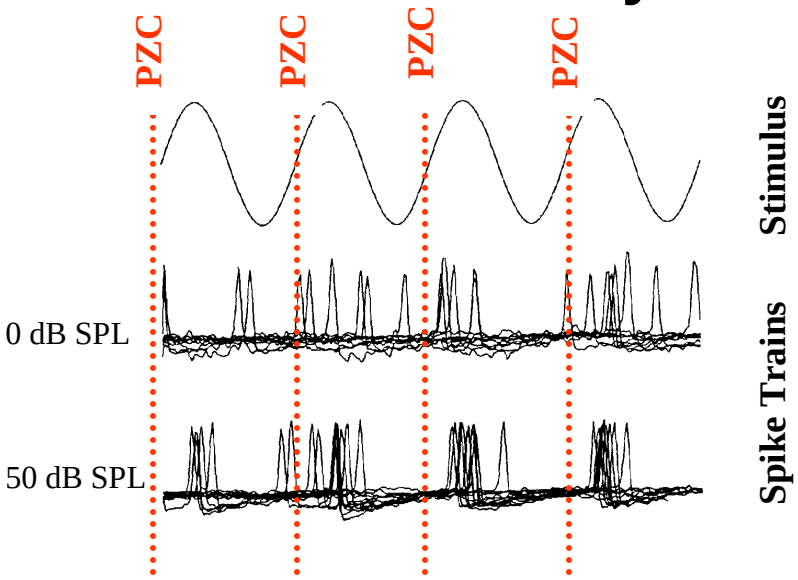
- Many cochlear nucleus regions receive input from all 3 SR groups
- One region, the small cell cap, only receives input from low and medium SR fibers

Rate vs. Synchrony Coding in ANFs

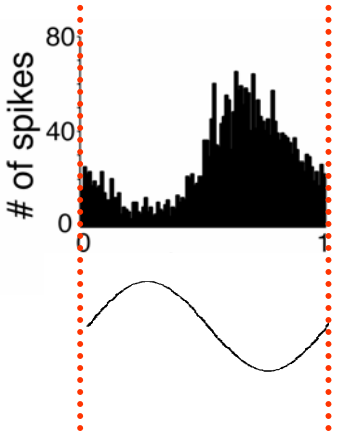


- Information is carried in ANFs as action potentials or “spikes”
- Spikes are stereotyped voltage pulses of identical amplitude
- Information is coded in ANFs by changes in average rate or in fine timing of spikes

