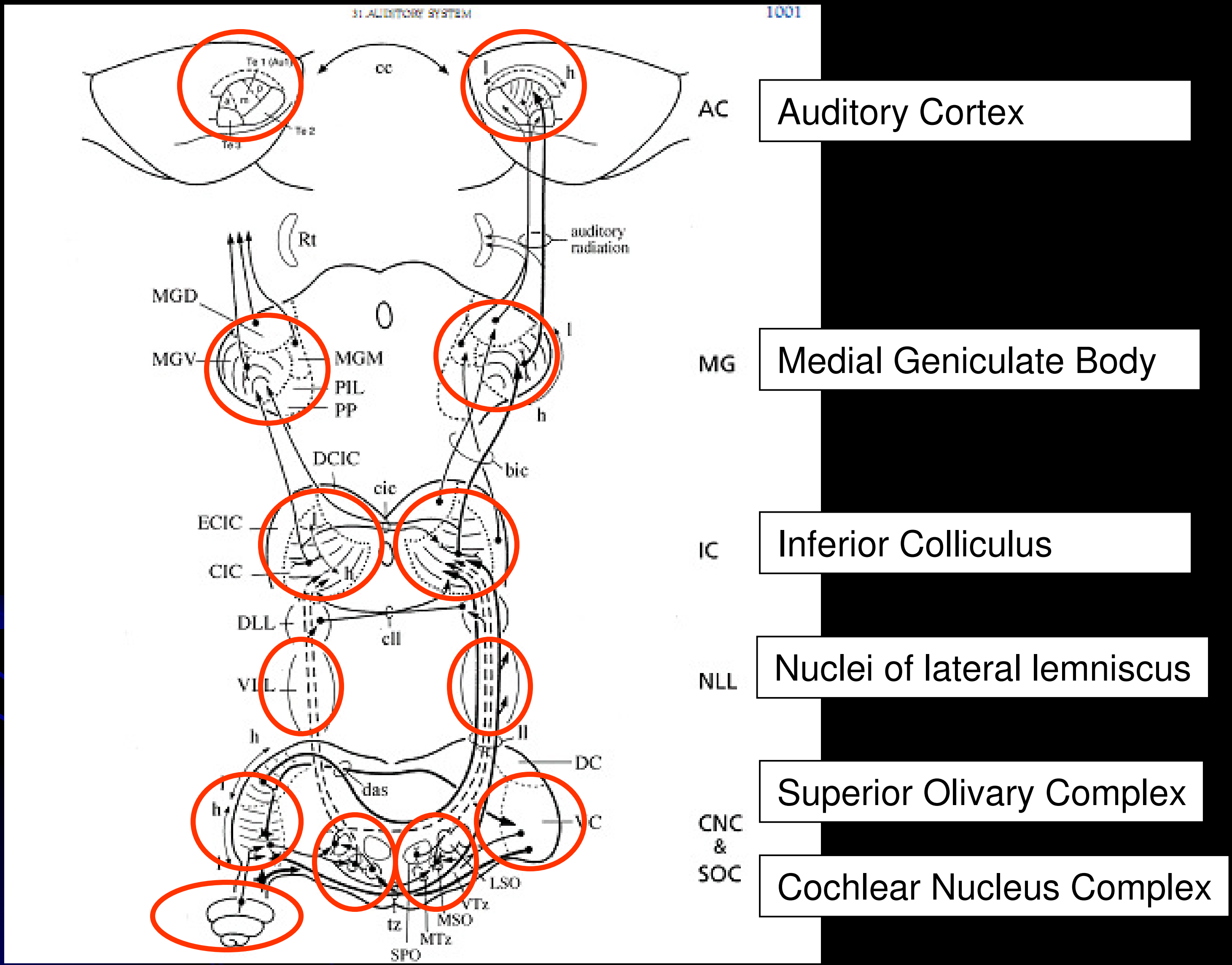
Tübingen Hearing Research Centre

University of Tübingen

Central Auditory Pathway

Central Auditory Projections



~ 8 (Human) ~ 20 (rodent) auditory fibers (AF) on a inner hair cell

Rat:

IHC → ~ 1000 x ~ 20 myelinated AFI = SG ~ 20.000 (95%)

(~121/mm, most dense, 25 % from base)

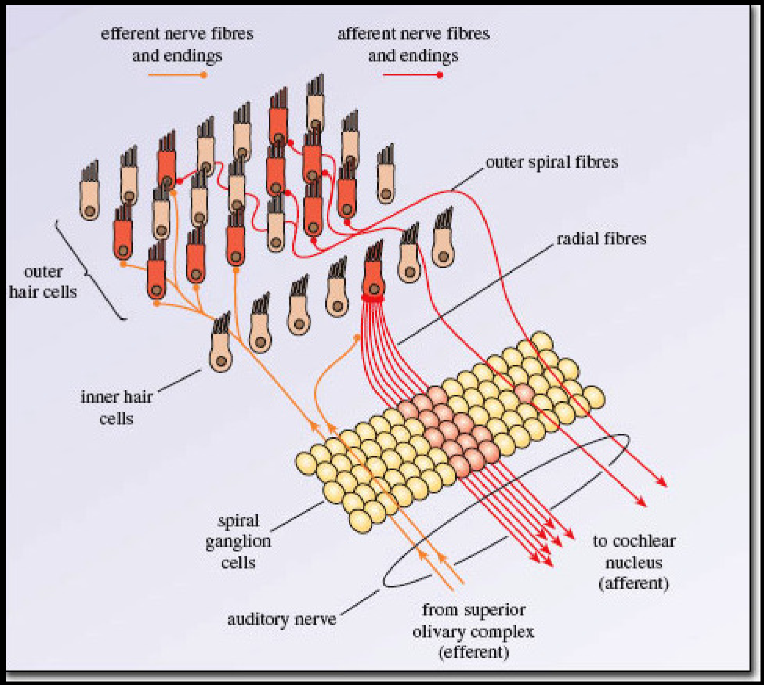
OHC → 3800-4000,~ 20 OHCs / unmyelinated AFII ~ 1000 SGs (5 %)

(~364/ mm; different density, base lower than apex)

Human:

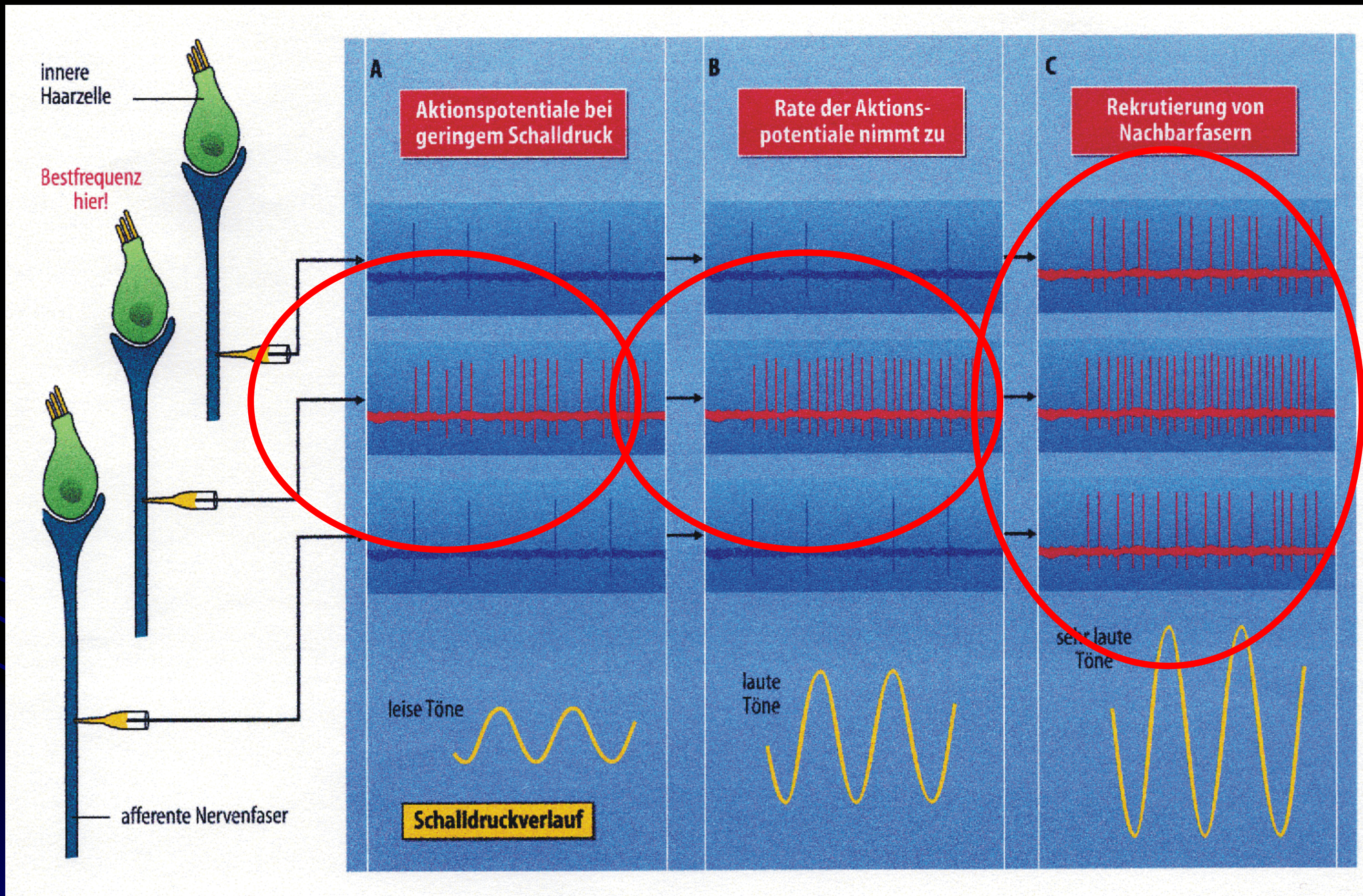
IHC→ ~ 3.500 x ~ 8 AFI = SG ~ 27.000

→ 12.000 OHCs



Cochlear amplifier enables IHCs to code sound at lowest SPL

Place Code- 1-16.000 Hz (humans)



Intensity from 1dB (20 µPascal)-130 dB (3 million-times louder) = OHCs

Inner hair cells give sound information to 2 auditory fiber types

Intensity: *20 µP (1dB) to 60.000.000 µPascal (120 dB)*

Cochlear Amplifier: 4 th root compression

↓

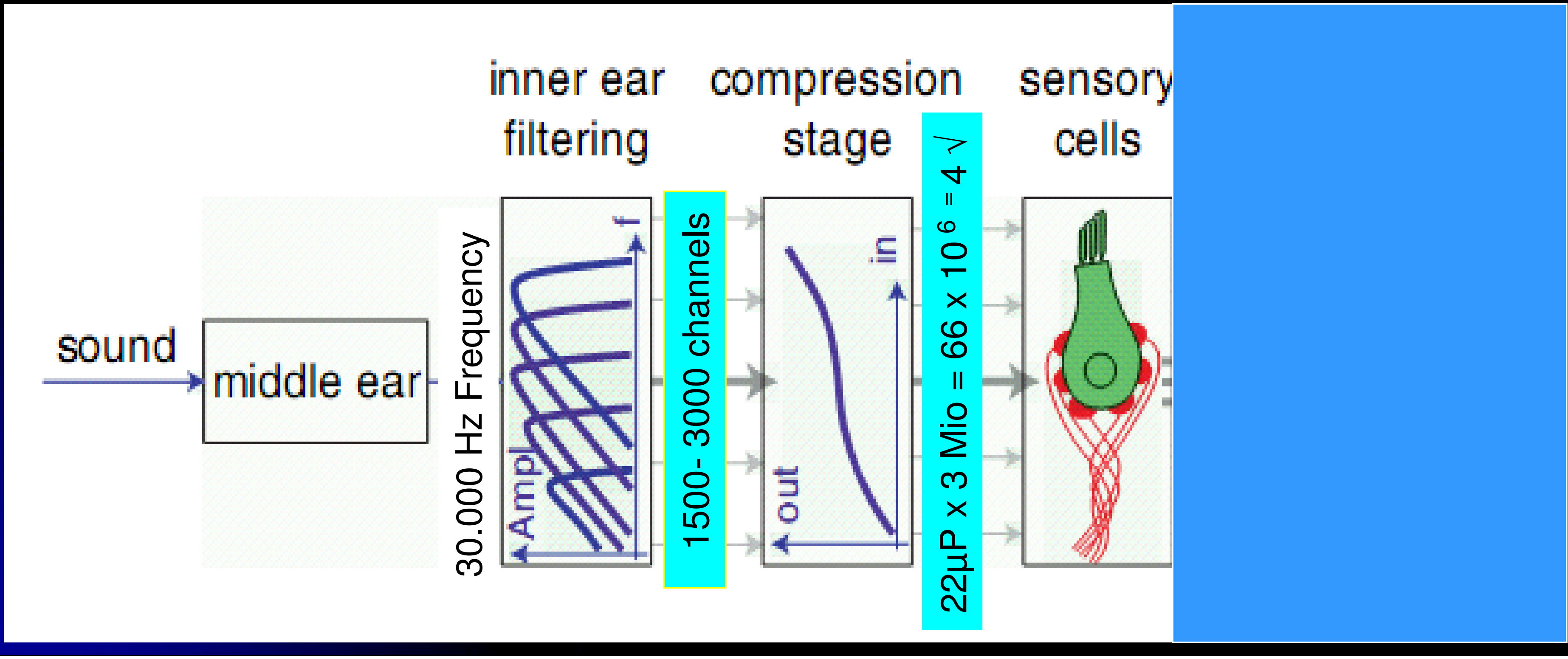
1500-3000 IHCs

↓

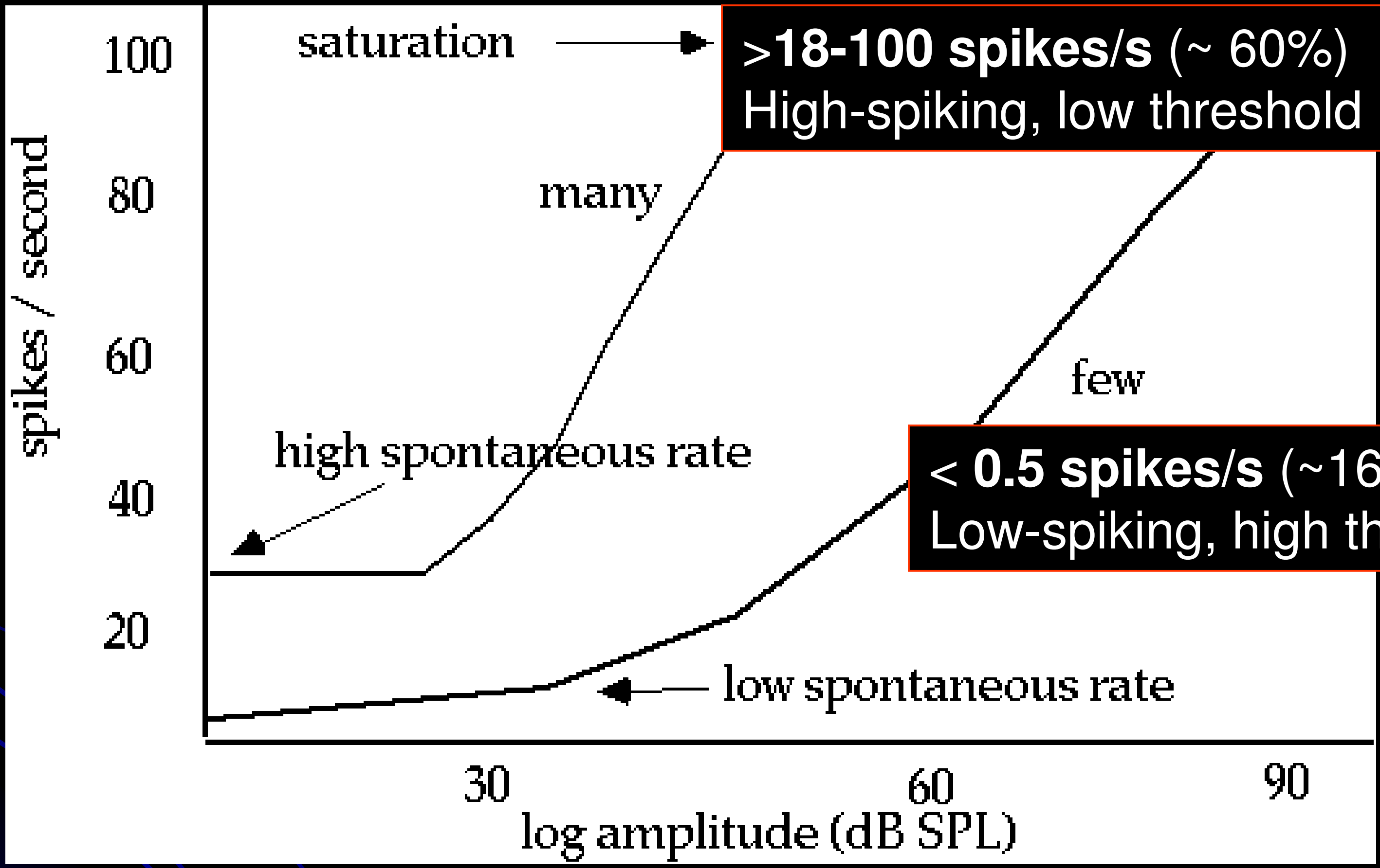
30.000 Hz (Place Code)

↓

> 2 AN Fibers that respond to different intensities (LS-HT, HS-LT)



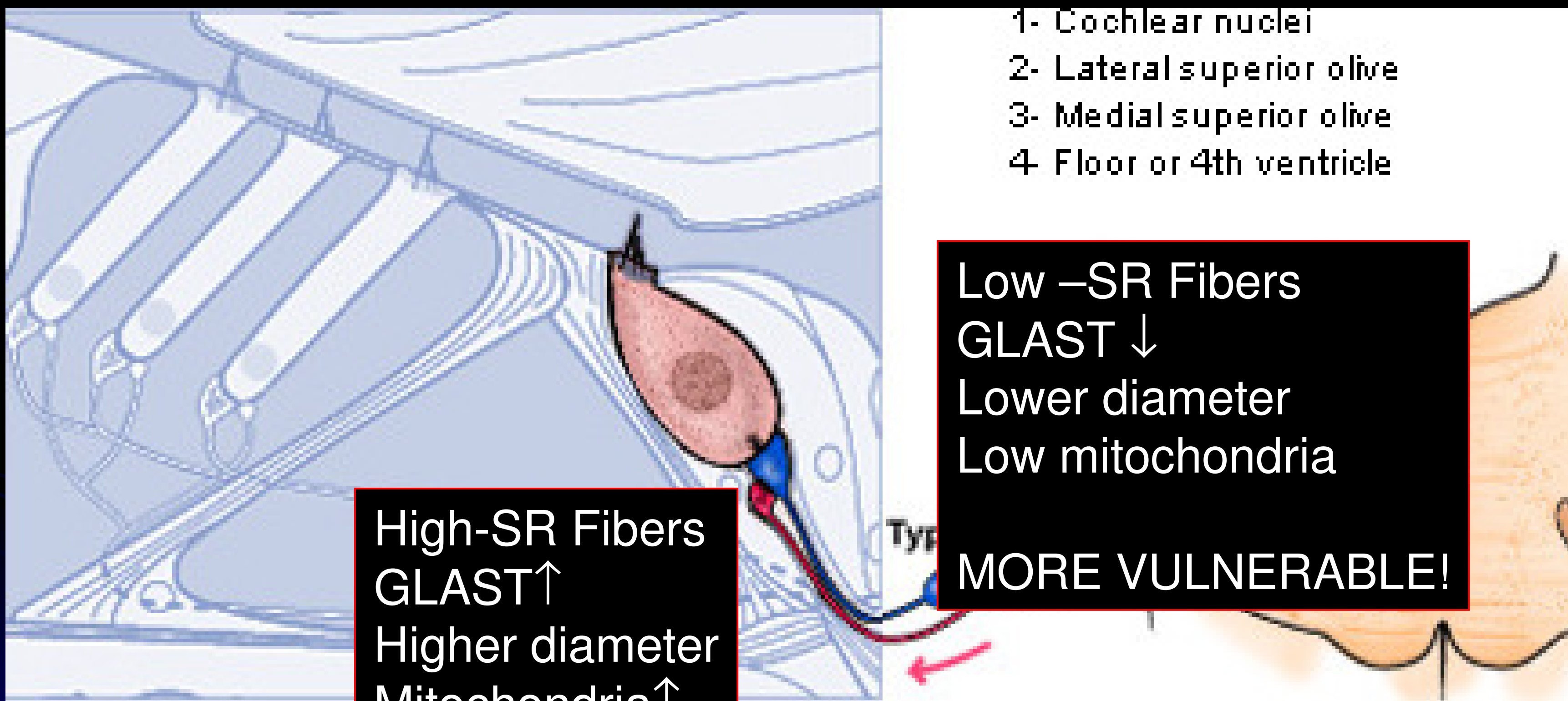
Intensity: is coded by > 2 AN fibers with different sensitivity



>18-100 spikes/s (~ 60%)
High-spiking, low threshold

< **0.5 spikes/s** (~16%)
Low-spiking, high threshold

Intensity: is coded by > 2 AN fibers with different sensitivity



High-SR Fibers
GLAST↑
Higher diameter
Mitochondria↑

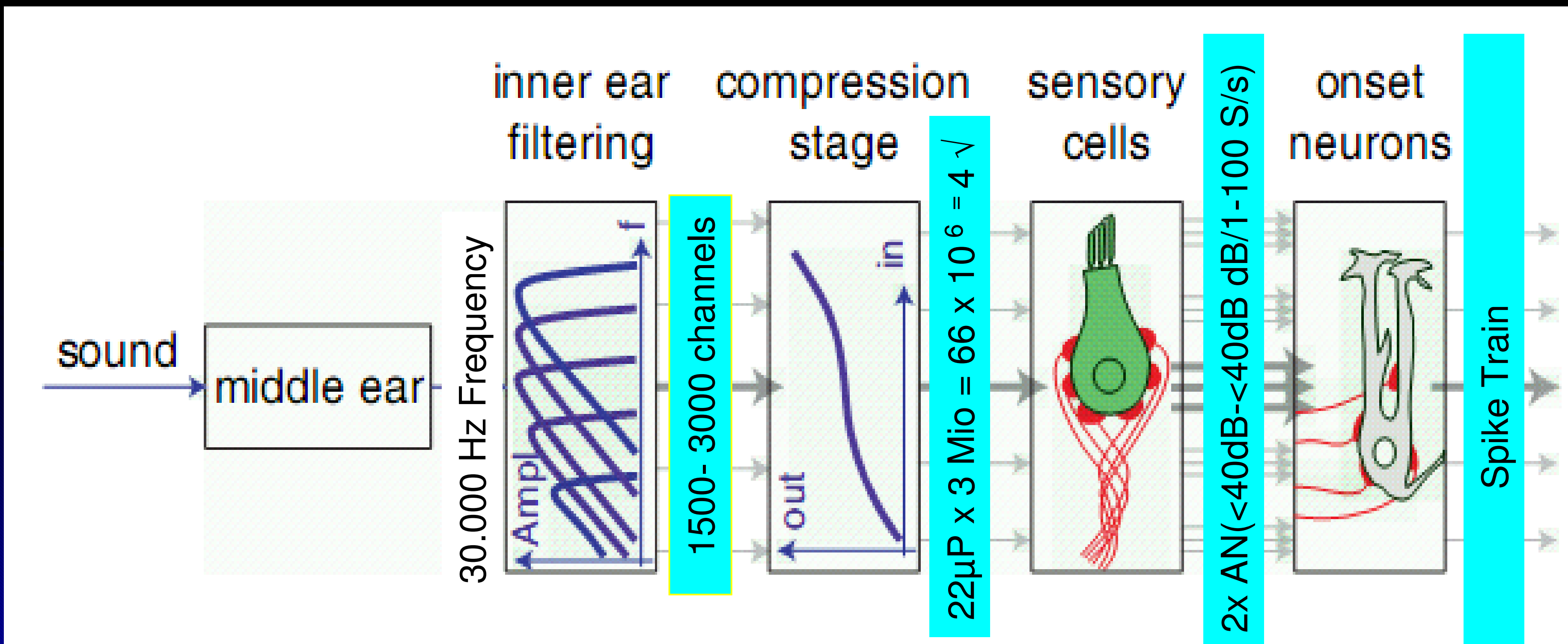
Low –SR Fibers
GLAST ↓
Lower diameter
Low mitochondria

MORE VULNERABLE!

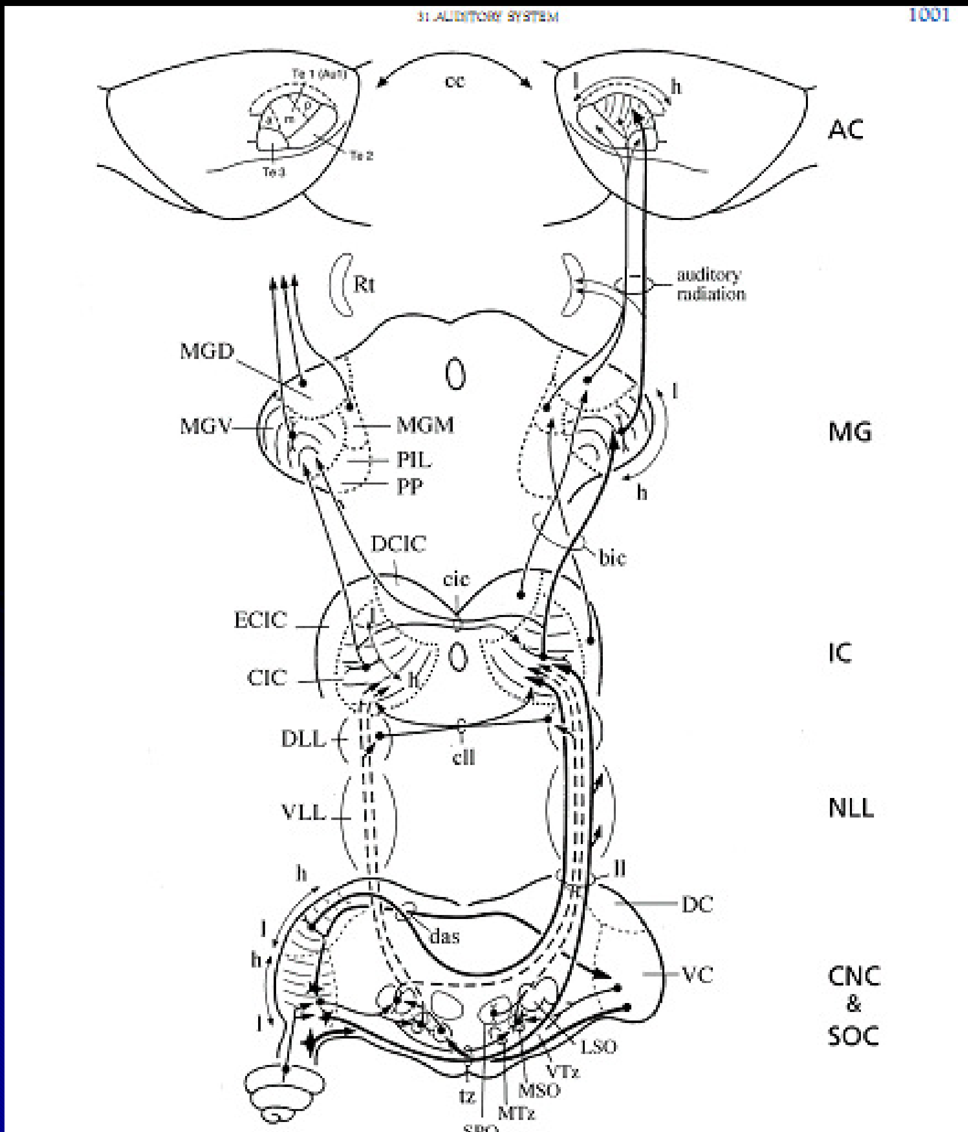
Information to the central auditory brain

•Information rate / AF = **1000 bits/s = 3.26 bits/spike** (Wang et al., Hemmert 2006).
•The speech signals (S/s) to the brainstem neurons = temporal resolution of 0.1ms
•90% of the information transmitted during the understanding of a single word is transmitted through the temporal information transferred within the first 73 ms (Onset-neurons/brainstem)

•Automatic speech recognitions systems rely on coarse temporal resolution of >10ms.

