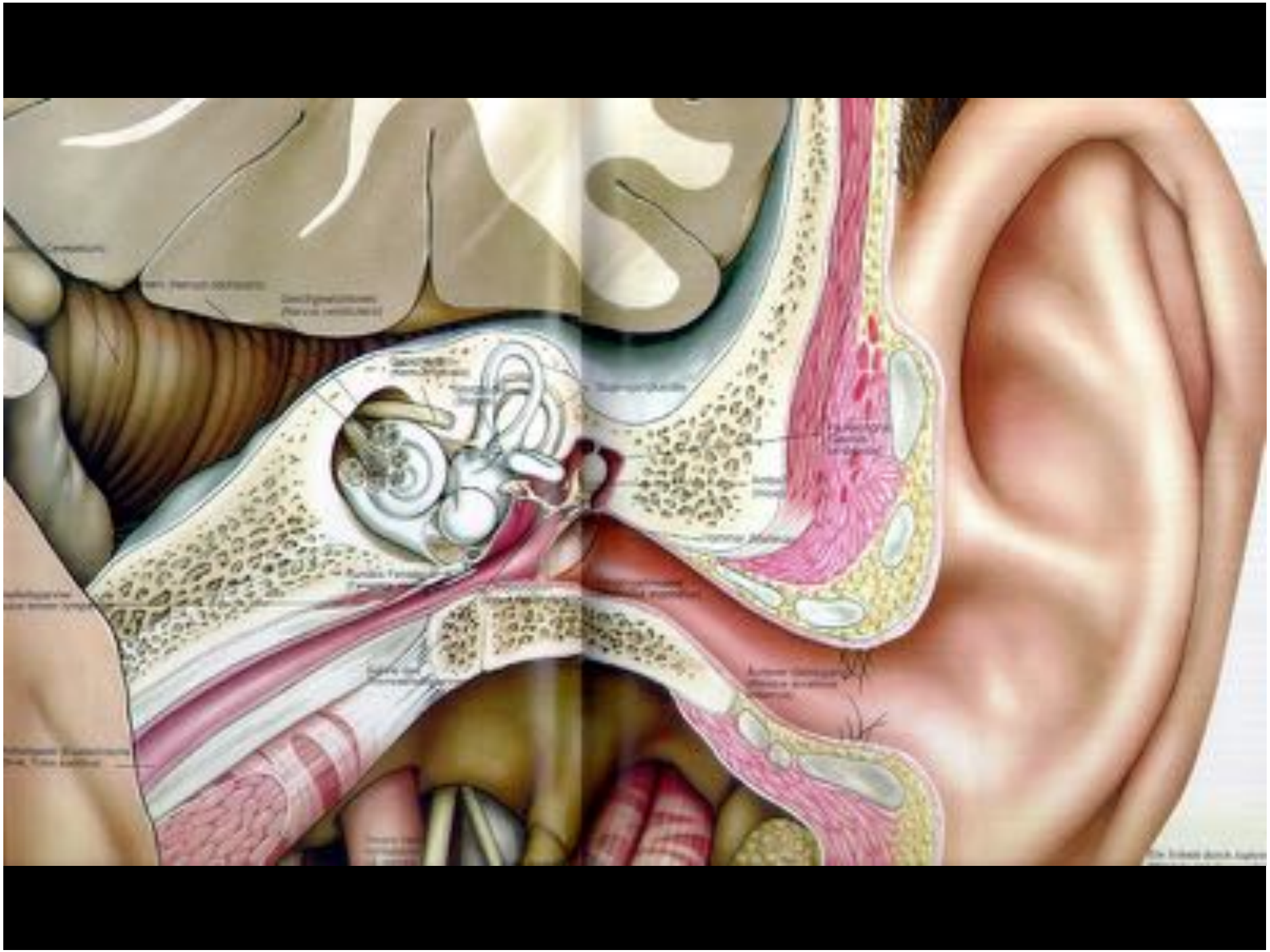
Universität Leipzig

Fakultät für Biowissenschaften, Pharmazie und Psychologie

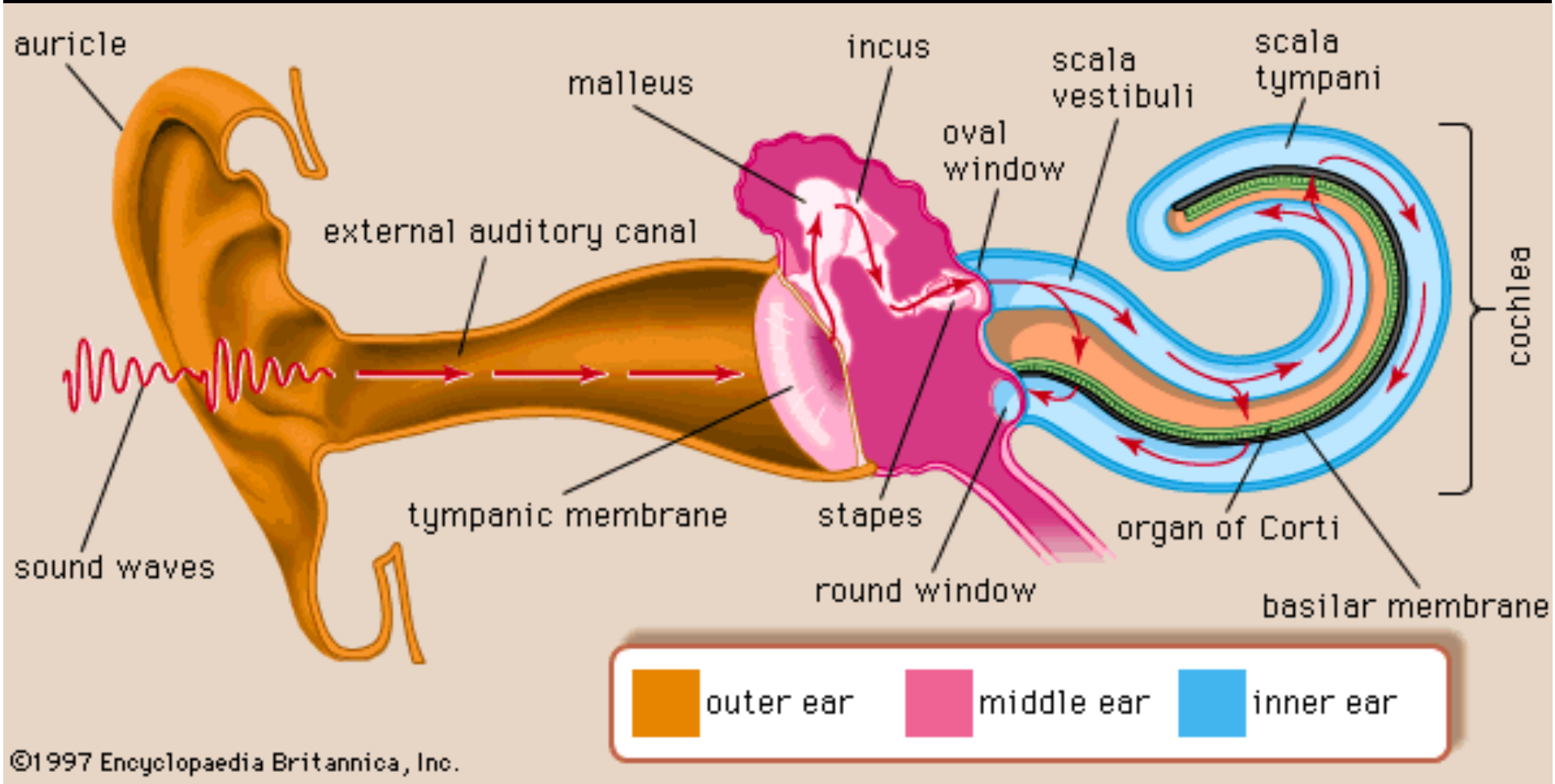
IMPRS NeuroCom

Marc Schönwiesner

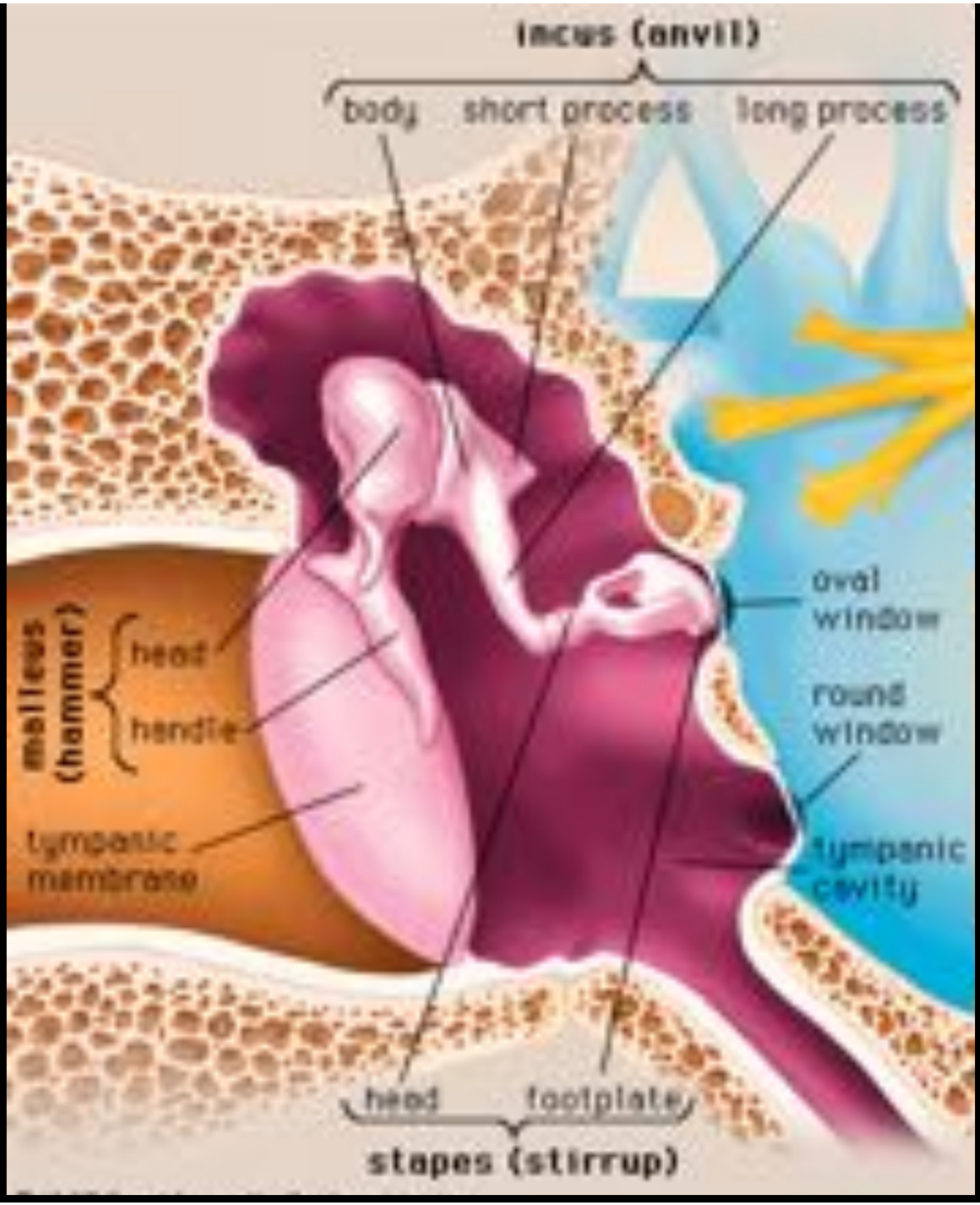
Auditory and vestibular system

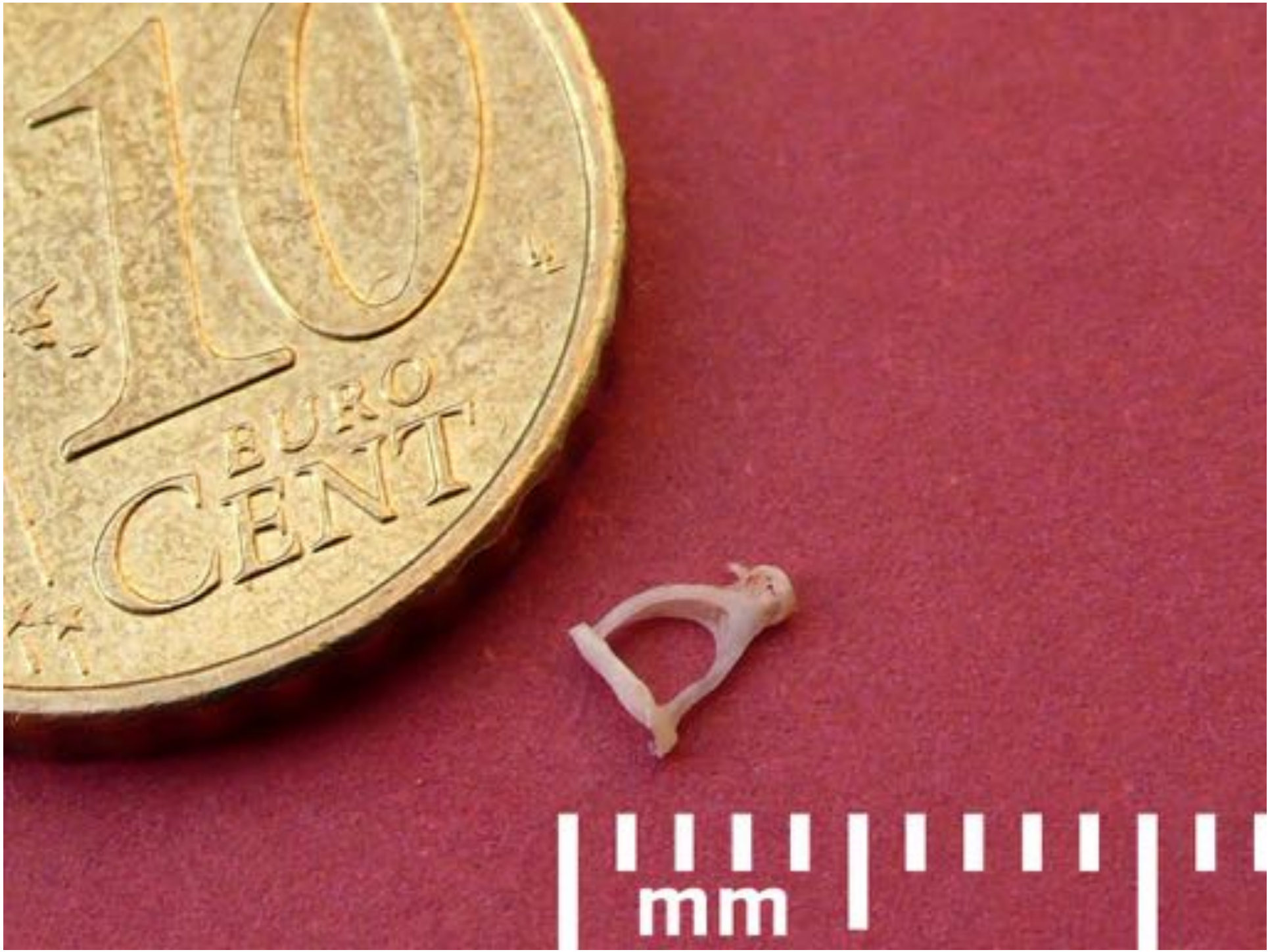



Michael Hawke MD / CC-BY-SA-4.0


auricle
malleus
incus
scala vestibuli
scala tympani
oval window
external auditory canal
cochlea
sound waves
tympanic membrane
stapes
round window
organ of Corti
basilar membrane
outer ear
middle ear
inner ear
©1997 Encyclopaedia Britannica, Inc.

The middle ear




10
EURO
CENT
mm

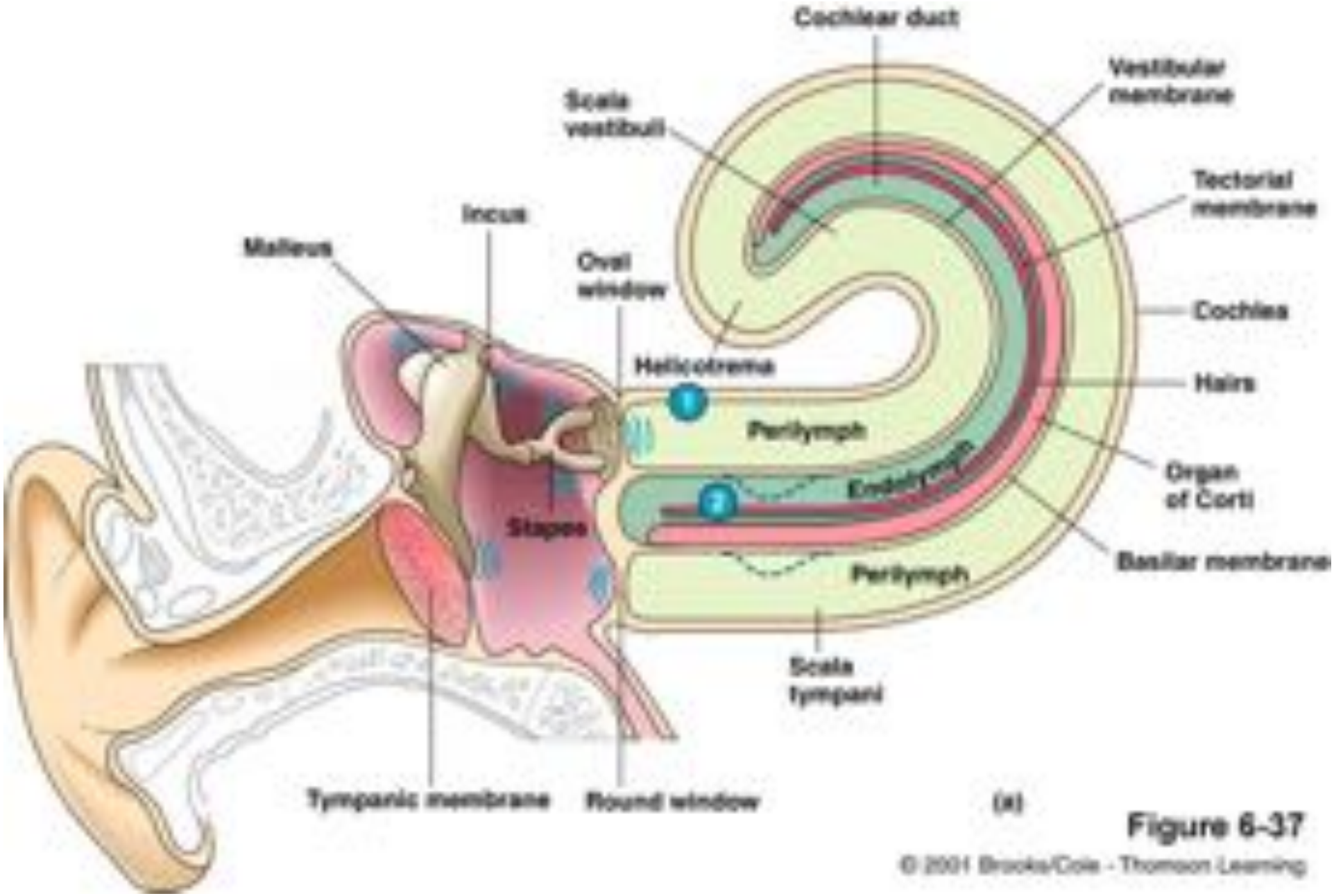
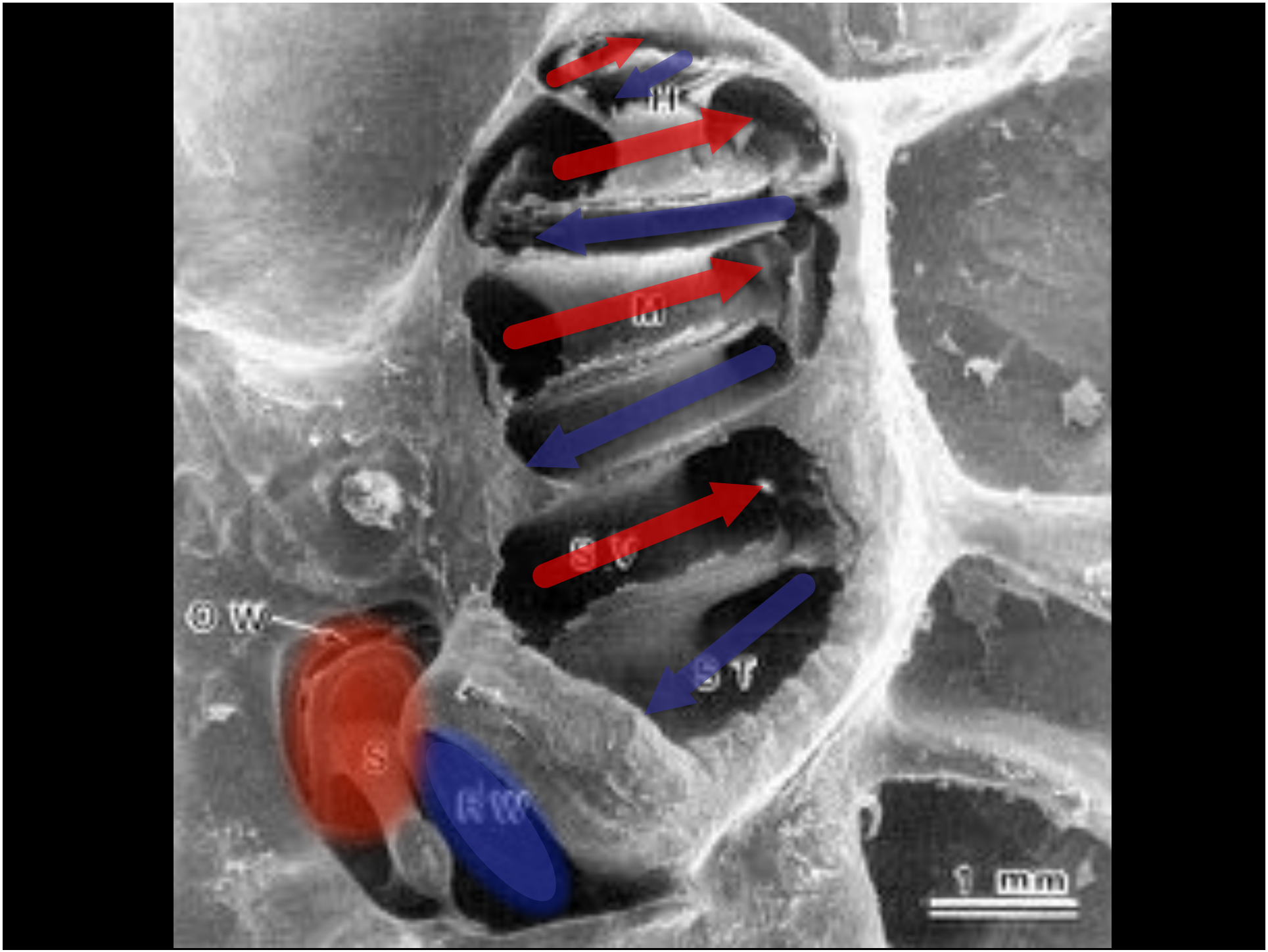
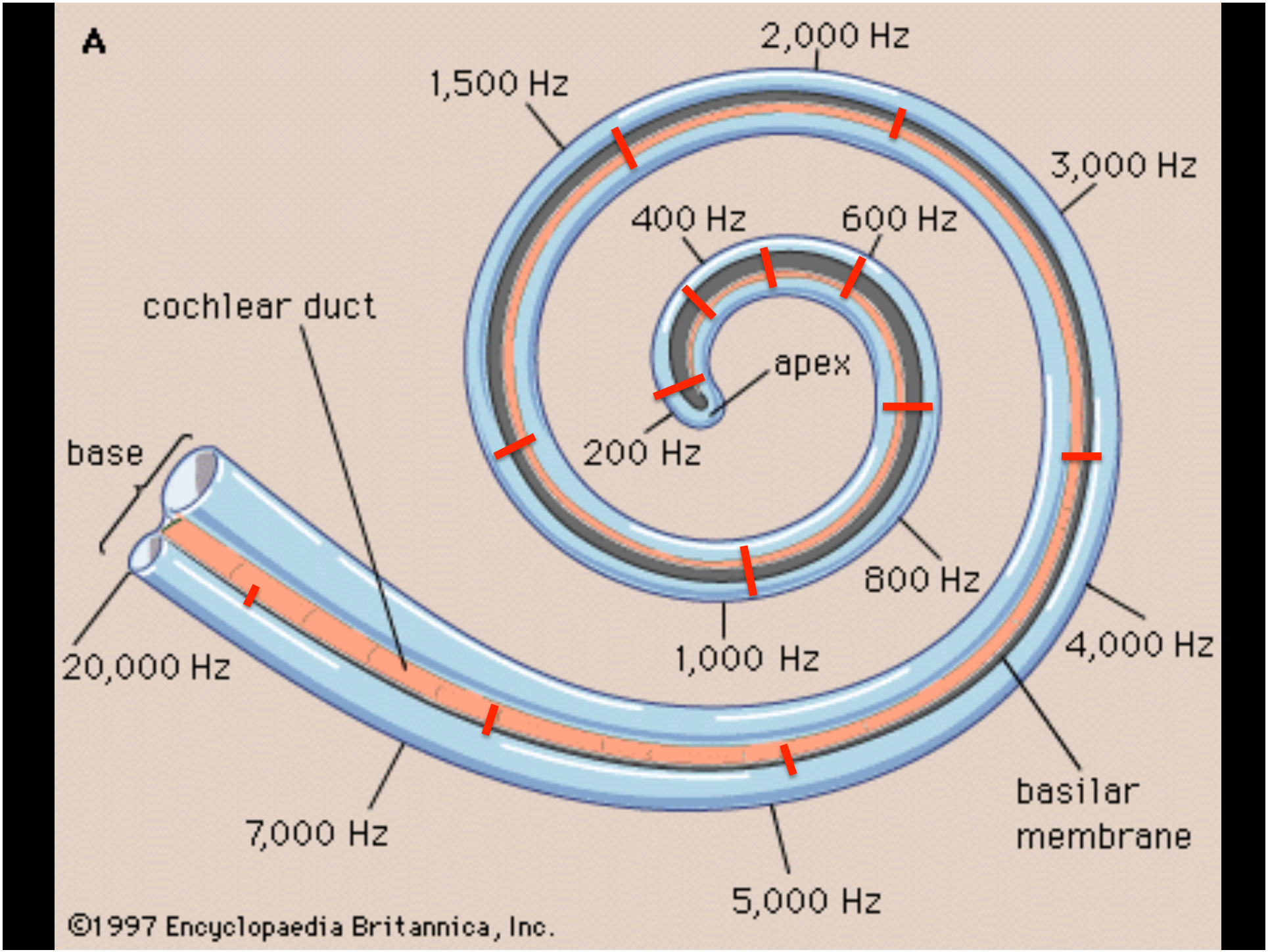