Synchrony Coding in ANFs

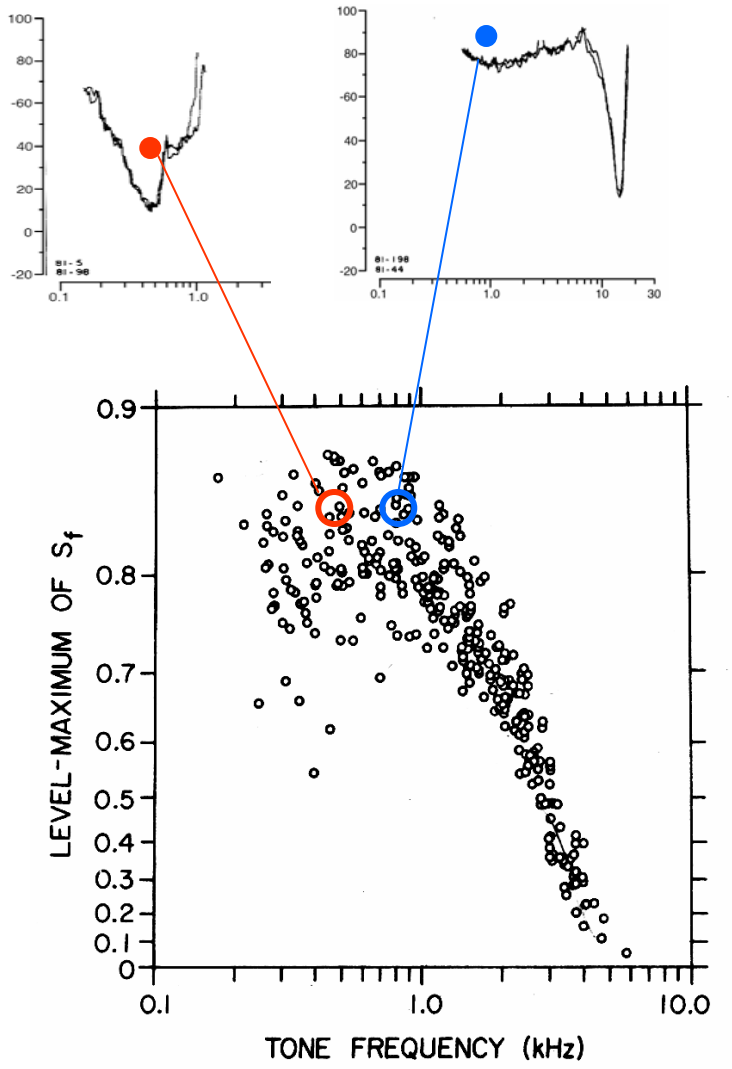


ANF spikes can “phase lock” with a tone



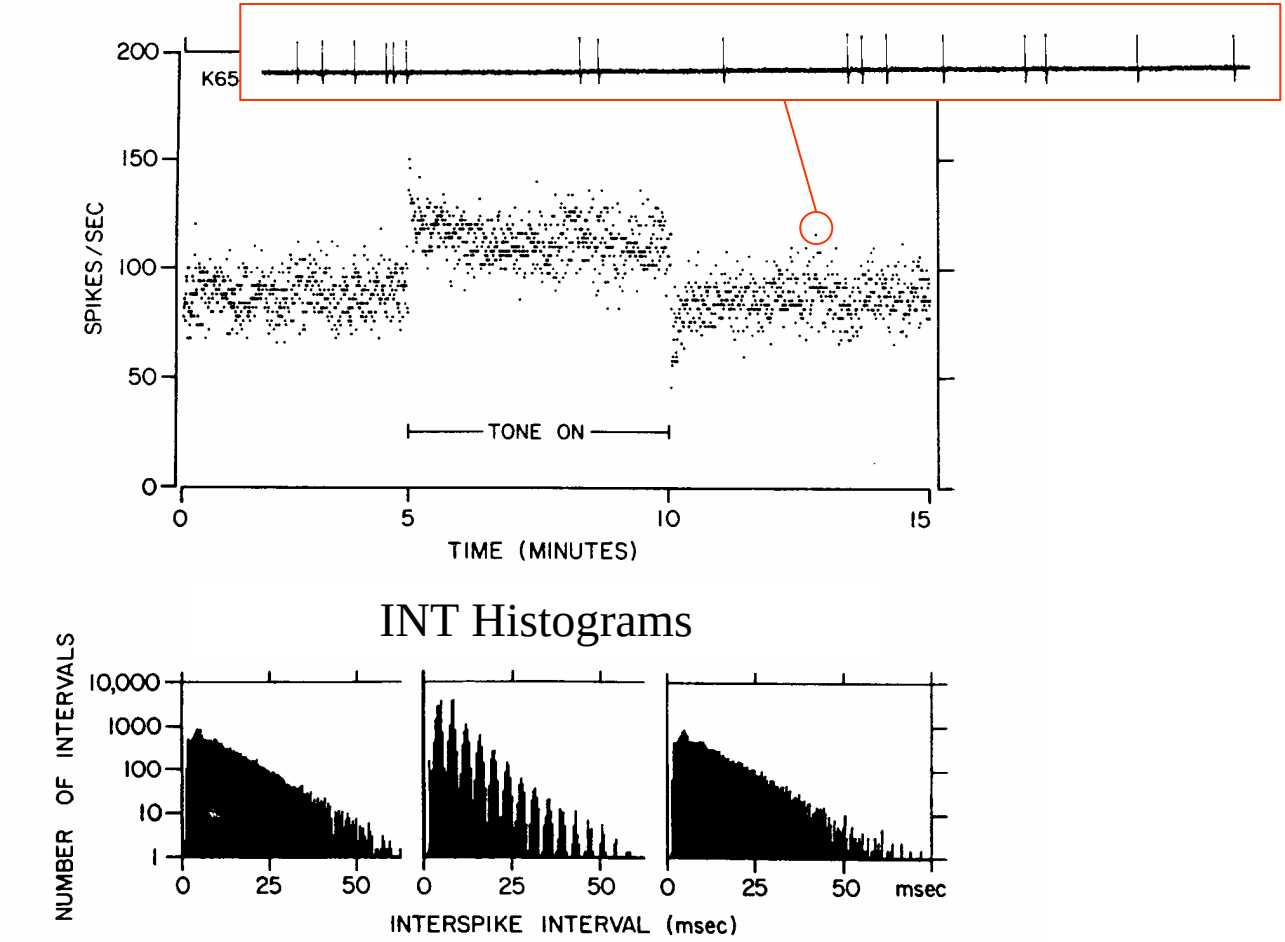
Positive **Z**ero **C**rossing Histogram