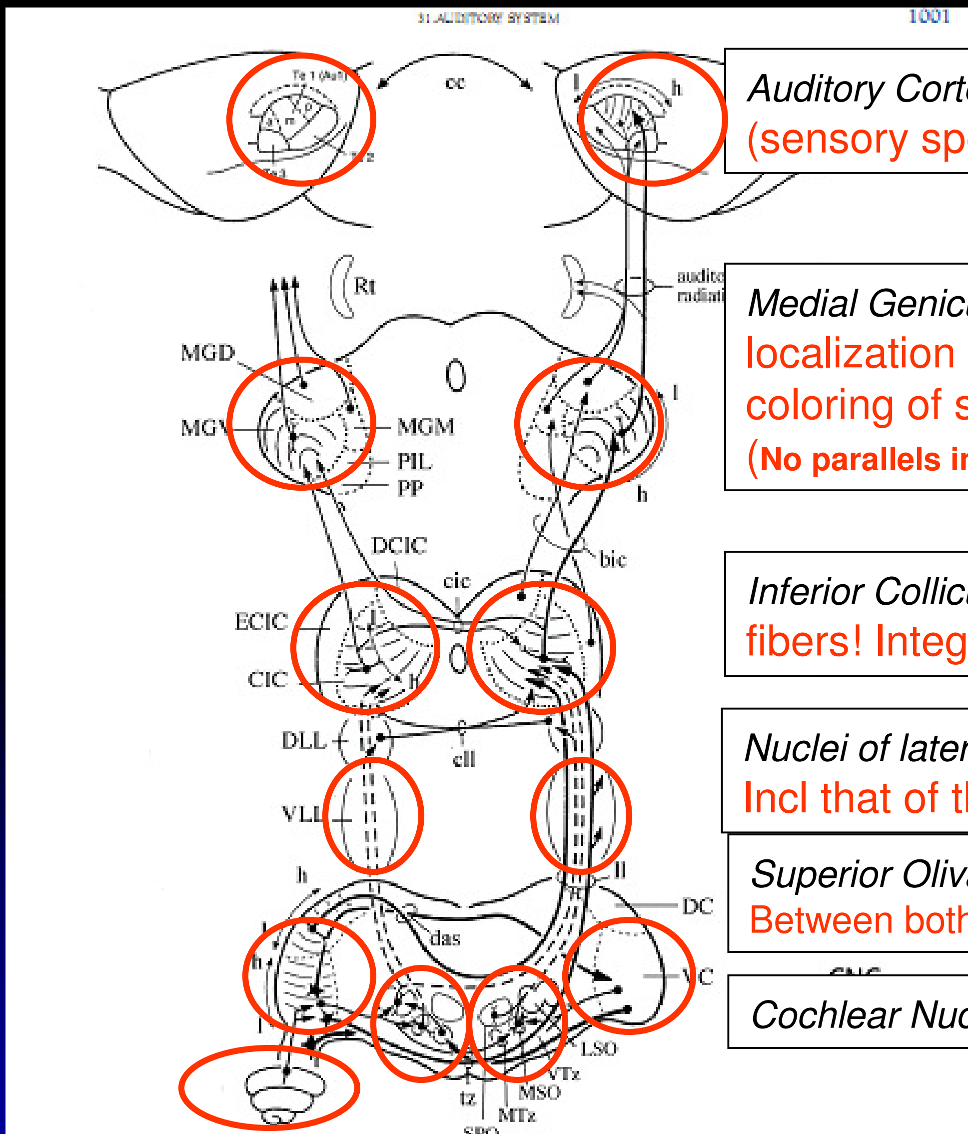


Information to the central auditory brain



Afferents projections are tonotopically organized, so that isofrequency lamina of the cochlea and CNC are connected with corresponding isofrequency laminae of the higher order centers

Function of central auditory brain nuclei



Auditory Cortex = sound perception, connected to Wernicke (sensory speech) and Broca (motoric speech centrum)

Medial Geniculate Body = sensory `relay` centre, spatial localization of sound by binaural processing, emotional coloring of sound impression
(**No parallels in the visuell or somatosensoric system!!**)

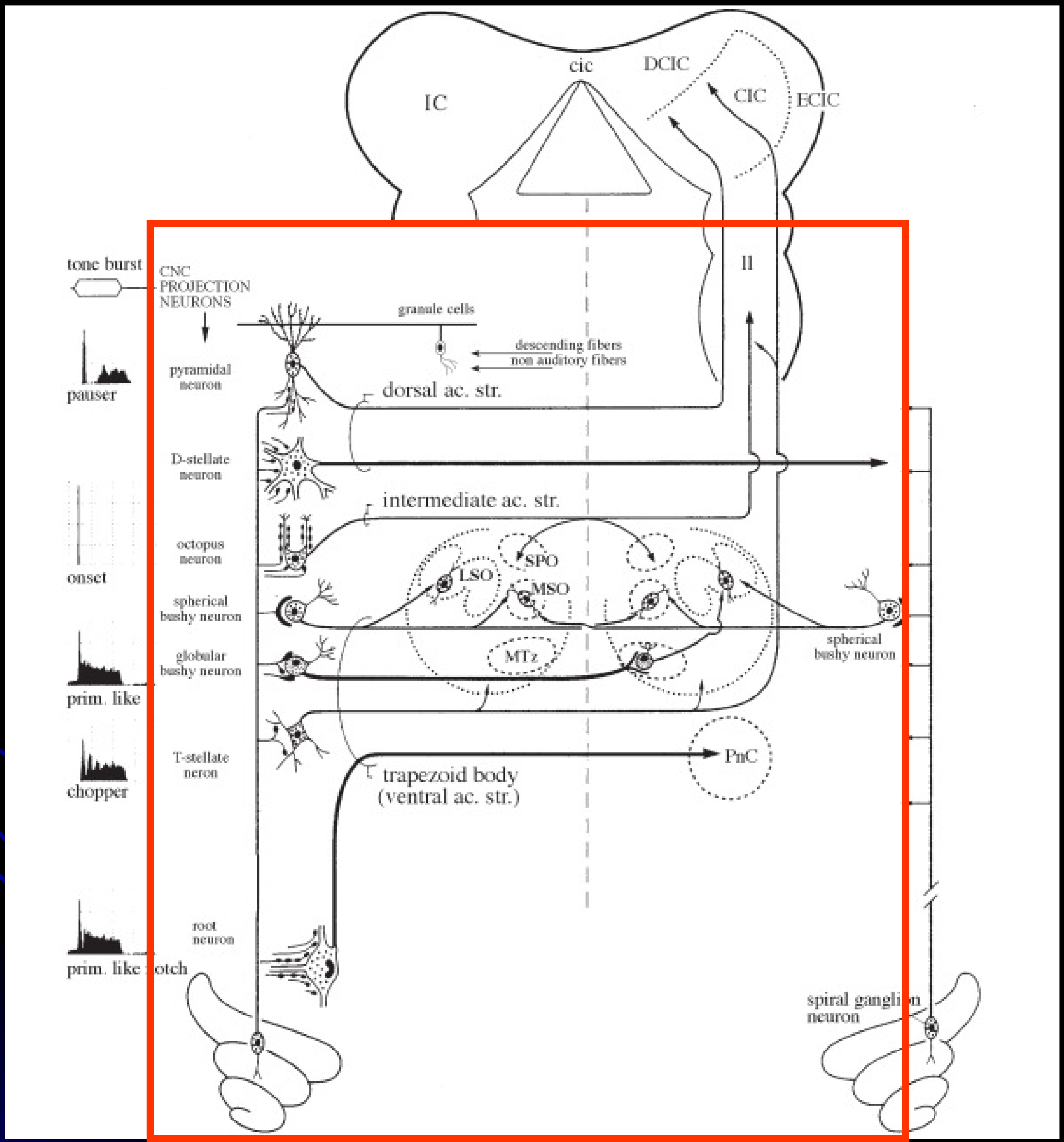
Inferior Colliculus= Relay center for most ascending auditory fibers! Integration of sound location; level detection, tuning

Nuclei of lateral lemniscus = transports ascending information Incl that of the other Side to the inferior colliculus

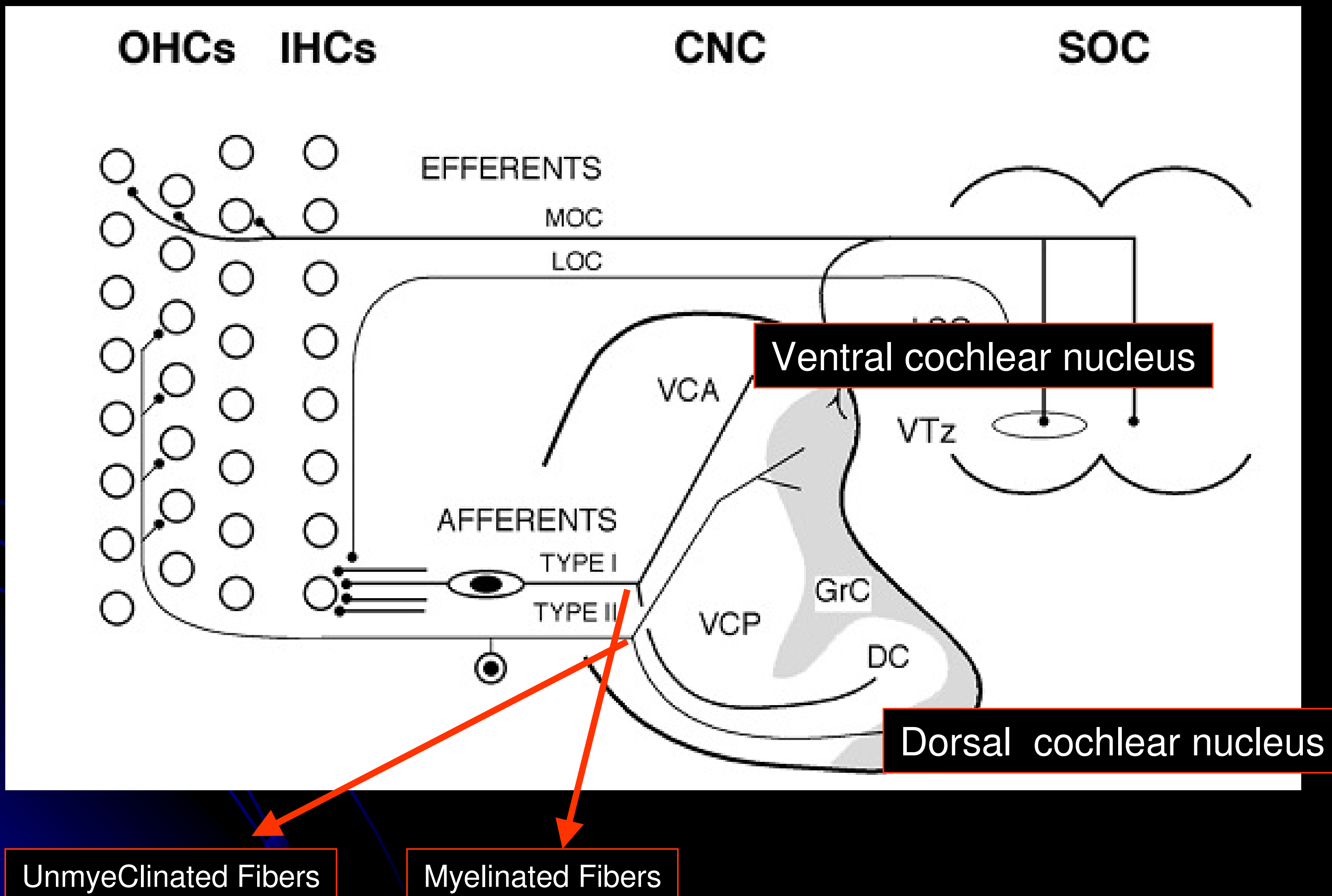
Superior Olivary Complex = Calculation of time differences Between both ears, information sound direction

Cochlear Nucleus Complex = *connection to the other side*

Cochlear Nucleus Complex (CNC)

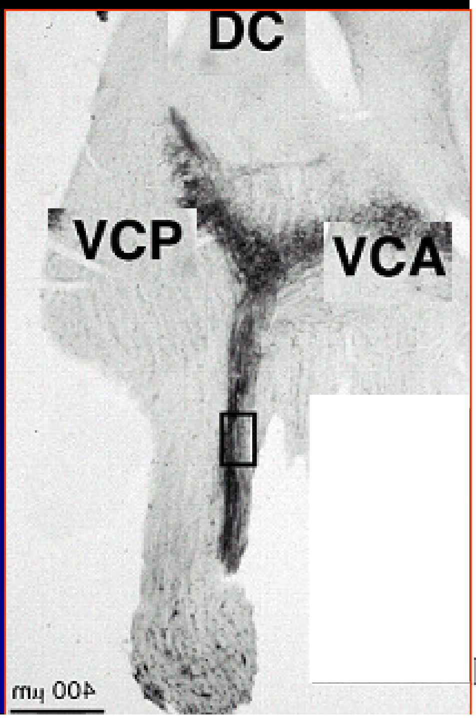


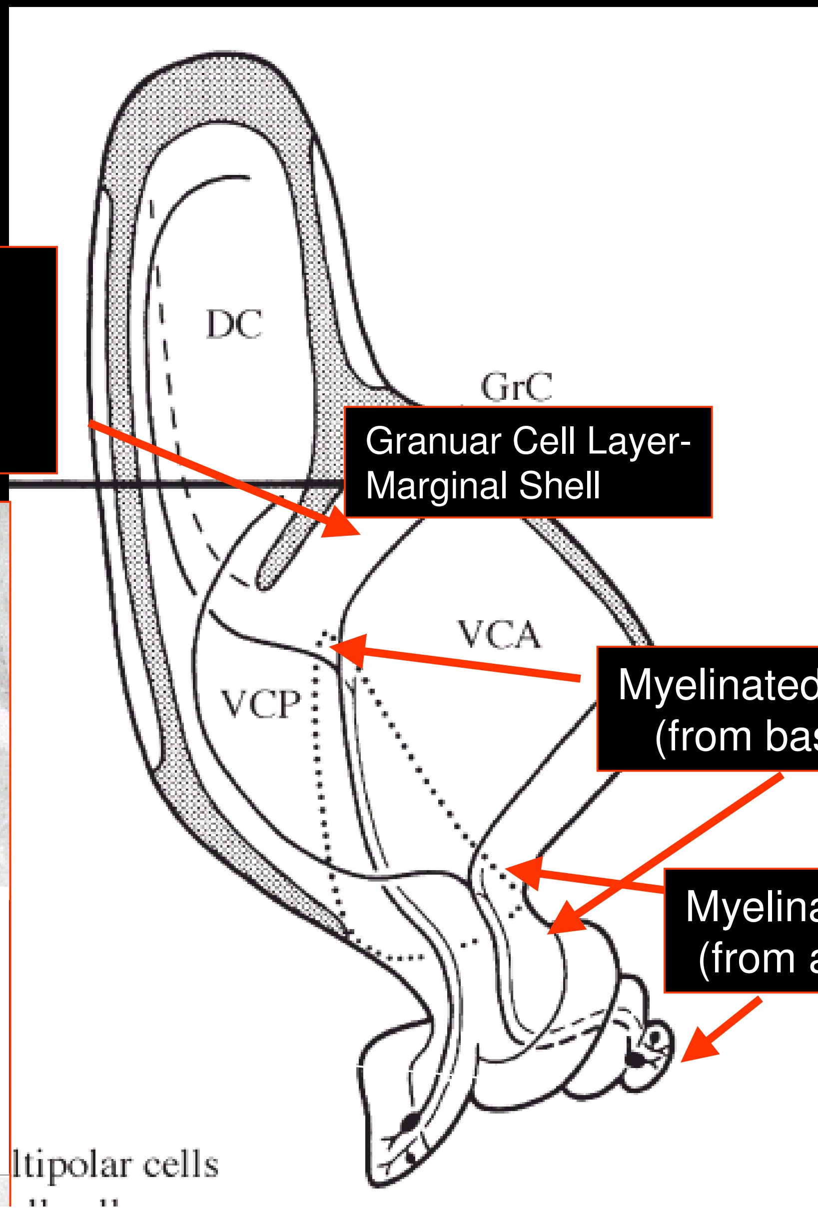
Afferents project to the ventral and dorsal cochlear nucleus complex (CNC)



CNC: Auditory nerve (afferents) bifurcate in the CNC tonotopically

Un-Myelinated **Type II** and **Low spiking** high threshold **AF-I** close to marg. shell



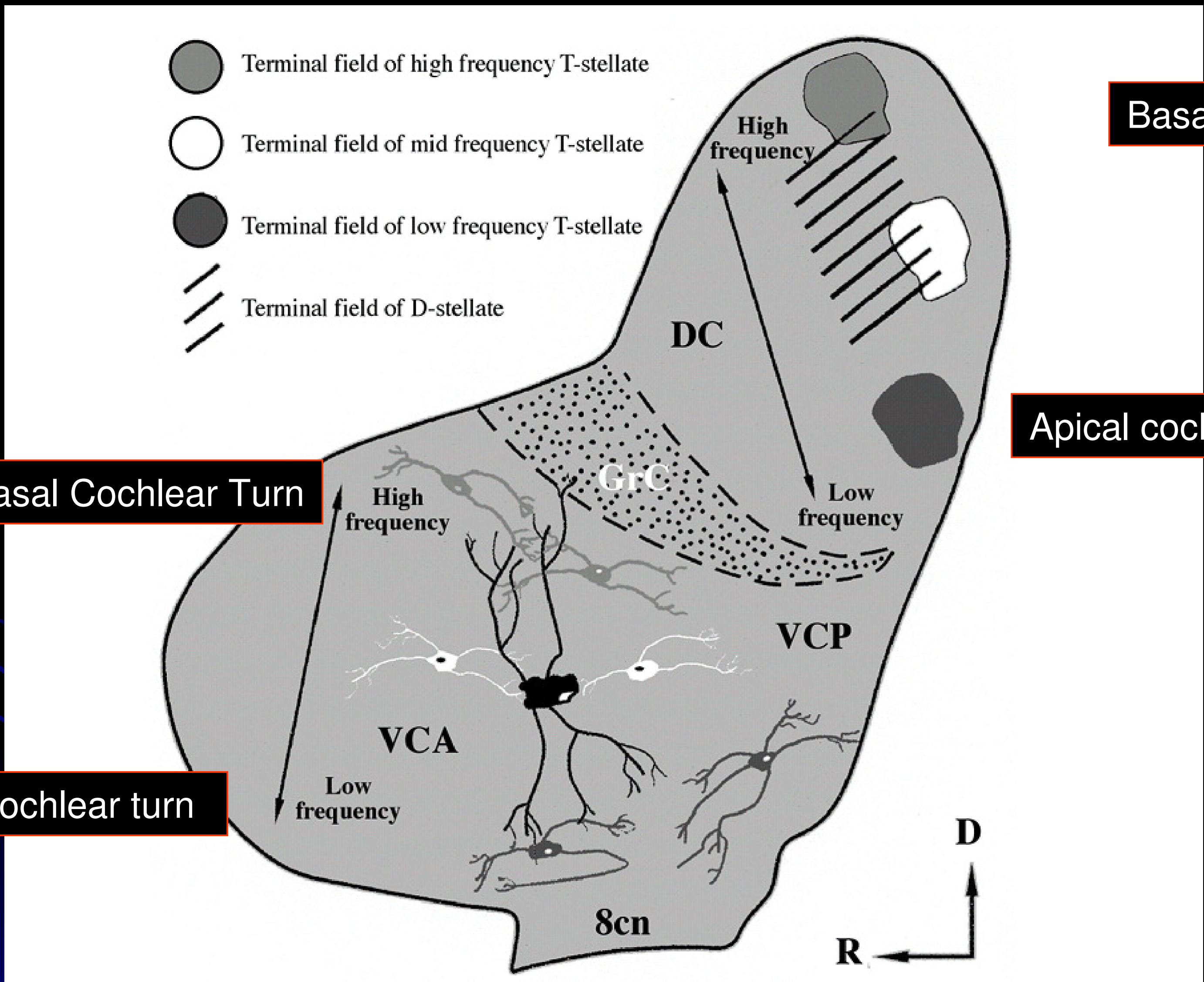


Granuar Cell Layer-Marginal Shell

Myelinated Type I **High Frequency** (from basal cochlear turn)

Myelinated Type I **Low Frequency** (from apical cochlear turns)

CNC: Anteroventral (VCA), Posteroventral (VCP), Dorsoventral (DC) Nucleus



Basal Cochlear Turn

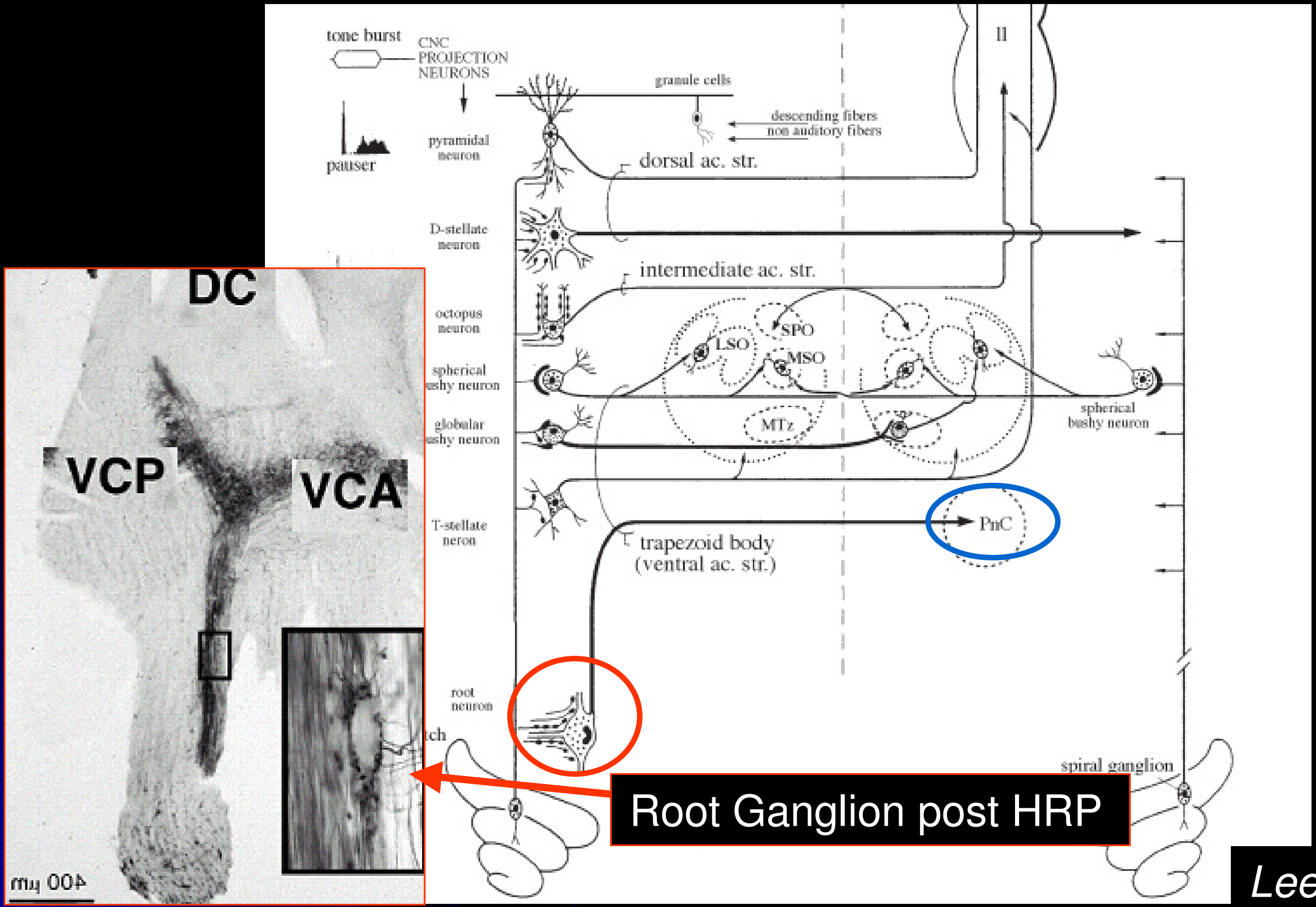
Apical cochlear turn

Basal Cochlear Turn

Apical cochlear turn

Root Cells → Startle reflex

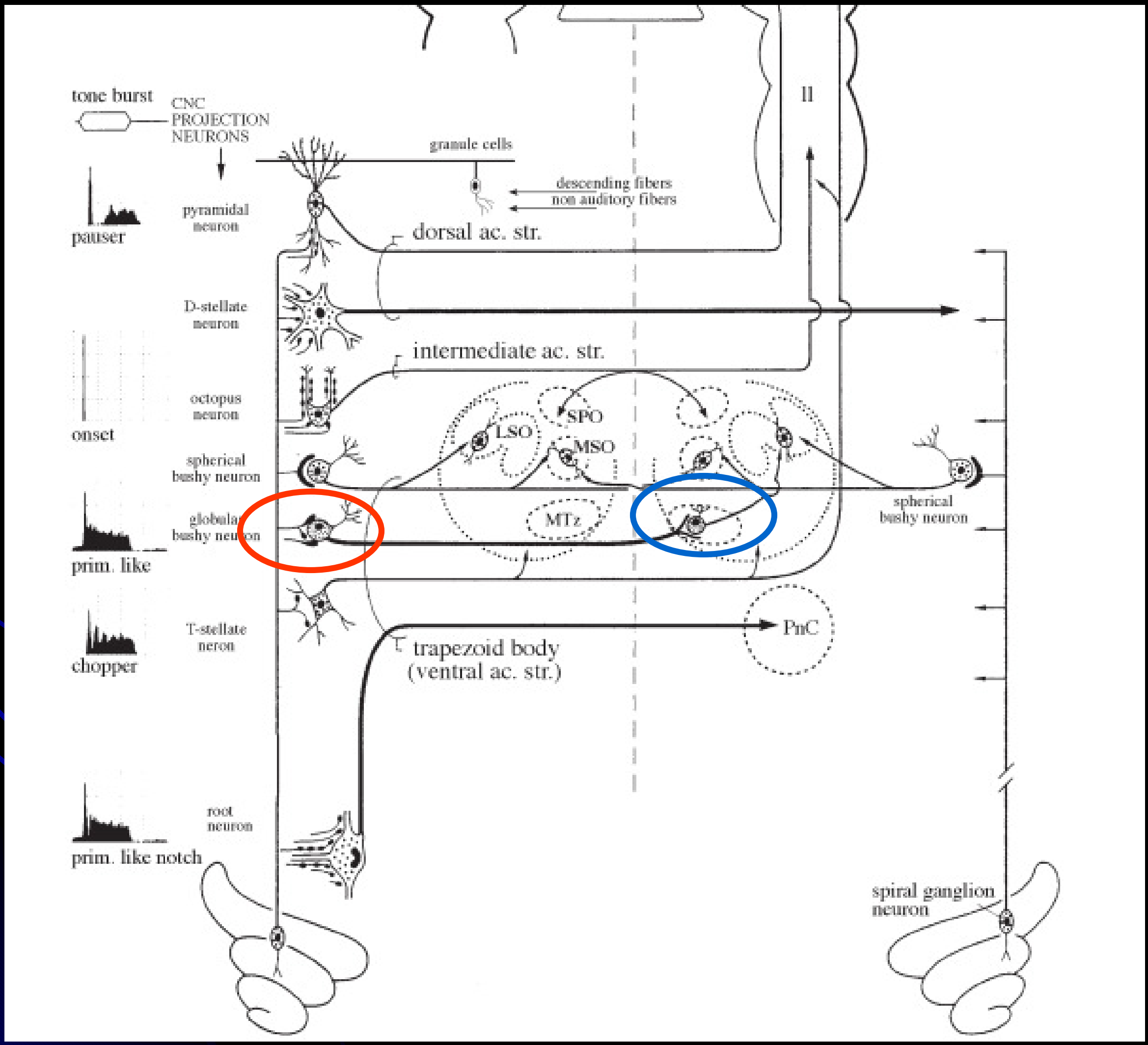
- Large cells scattered in the cochlear nerve root
- Many boutons from afferent cochlear nerve
- Projects to contralateral reticular pontine nucleus
- Participate to startle reflex



Lee Y et al., 1996

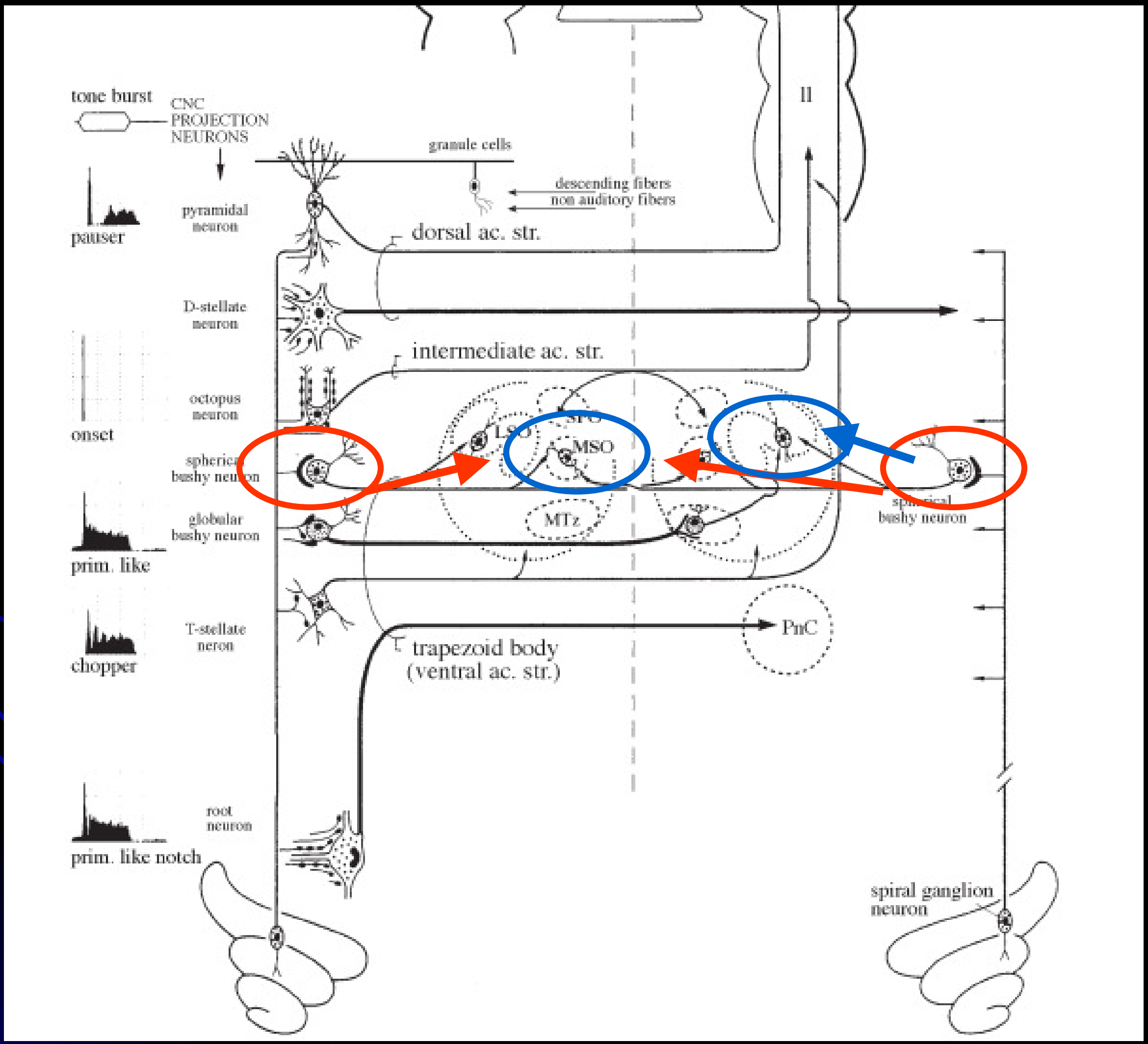
Globular bushy cells → Sound localization