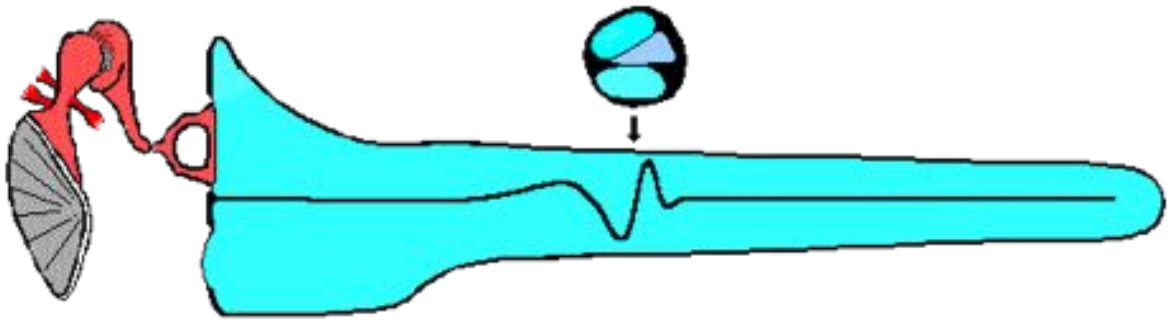
Figure 6-37


Wellcome Images


1 mm

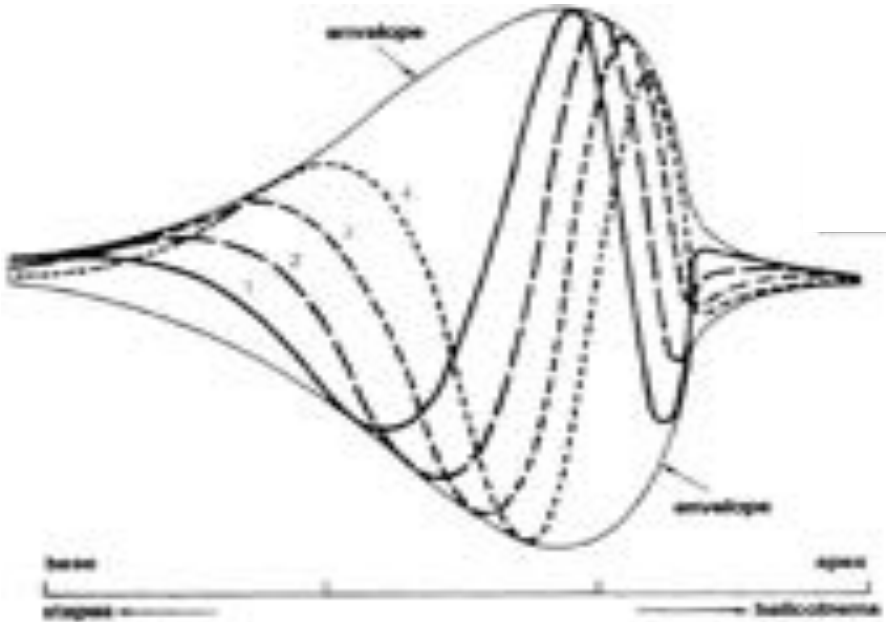

A
2,000 Hz
1,500 Hz
3,000 Hz
400 Hz
600 Hz
cochlear duct
apex
200 Hz
base
800 Hz
20,000 Hz
1,000 Hz
4,000 Hz
basilar membrane
7,000 Hz
5,000 Hz
©1997 Encyclopaedia Britannica, Inc.

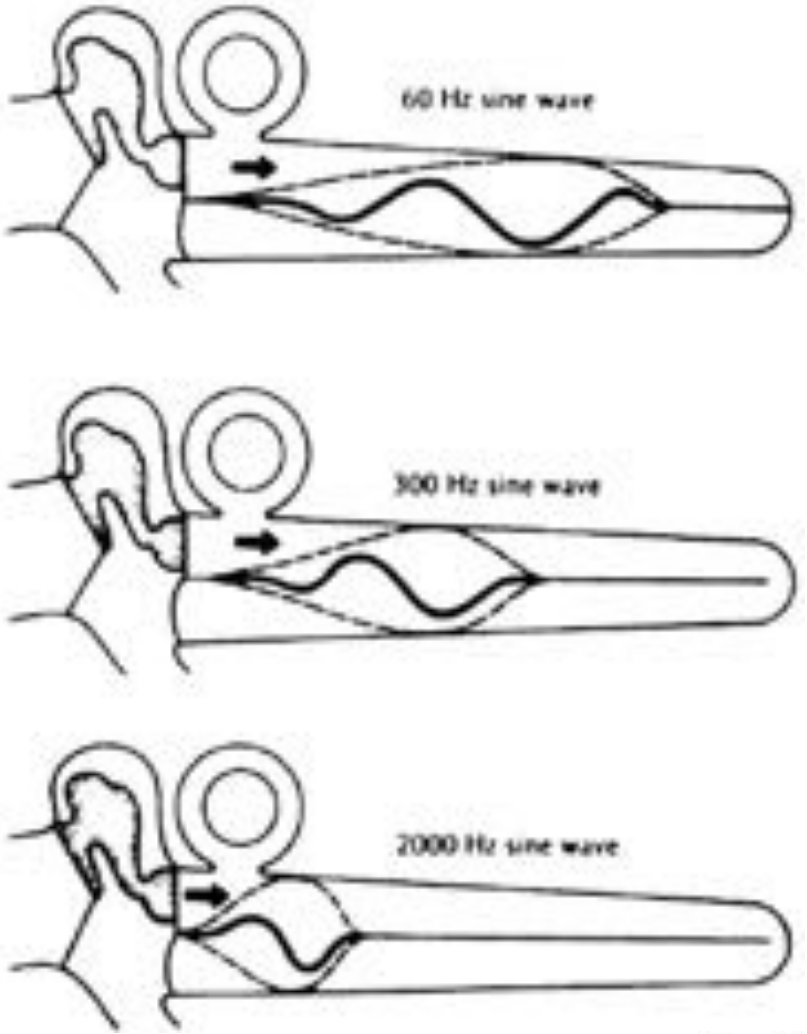
Bekesy's fluid model



The traveling wave

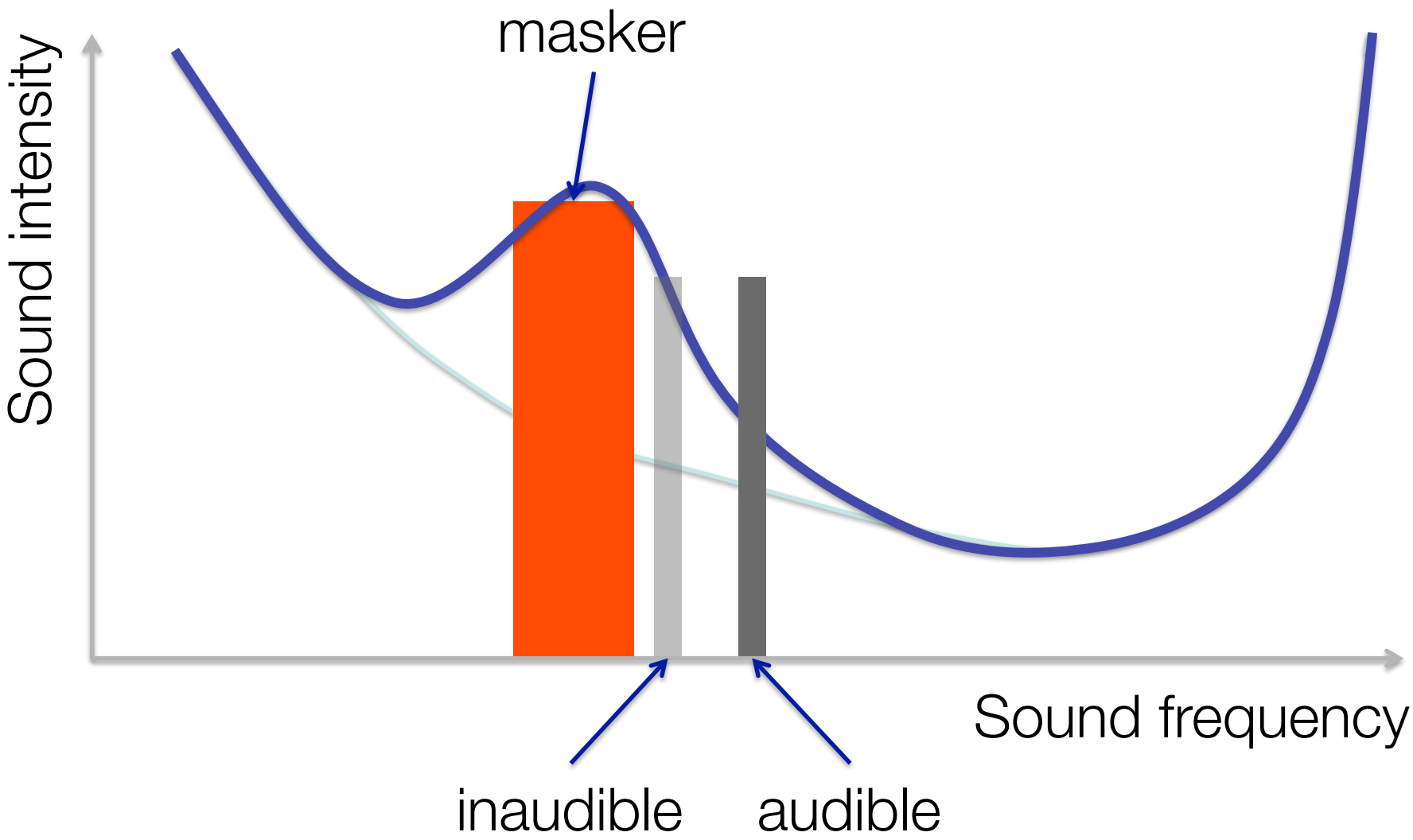
Problem: traveling waves have very broad peaks – frequency discrimination can not be based on the location of the peak vibration!





from Yost, 2000

Masking


masker
Sound intensity
Sound frequency
inaudible
audible

Masking and mp3 encoding

Idea: signals that are inaudible because of masking can be removed from the file to save space.

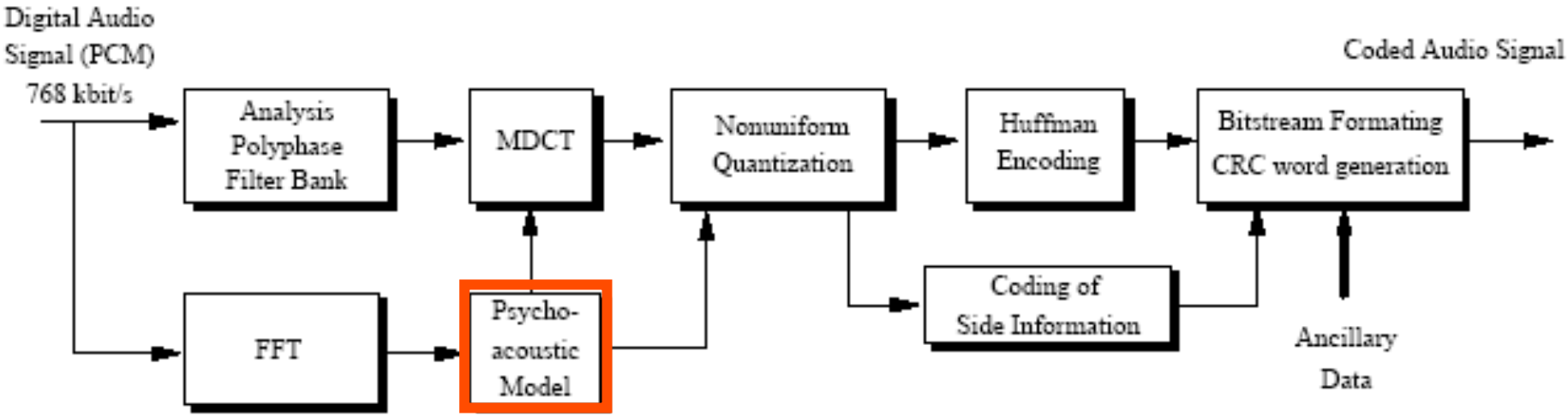
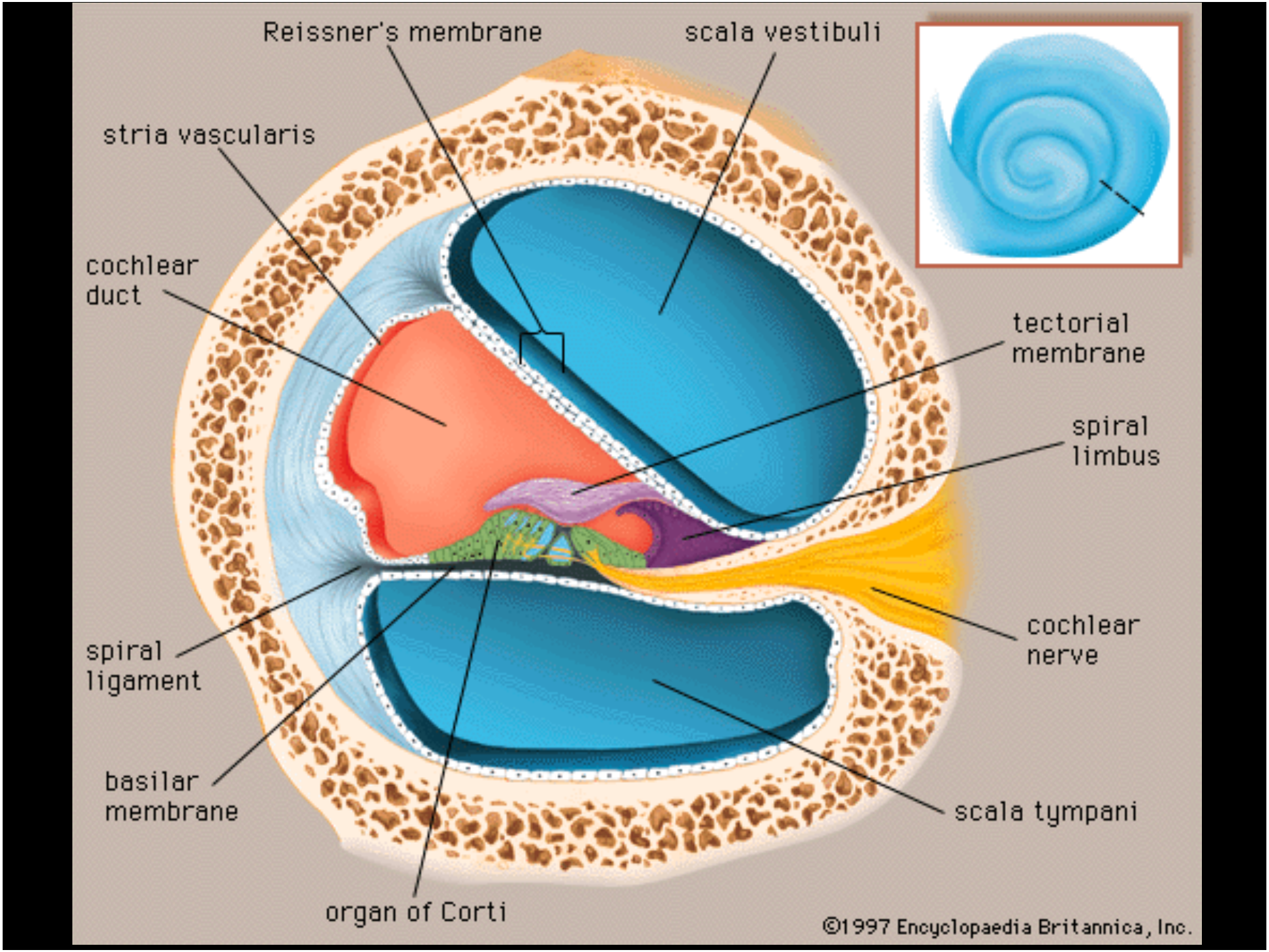