PZC Histograms show synchrony:
Synchronization index (SI) quantifies synchrony



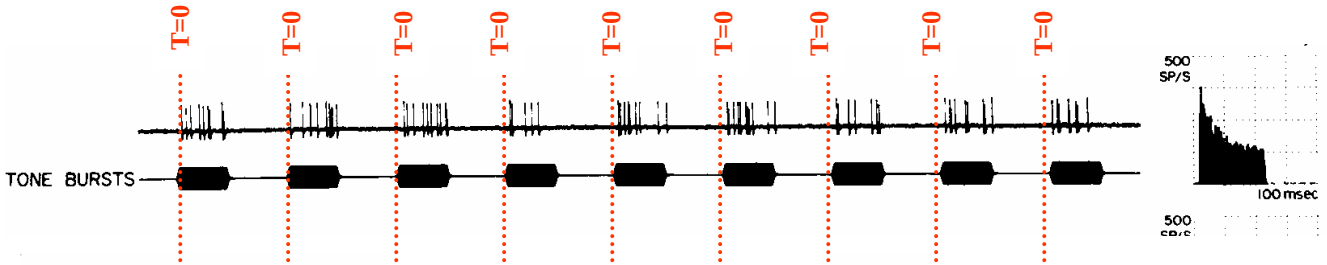
Synchrony falls for f > 1.0 kHz
irrespective of CF