- GB → many small axosomatic terminals from the auditory nerve
- GB → project to the contralateral trapezoid body (Centro and Ryugo, 1989)
- GB → transmit precise temporal information necessary for sound localization

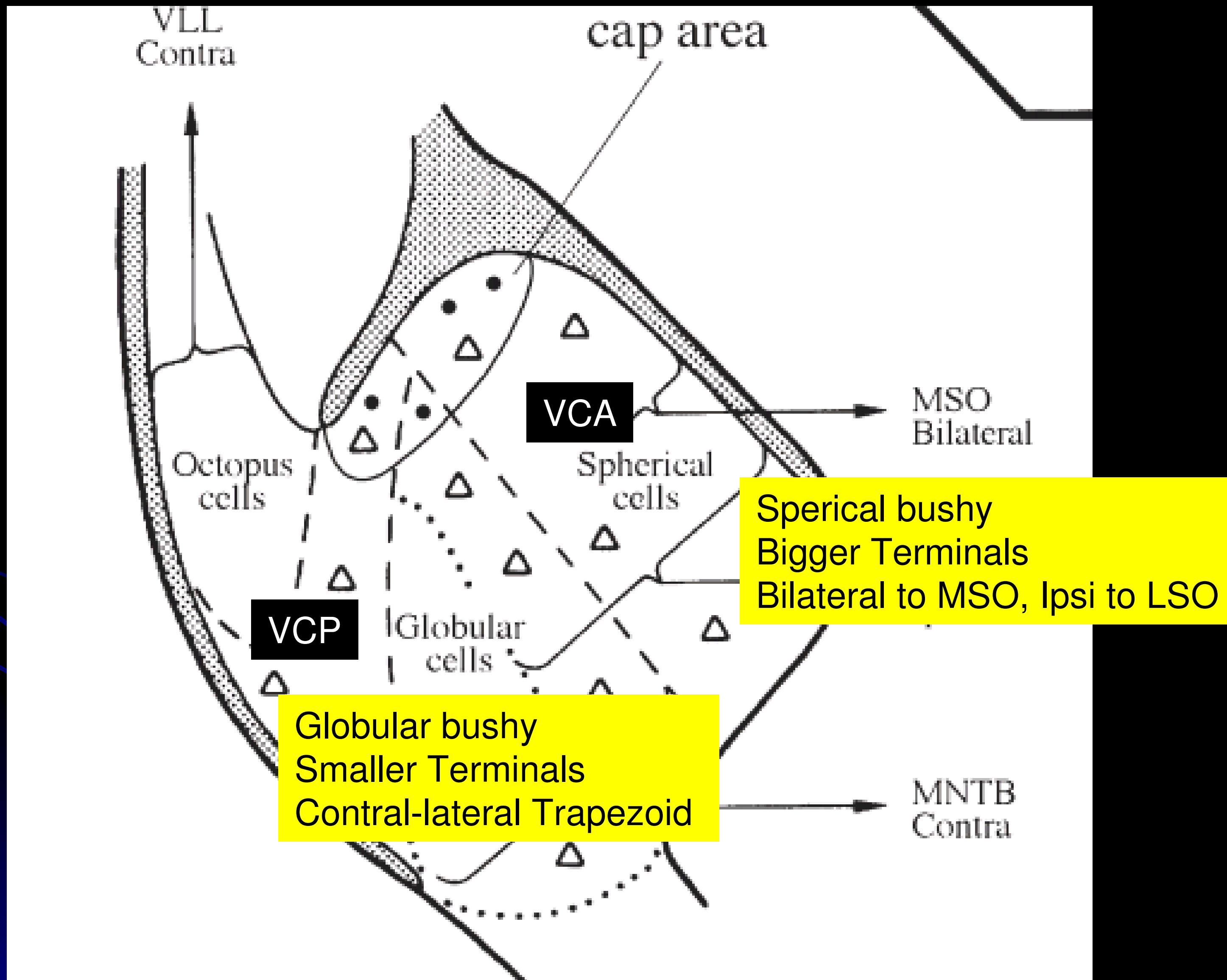


Spherical bushy cells → Sound localization

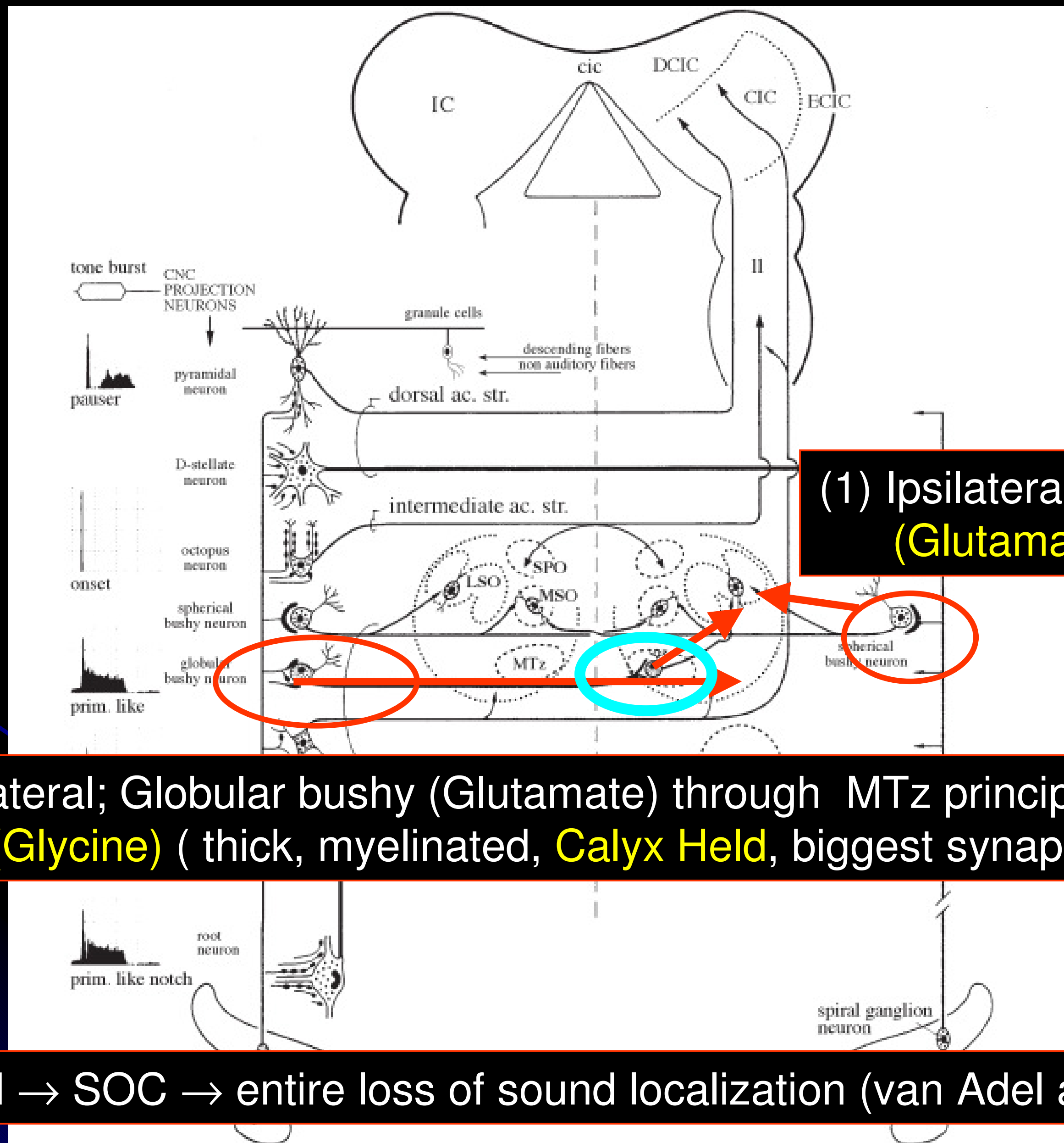
- SB → few large axosomatic terminal, the bulbs of Held (Centro & Ryugo, 1989)
- SB → project bilateral to MSO, ipsi to LSO (Harrison and Warr, 1962)
- SB → transmit precise temporal information necessary for sound localization



Globular and spherical bushy cells → Sound localization



Superior Olivary Complex (SOC): Directional hearing

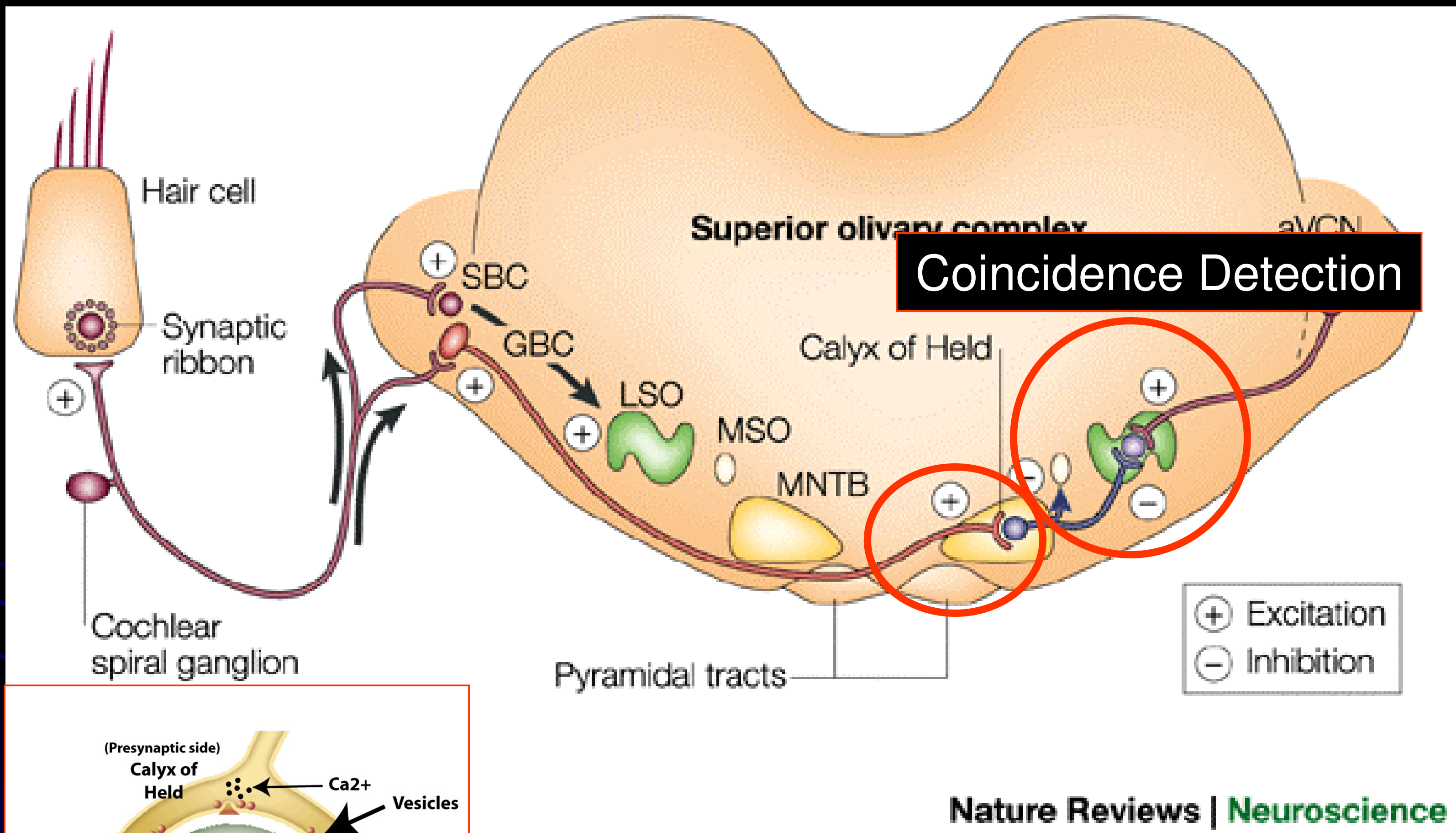


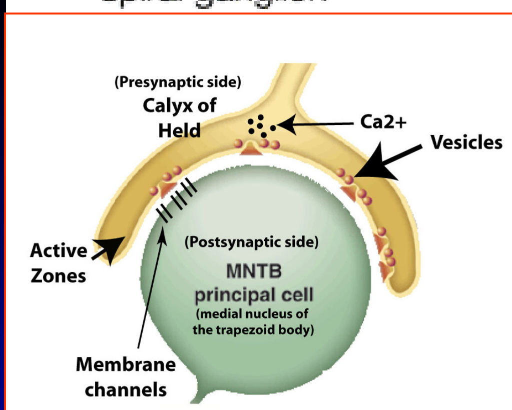
(1) Ipsilateral; Sperical cells (Glutamate)

(2) Contralateral; Globular bushy (Glutamate) through MTz principle cells: from MTz (Glycine) (thick, myelinated, Calyx Held, biggest synapse of the brain!)

Kainic acid → SOC → entire loss of sound localization (van Adel and Kelly, 1998)

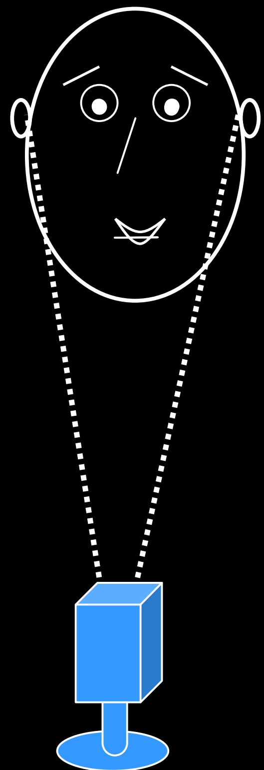
Superior Olivary Complex (SOC): Directional hearing