Figure 2.1: *Block diagram of MPEG/Audio encoder.*


Reissner's membrane
scala vestibuli
stria vascularis
cochlear duct
tectorial membrane
spiral limbus
spiral ligament
cochlear nerve
basilar membrane
scala tympani
organ of Corti
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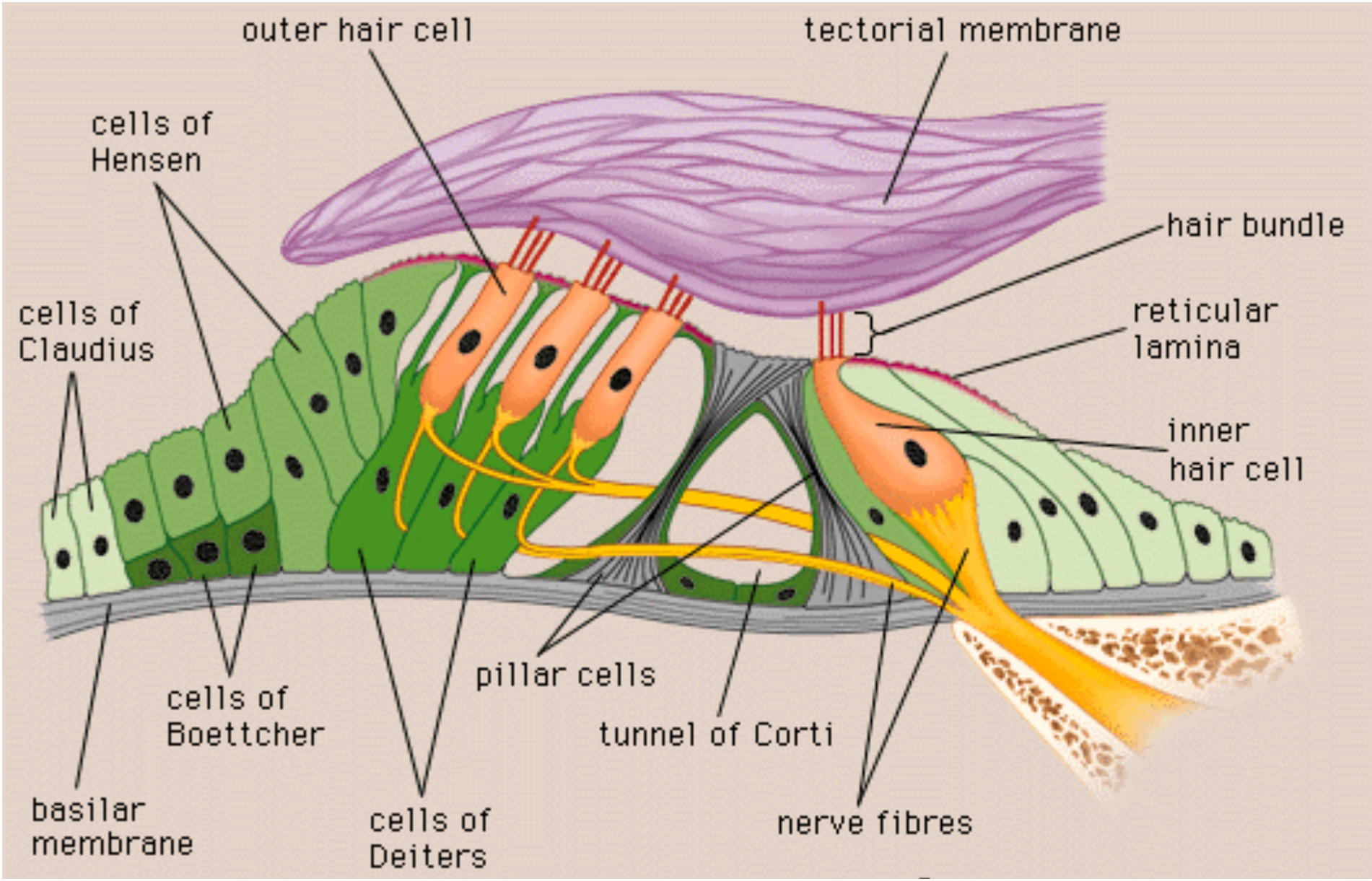
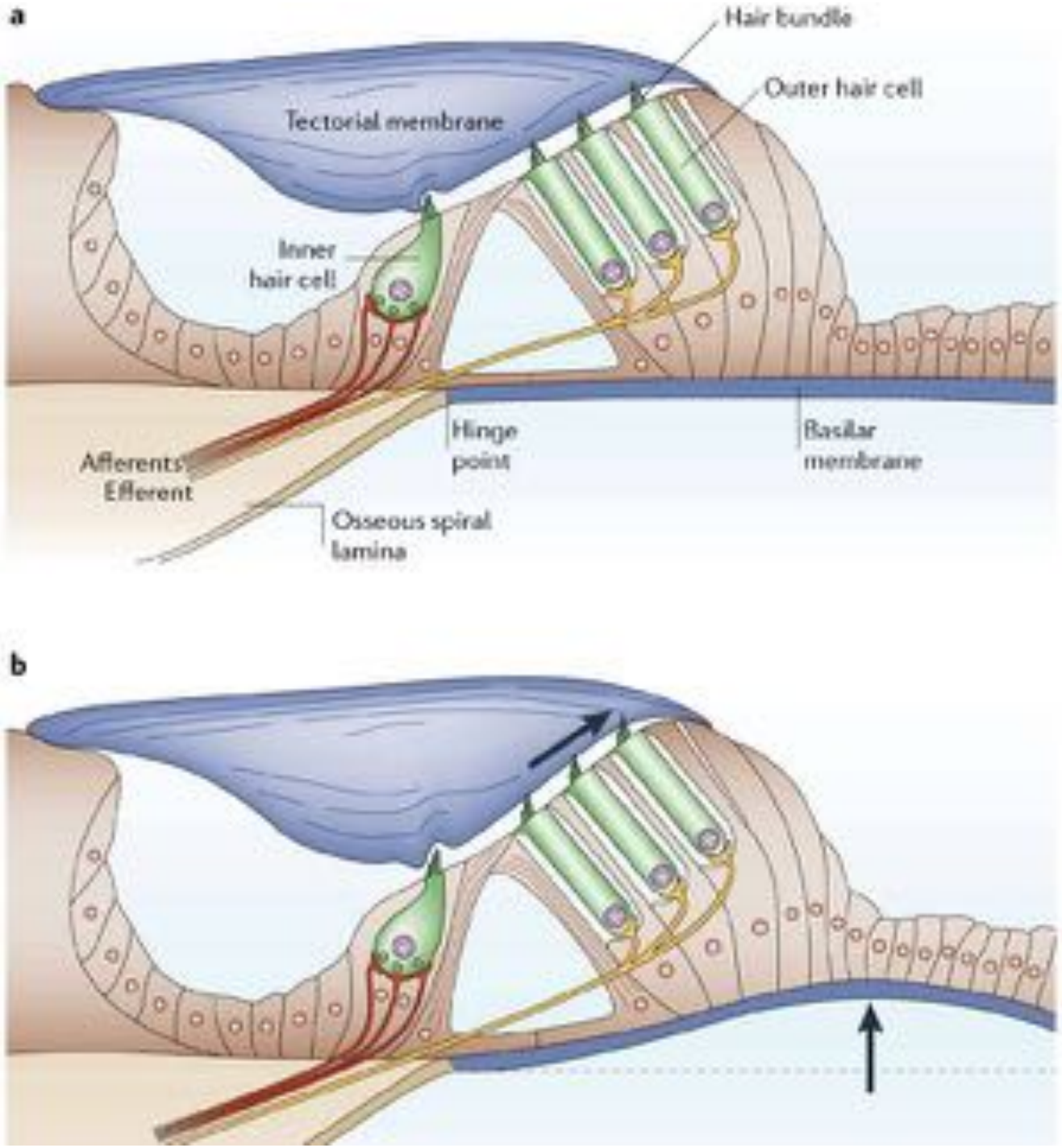
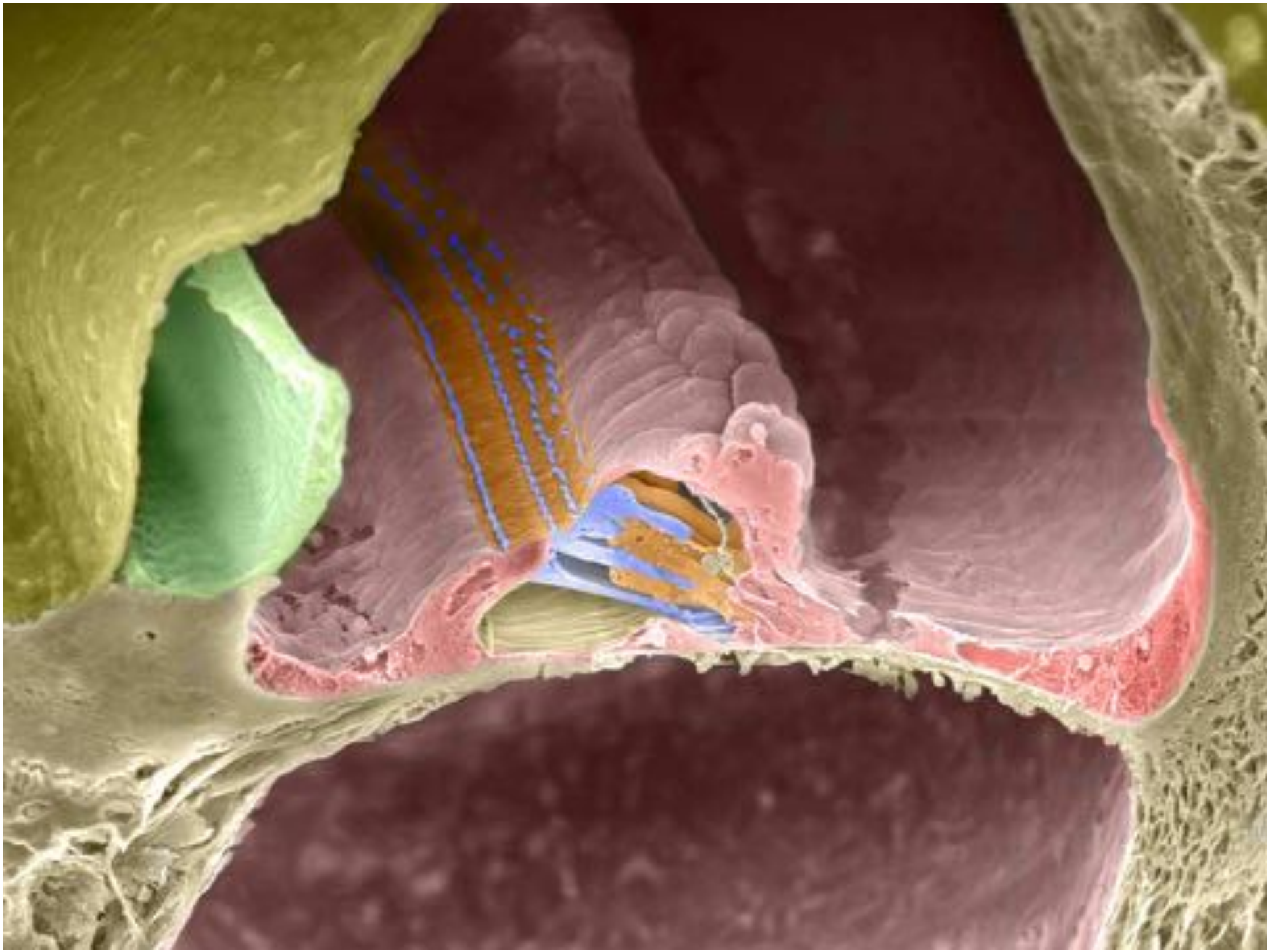
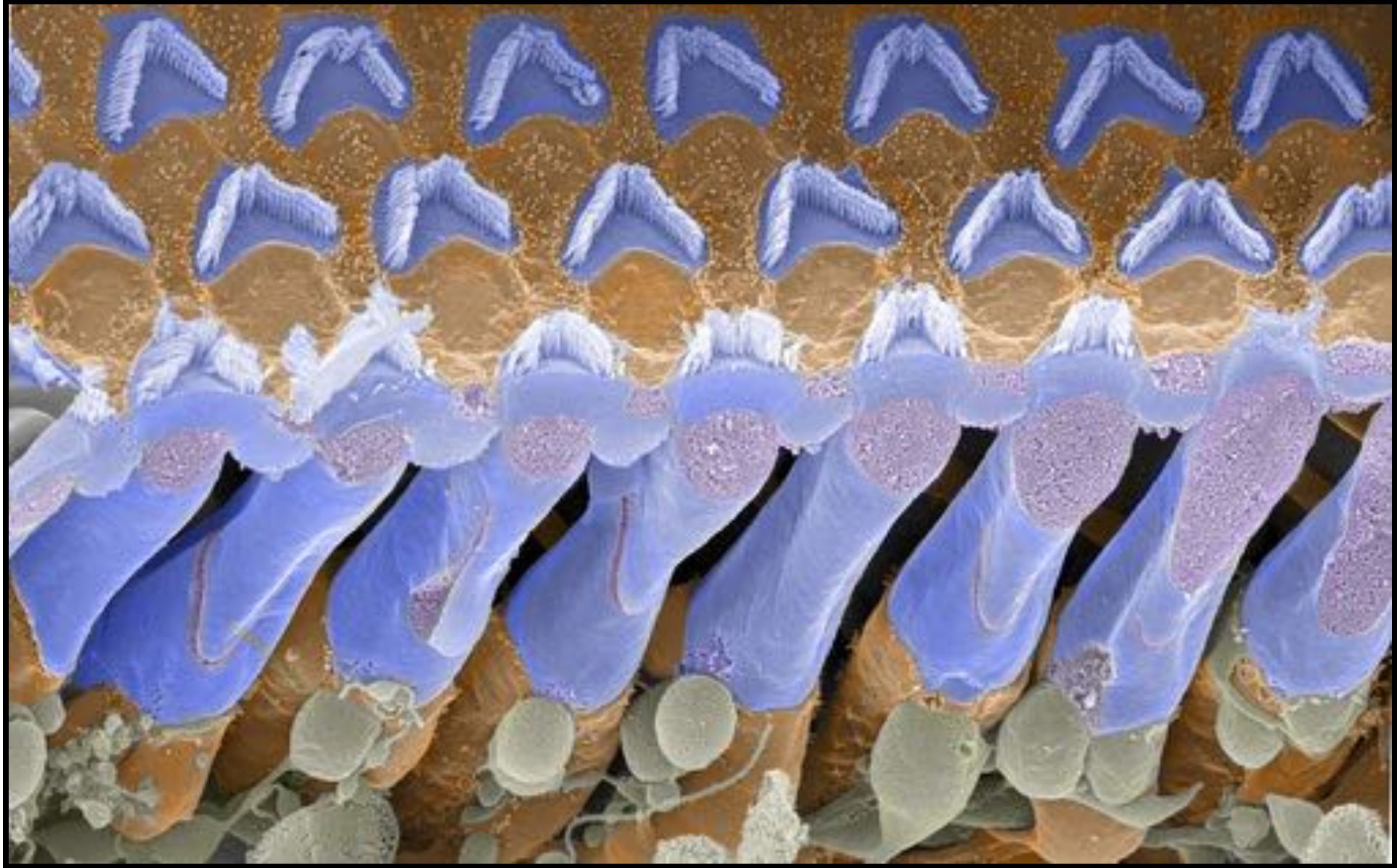
The organ of Corti

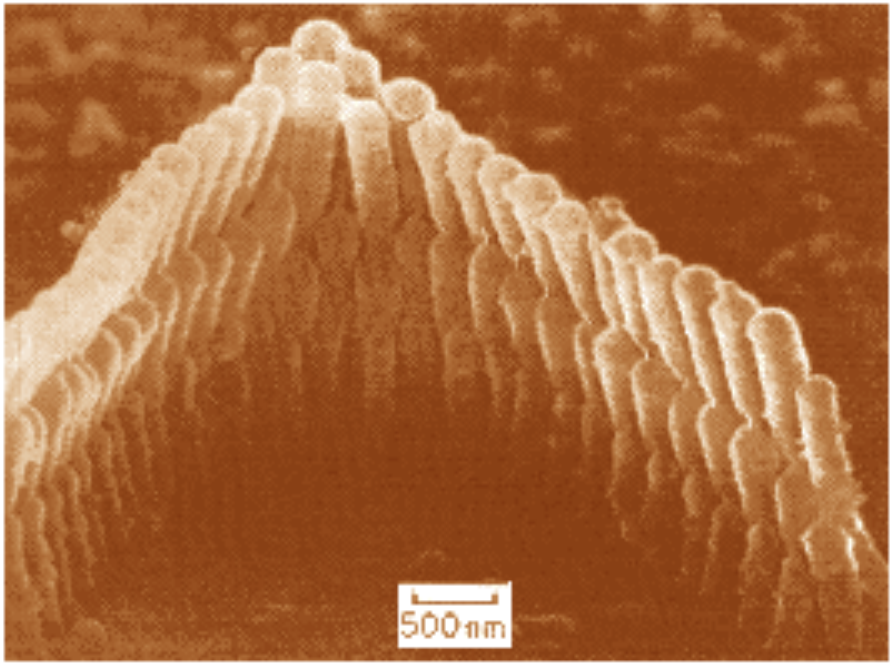


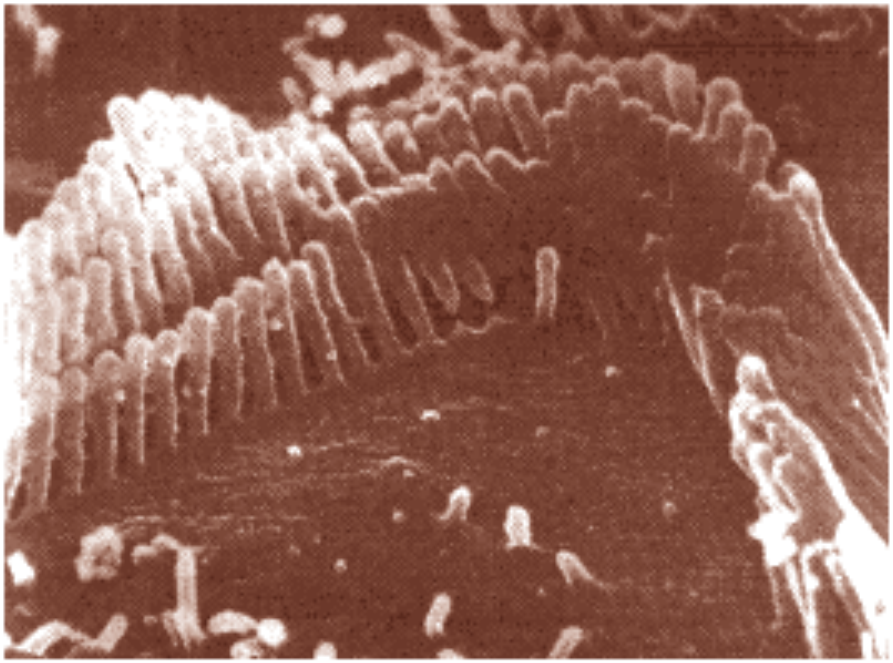

a
Hair bundle
Outer hair cell
Tectorial membrane
Inner
hair cell
Hinge
point
Basilar
membrane
Afferents
Efferent
Osseous spiral
lamina
b