Rate vs Synchrony Coding

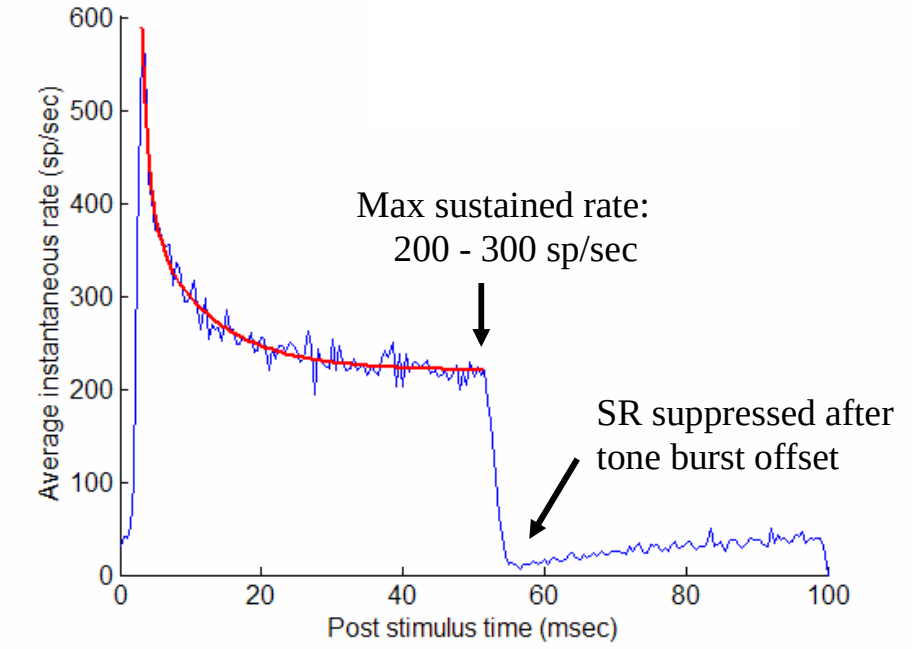


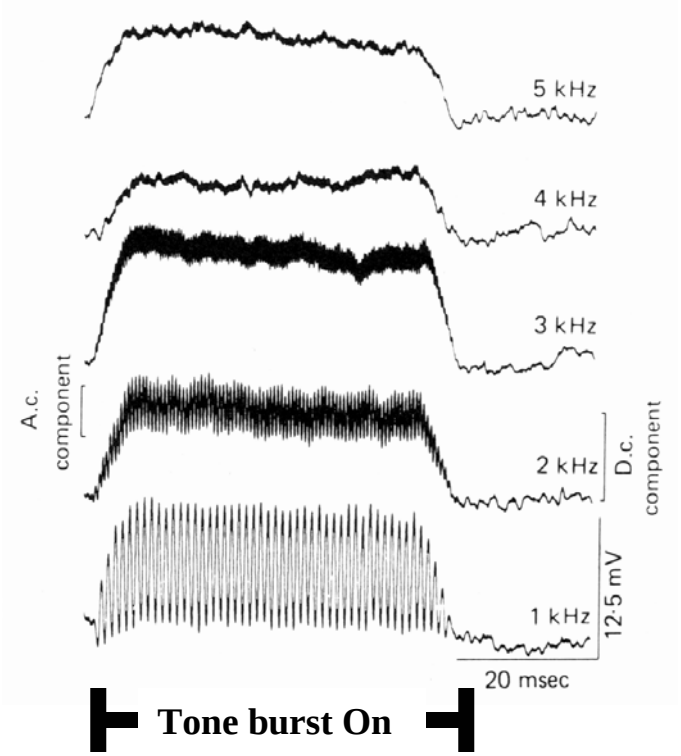
- Synchrony also seen in INT (interspike interval) histograms
- Preferred intervals in INT histogram during tones = 1/CF
- INT histograms of SR: Poisson process with a dead time
- Interspike intervals are random.