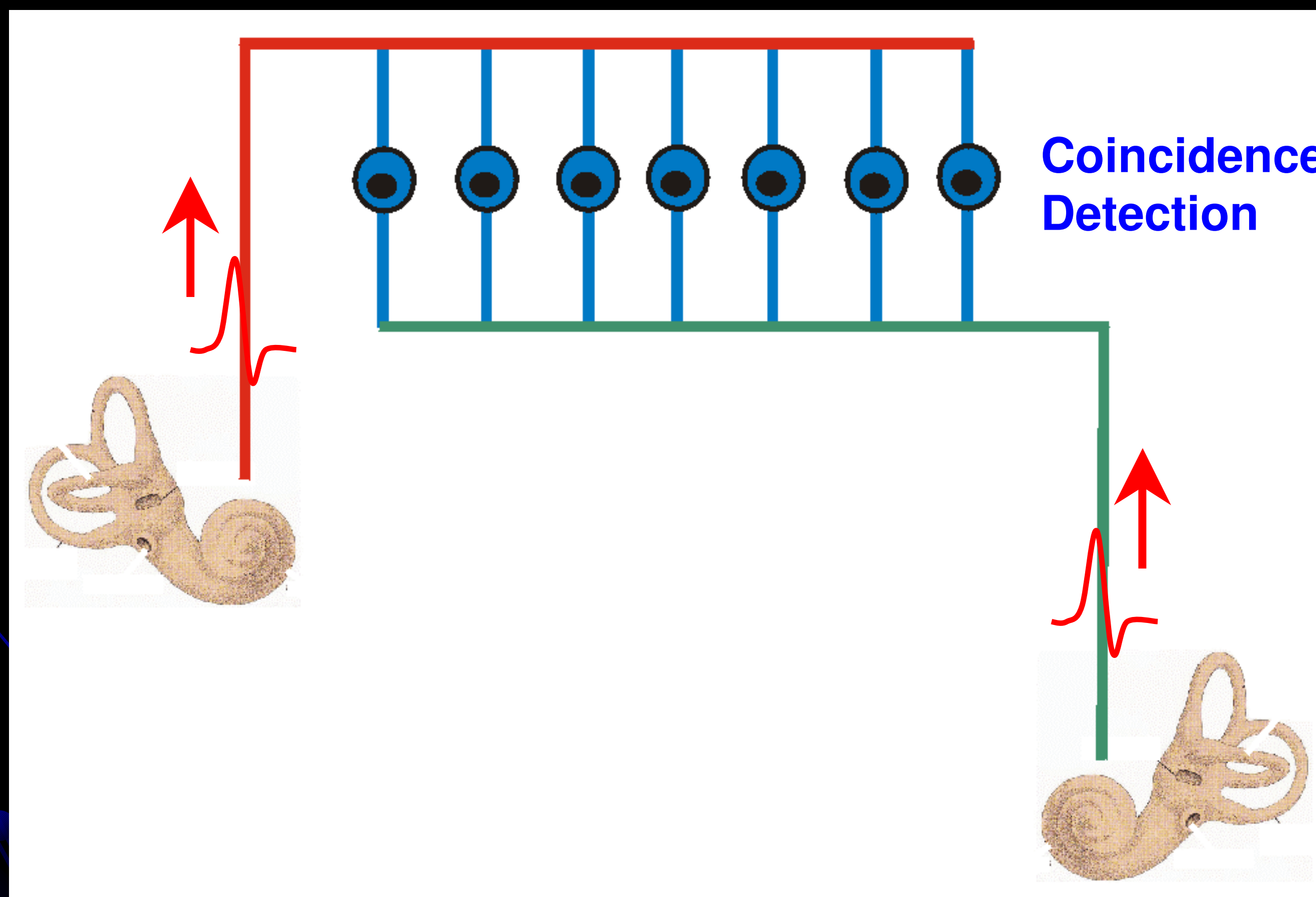




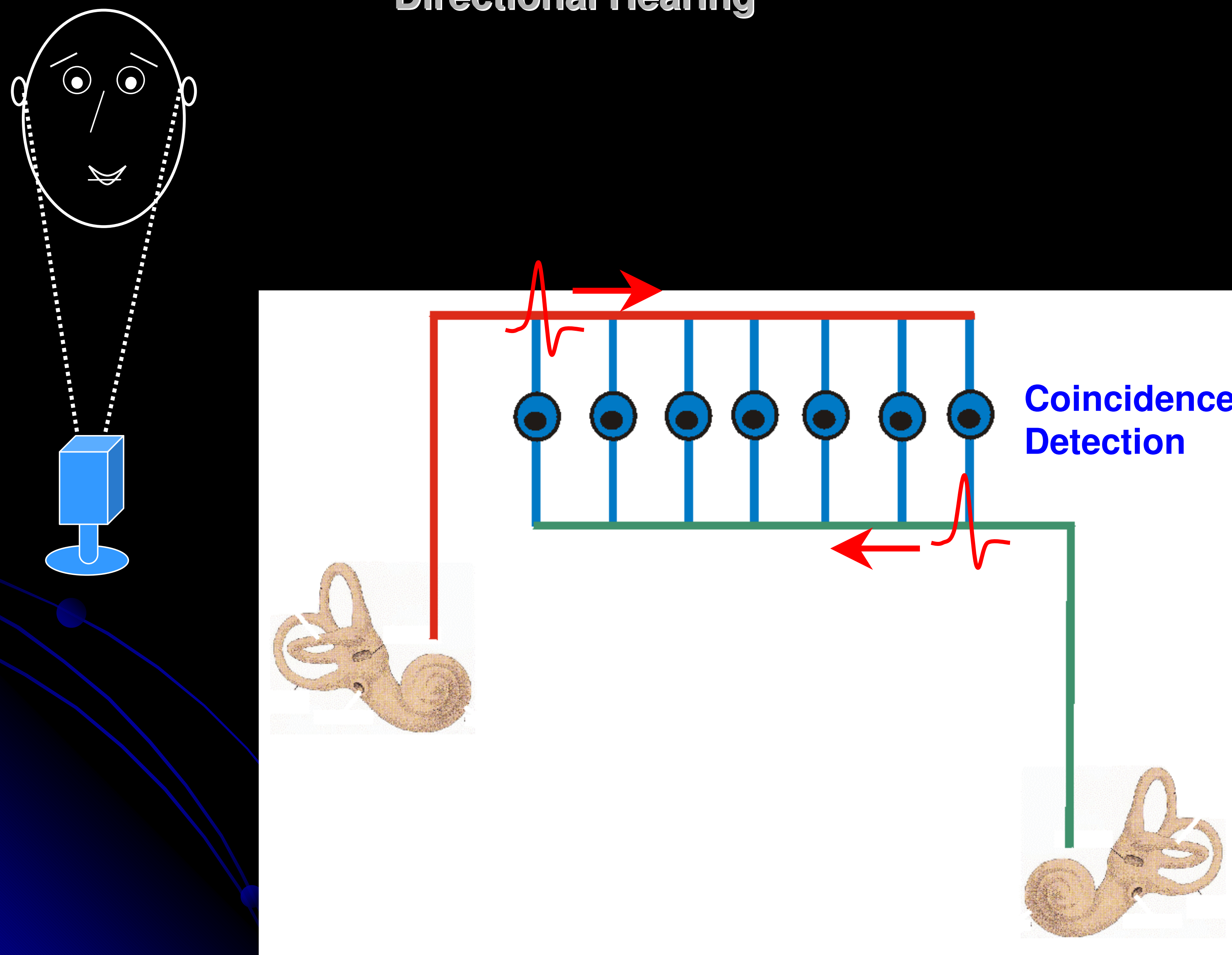
Gersdorff H, 2002

Directional Hearing

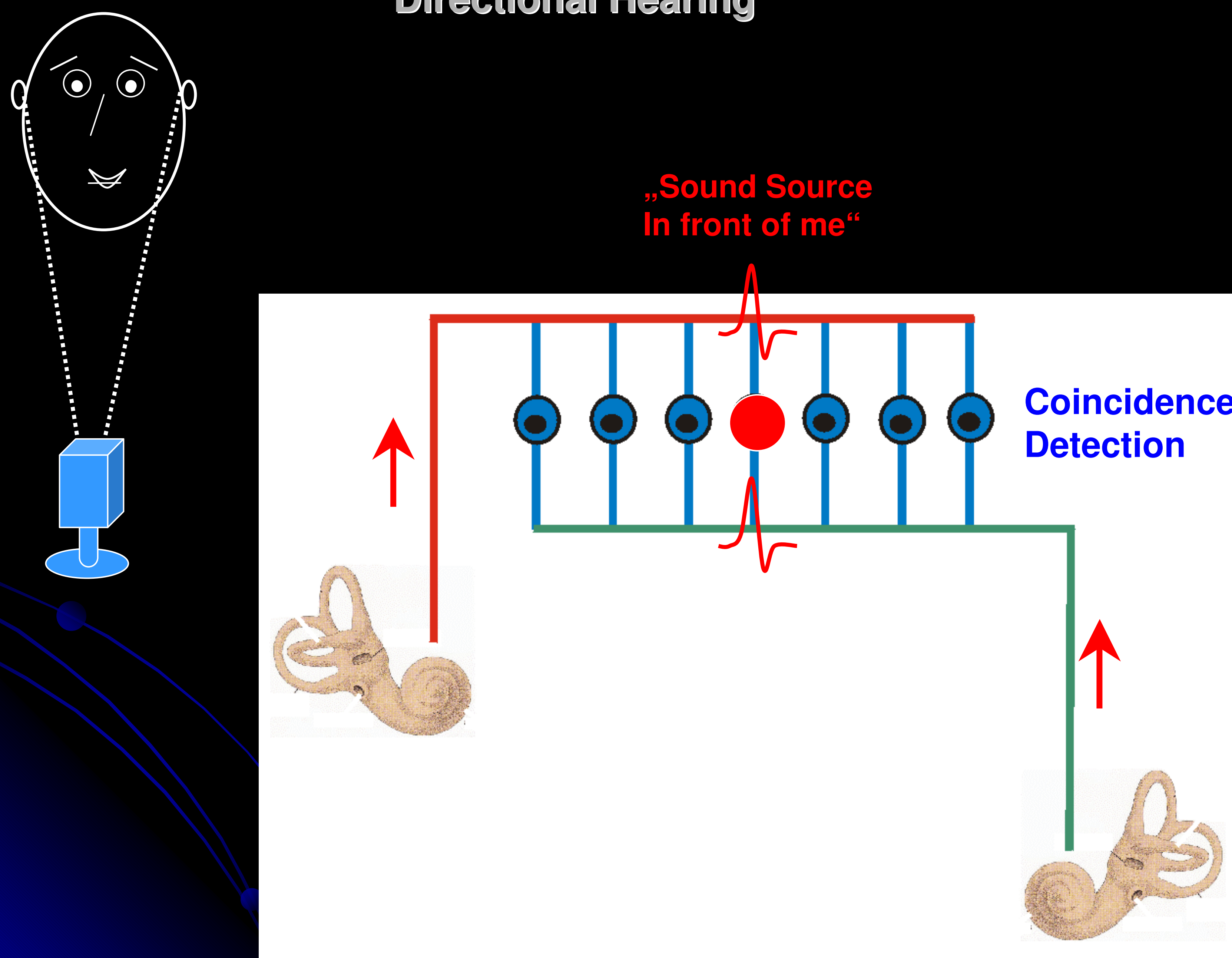


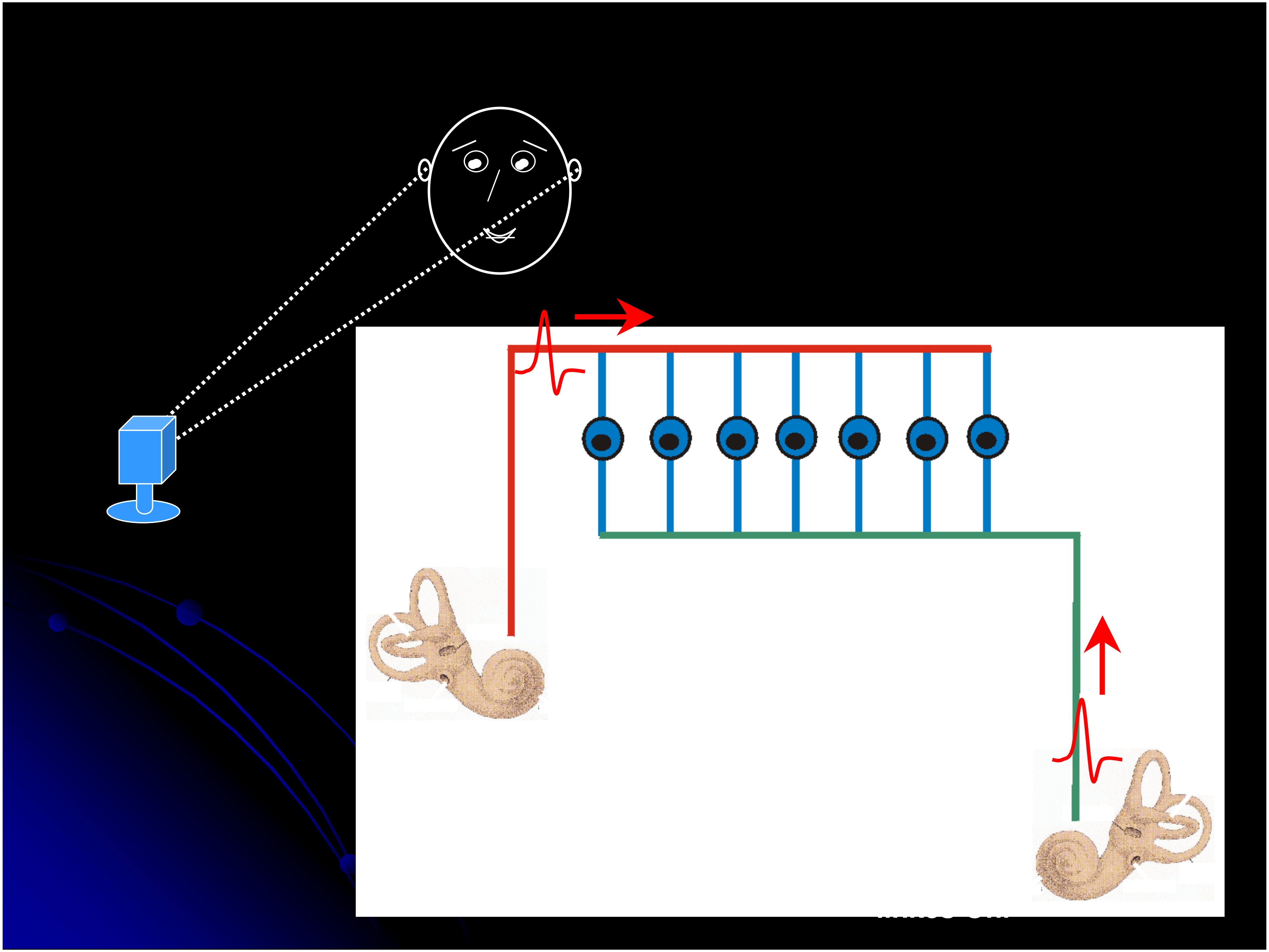


Directional Hearing

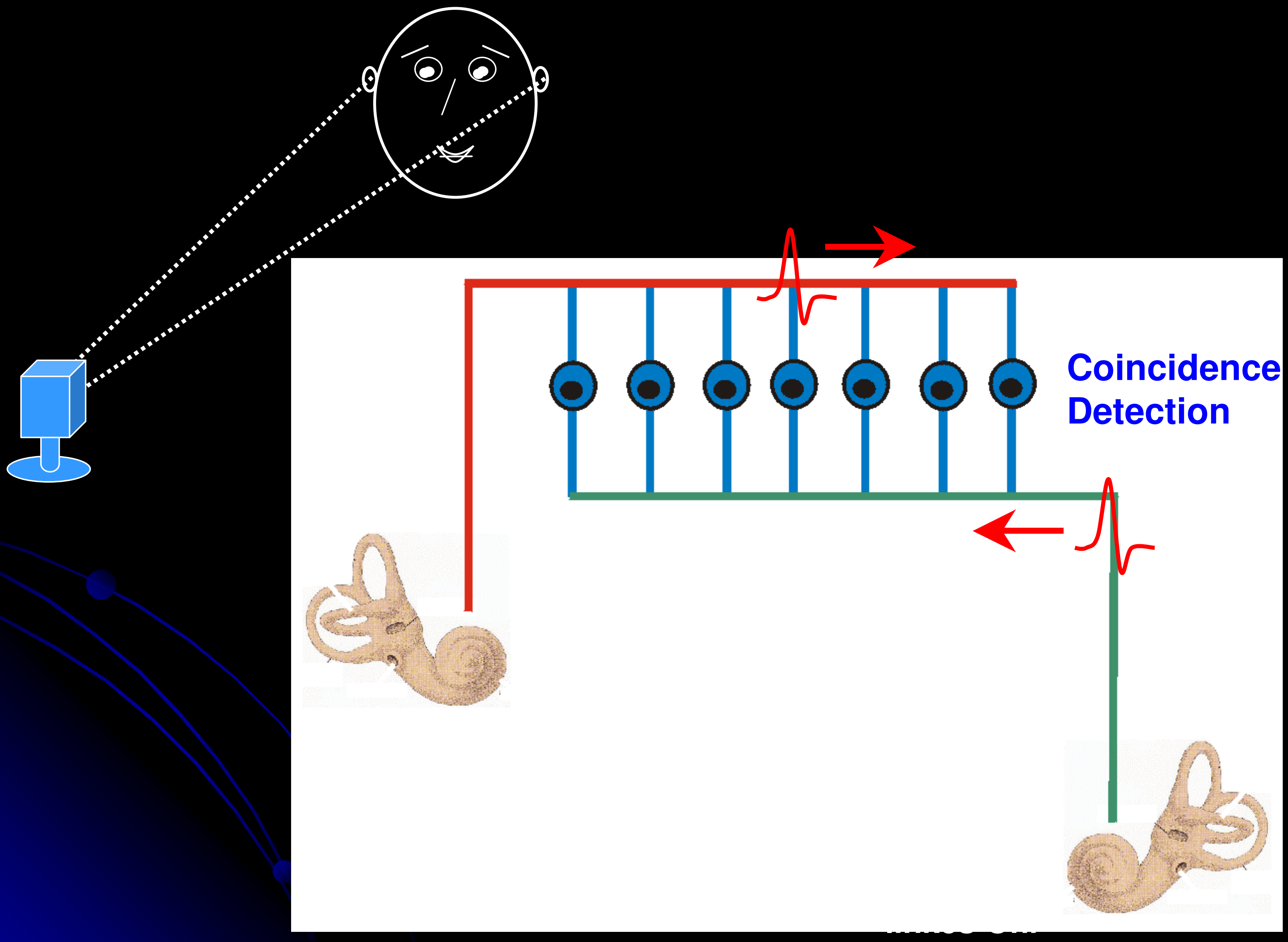


Directional Hearing

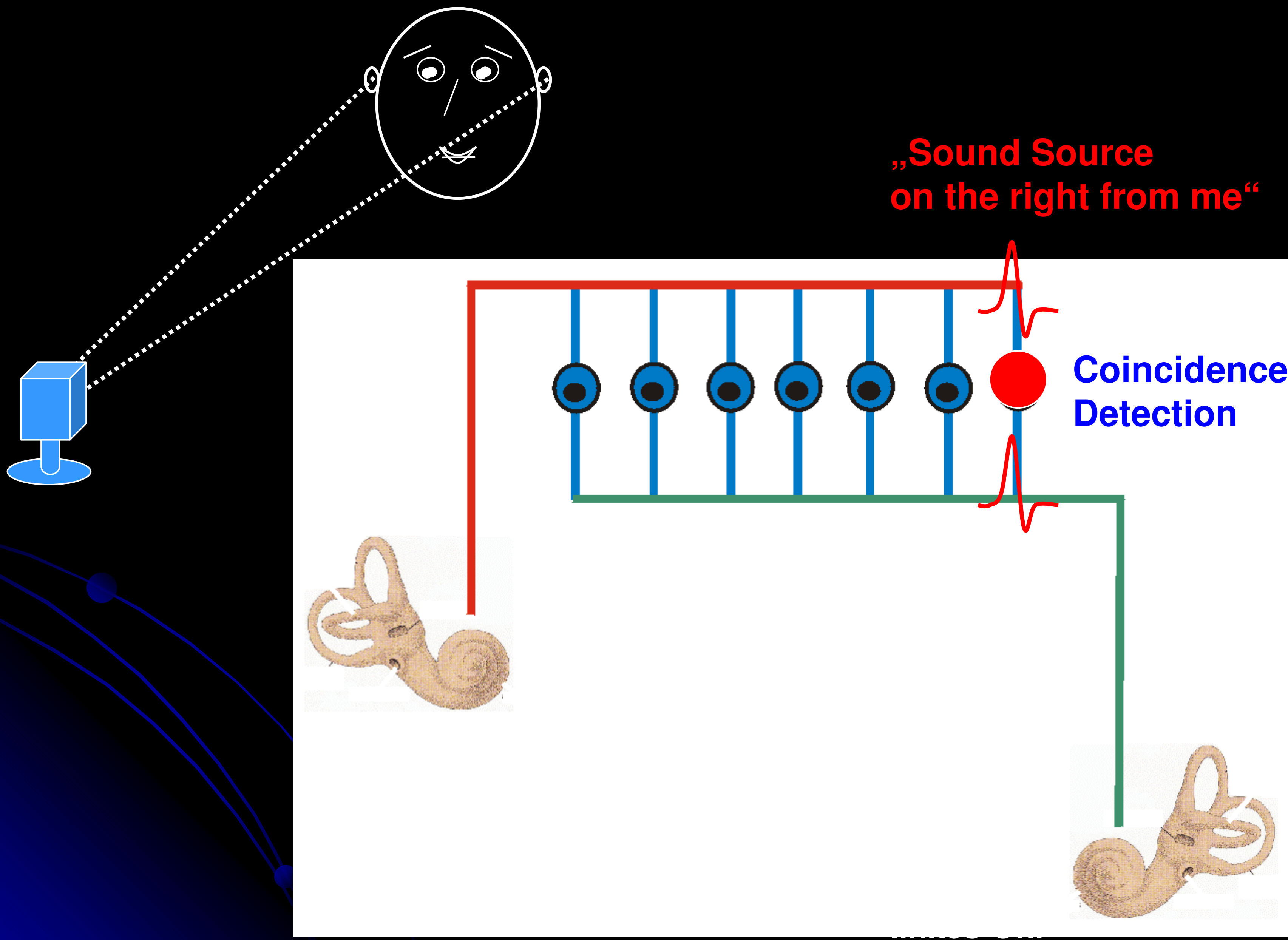




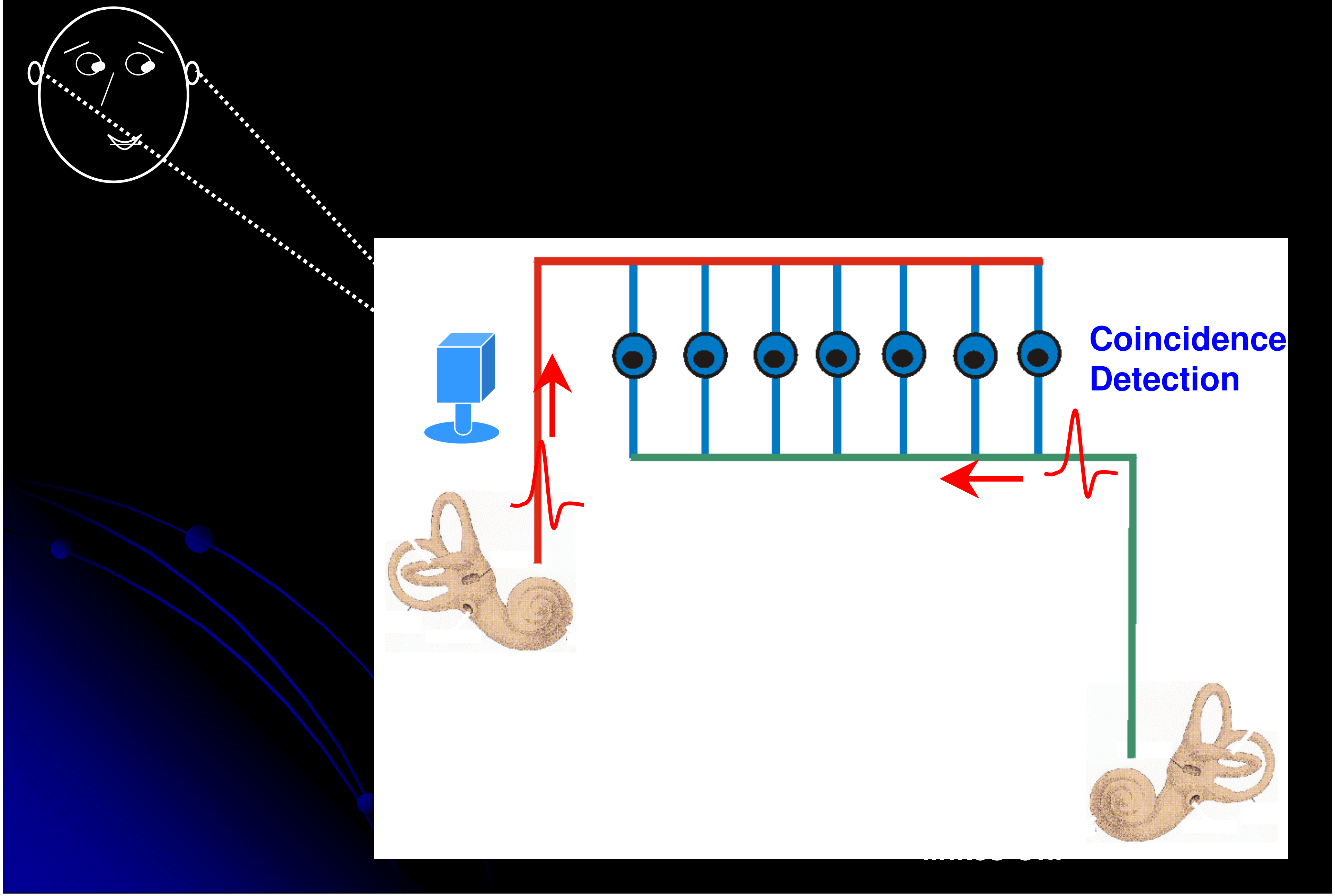
Directional Hearing



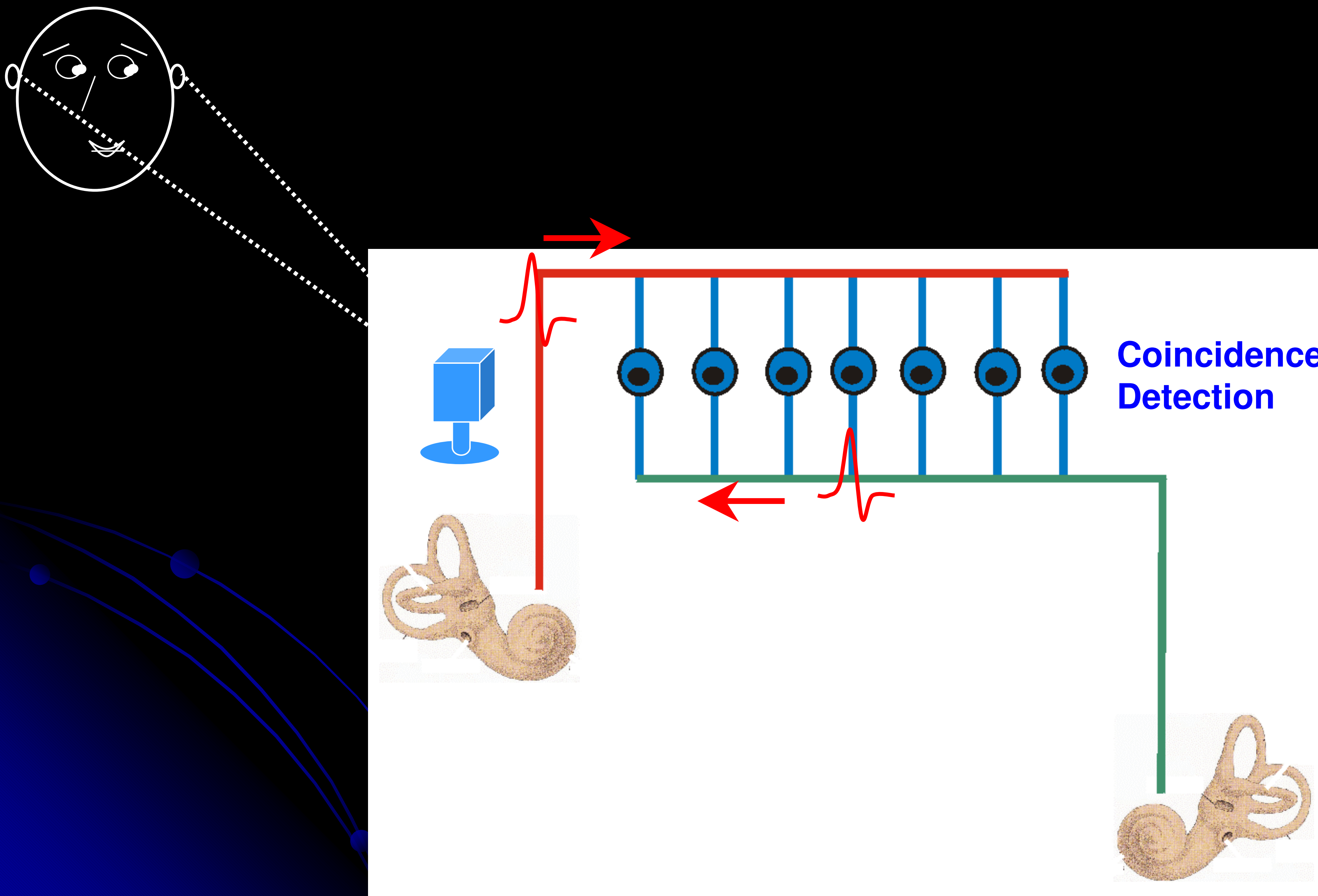
Directional Hearing



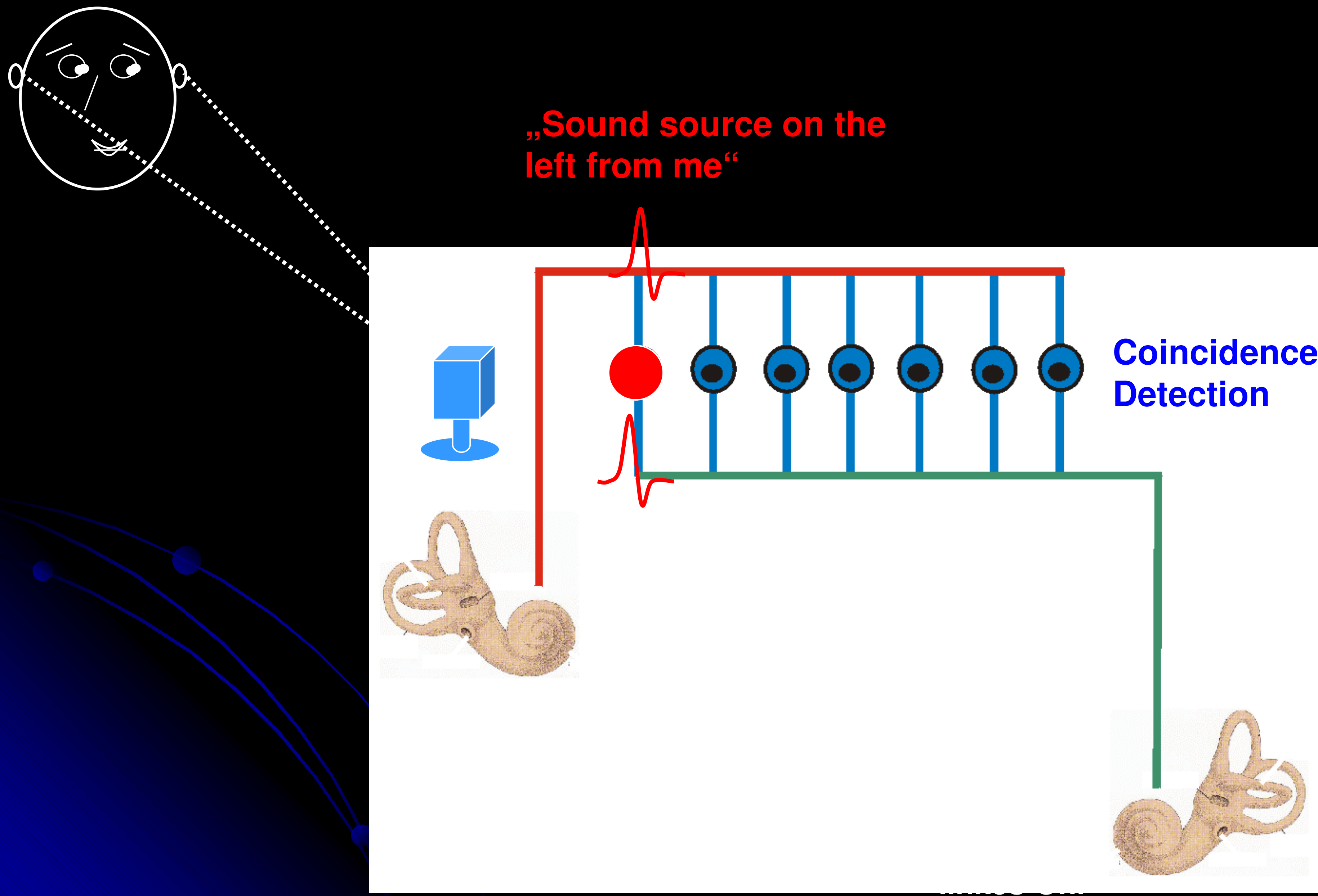
Directional Hearing

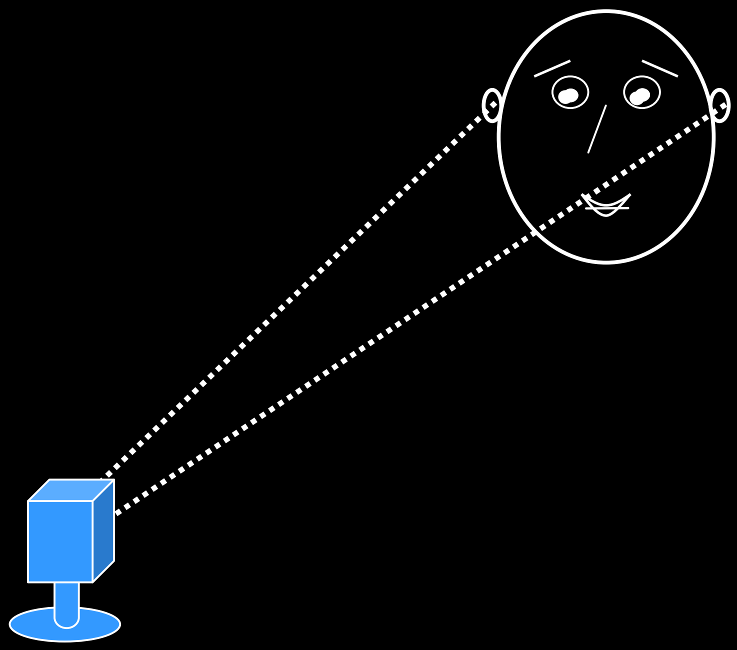


Directional Hearing



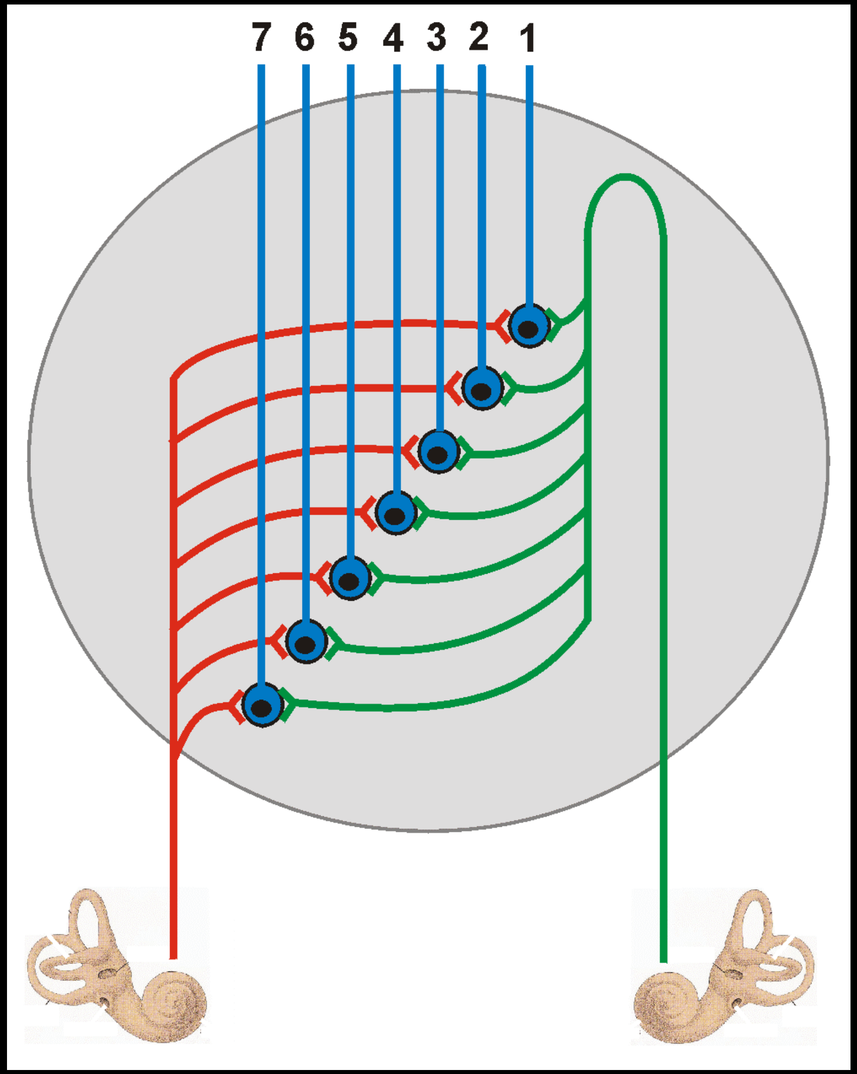
Directional Hearing





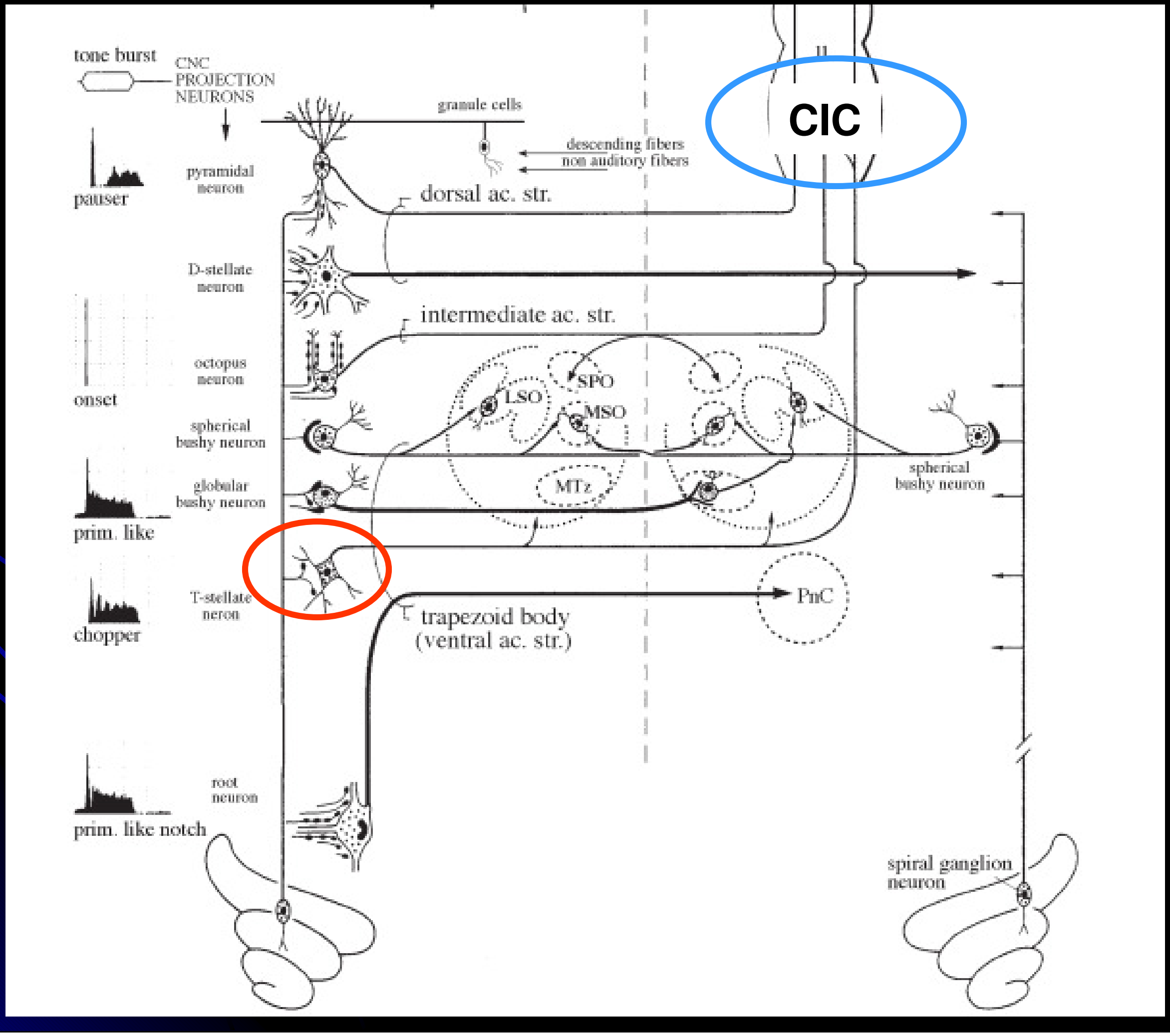
On hearing with more than one ear:
Lession from evolution