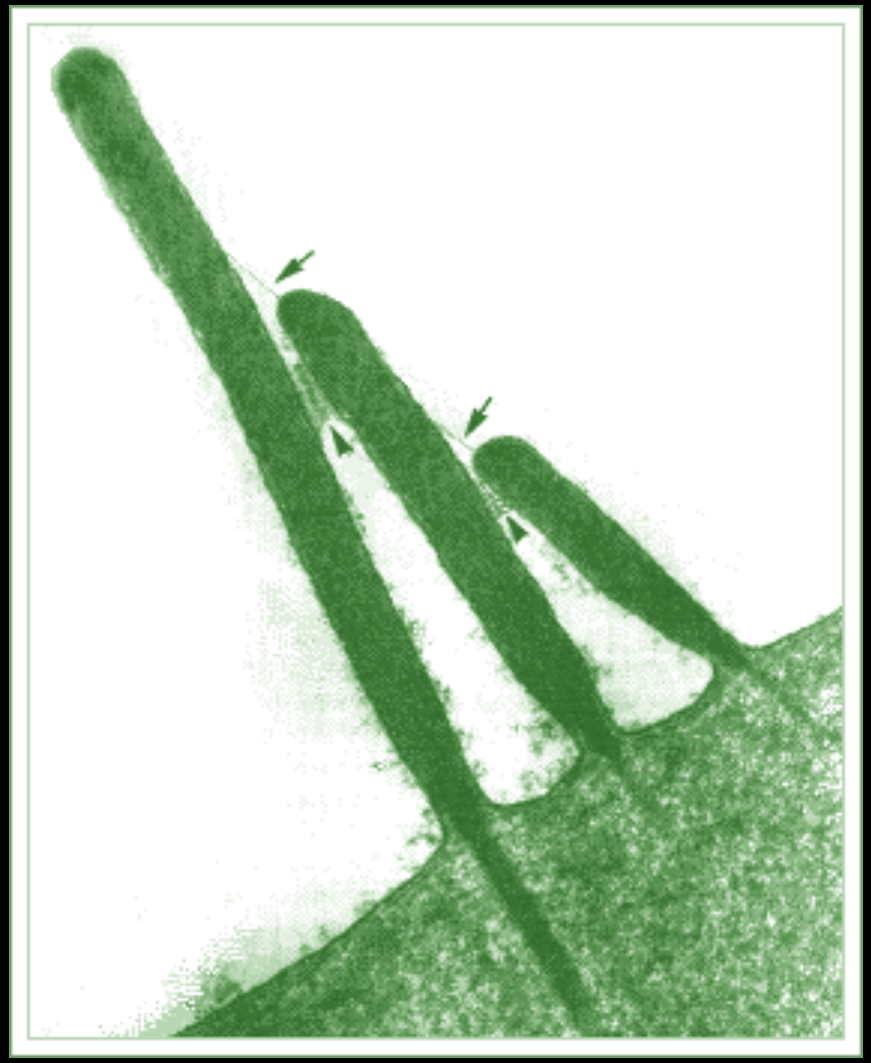


Hair cells

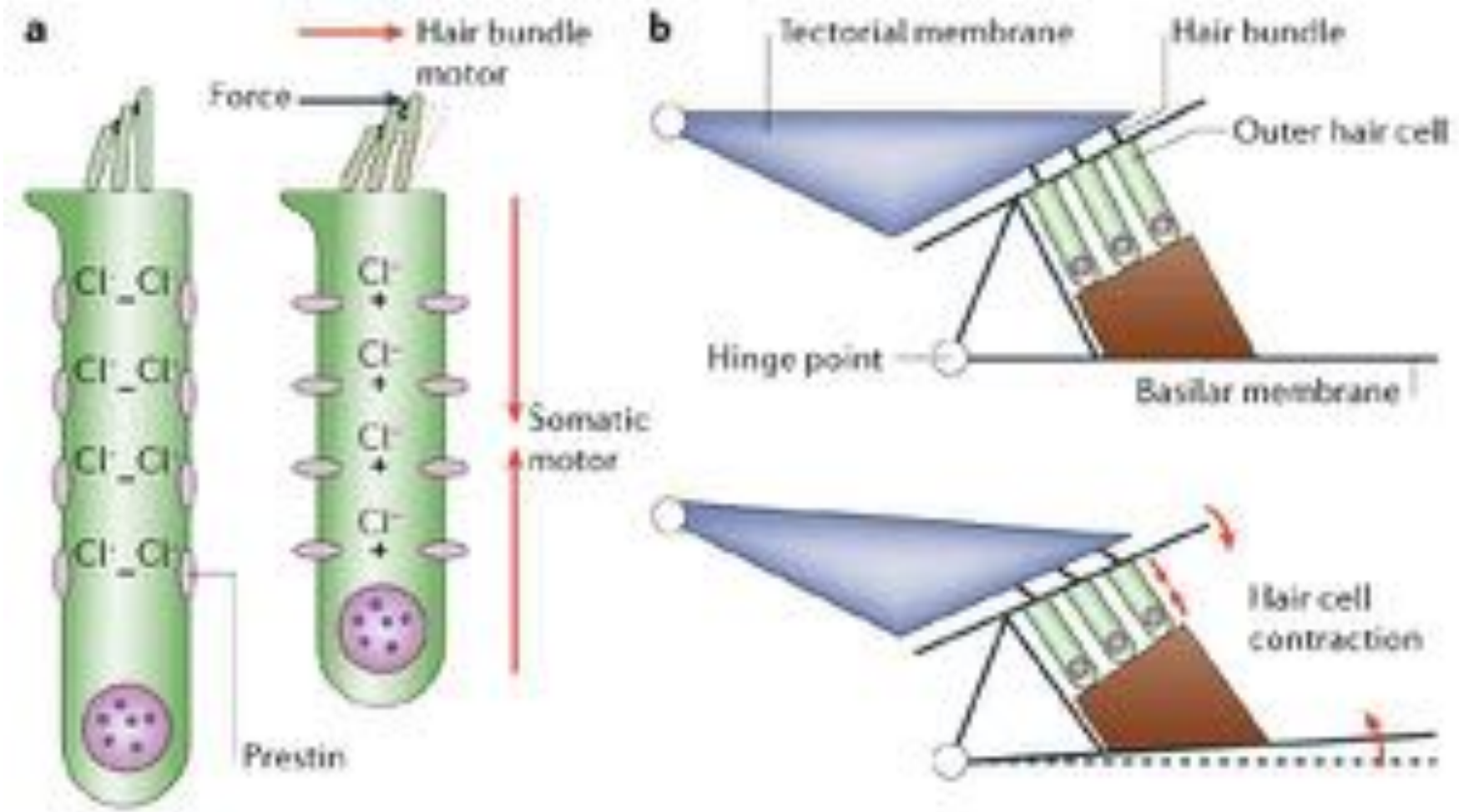



500 nm



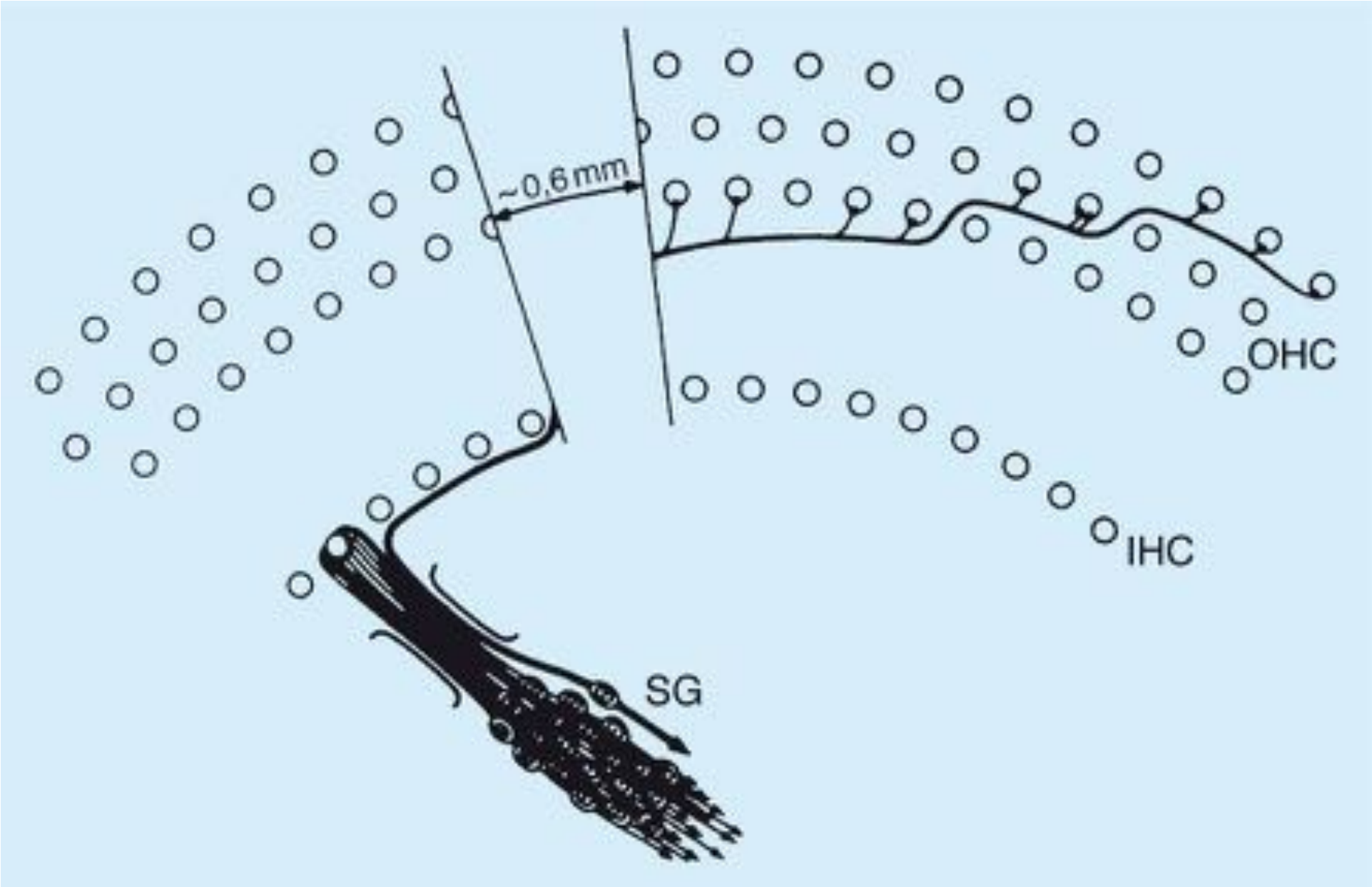


Outer hair cell motility

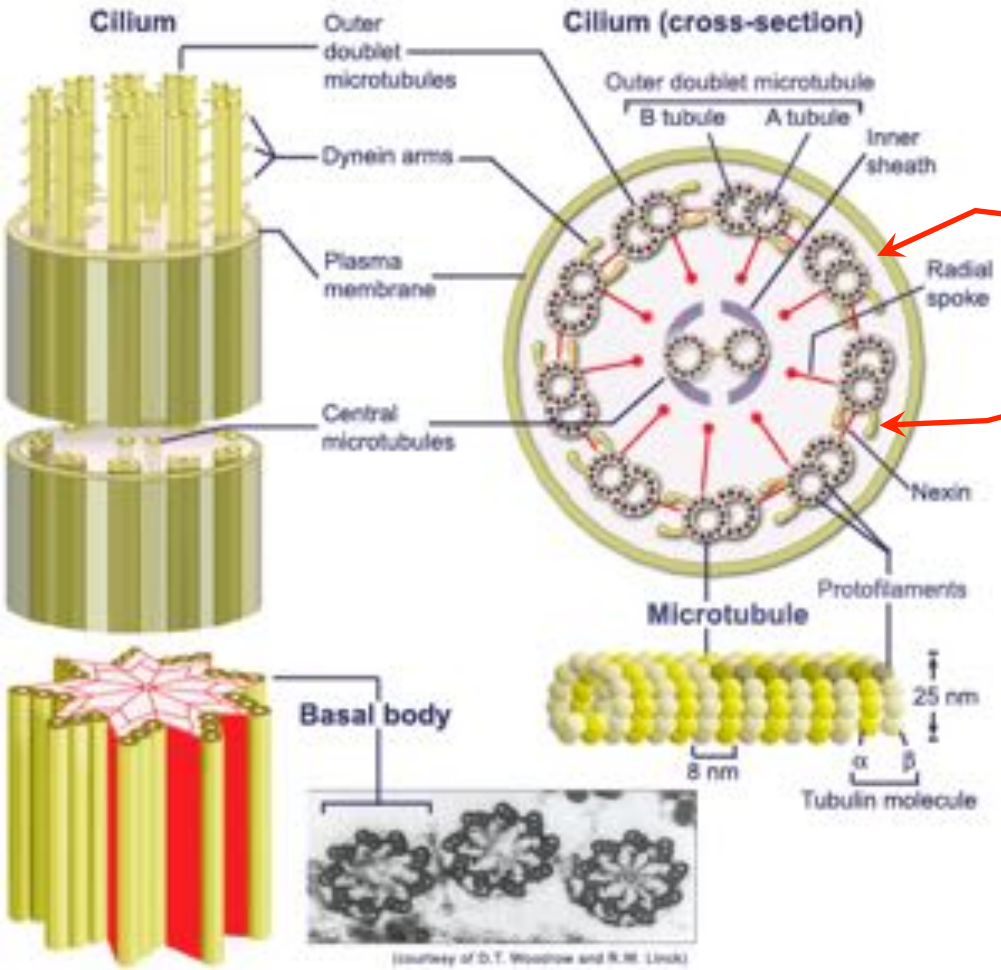


The active cochlea model (video by J. Ashmore 1987)

Connections from outer and inner hair cells

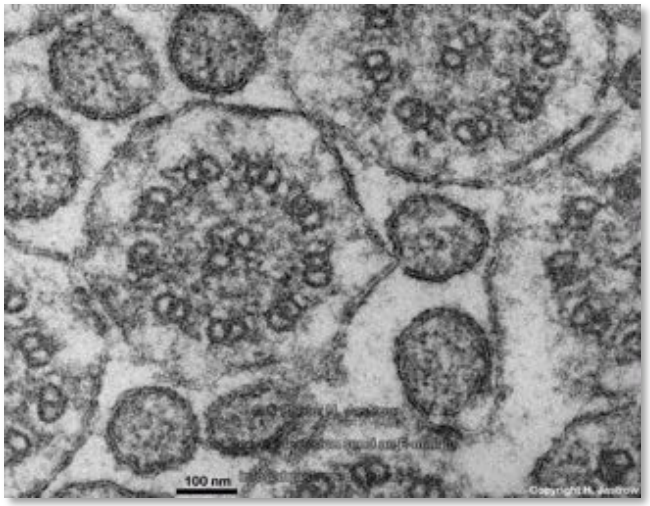


Microtubule inside of a cilium



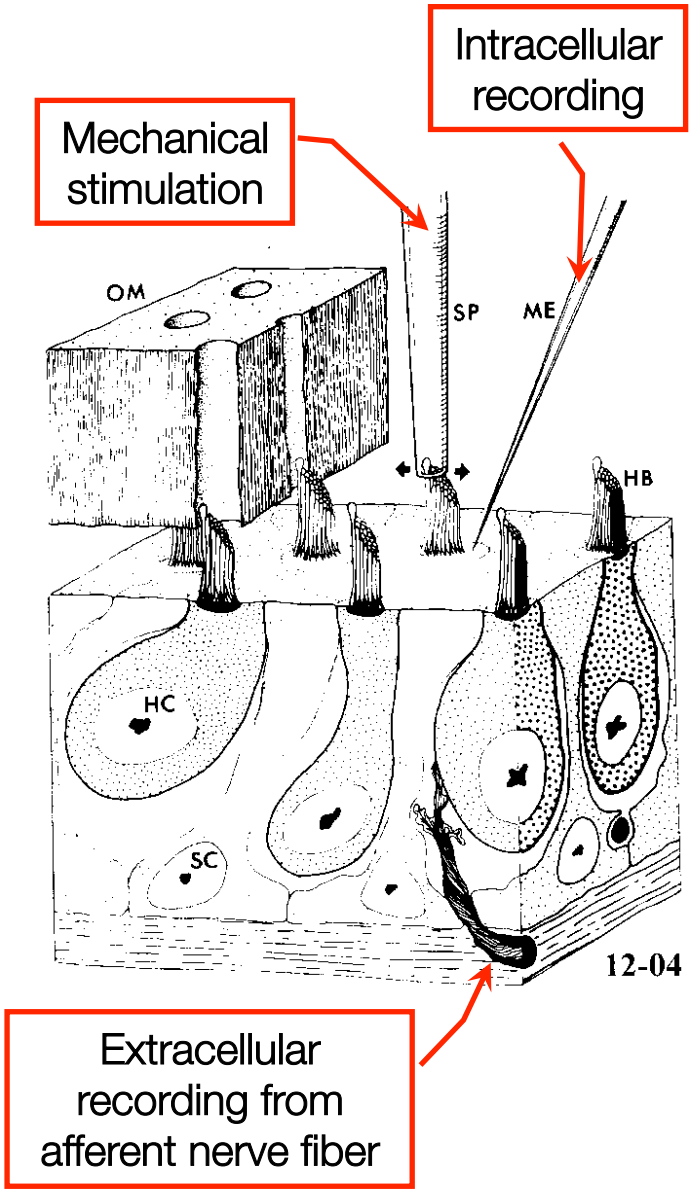
9 doublet microtubules
+ 2 central microtubule

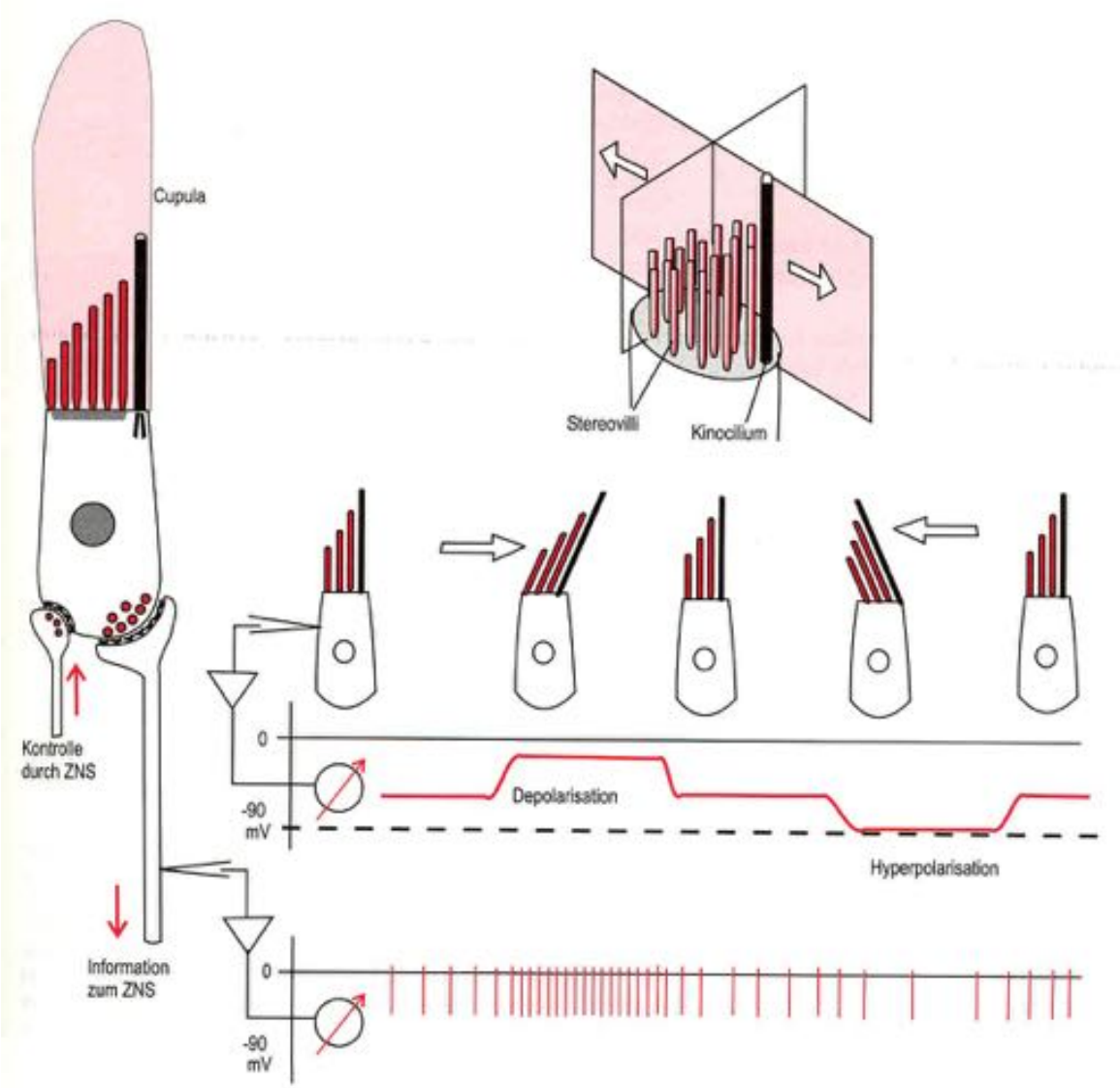
Dynein arms



http://scienceblogs.com/transcript/upload/2006/08/axoneme.gif /www.uni-mainz.de/FB/Medizin/Anatomie

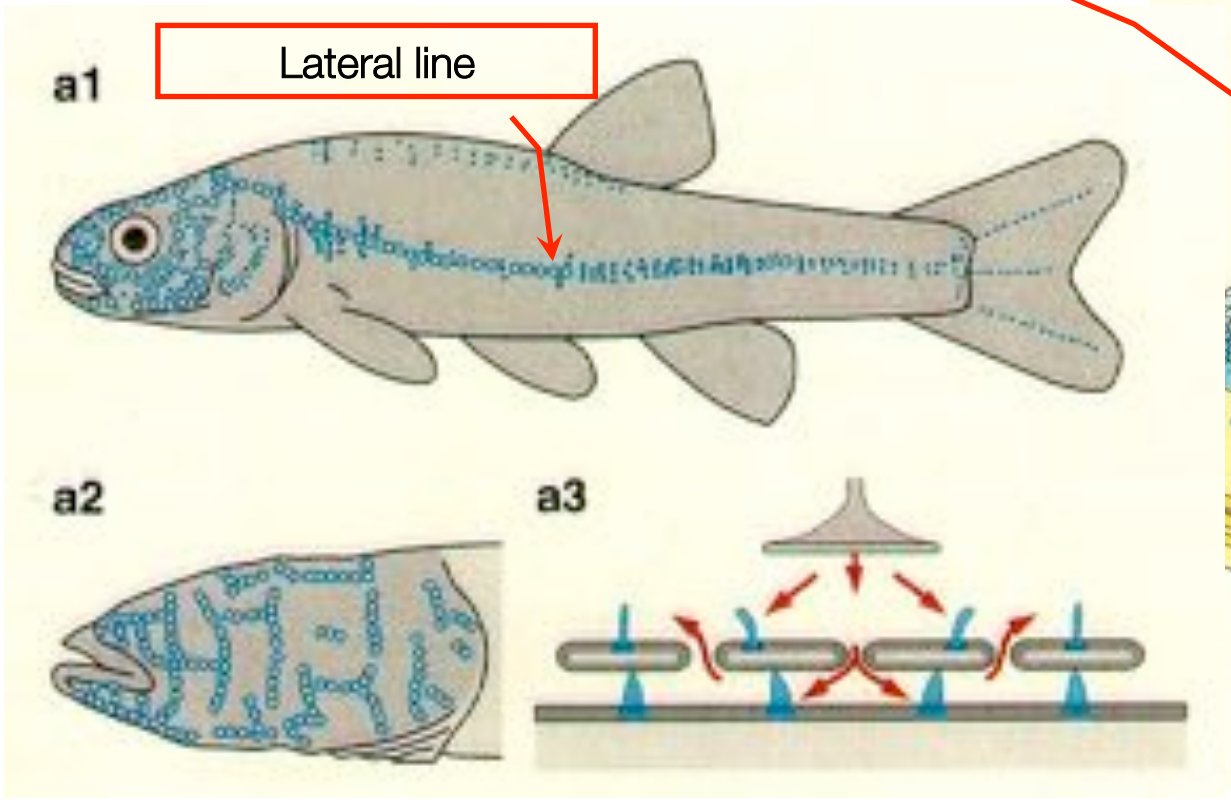
Tilting of stereocilia bundles cause graded de- or hyperpolarization in hair cells (and modulation of action potential rates in afferent nerve fibers)