Adaptation in AN response



Post **S**timulus **T**ime Histogram

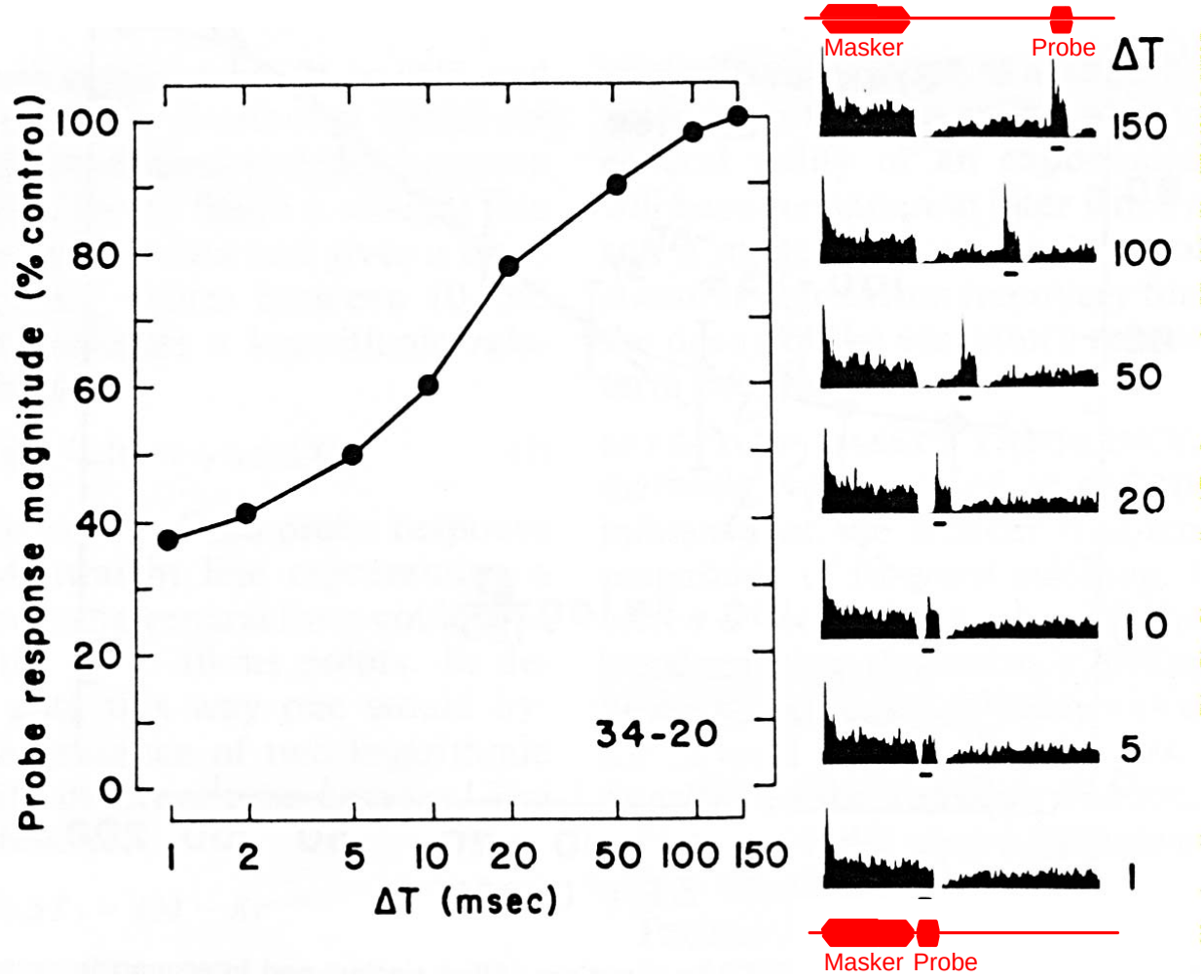




- AN discharge rate adapts: onset > steady state
- Adaptation fit by two exponentials:
  τ_1=3 msec and τ_2=60 msec

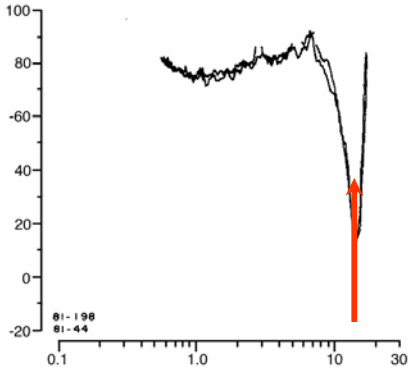
- Adaptation NOT in hair cell.
- Adaptation arises in synaptic transmission: vesicle depletion

Adaptation and forward masking in AN response

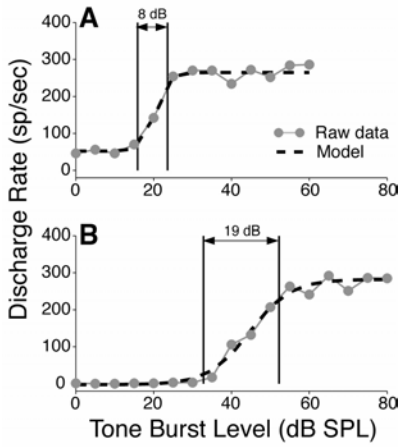


•Adaptation decreases ANF response to “probe” tone for at least 100 msec after “masker” tone offset
•This phenomenon is the basis for “forward masking” seen psychophysically