Nature Neurosci 2009,
Schnupp and Carr



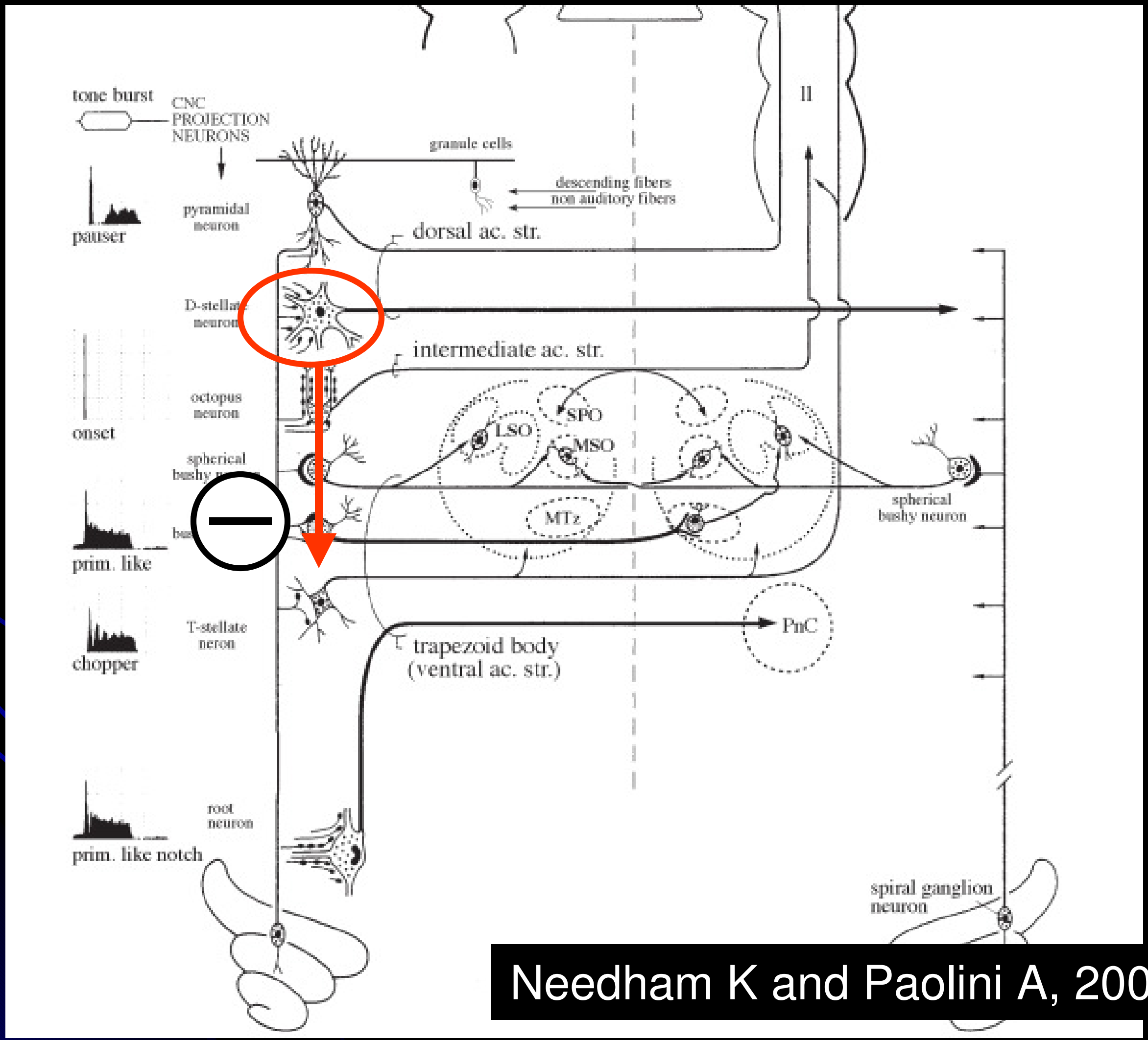
T- Stellate cells → Frequency spec. Sound Intensity to IC

- •T-S → glutamatergic → through SOC, through ILL → **Central IC**
- •T-S → respond with `chopper` responses (repeated firing pattern) to tone burst
- •T-S → frequency-specific collaterals to VCN- and DCN
- •T-S → **frequency specific** excitatory information about the **stimulus level!!**



D- Stellate cells → tuning of T-S intensity information

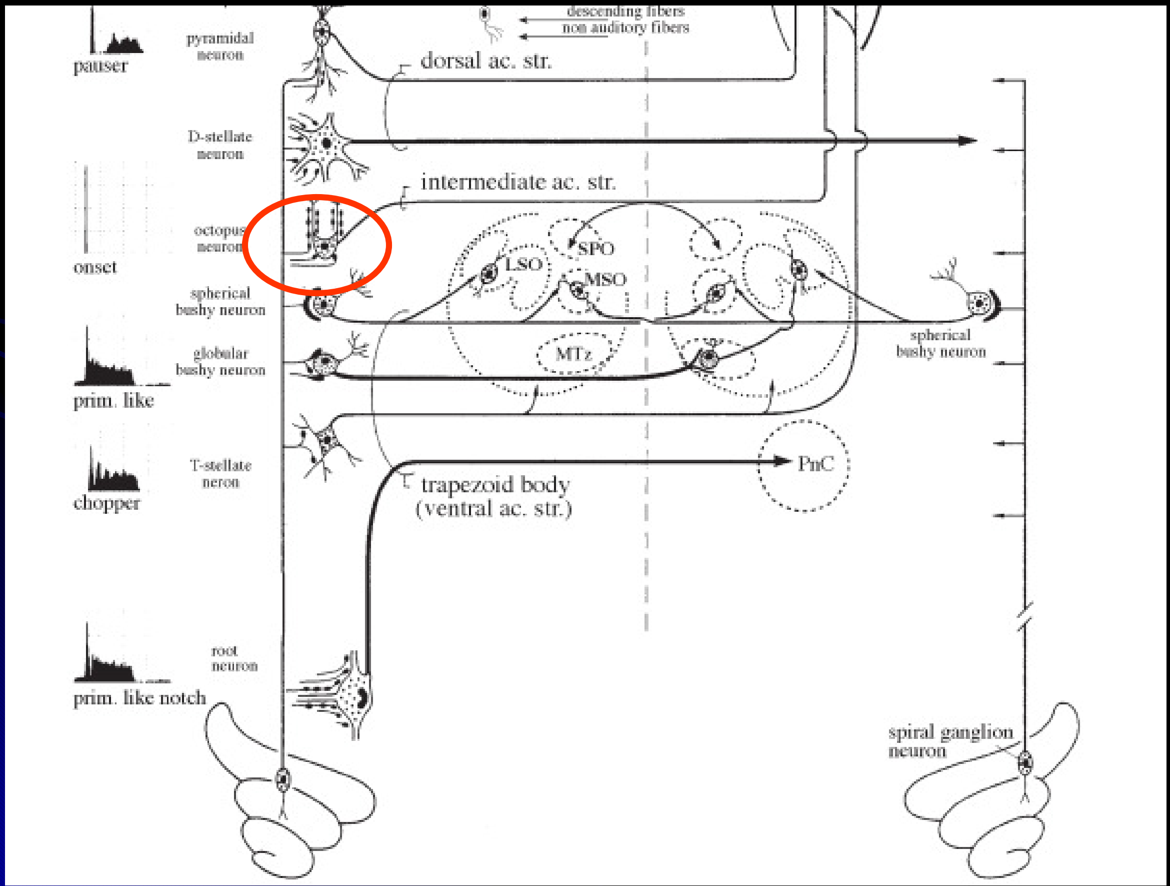
- D-S → project ipsi and contralateral inhibitory (Glycin) to the CNC
- D-S → respond to broad band stimulus upon change of timing & synchrony of T-S!
- D-S → Sharpens coding of spectral peaks of narrow tuned T-S → lateral inhibition!

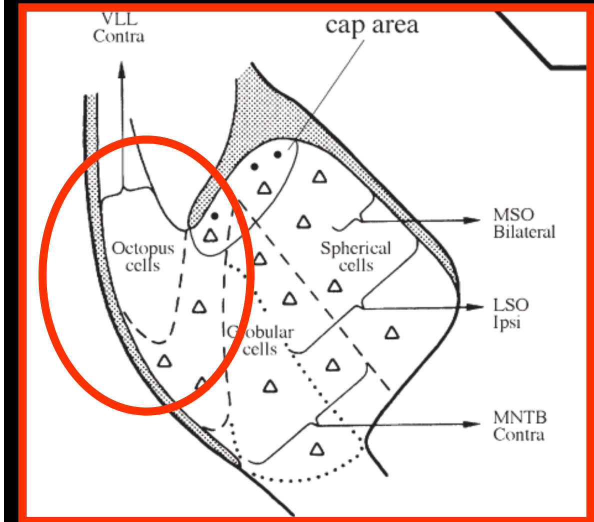


Needham K and Paolini A, 2003 J Neurosci

Octopus cells → detect synchronization of AN-fibers → speech

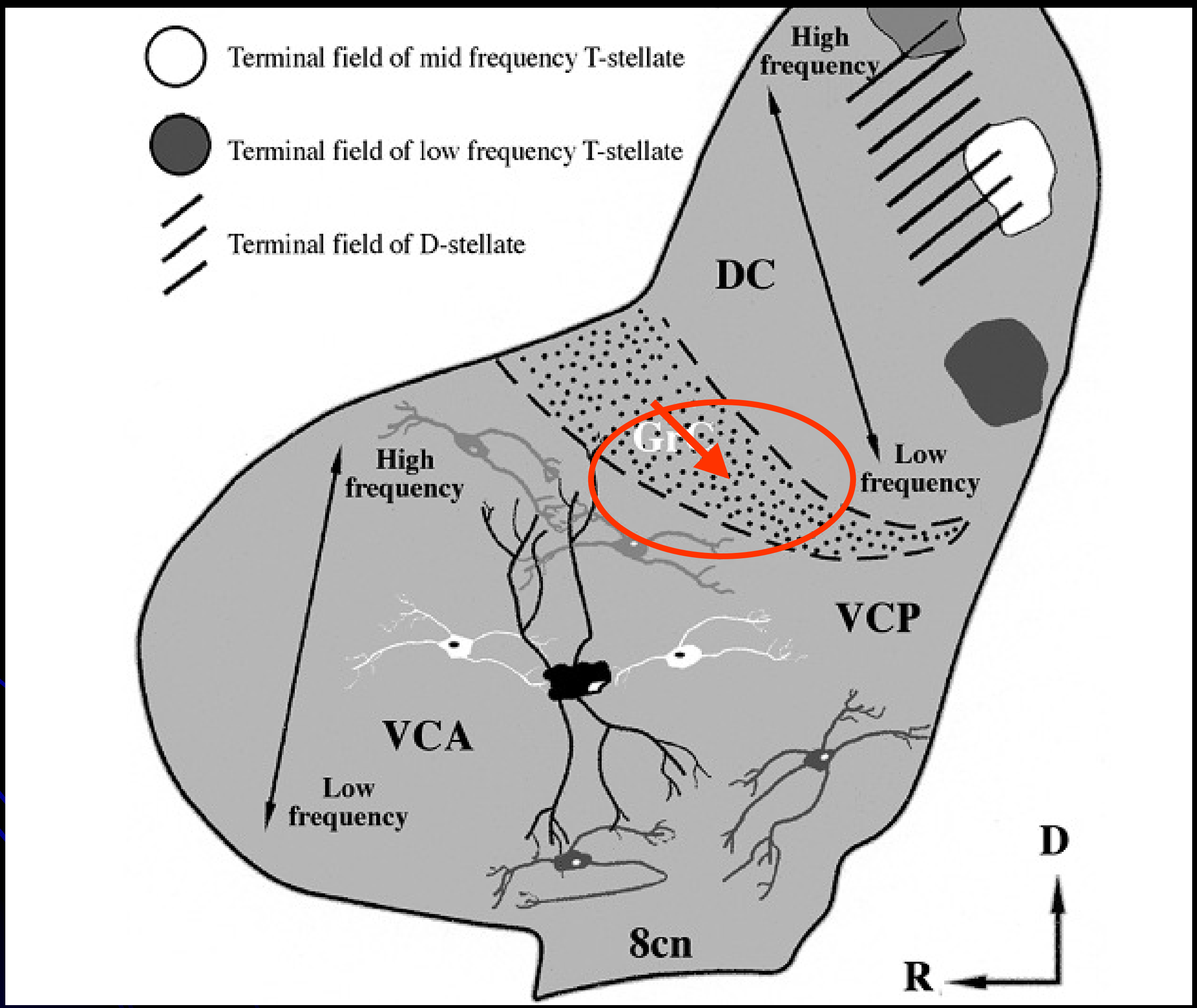
•O-N → Onset-Neurons- small terminals
•O-N → Respond to tone bursts with a single spike
•O-N → Project to Trapezoid Body and Ventral LL
•90% of the information transmitted during the understanding of a single word is transmitted through the temporal information transferred within the first 73 ms!!!!





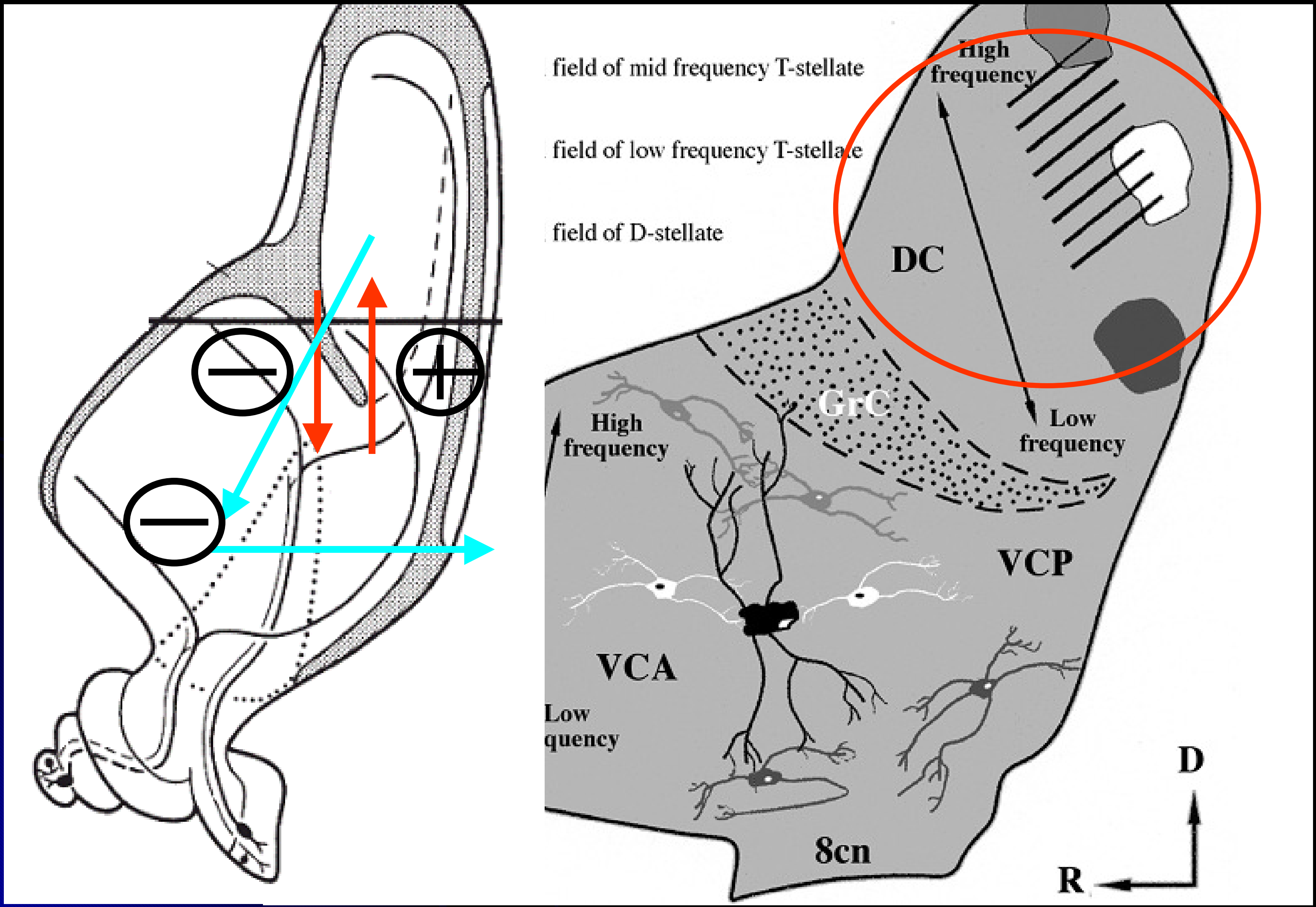
CAP region → Sound stimulus intensity

- Both AFI (low spiking) and AFII terminate on small GLYCIN- GABAergic N in CAP -R
- Provide information about stimulus intensity as a part of a feedback gain control



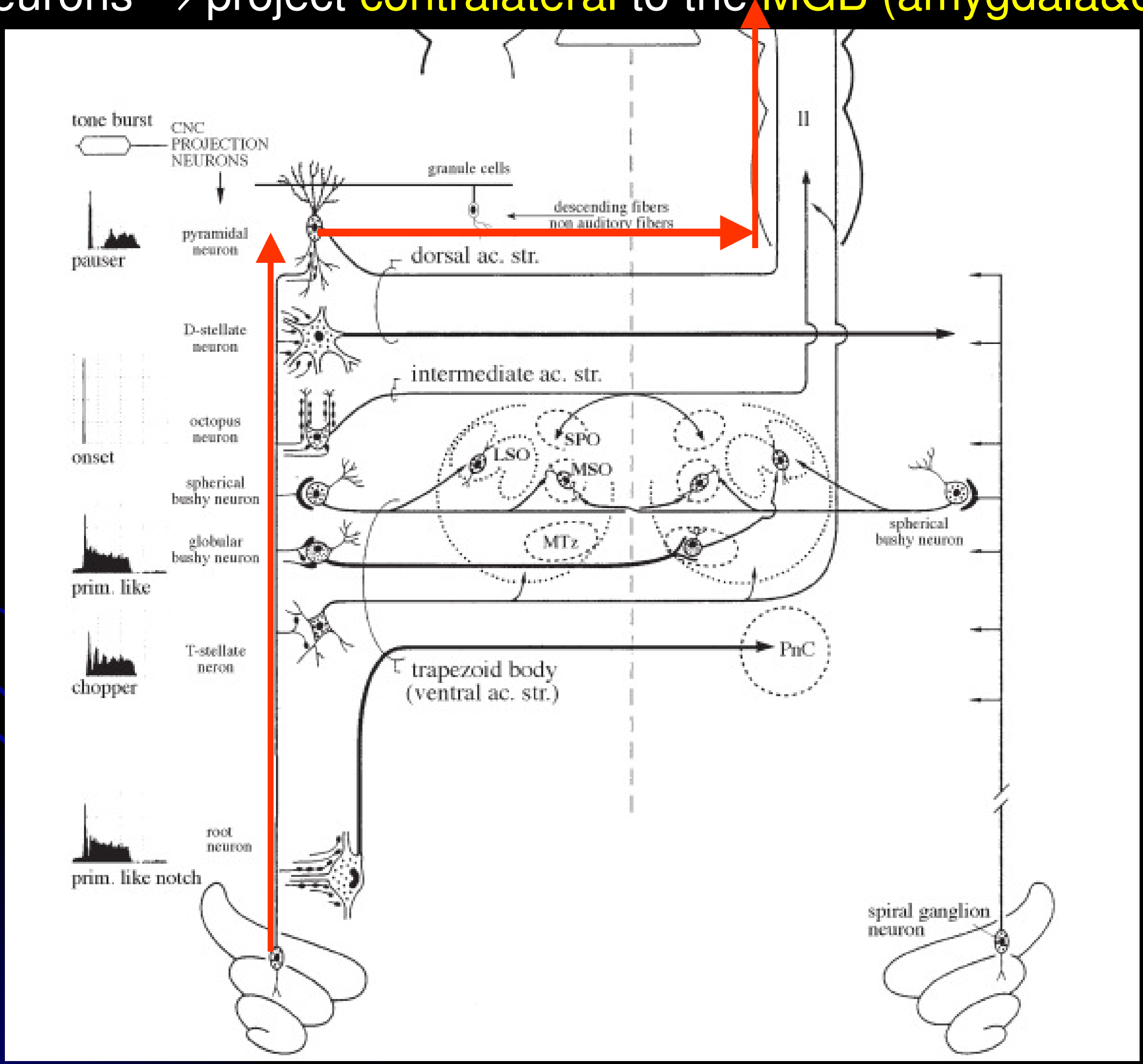
Dorsal cochlear nucleus → Spectral contrast detection

- Large interneurons (GABAergic & Glycinergic)
- Tuberculoventral system connects VC and DC reciprocally: spectral contrast detectors
- VC neurons (Bushy, Stellate) get inhibitory (GABA) input from DC

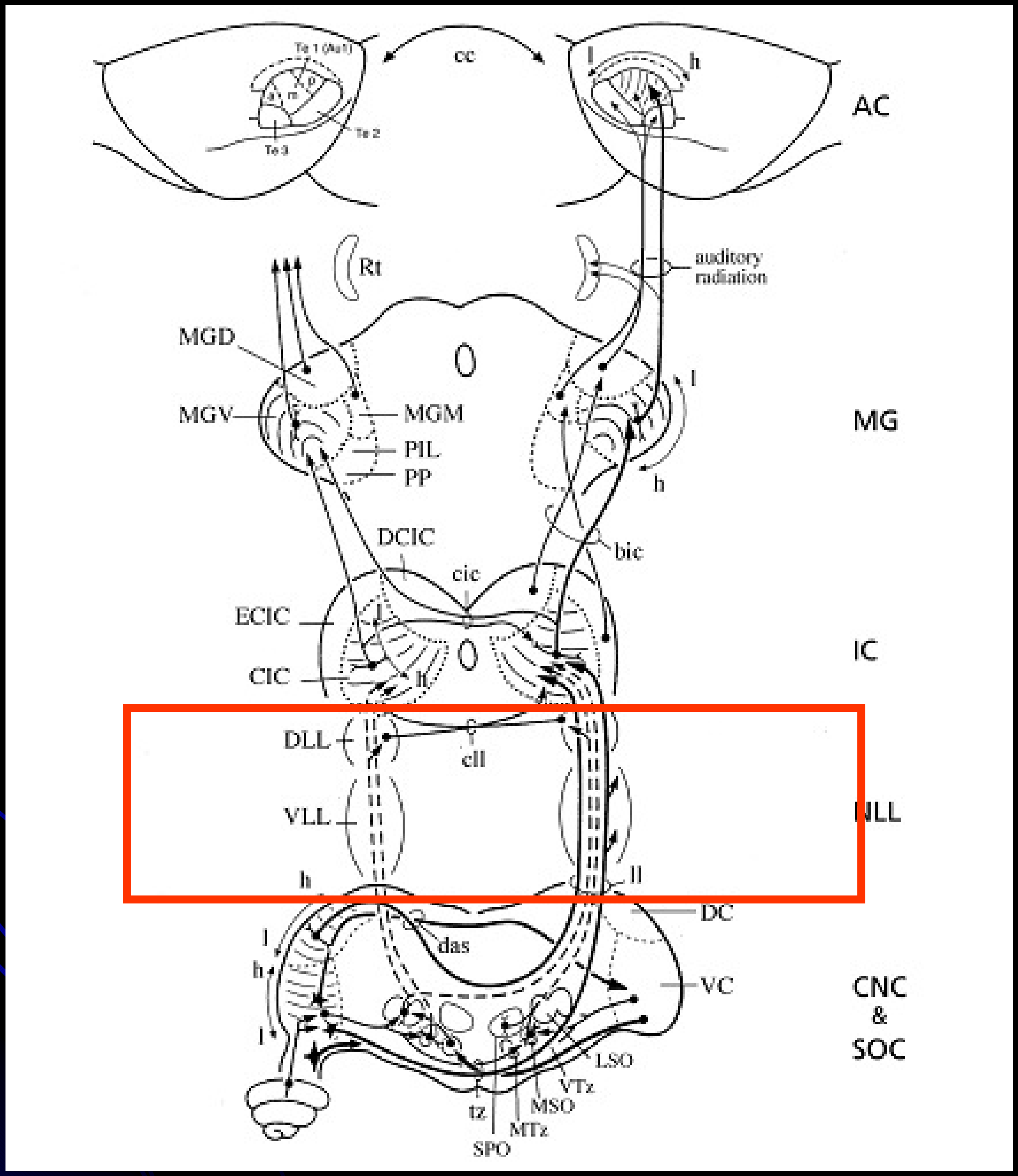


Dorsal cochlear nucleus → Spectral contrast detection

- Interneuron project on bipolar (fusiform) pyramidal neuron
- Pyramidal neurons → project contralateral to the CIC
- Pyramidal neurons → project contralateral to the MGB (amygdala&caudate putamen)

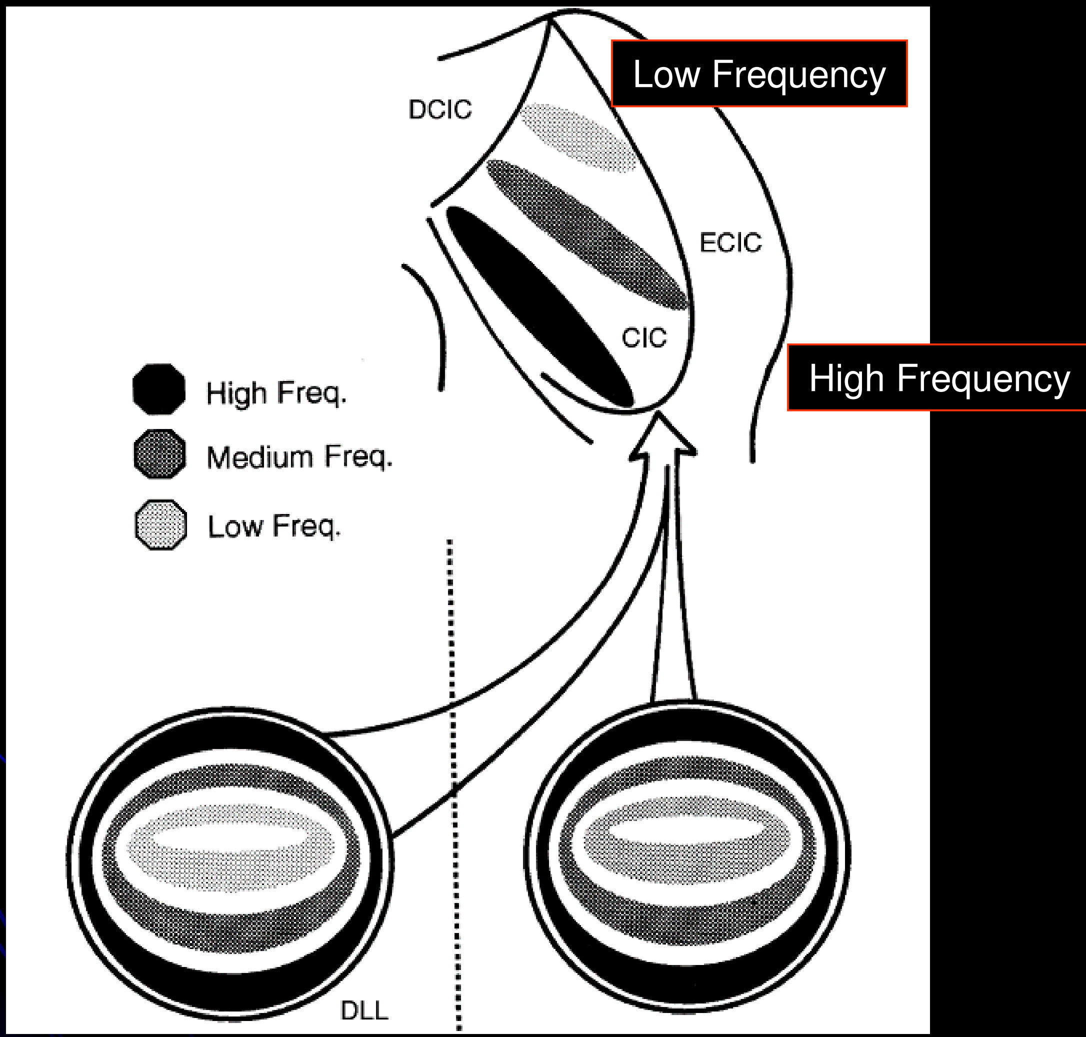


Ventral & Dorsal nucleus of lateral lemniscus to the IC



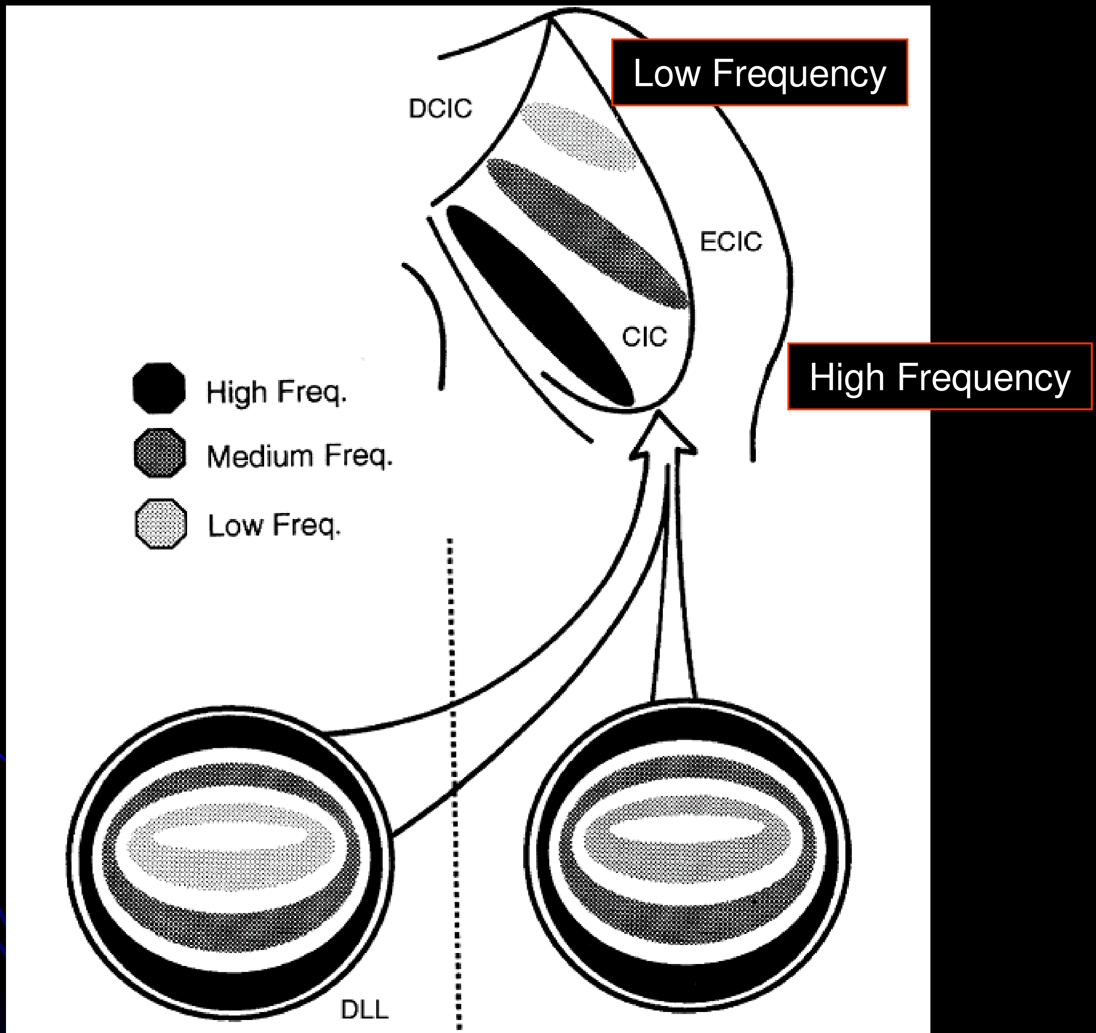
Ventral Nucleus of Lateral Lemniscus → Sound intensity