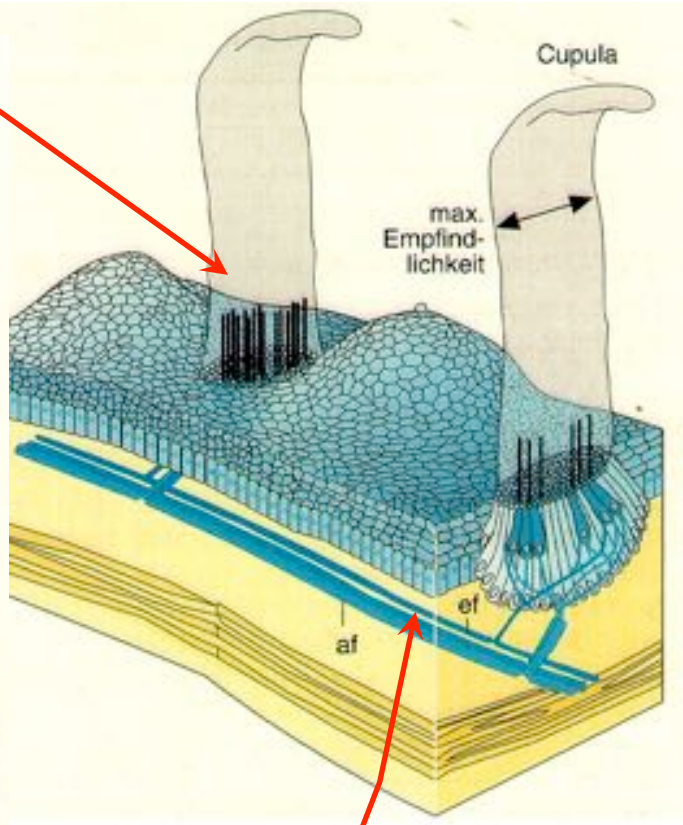




The lateral line system

Adequate stimulus: Tilting of stereovilli by water movement





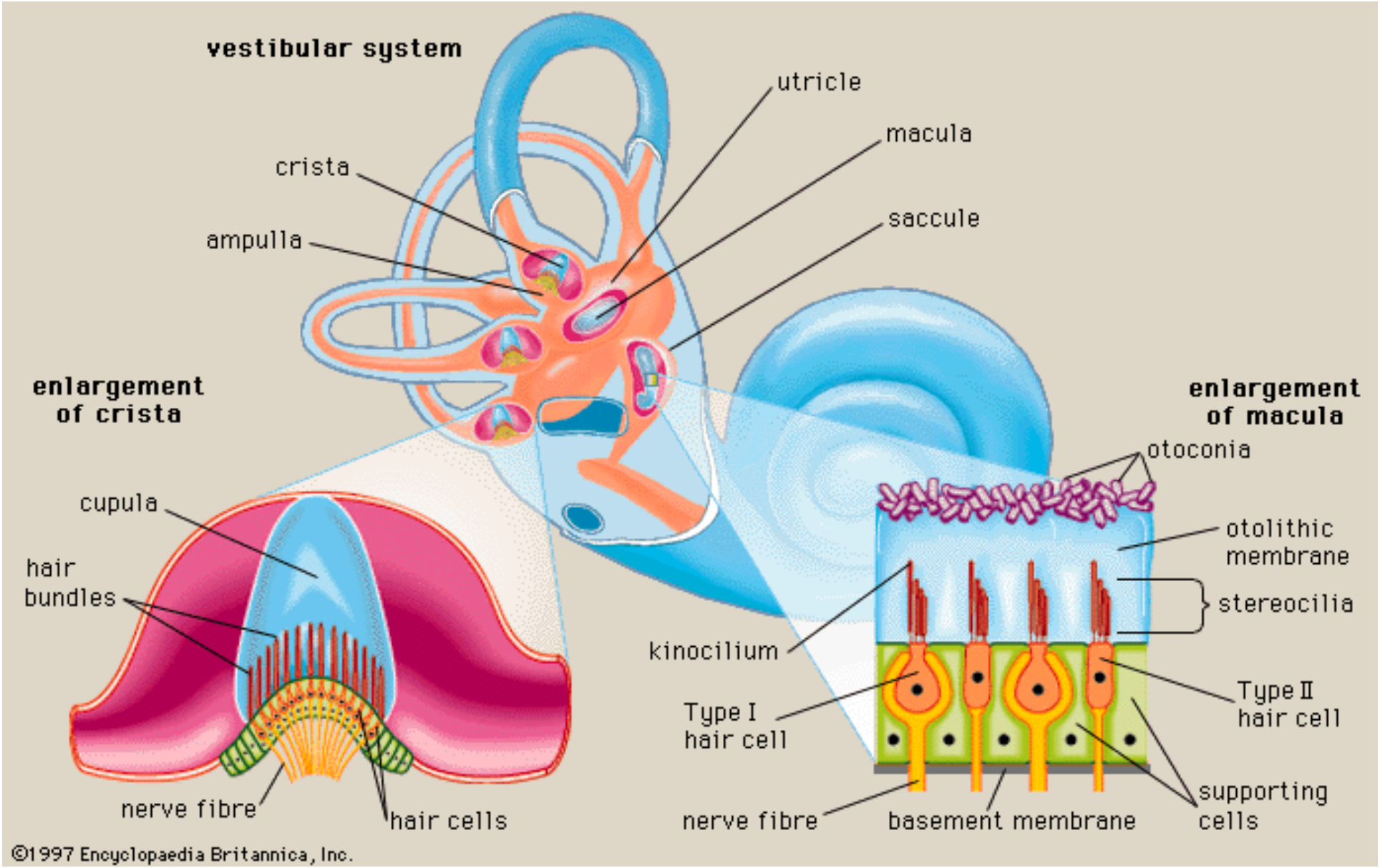
Afferent and efferent innervation

Dudel, Menzel, Schmidt

Hair cell: One type of sensory cell, different functions through specific accessory structures

A. Perception and integration of water-flow pattern at the body surface

Vestibular system



Vestibular system

The vestibular labyrinth answers two basic questions:
Where am I going?
Which way is up?

The vestibular labyrinth answers the two questions by sensing:

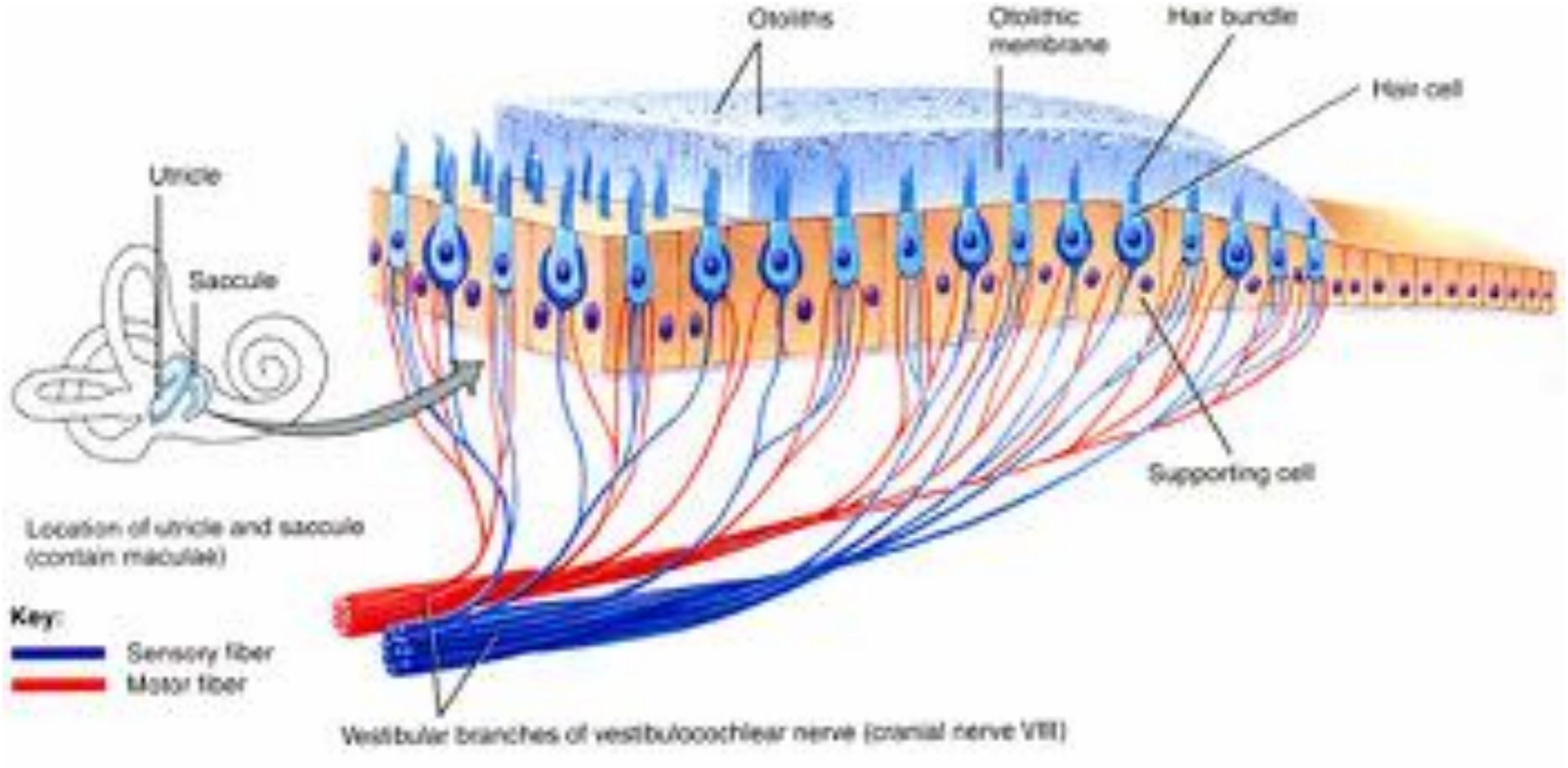
Head angular acceleration (semicircular canals) = Head rotation

Head linear acceleration (saccule and utricle) = Translational motion.

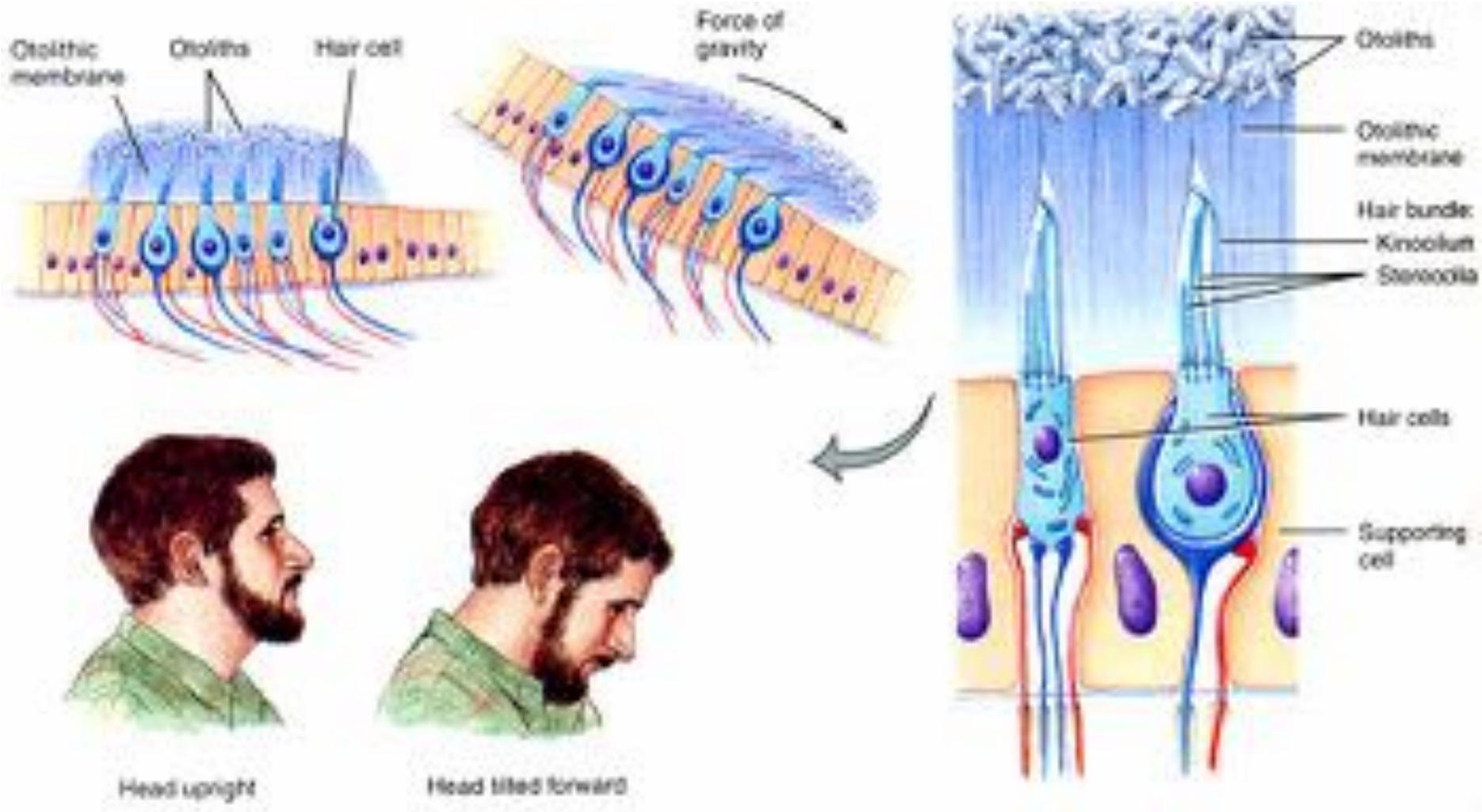
Gravity (and by extension head tilt)

The maculae

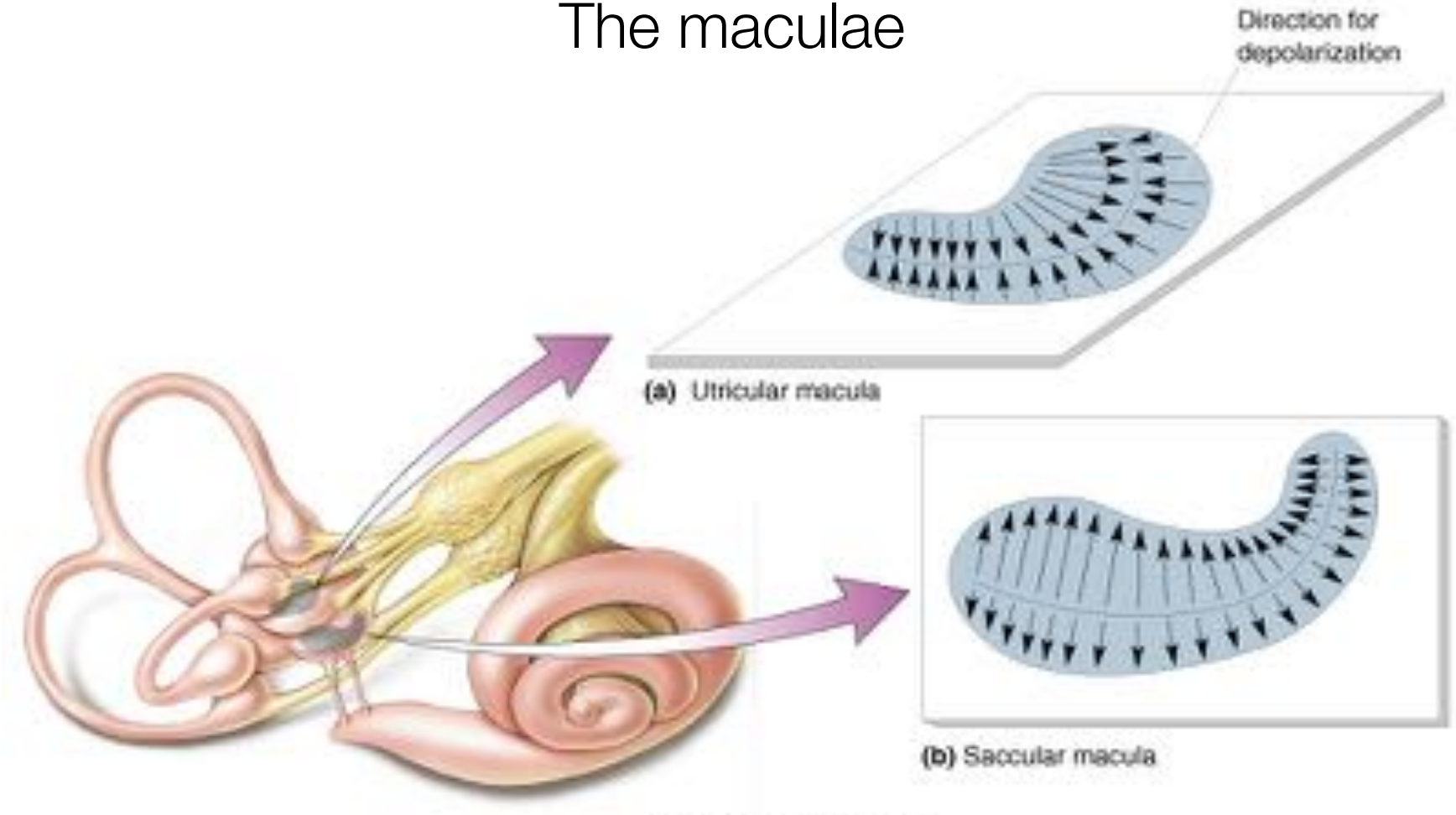
Hair cell cilia are embedded in a gelatinous otolithic membrane (above the macula) covered with calcium carbonate particles (otoconia or otoliths). Tilting of the head moves otoliths due to gravity and bends cilia of hair cells.