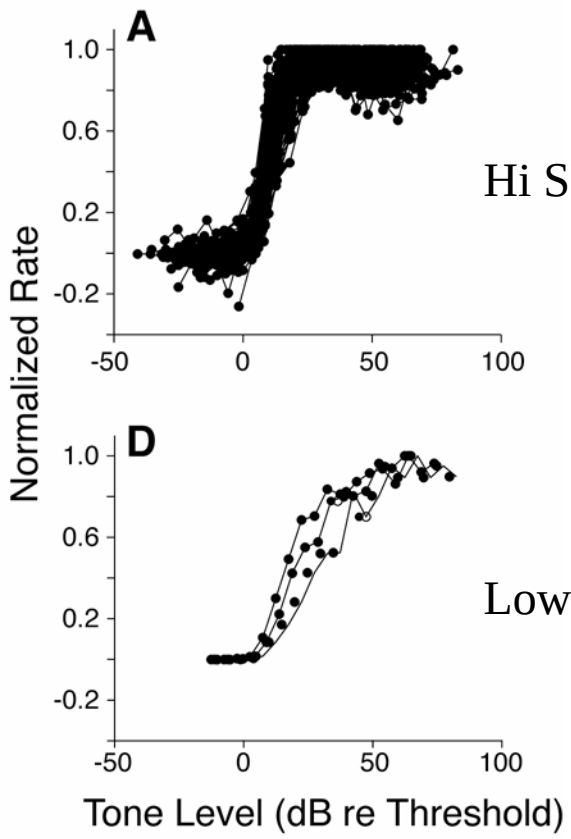
Saturation and dynamic range



•Dynamic range is measured by increasing level of CF tone



•Dynamic range is defined as the range of SPLs over which discharge rate increases