- Ventral NLL → Information of D-T-Stellate, Octopus, Trapezoid, MSO, CIC,
- Ventral NLL → Intensity; perception of vocalization, speech like communication

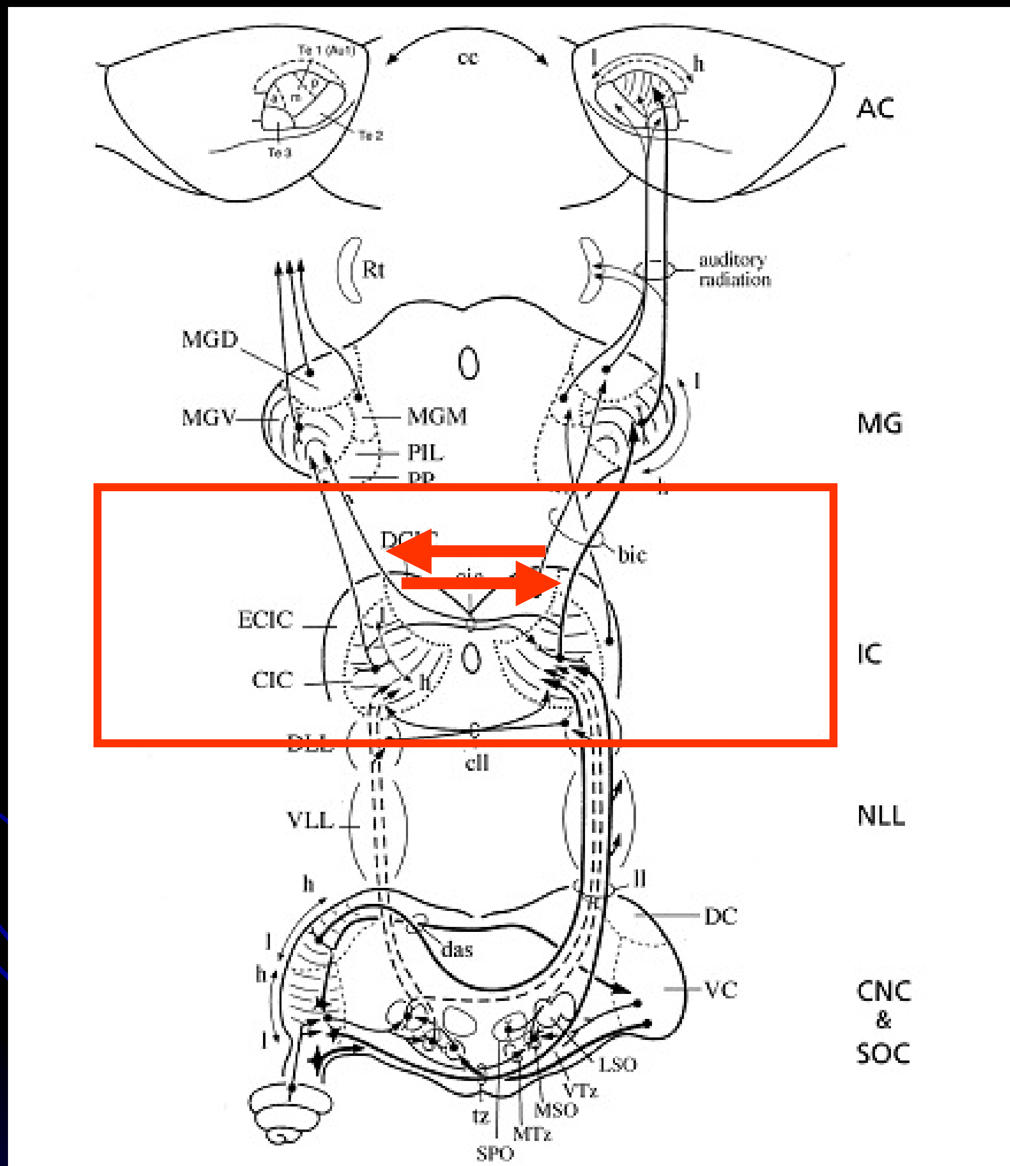


Dorsal Nucleus of Lateral Lemniscus → Sound localization

•Dorsal NLL- binaural; accurate sound localization, binaural processing

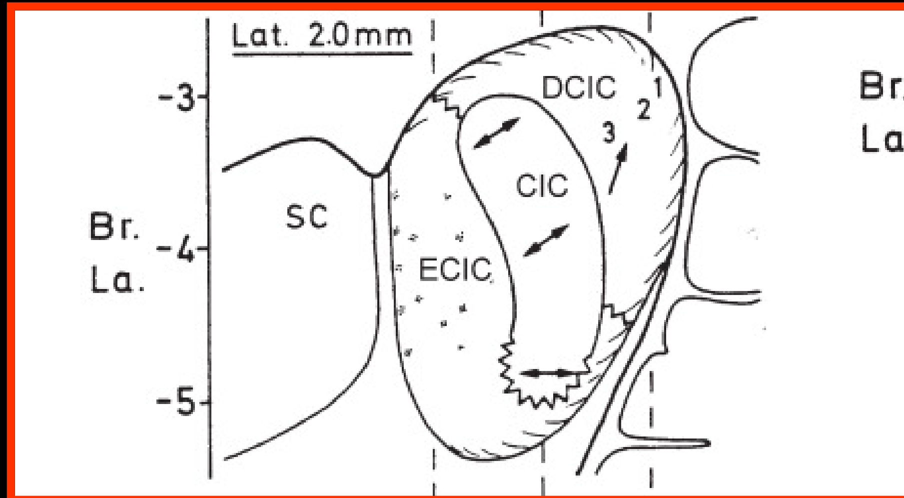


Inferior Colliculus → integration of intensity & directionality

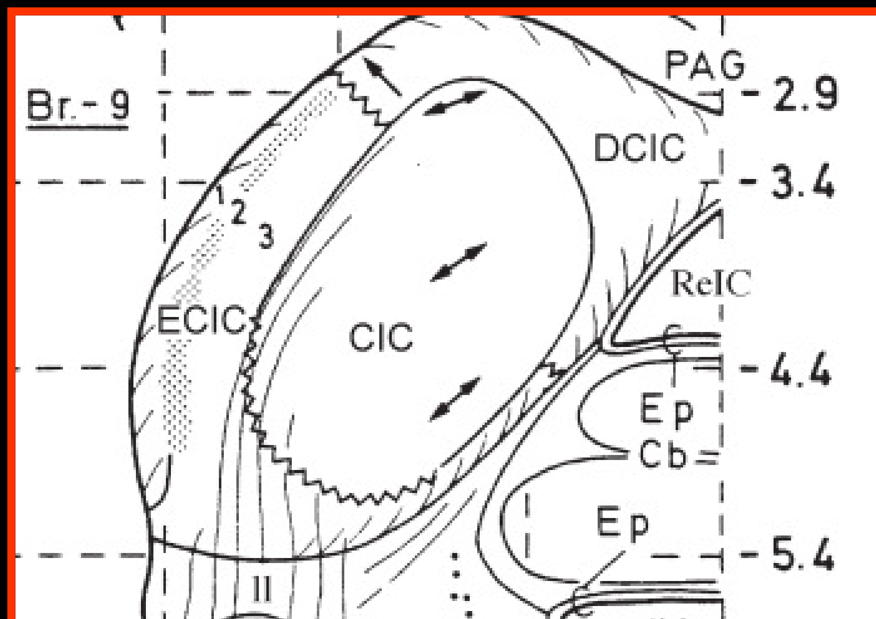


Inferior Colliculus

Sagital

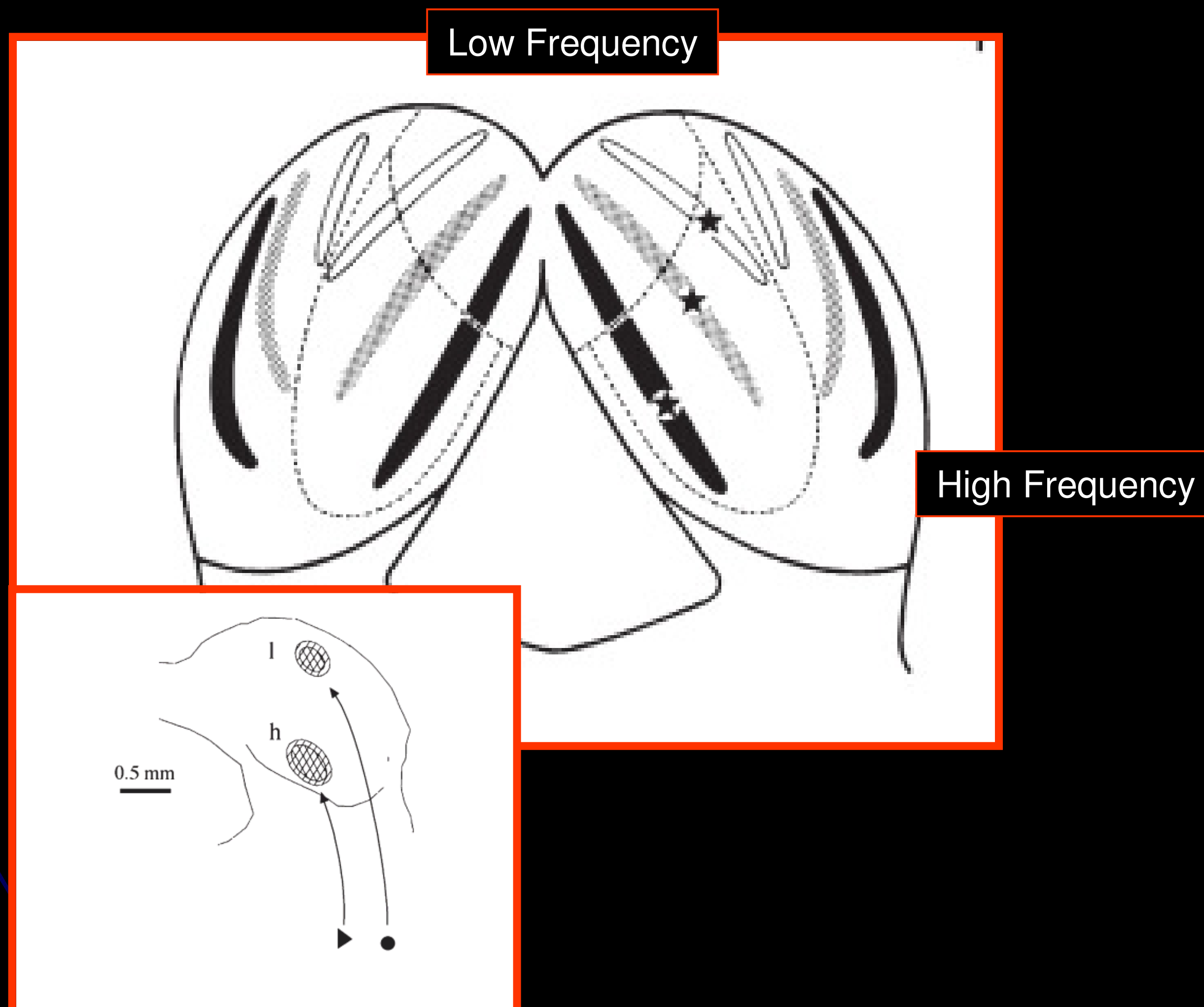


Frontal



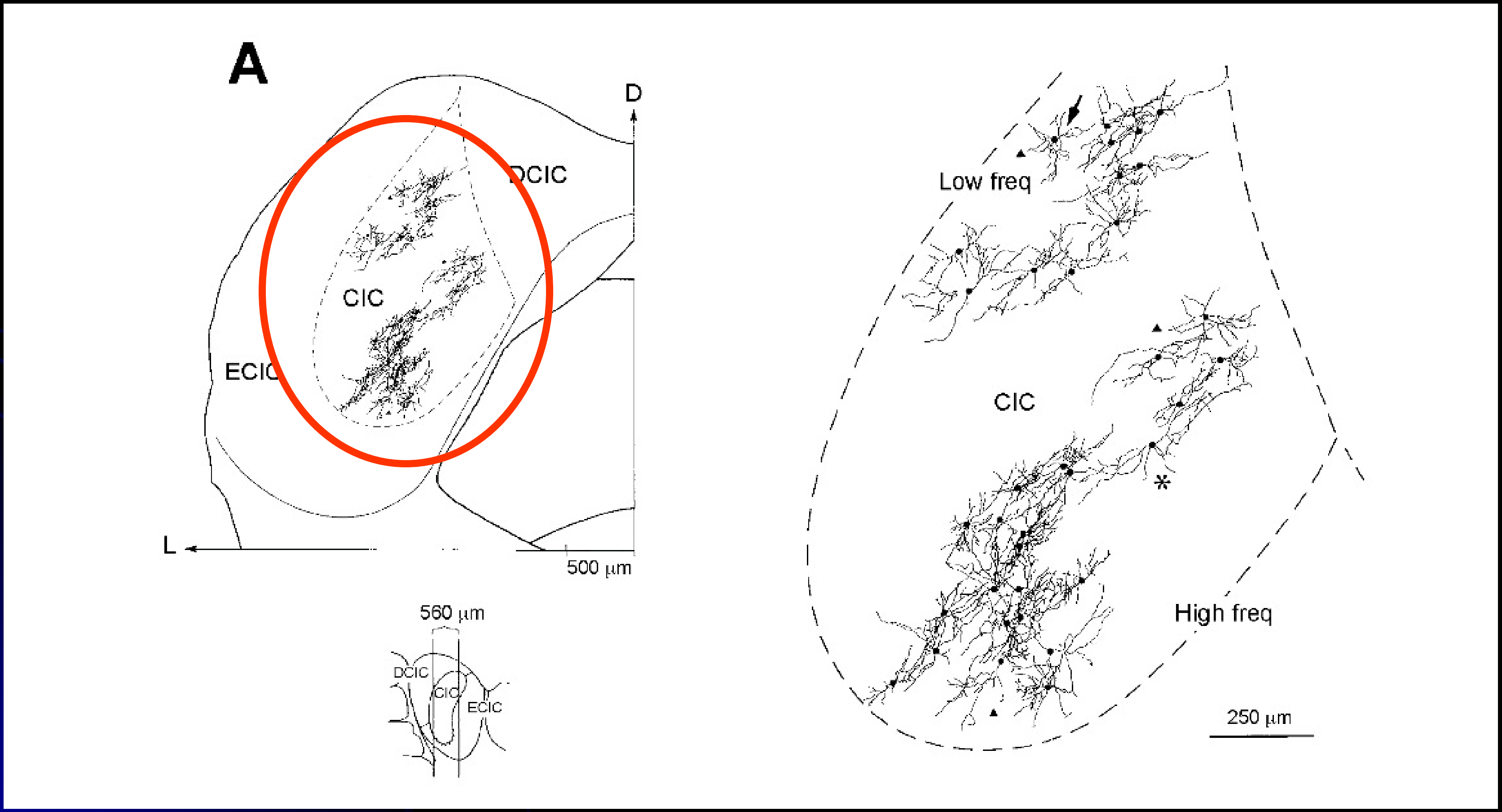
Inferior Colliculus

•Highly organized representation of acoustic signals based on spectral and temporal signals



Central Nucleus Inferior Colliculus → Integration of Sound

CIC → Conta & Ipsilateral Input **from all lower** brainstem nuclei,
CIC → GABAergic & Glutamatergic **to MGB** (reg. thalam. spike pattern)

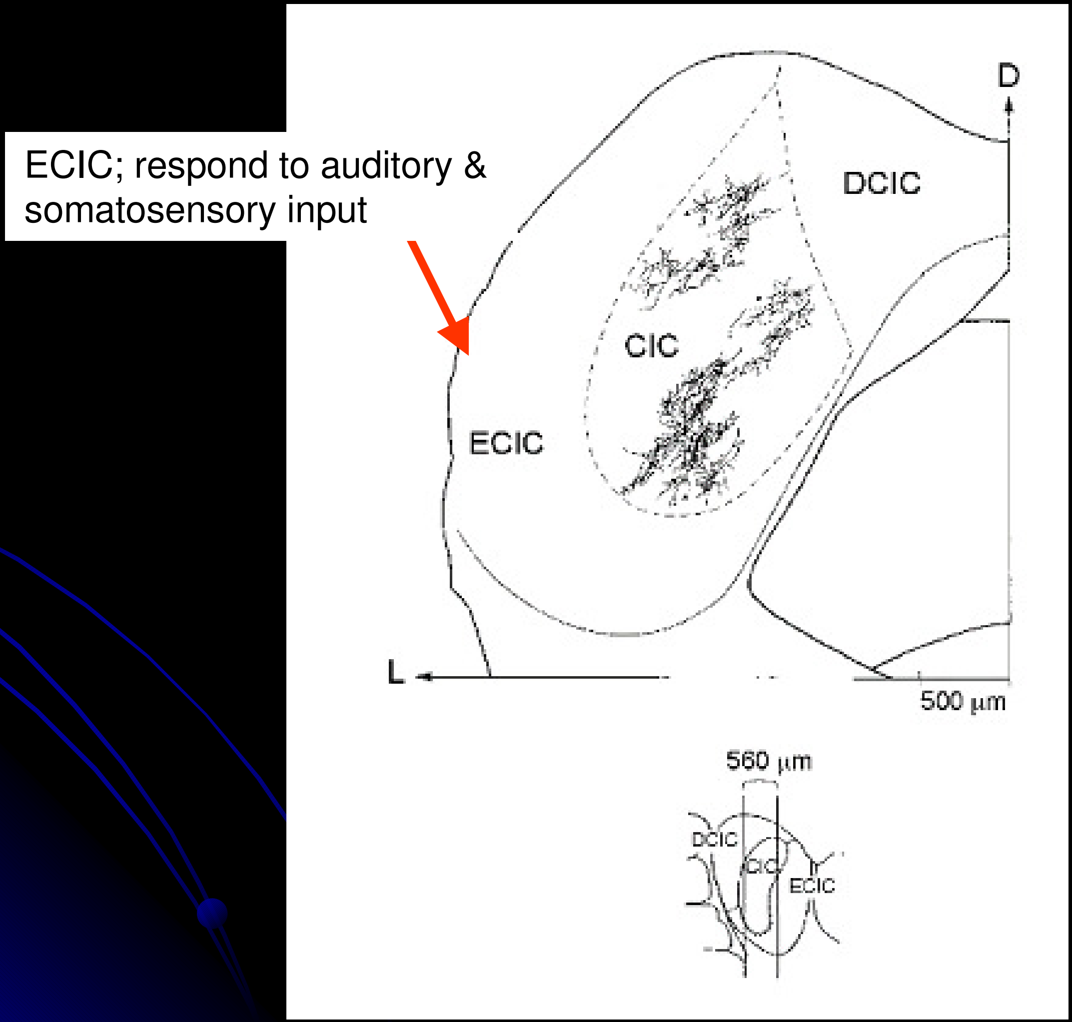


External Cortex of IC→ respond to overall somatosensory input

ECIC → projects to dorsal & medial MGB;

ECIC → receives input from non-lemniscal parts of the auditory system

ECIC → ipsi-MGB, trigeminus, substantia nigra, periventrical nucleus etc

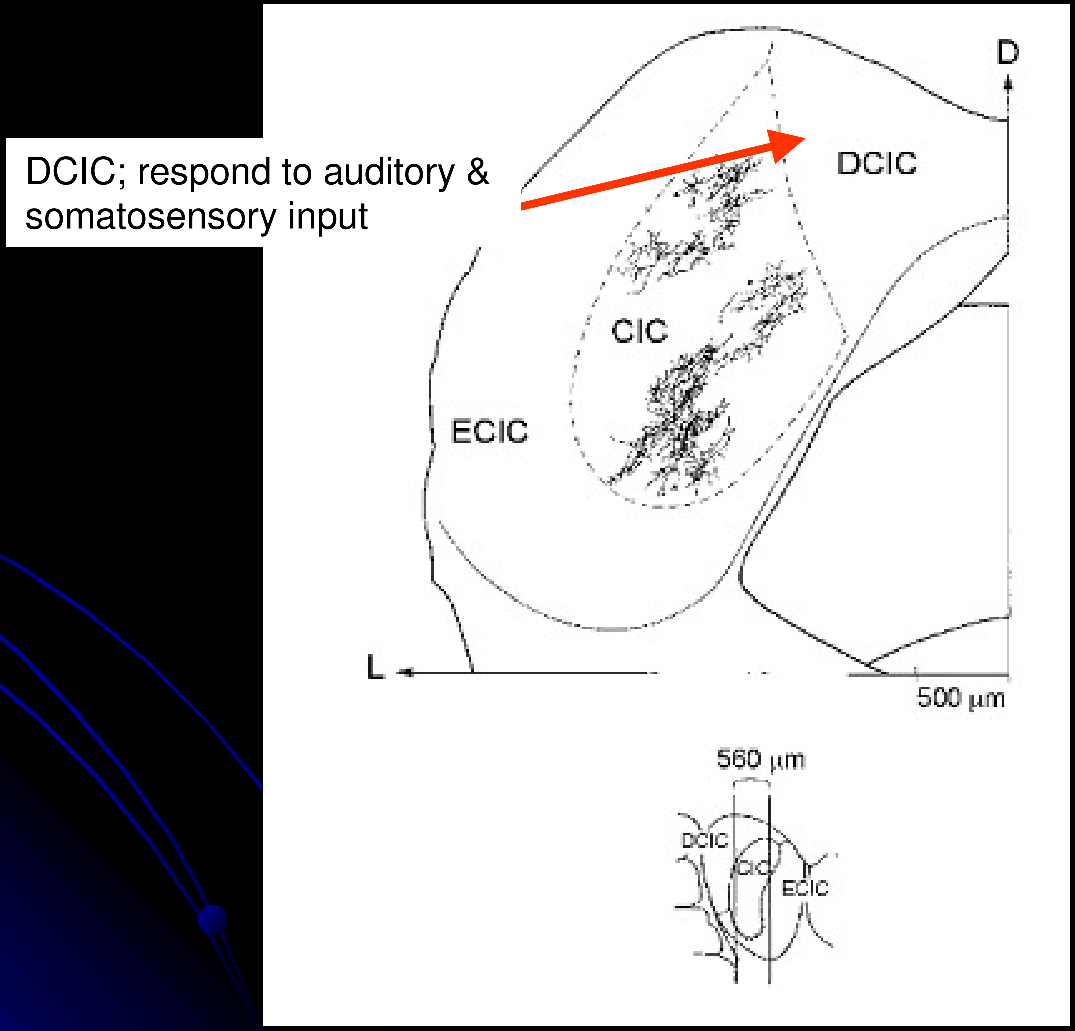


Dorsal Cortex of IC→ respond to overall somatosensory input

DCIC → input to dorsal MGB,

DCIC → receives input from auditory cortex,non-lemniscal auditory parts

Commisural connections→ Glutamate & GABAergic→ dors & med MGB;

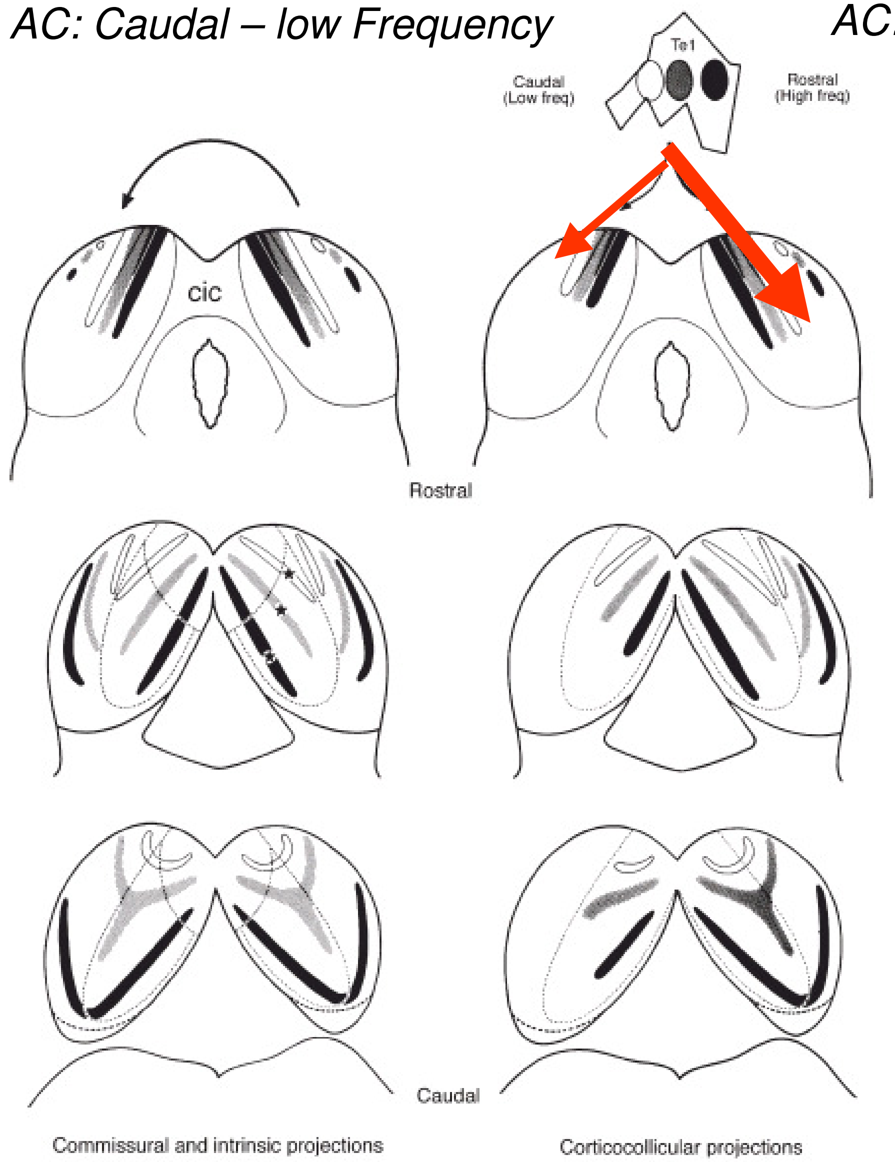


Inferior Colliculus → gets descending information from AC

- Ascending more ventrally; Descending more dorsally

AC: Caudal – low Frequency

AC: Rostral – high Frequency

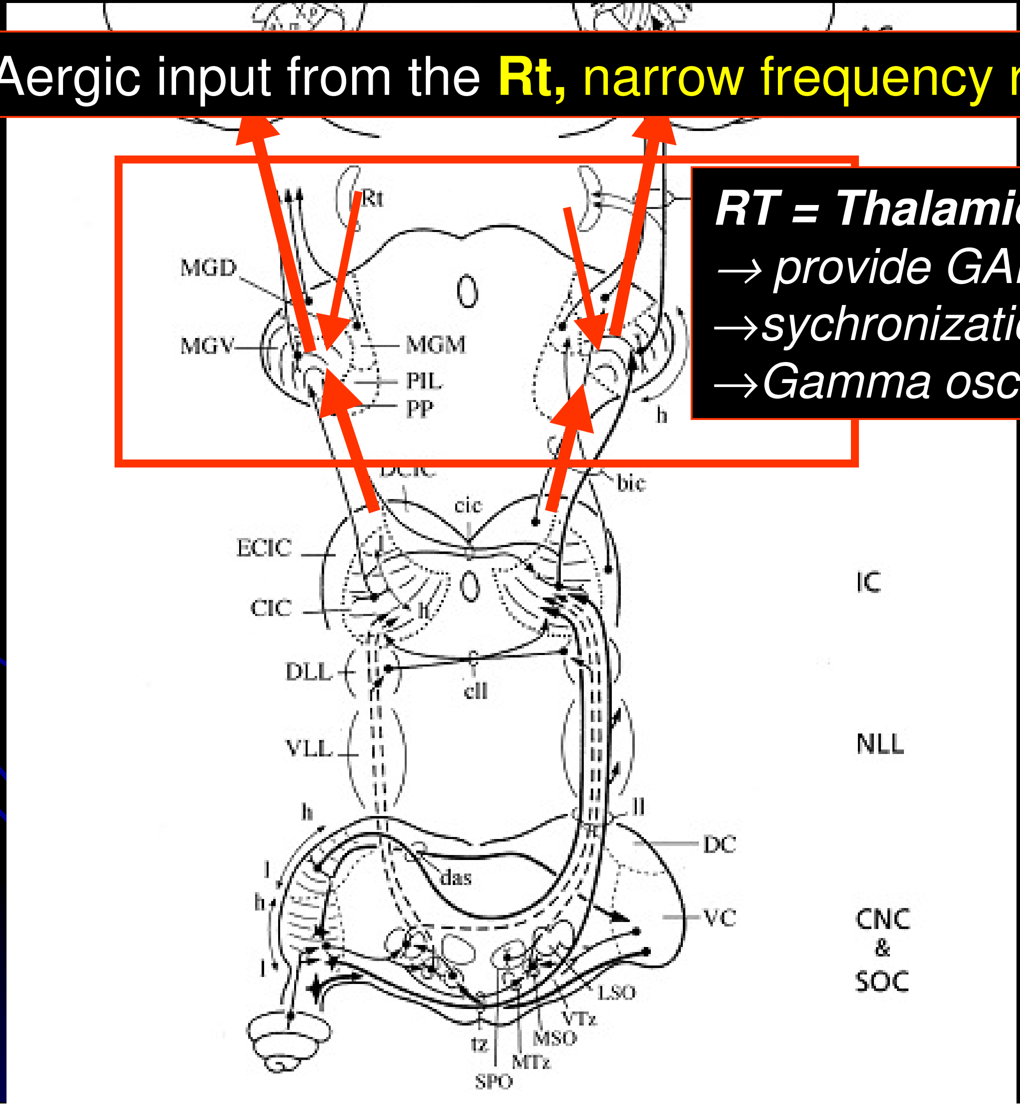


Medial Geniculate Body→ Relay frequency, intensity, binaural Sound

MGV → Ipsilateral IC Input, →NMDA/Glutamat (<1%GABA)