The maculae

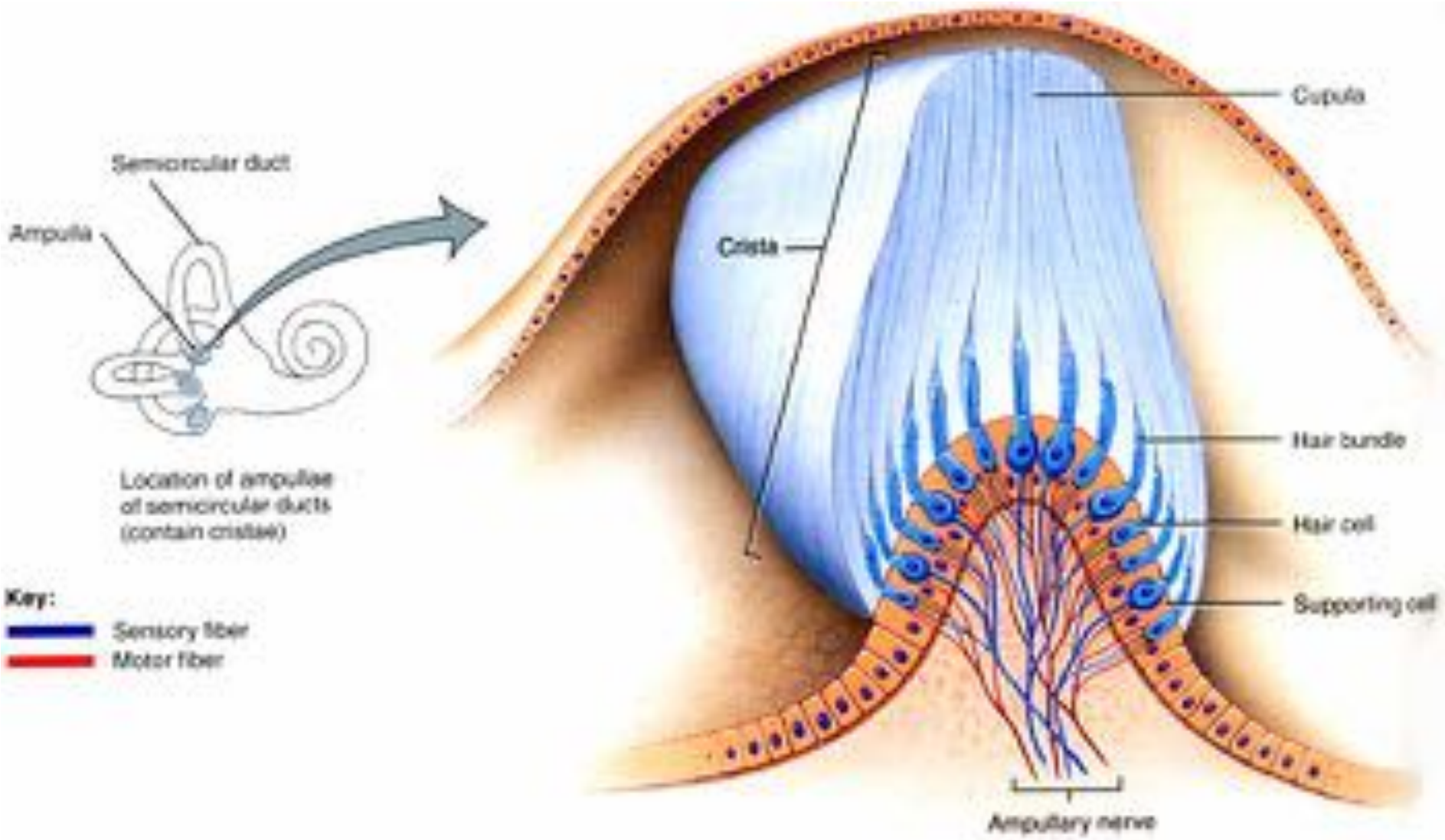

Otolithic membrane
Otoliths
Hair cell
Force of gravity
Head upright
Head tilted forward
Otoliths
Otolithic membrane
Hair bundle:
Kinocilium
Stereocilia
Hair cells
Supporting cell

The maculae

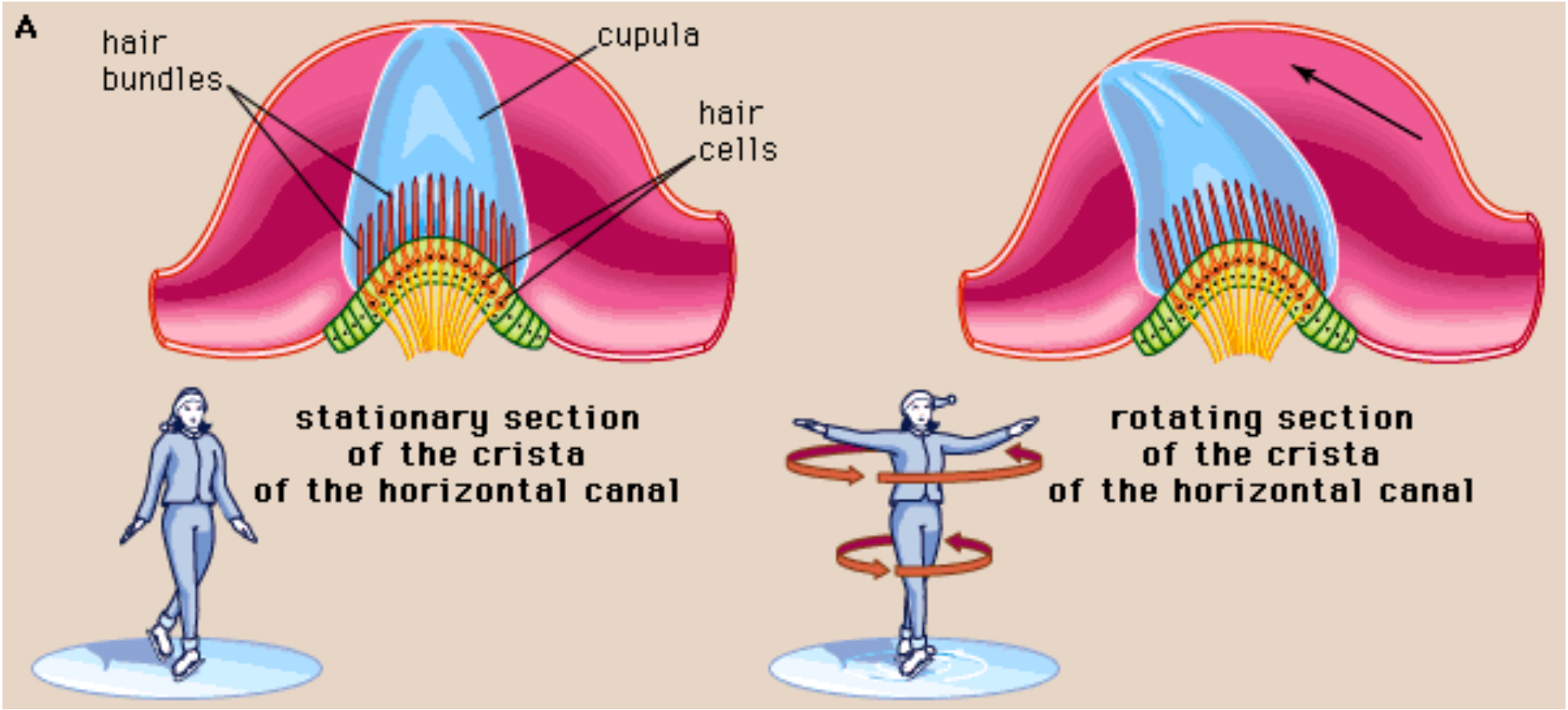


The utricular macula is horizontal, while the saccular macula is vertical. Orientation within each organ for preferred deflection is indicated by arrows, allowing for detection of linear acceleration from almost any direction.

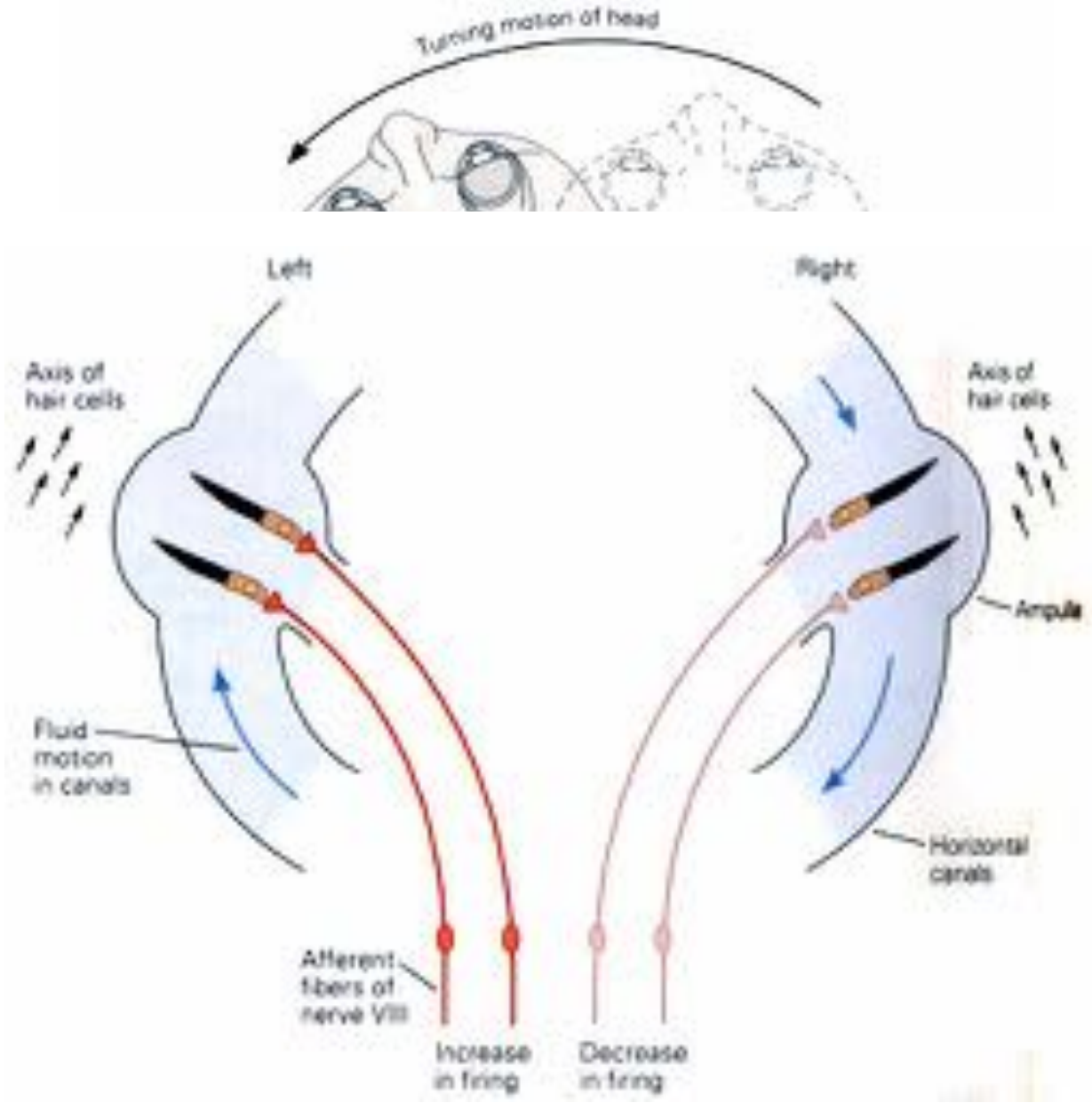
The crista ampullaris



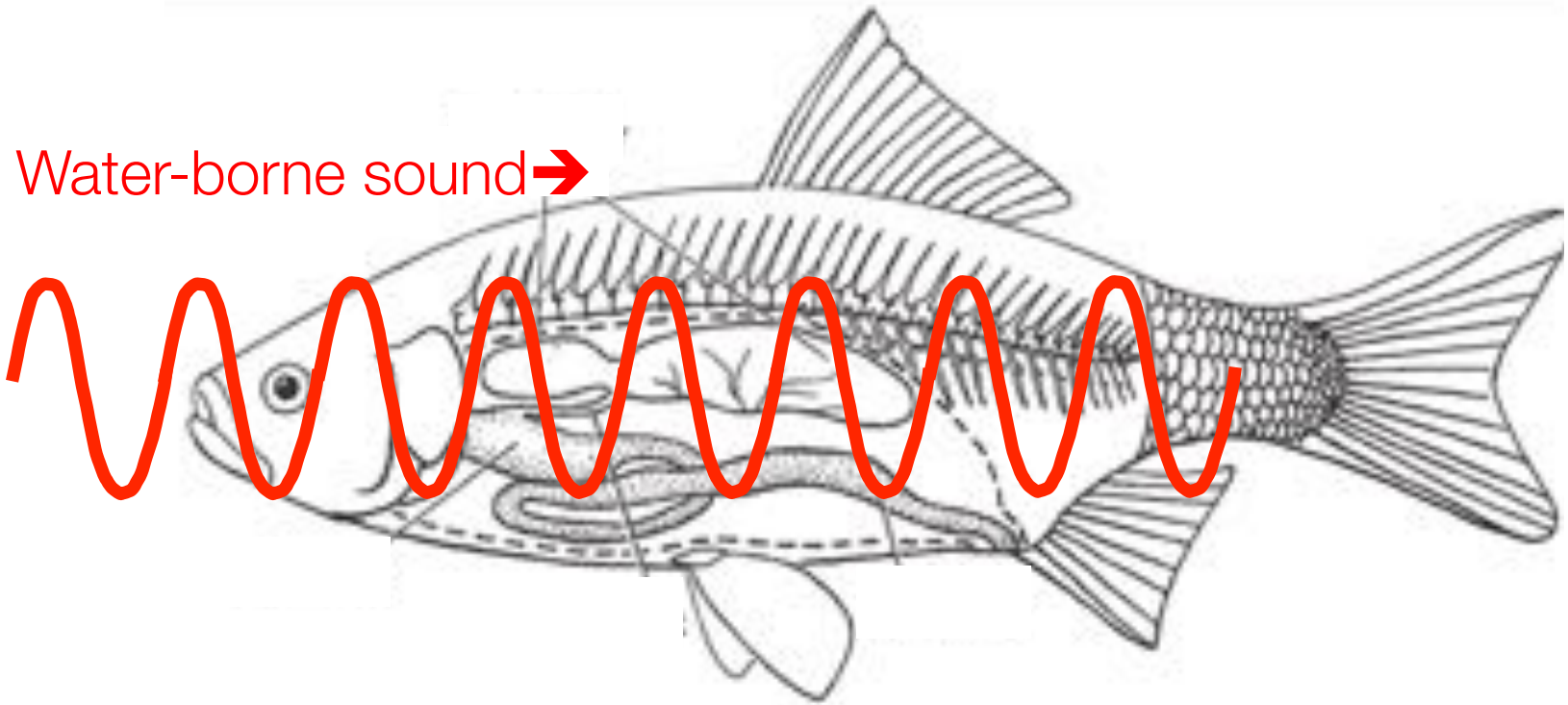
The crista ampullaris



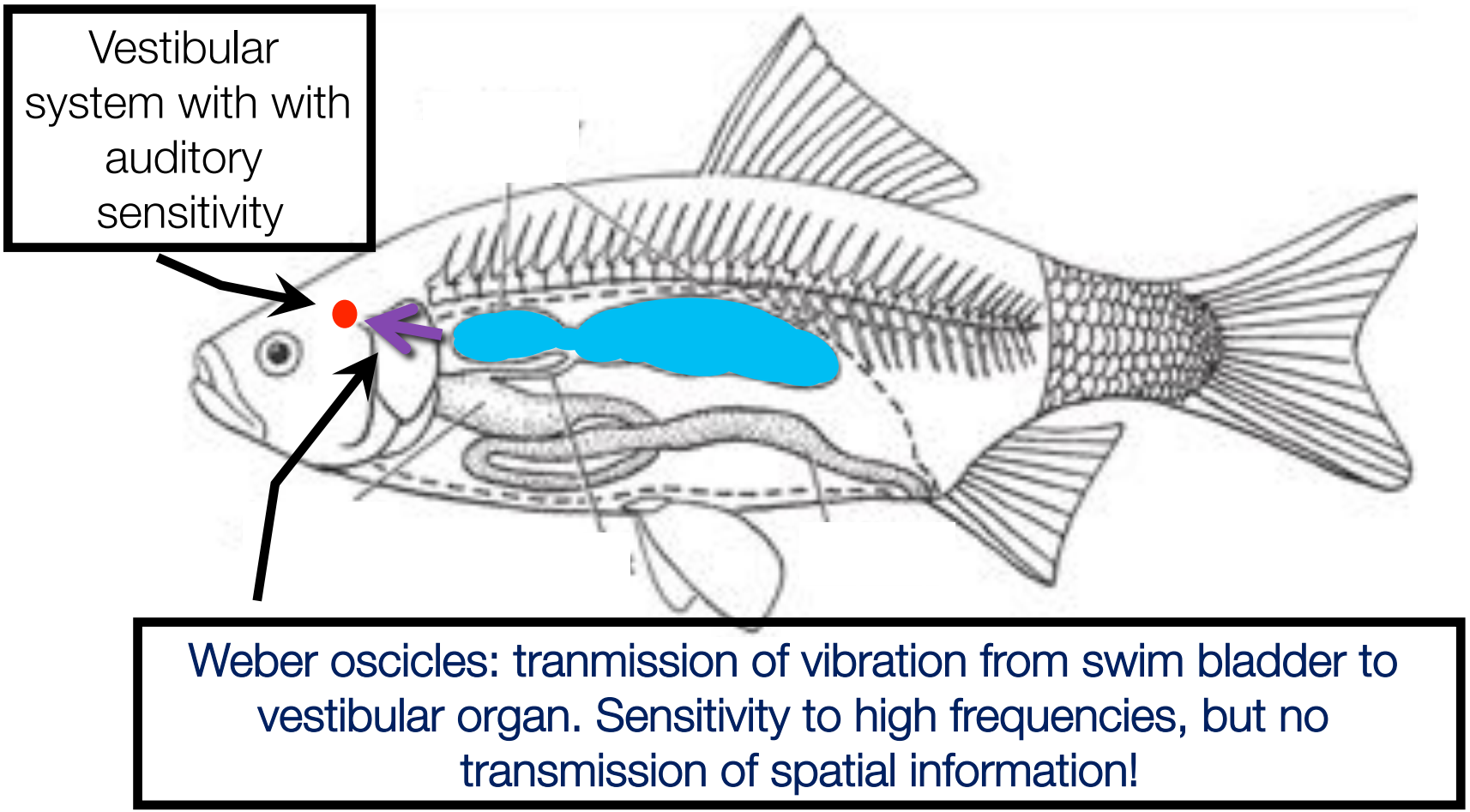
The crista ampullaris



Basic auditory sensitivity in fish though direct activation of utricular haircells by water-borne sound



Vibrations of swim bladder are transmitted to the vestibular/hearing organ



Hair cell: One type of sensory cell, different functions through specific accessory structures

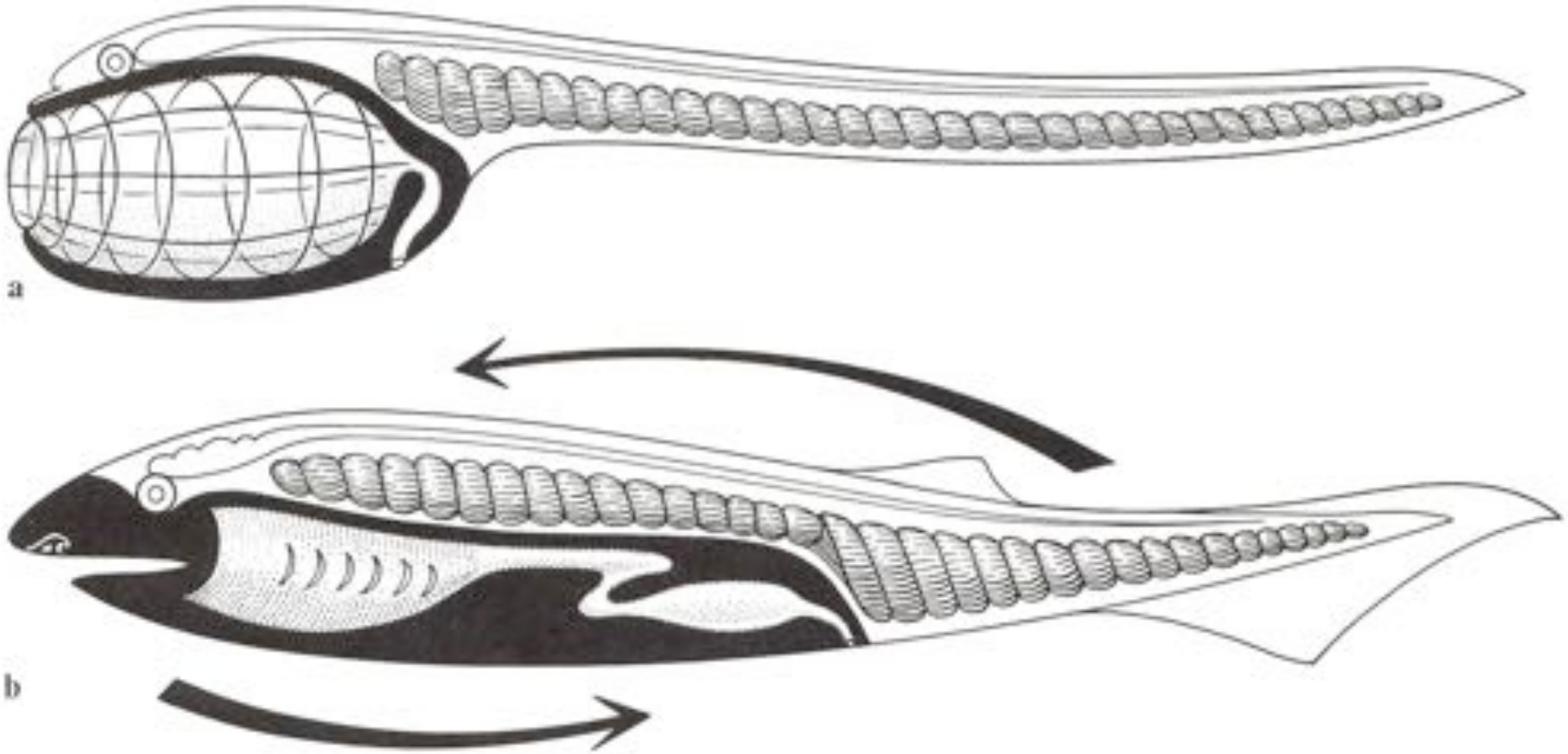
A. Perception and integration of water-flow pattern at the body surface

B. Perception of posture in space and of rotational acceleration and linear acceleration

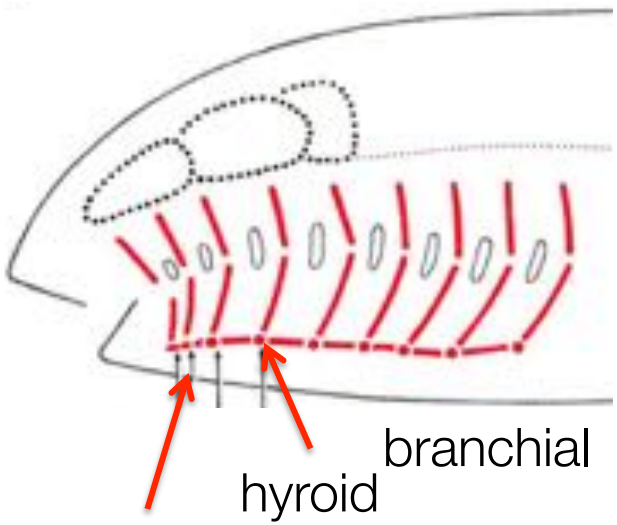
C. Perception of sound by hair cells in the utricle (low frequency)

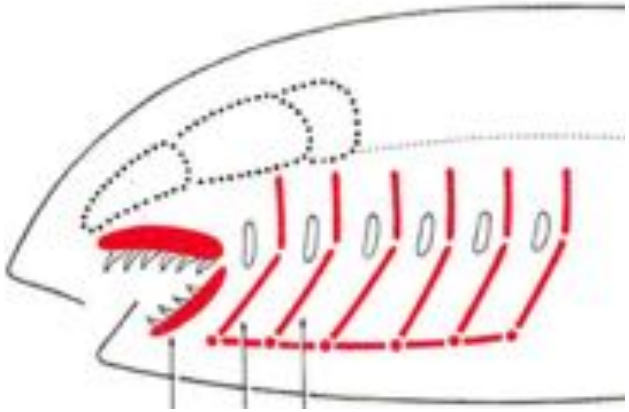
D. Sound perception by gas filled swim bladder (high frequency)