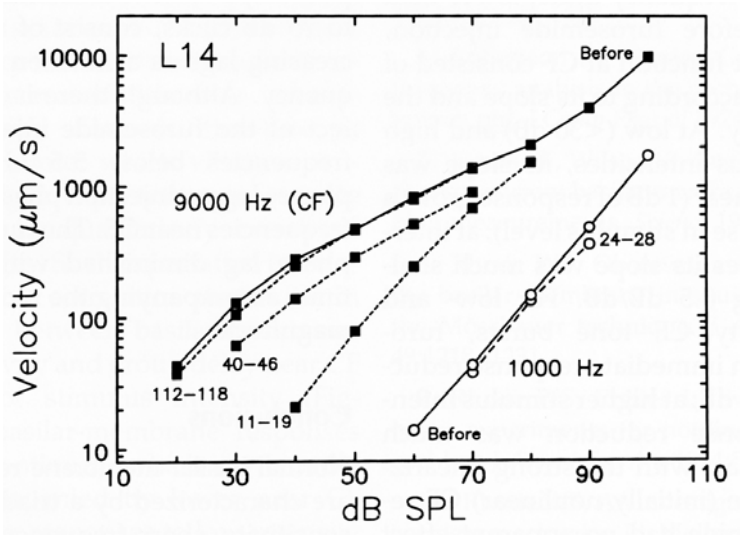


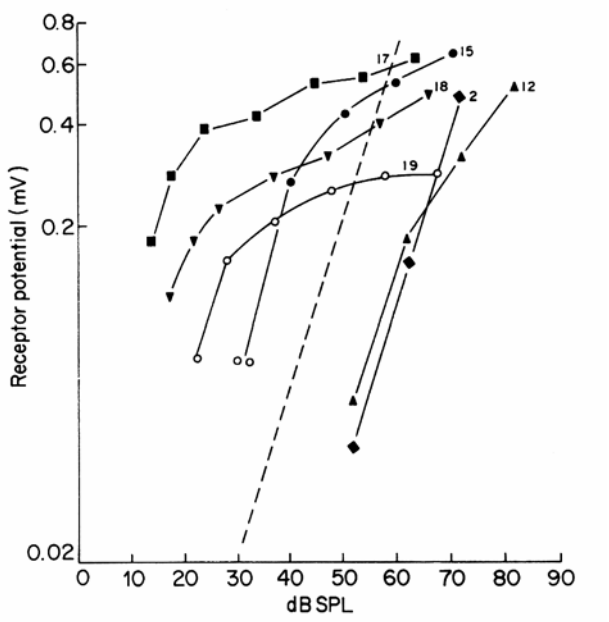
Hi SR Fibers

Low-SR Fibers

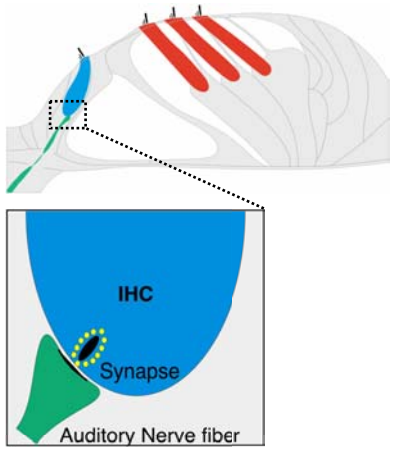
•Dynamic range (DR) is < 30 dB in all ANFs:
•High-SR fibers: hard saturation and small DRs (~20 dB);
•Low-SR fibers: sloping saturation and larger DRs (~30dB)

Saturation and dynamic range



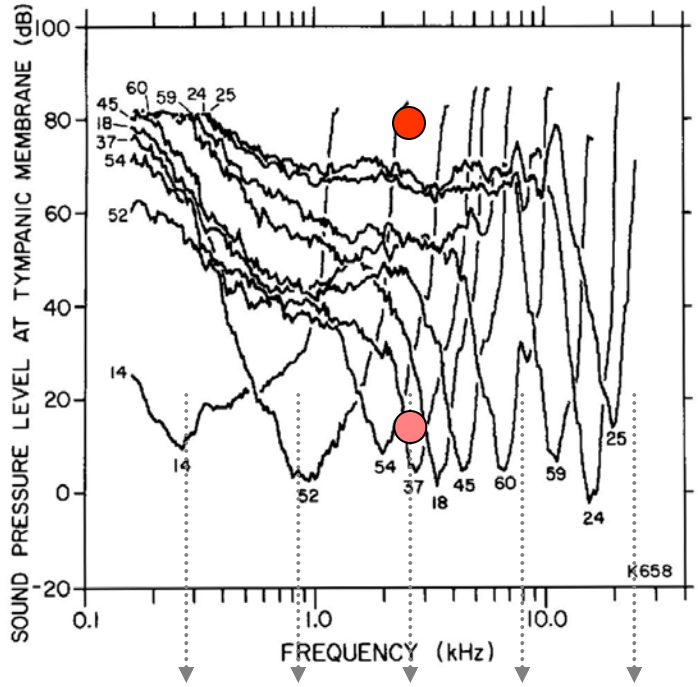


- Basilar membrane motion does not saturate
- IHC shows wide dynamic range (>50 dB)



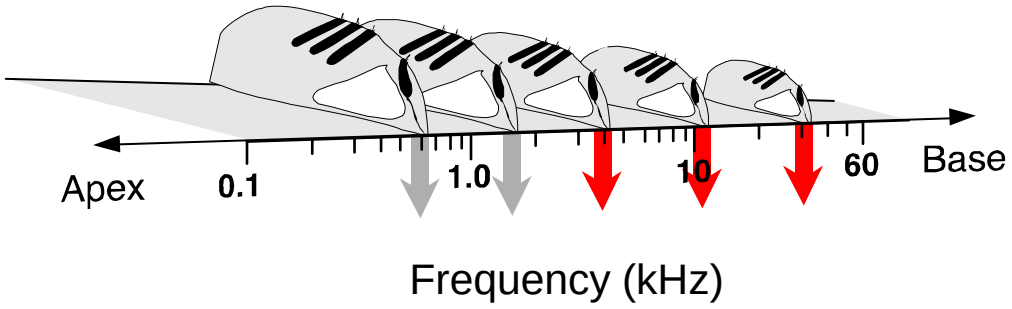
Saturation arises at the IHC/ANF synapse