MGV → projects to TE1, primary auditory cortex

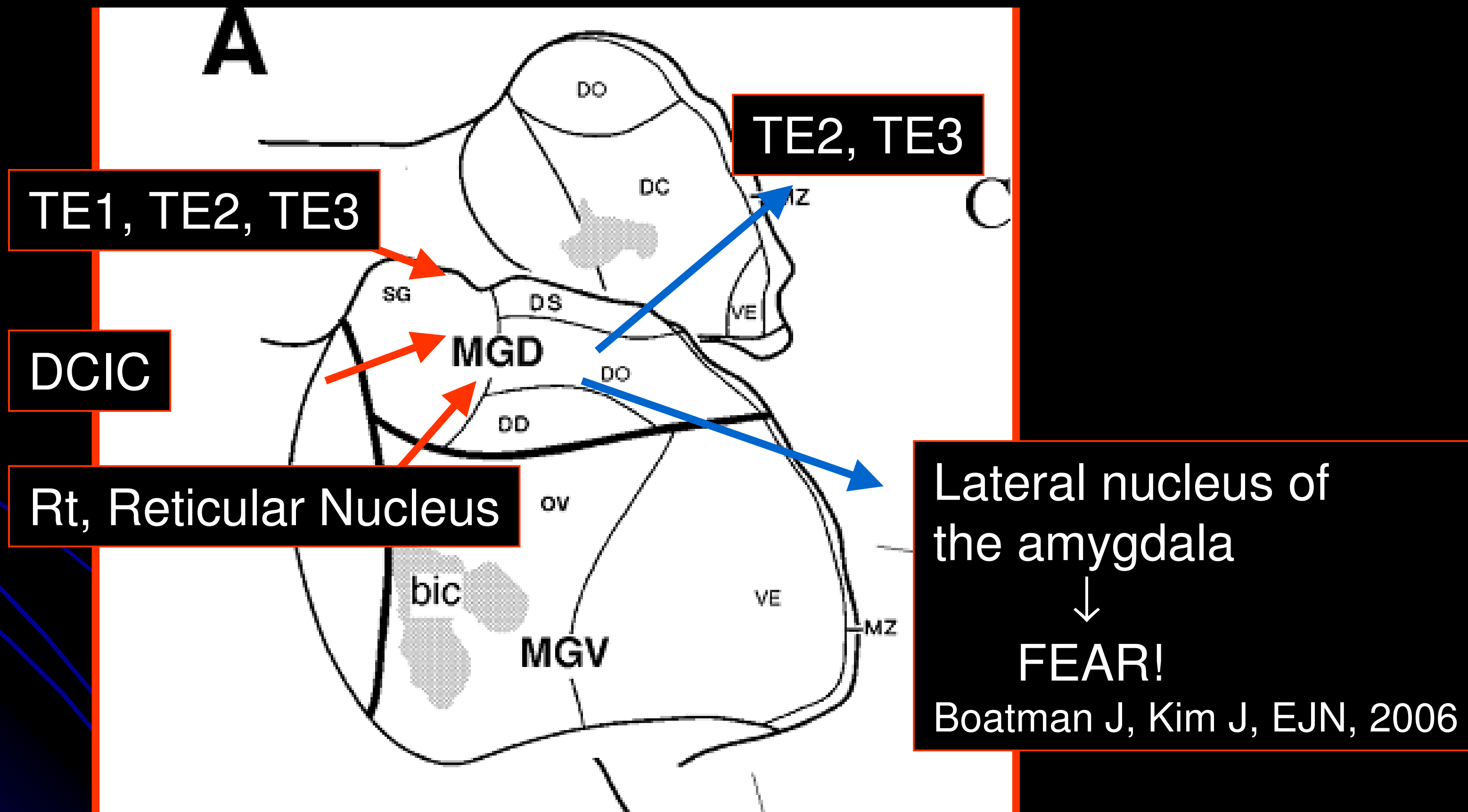
MGV → GABAergic input from the **Rt,** narrow frequency response, cognition?



RT = Thalamic reticular nucleus
→ provide GABAergic input to MG
→sychronization of MG responses
→Gamma oscillations, 40 Hz

Dorsal Part of the MGB→ Auditory processing

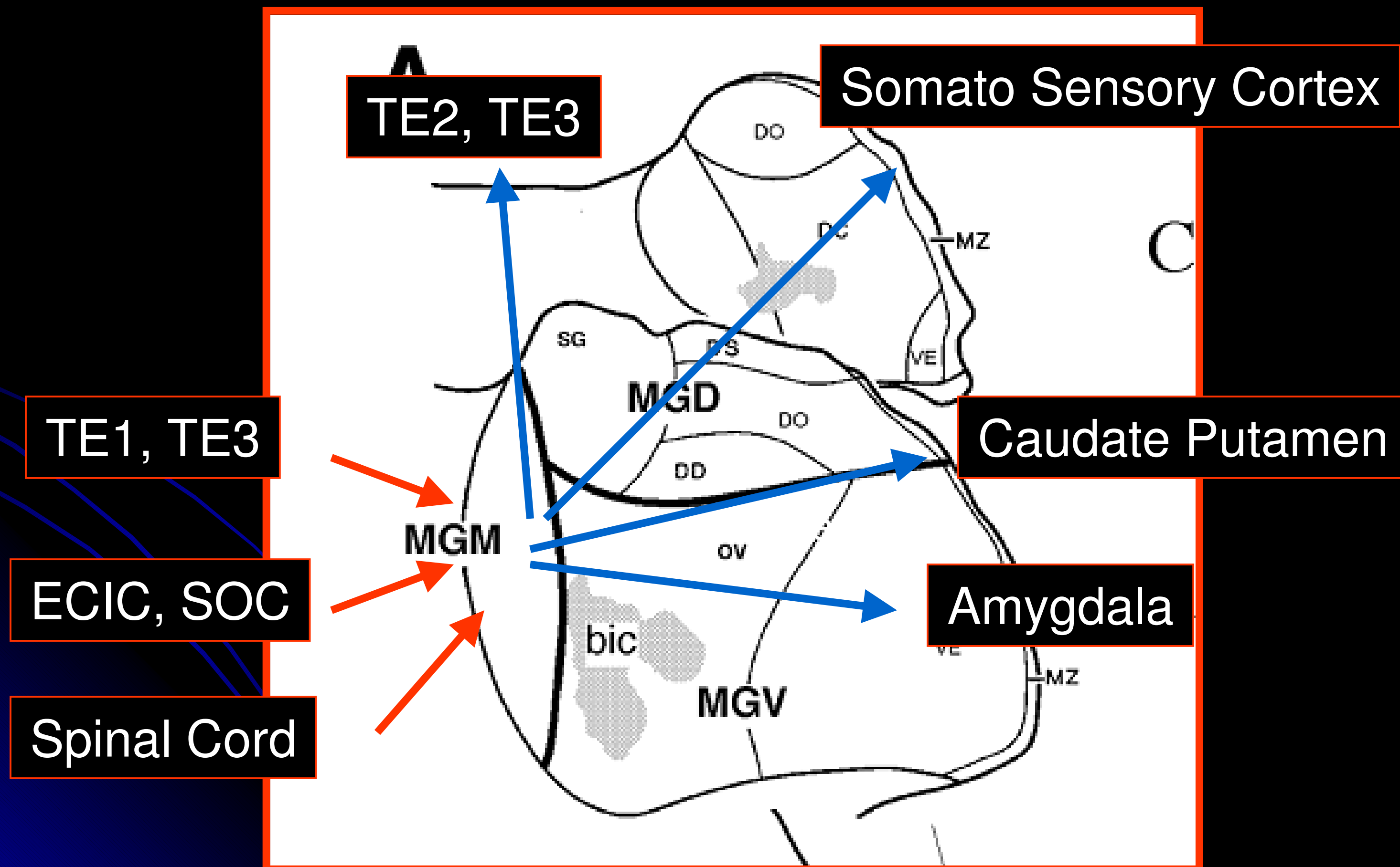
MGD → input (Glut & GABAergi) from ipsi-DCIC (non-lemniscal)
MGD → input (Glut) from TE1, TE2, TE3
MGD → input from Rt
MGD → output to the limbic system,TE2,TE3



Boatman J, Kim J, EJN, 2006

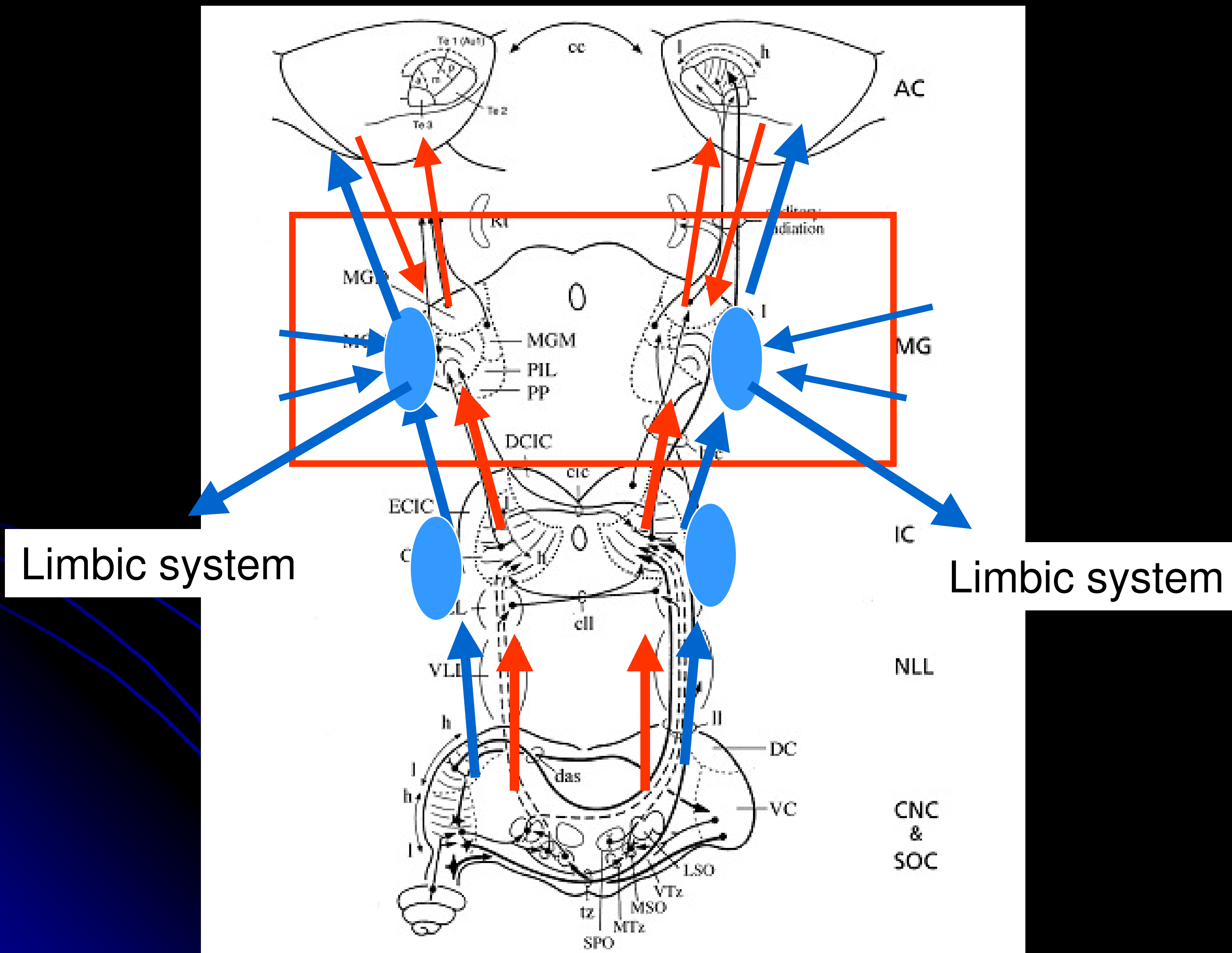
Medial Part of the MGB→ Emotional Learning

MGM → input from TE1,TE3, ECIC, Spinal cord etc
MGM → input GABAergic input from the **Rt** (GABA-A,B)
MGM → output to limbic system

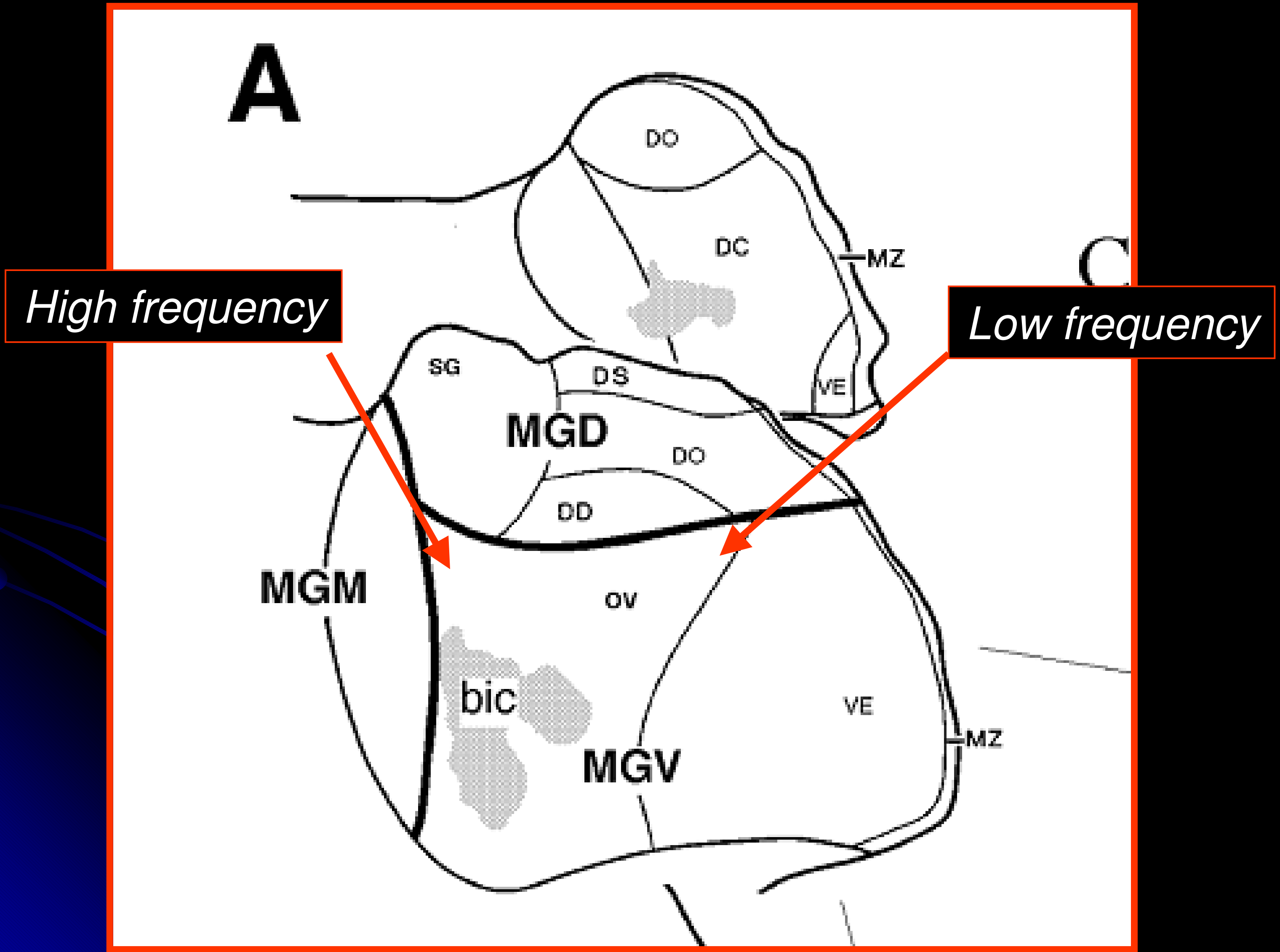


MGV → auditory information → lemniscal parts → TE1

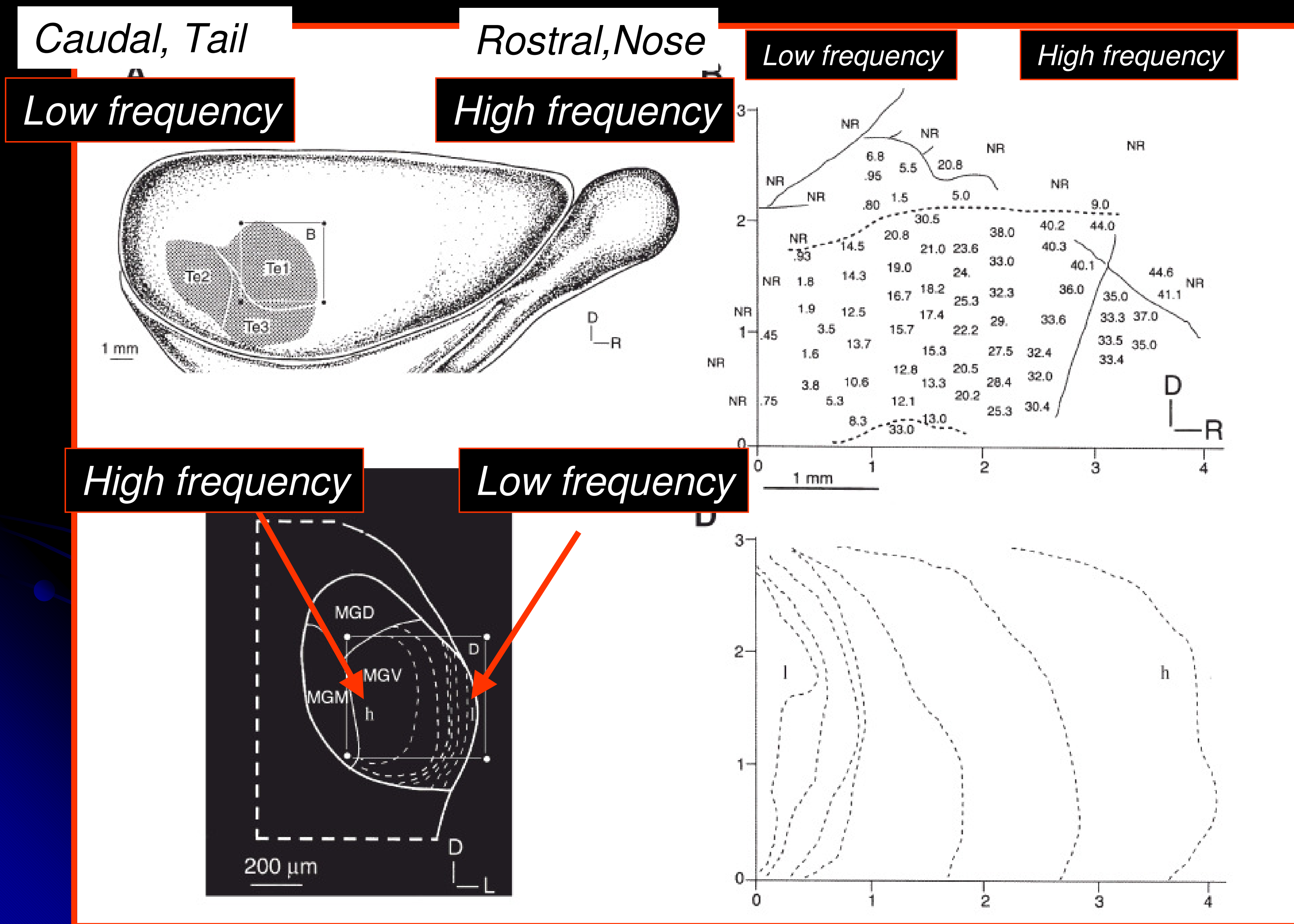
MGD,MGM→somatosensory → non-lemniscal parts → TE2,3+limbic system



MGV→ Auditory processing → tonotopically organized



MGV→ frequency map → primary auditory cortex TE1



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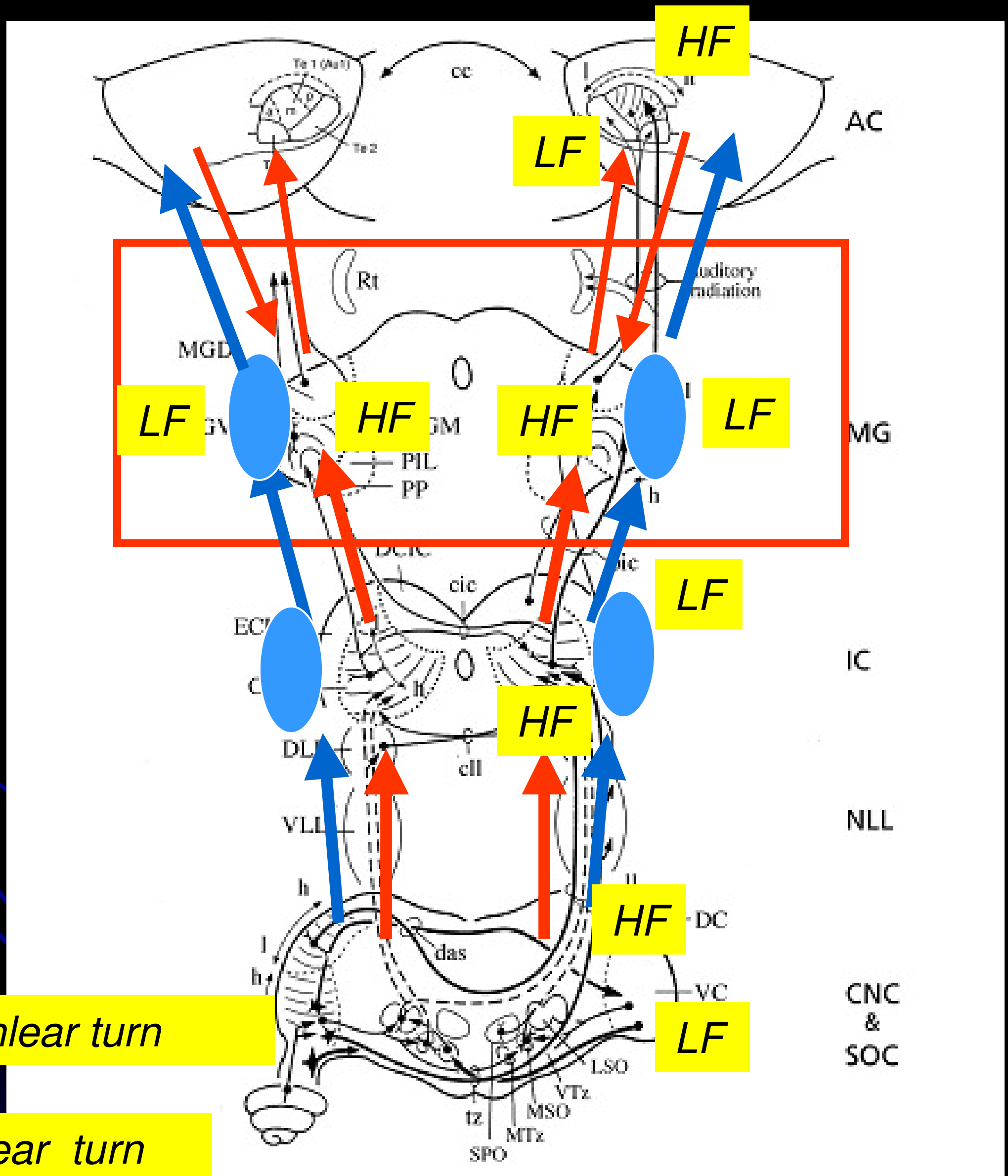
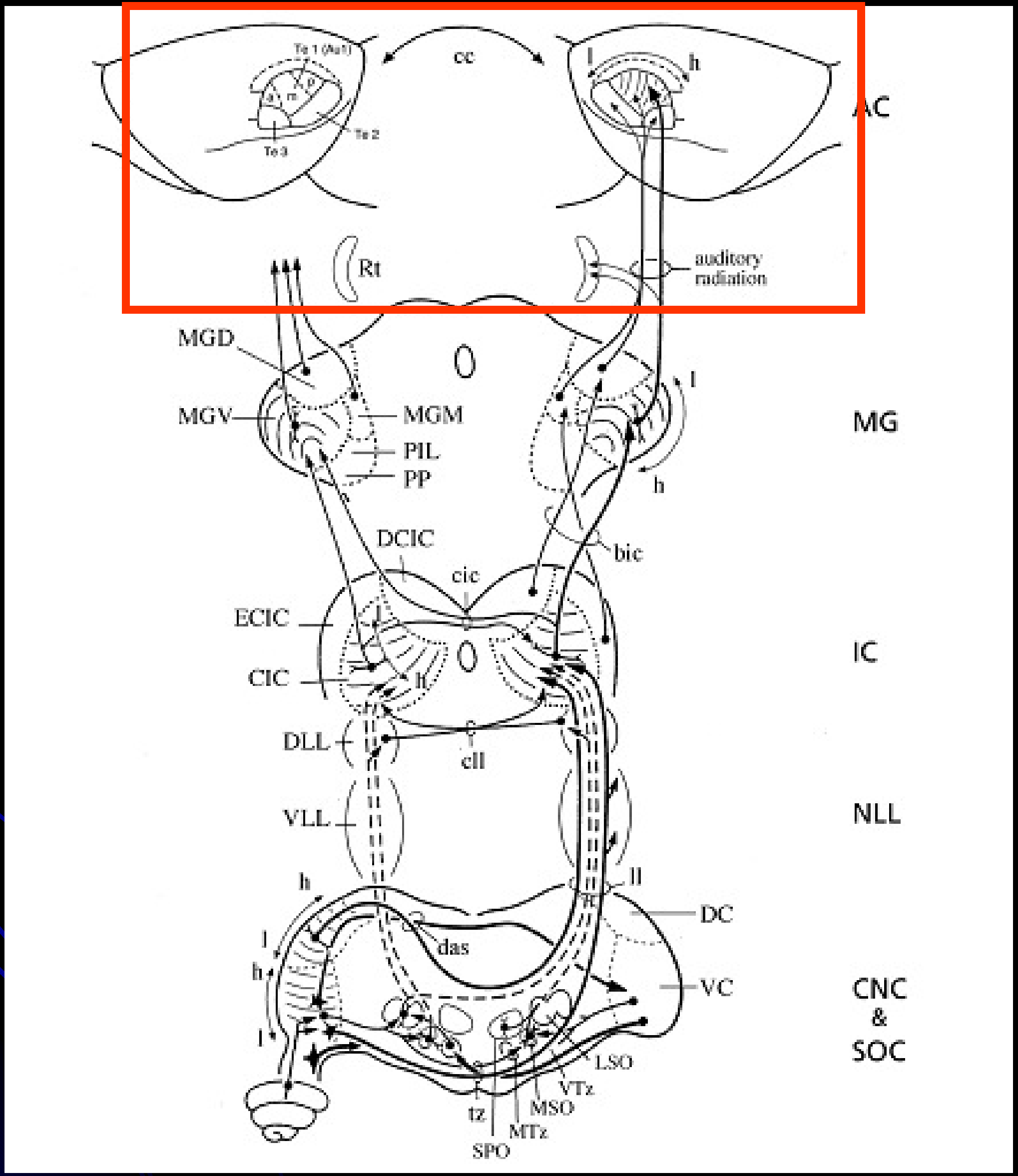
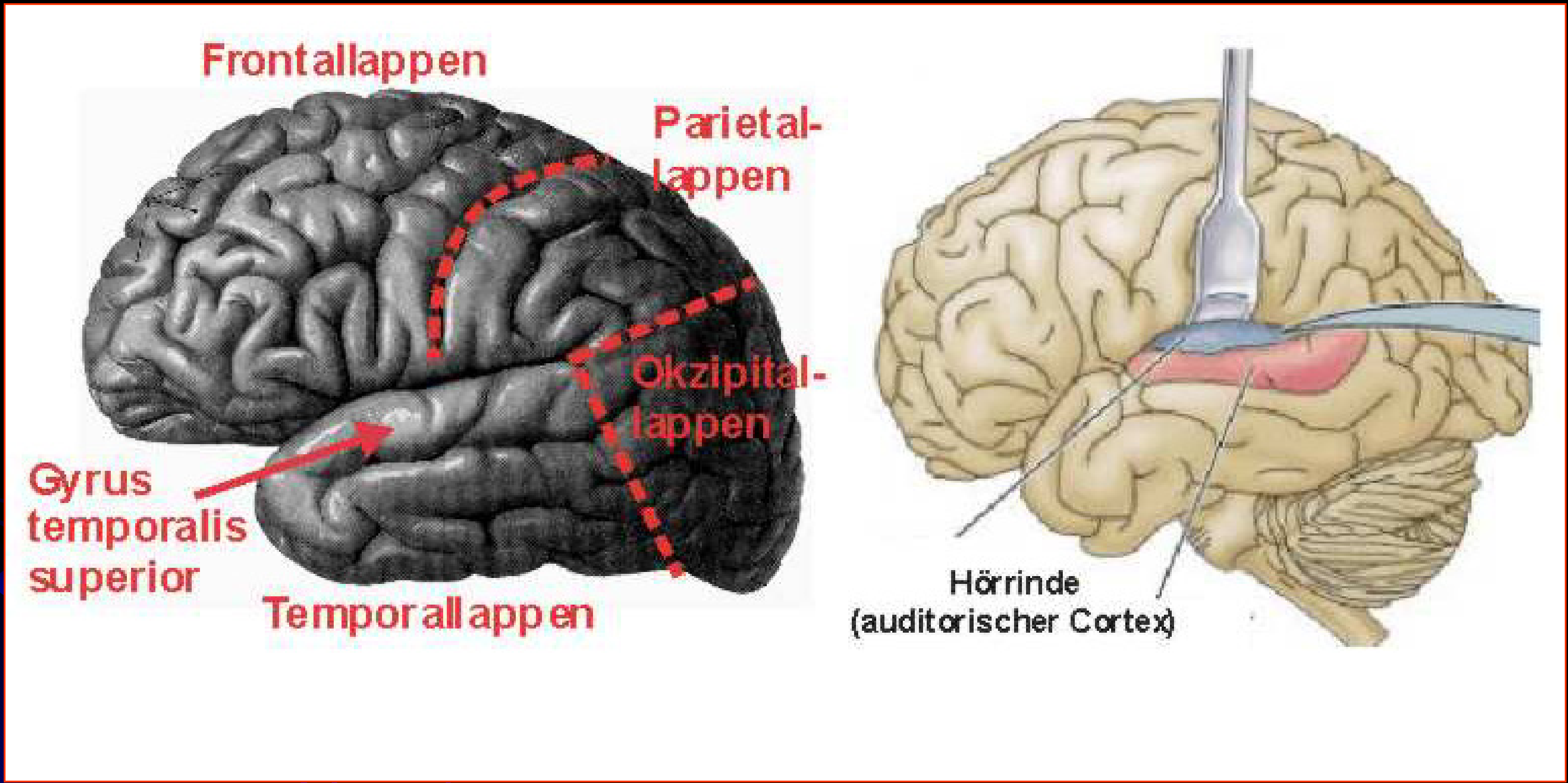