Early vertebrates were jawless fish: Food intake by filtering water through a branchial gut

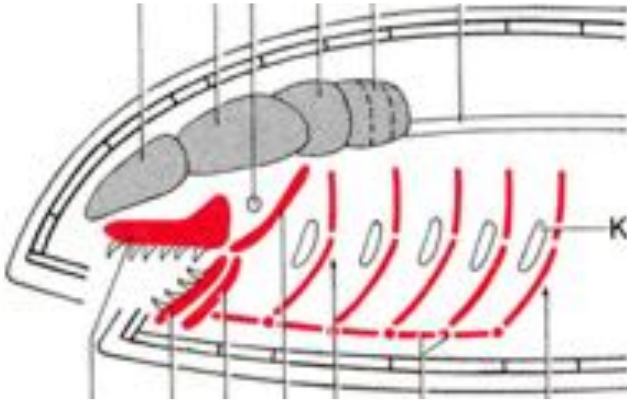


Jaws developed from branchial archs

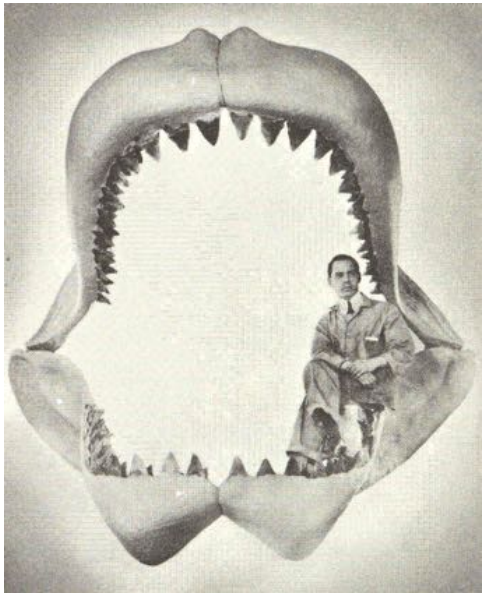




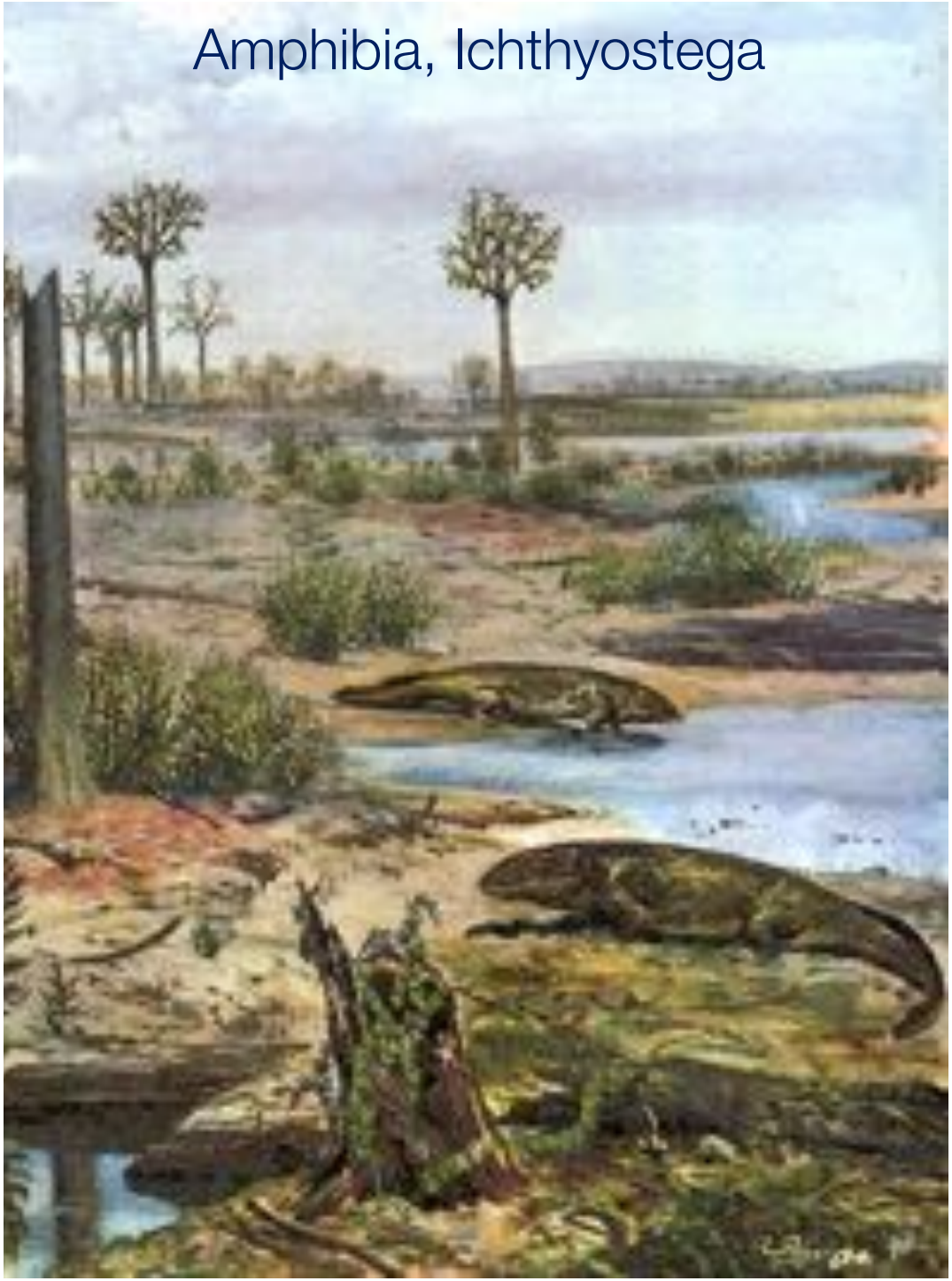
Primary jaw
= mandibular

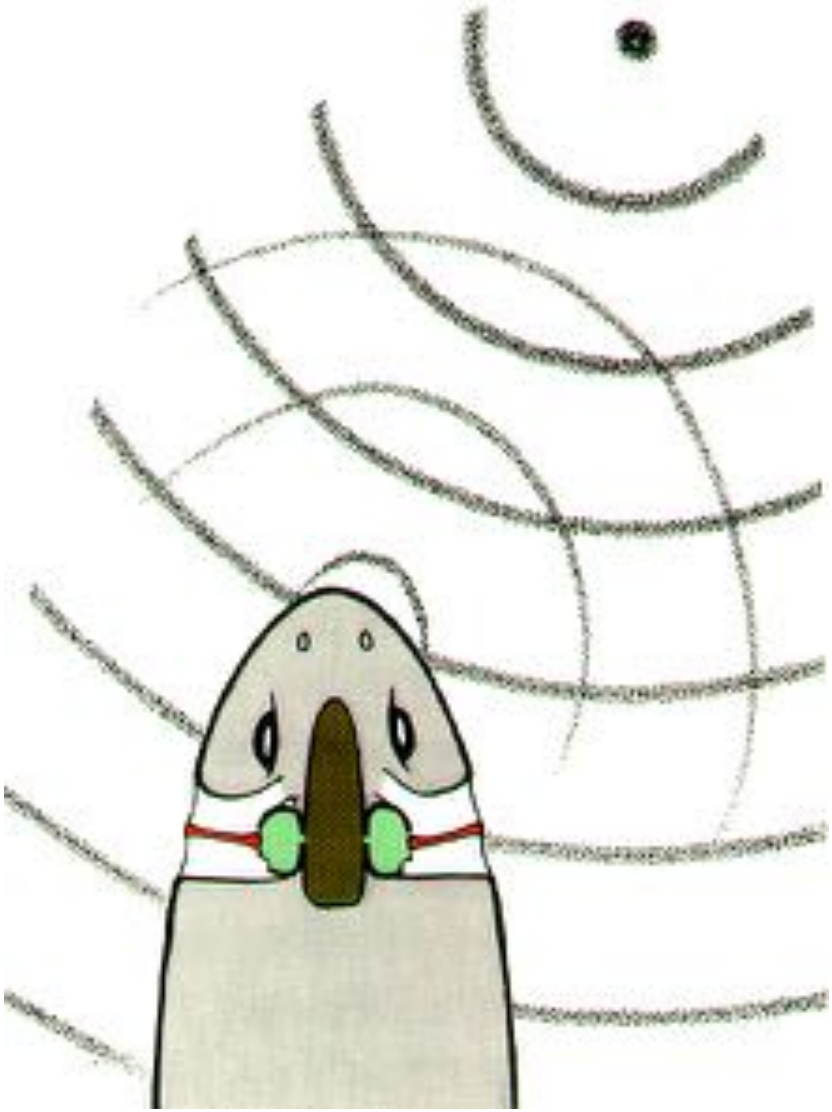


hyroid connects
jaw to cranium



Amphibia, Ichthyostega





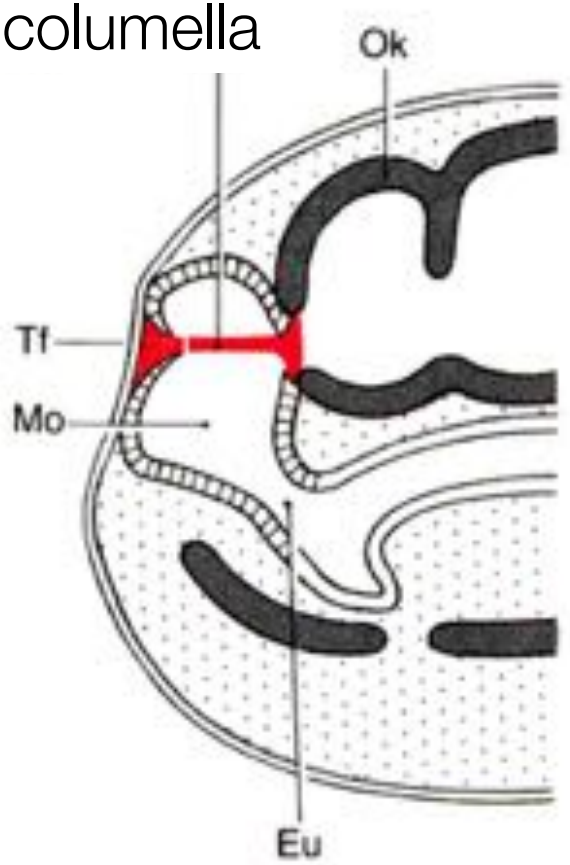
Ear capsule

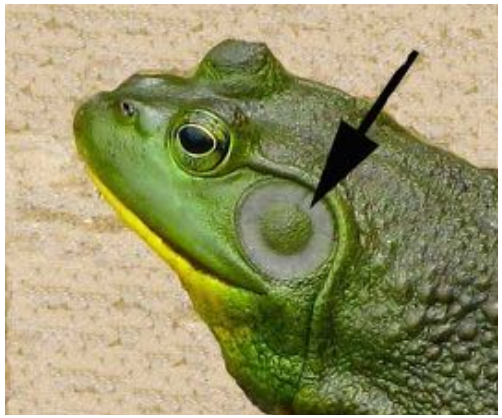
hyroid

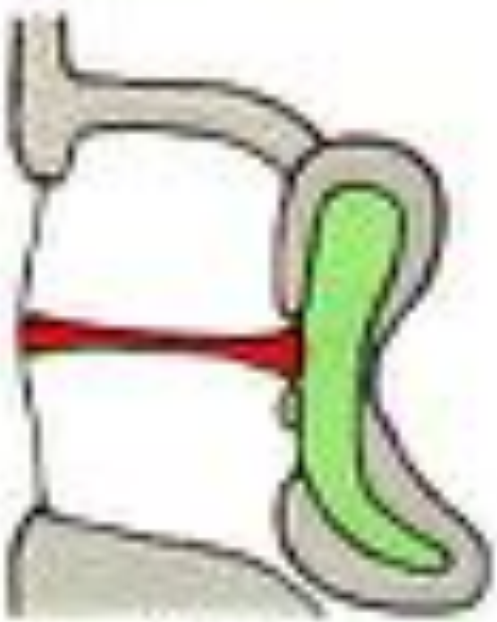
spiraculum

mouth cavity

columella

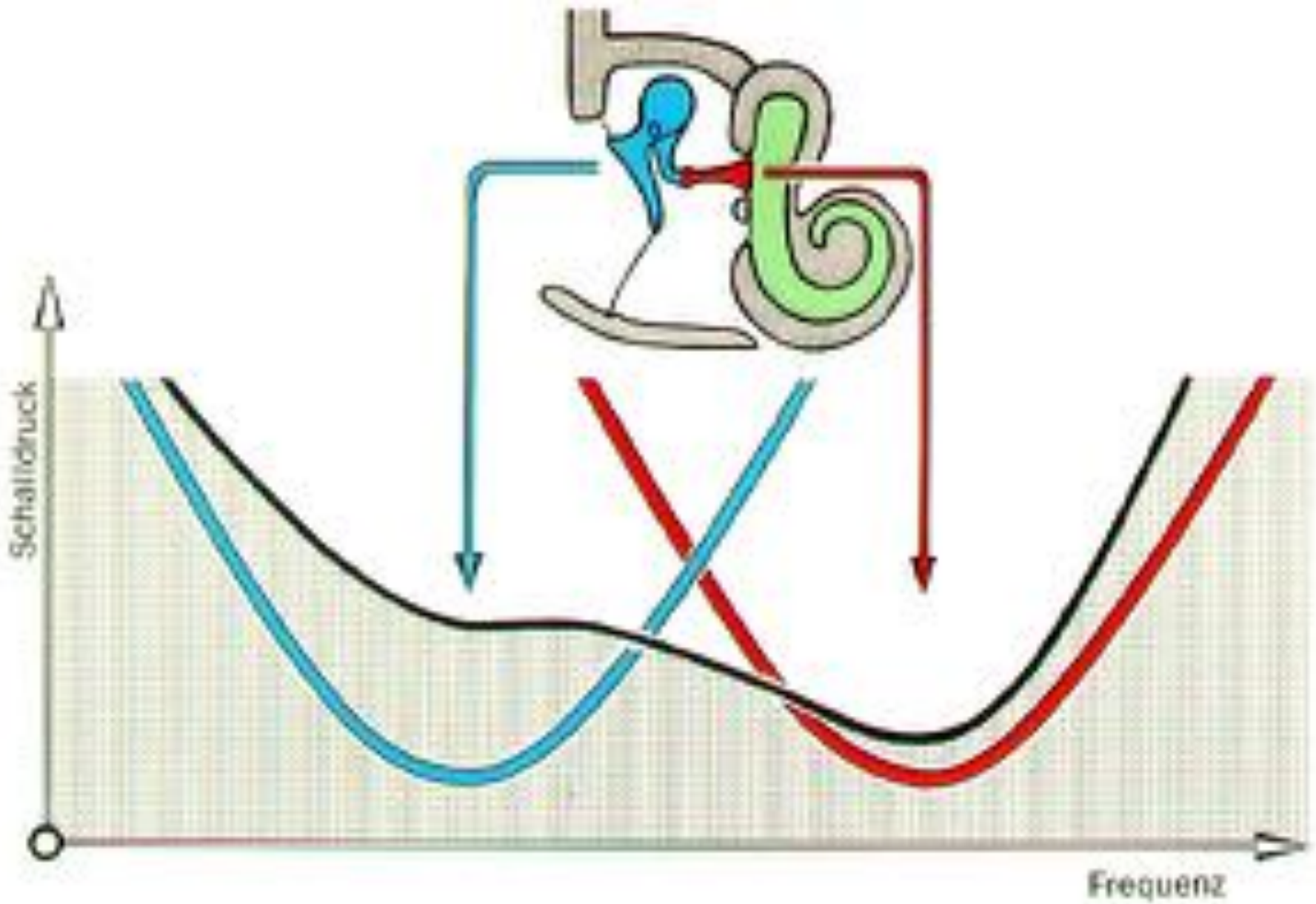






Reptiles / birds

Mammals


Schalldruck
Frequenz

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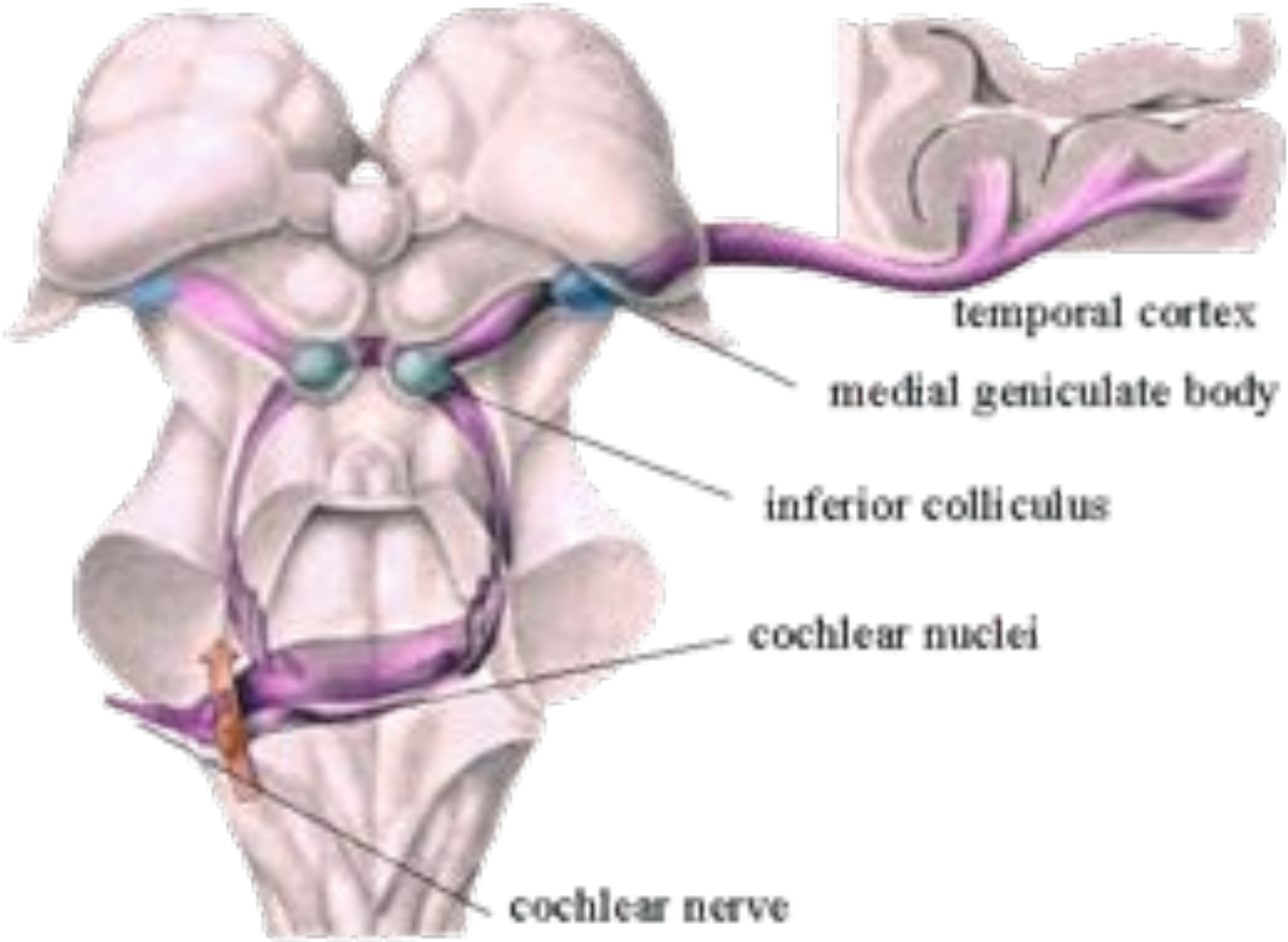
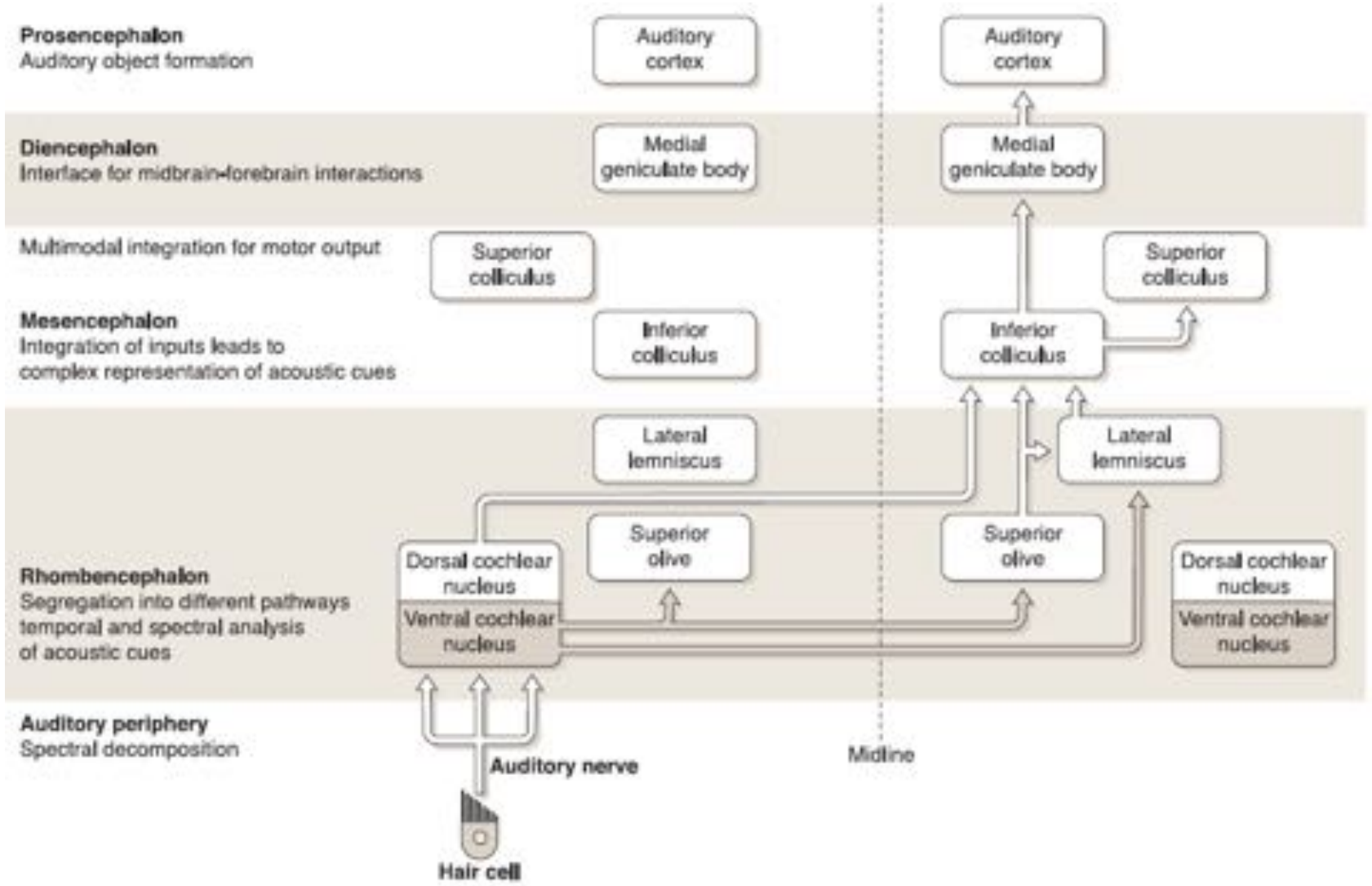
D. Sound perception by gas filled swim bladder (high frequency)