Saturation of ANF response and the “Rate-Place” code

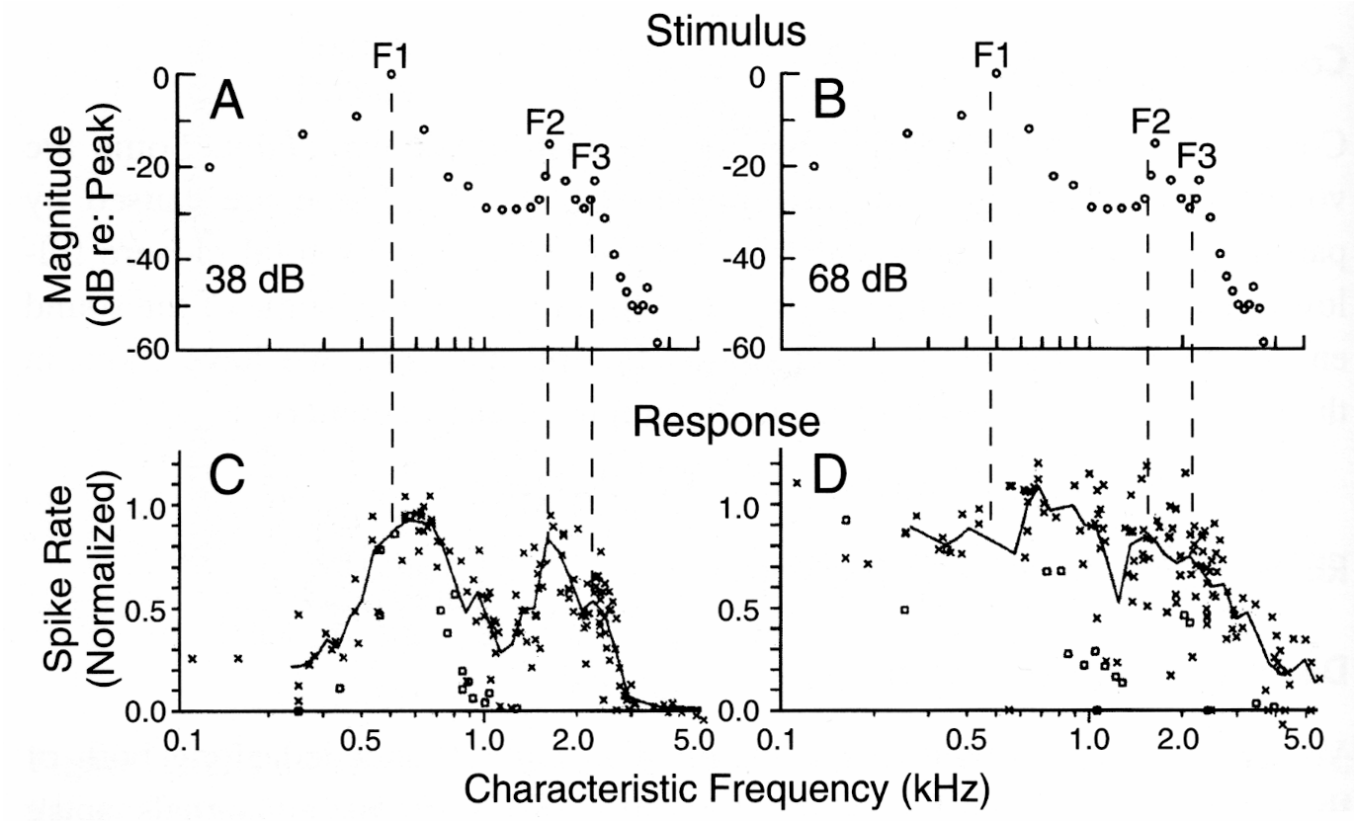


- Cochlea is like a filter bank
- Brain might use Rate vs. Place to infer spectrum

- Saturation non-linearity compromises fidelity



Saturation of ANF response and the “Rate-Place” code



ANF response rate vs CF for a vowel at two SPLs

- At low SPLs, formants are visible in rate-vs-place profile
- At high SPLs, the formant peaks are less obvious
- Spectral information is also present in synchrony of response

Flowchart View