HF, basal cochlear turn

LF, apical cochlear turn

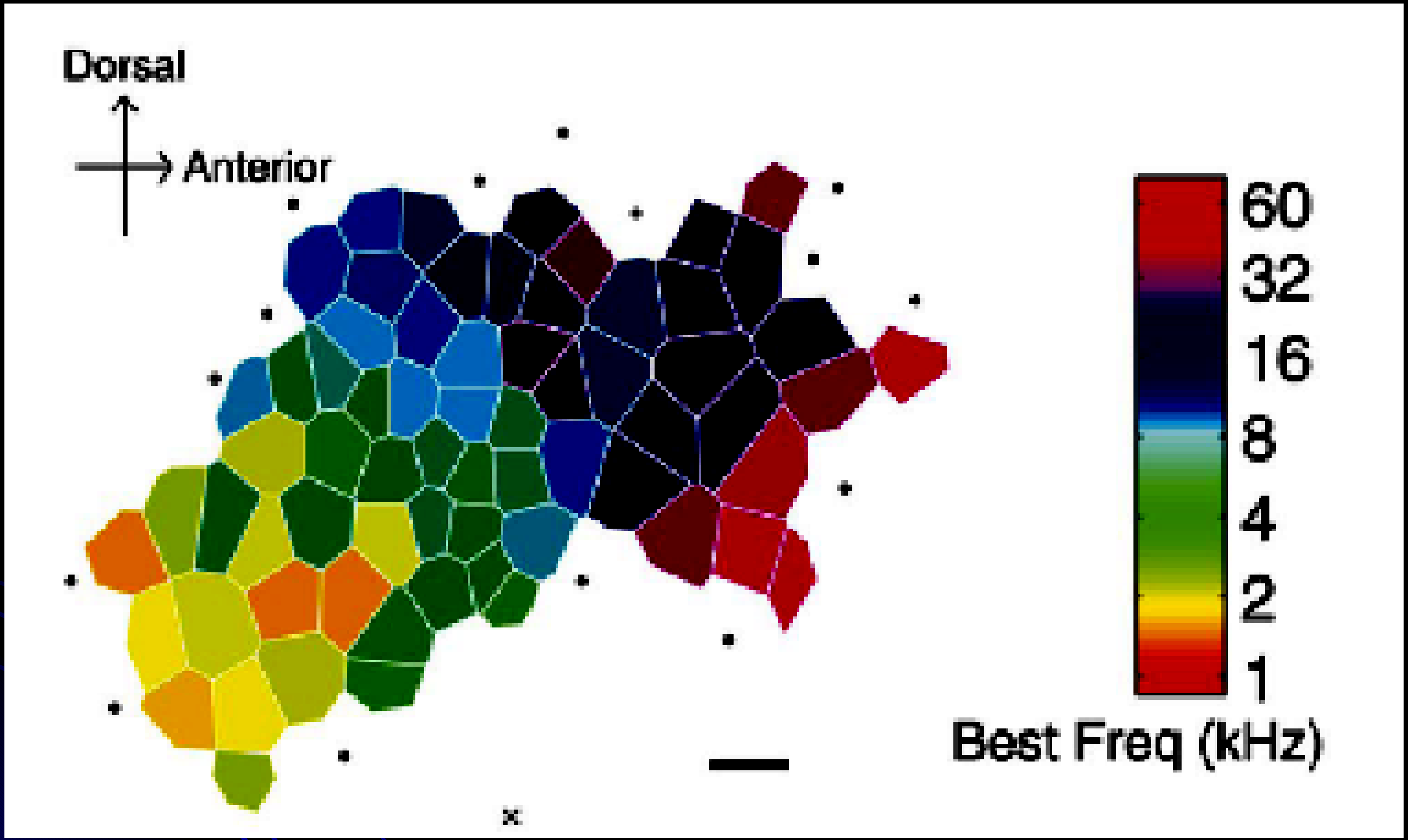
Auditory Cortex → Auditory Perception





Frontallappen
Parietal-
lappen
Okzipital-
lappen
Gyrus
temporalis
superior
Temporallappen
Hörrinde
(auditorischer Cortex)

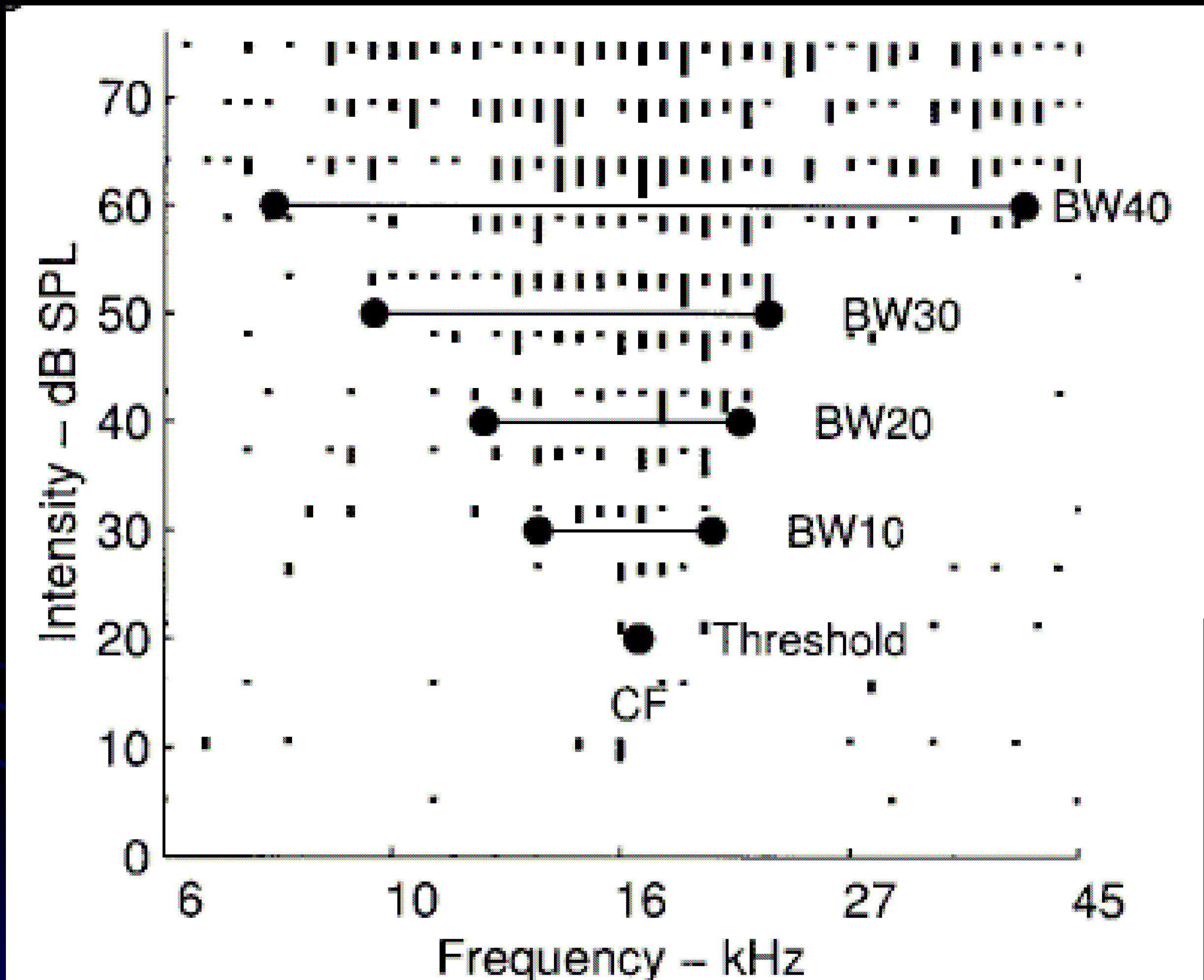
Tonotopic map of the primary auditory cortex TE1



Representative CF map of the primary auditory cortex (A1) of the rat;
Microelectrode recording from cortex depth of ~ 550 µm (layers IV/V)

Kilgard et al., 2001

Primary auditory cortex (A1) → tuning curve



Length;
Number of spikes evoked by a tone

CF:
Frequency that elicits a Constant neural response at the lowest intensity threshold

Bandwidth (BW):
Range of frequencies the Neurons are responsive to at the specified Intensity above Threshold, expressed in octaves

Kilgard et al., 2001

Primary auditory cortex (A1) → Neuronal cell types

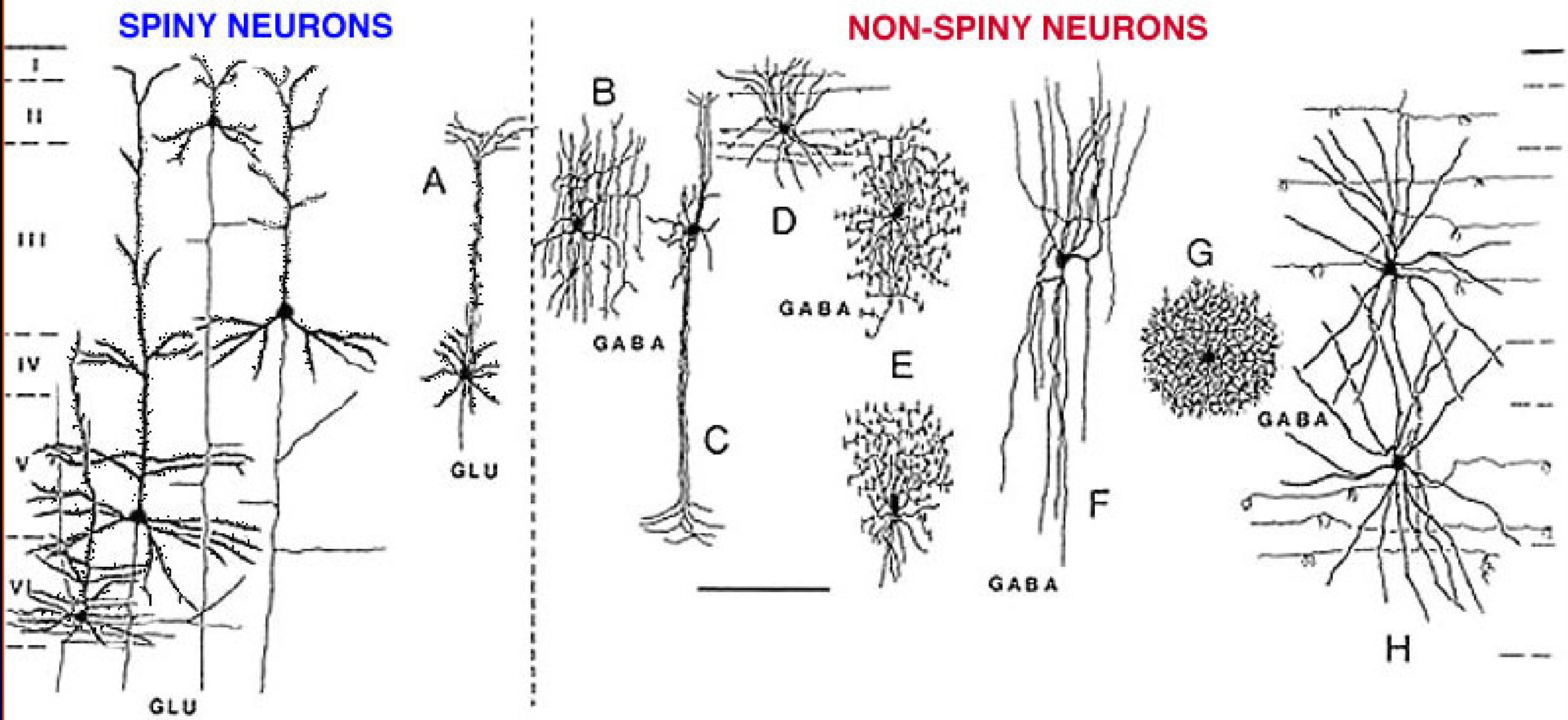
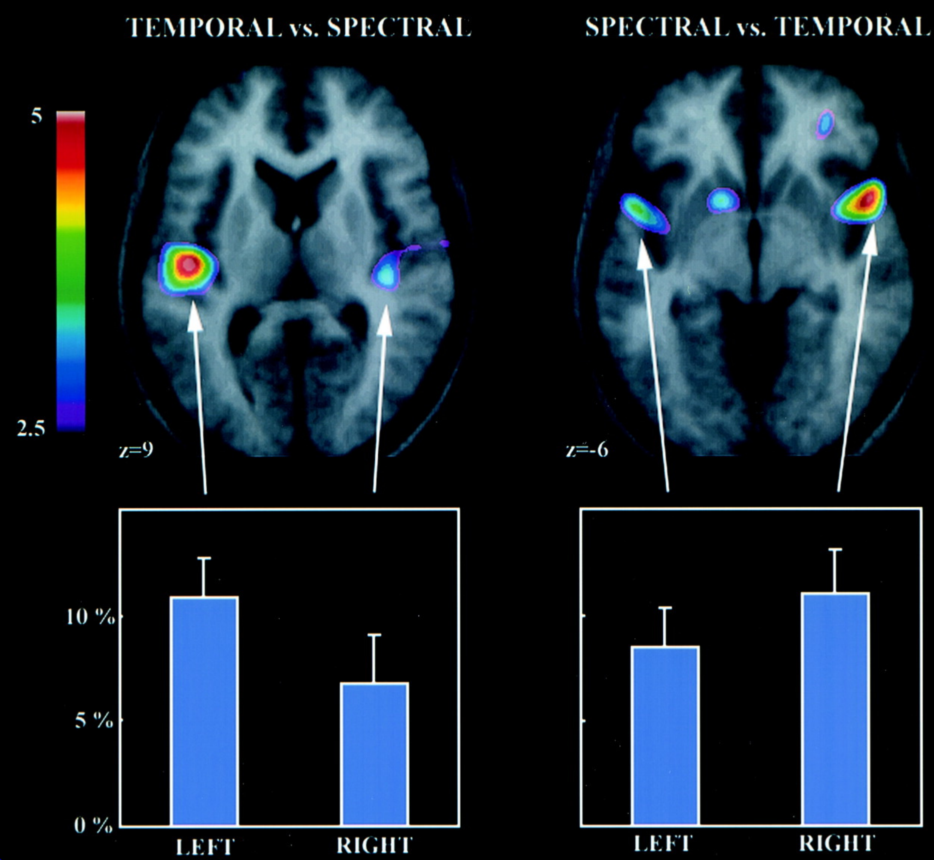


Figure 12. Basic cell types in the monkey cerebral cortex. Left: spiny neurons that include pyramidal cells and stellate cells (A). Spiny neurons utilize the neurotransmitter glutamate (Glu). Right: smooth cells that use the neurotransmitter GABA. B, cell with local axon arcades; C, double bouquet cell; D, H, basket cells; E, chandelier cells; F, bitufted, usually peptide-containing cell; G, neurogliaform cell.

Representation of temporal (left), spectral (right) information

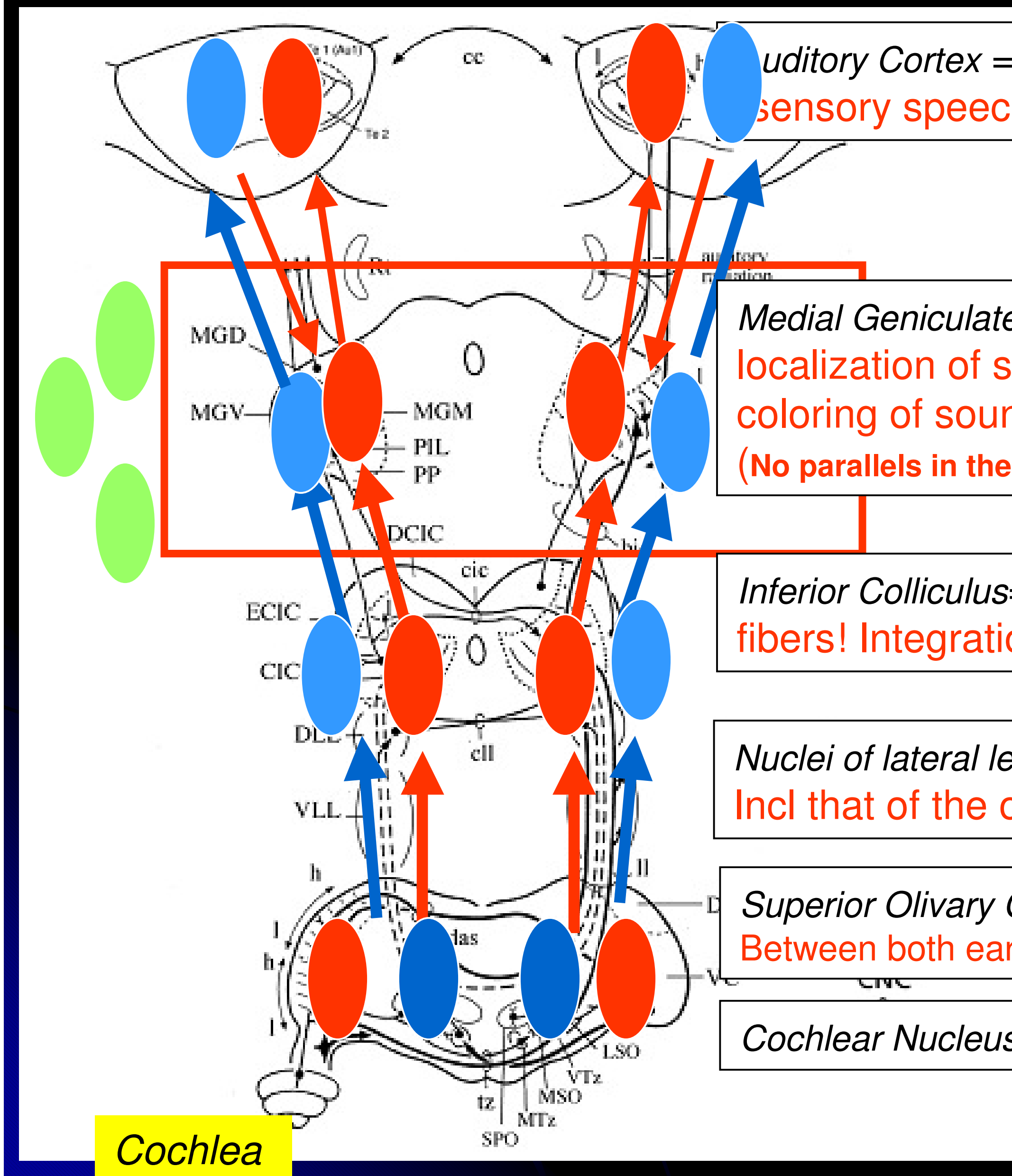


Left: higher myelinized → wide-spread columms → predominant role in complex speech encoding → better information speed

Right: Tighter columms → less myelinated → denser spectral information → musical perception

Human Cortex: Zatorre & Berlin 2001

Summary:



uditory Cortex = sound perception, connected to Wernicke sensory speech) and Broca (motoric speech centrum)

Medial Geniculate Body = sensory `relay` centre, spatial localization of sound by binaural processing, emotional coloring of sound impression (**No parallels in the visuell or somatosensoric system!!**)

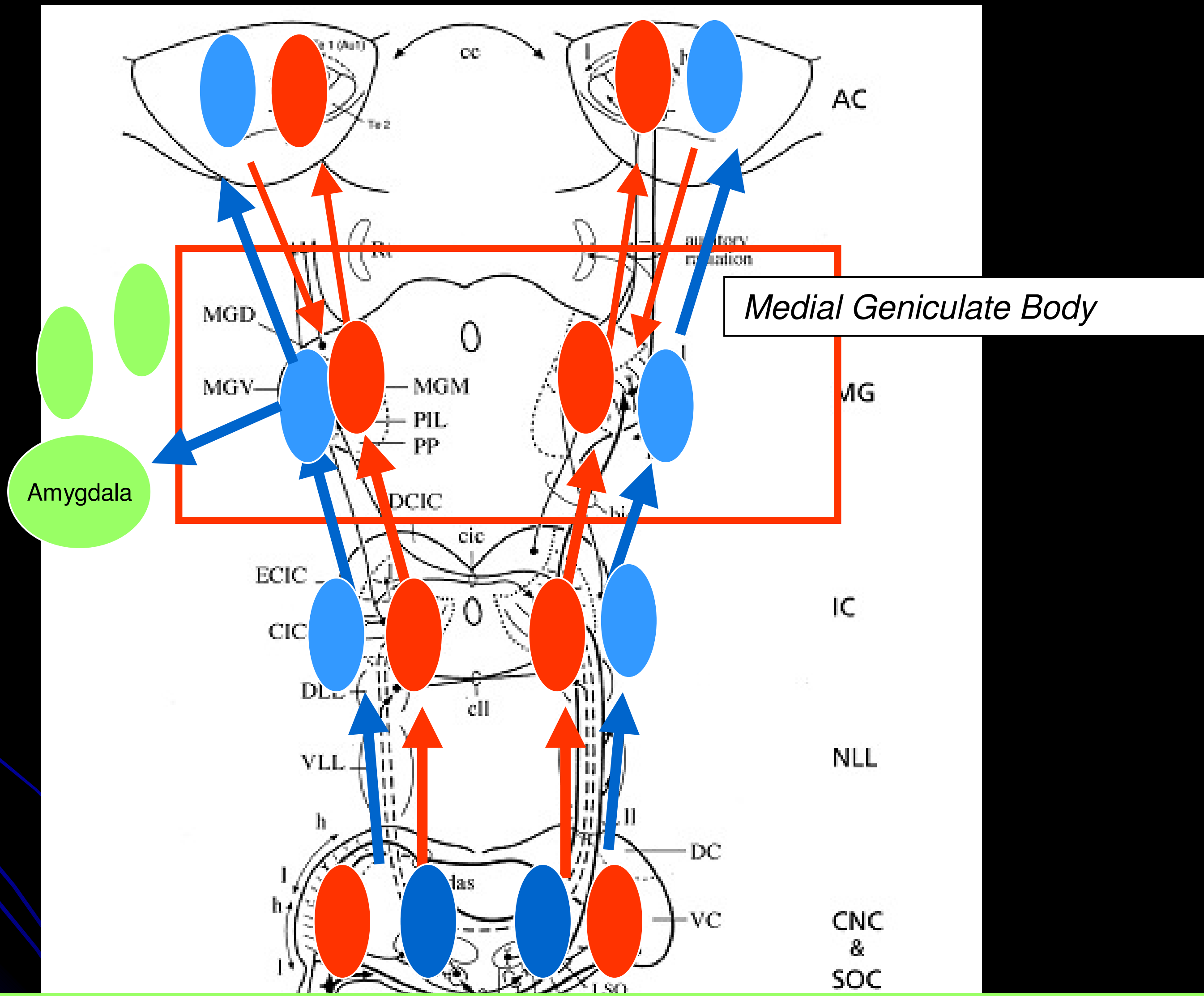
Inferior Colliculus= Relay center for most ascending auditory fibers! Integration of sound location; level detection, tuning

Nuclei of lateral lemniscus = transports ascending information Incl that of the other Side to the inferior colliculus

Superior Olivary Complex = Calculation of time differences Between both ears, information sound direction

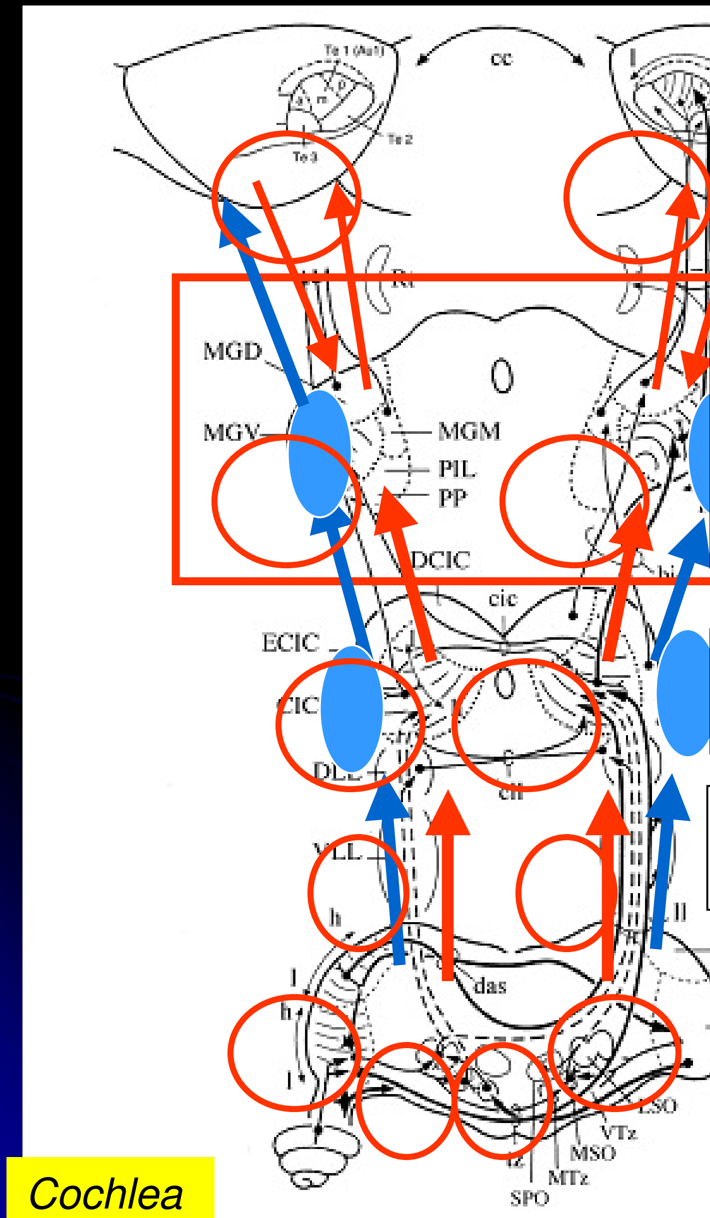
Cochlear Nucleus Complex = *connection to the other side*

Summary:



Increased amygdala activation to emotional auditory stimuli in the blind Corinna Klinge[1], Brigitte Röder[2] and Christian Büchel[1] , BRAIN 2010

Summary:



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