E. Middle ear: Acoustic impedance matching of incoming sound

F. Mammalian middle ear: Major expansion of the frequency range transmitted to the inner ear

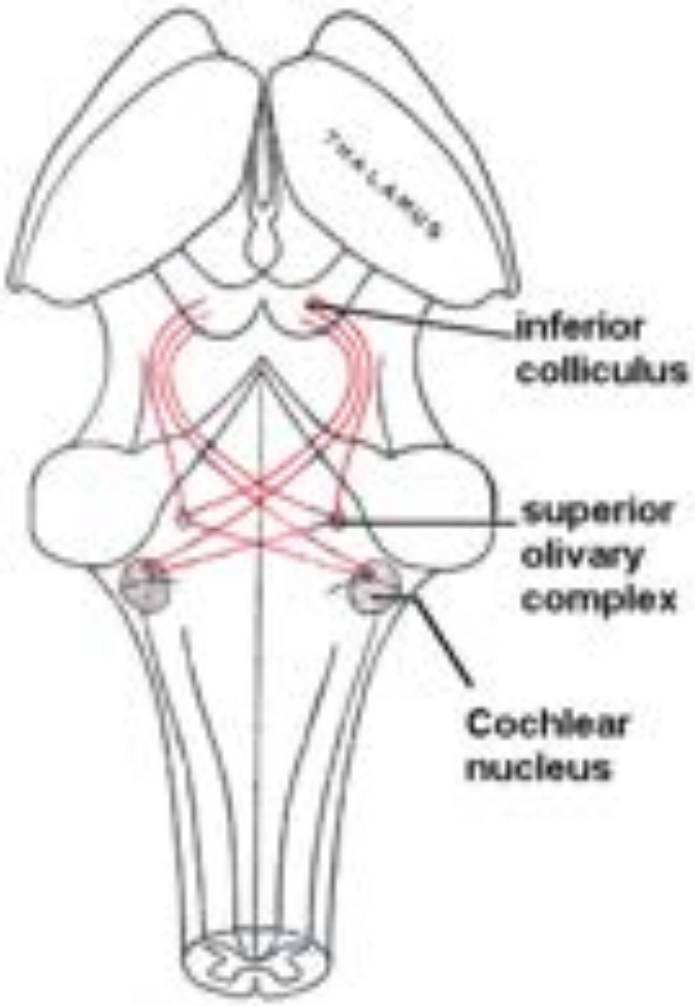
The ascending auditory pathway

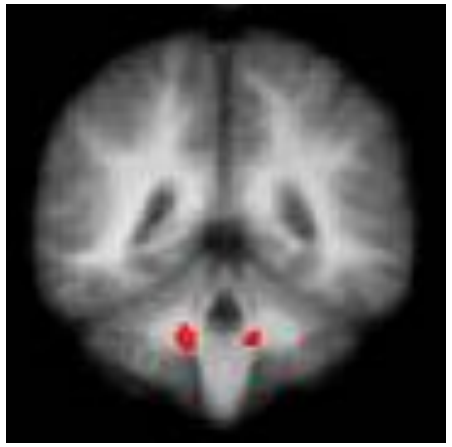


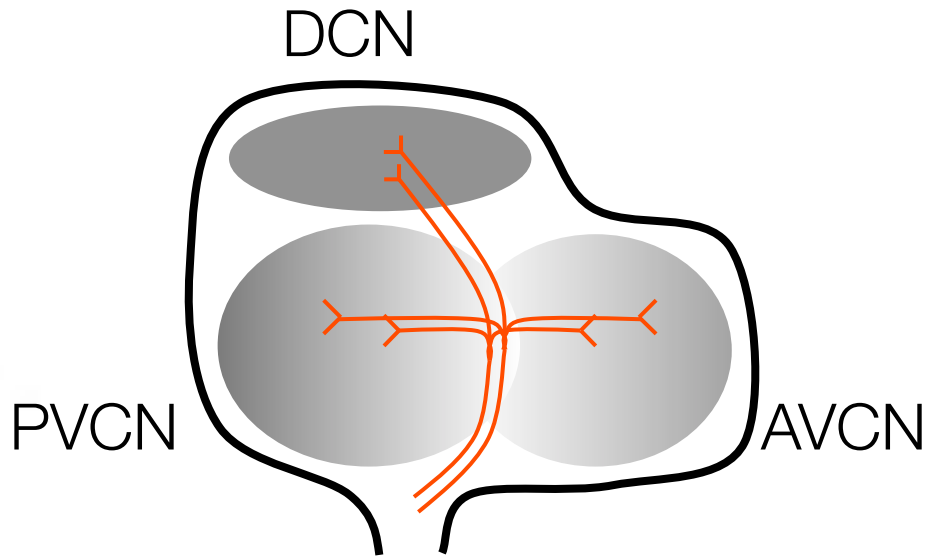


Modified from Grothe, Pecka, McAlpine (2010)

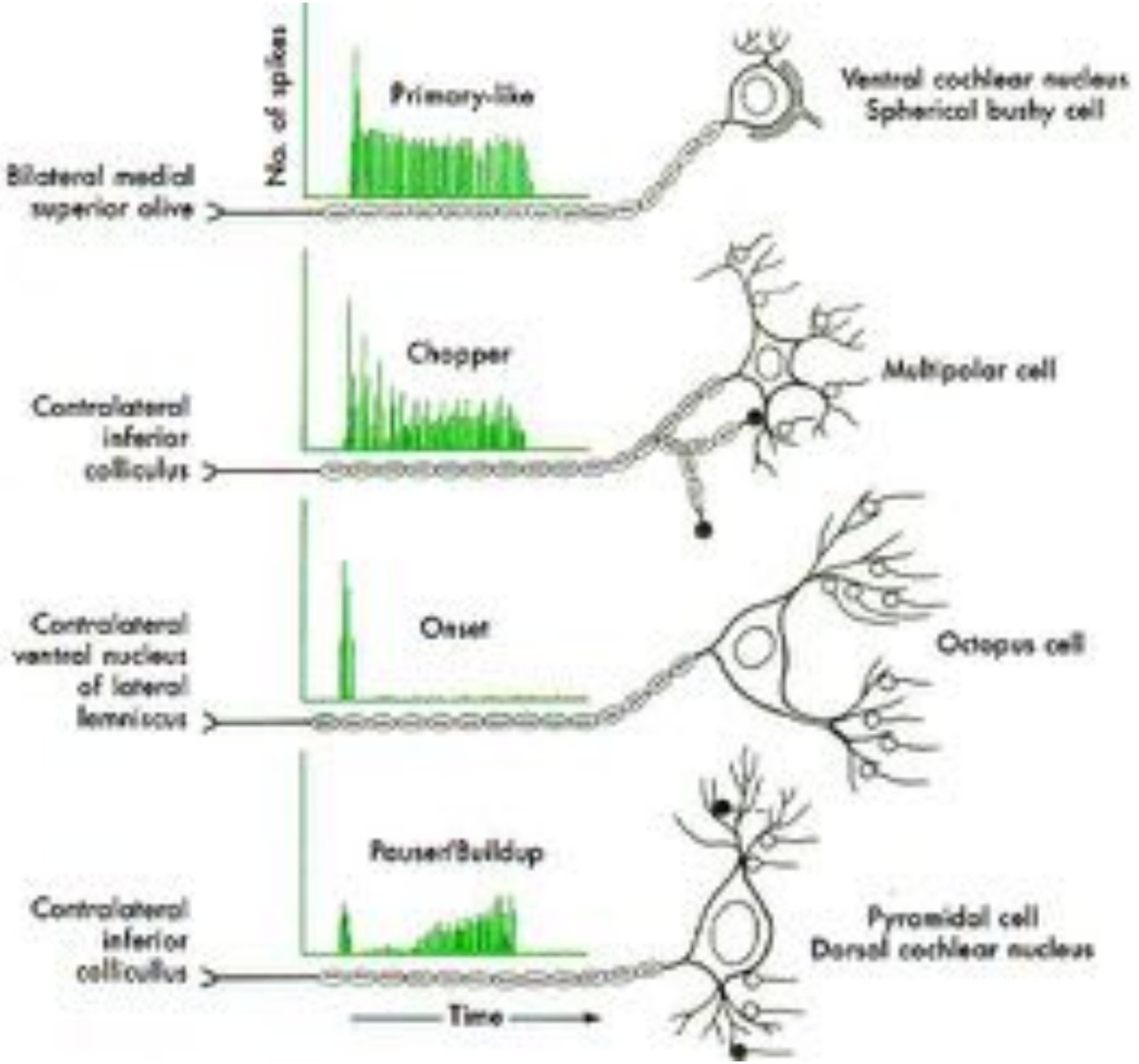
The nucleus cochlearis



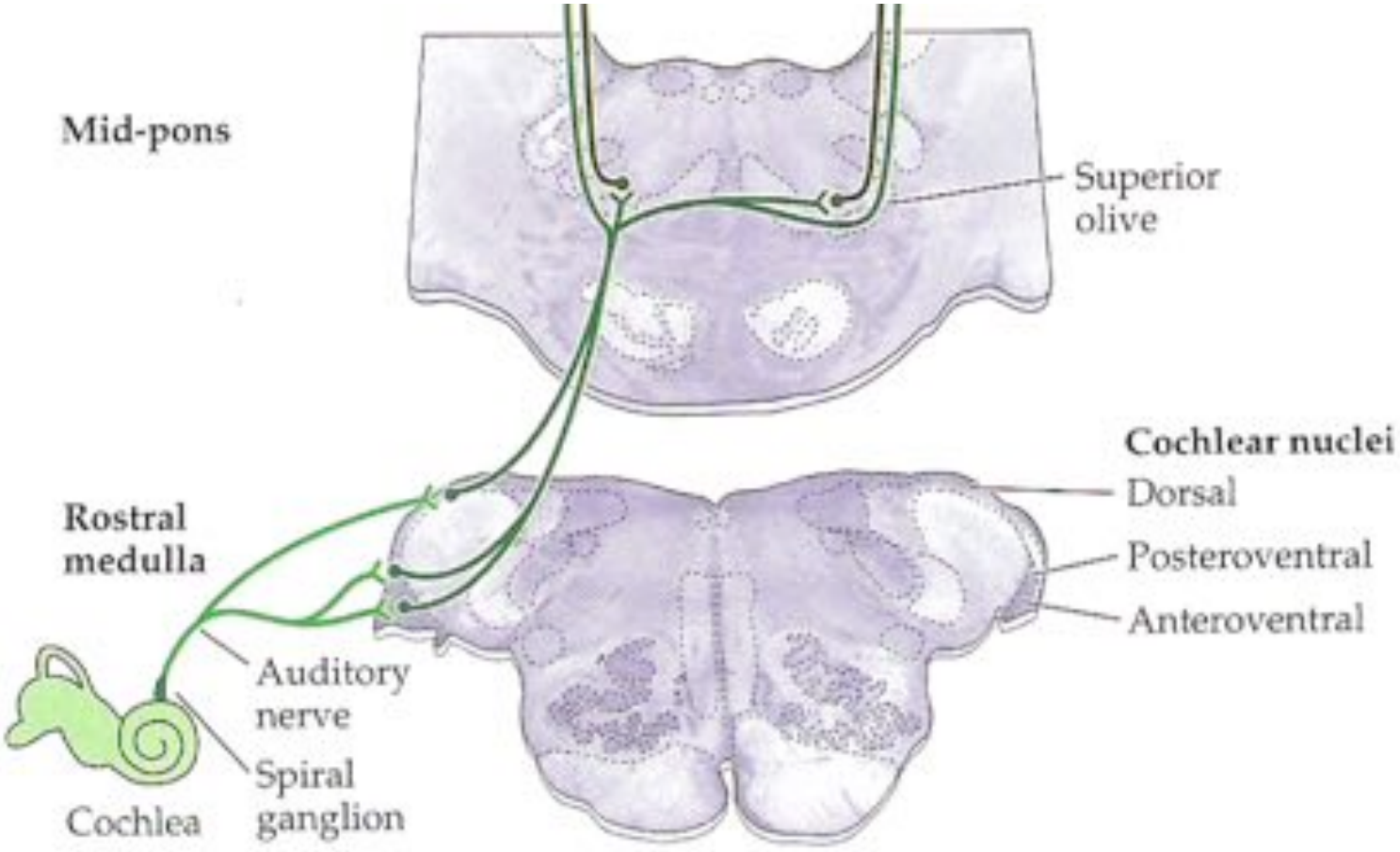




Response types and cell types in the nucleus cochlearis

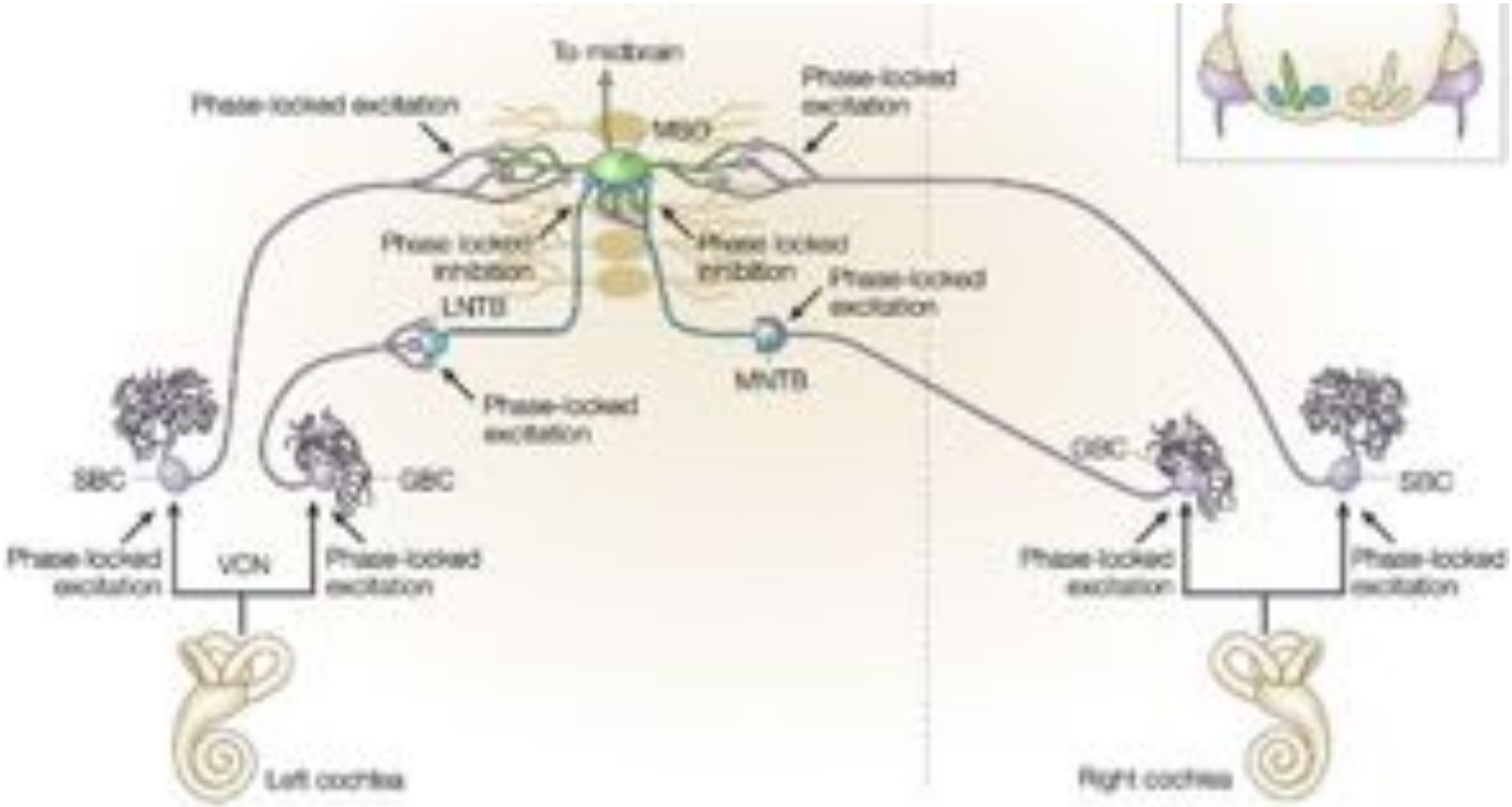


The superior olivary complex

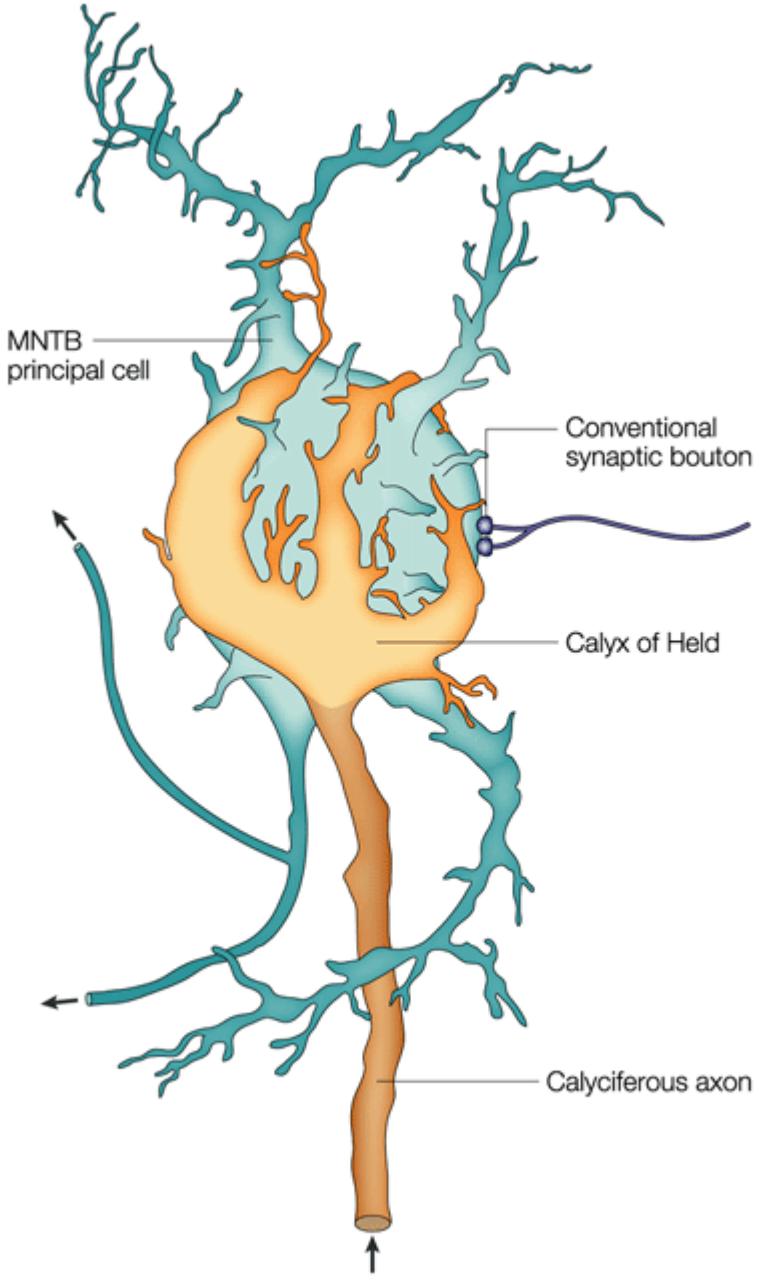


The superior olivary complex

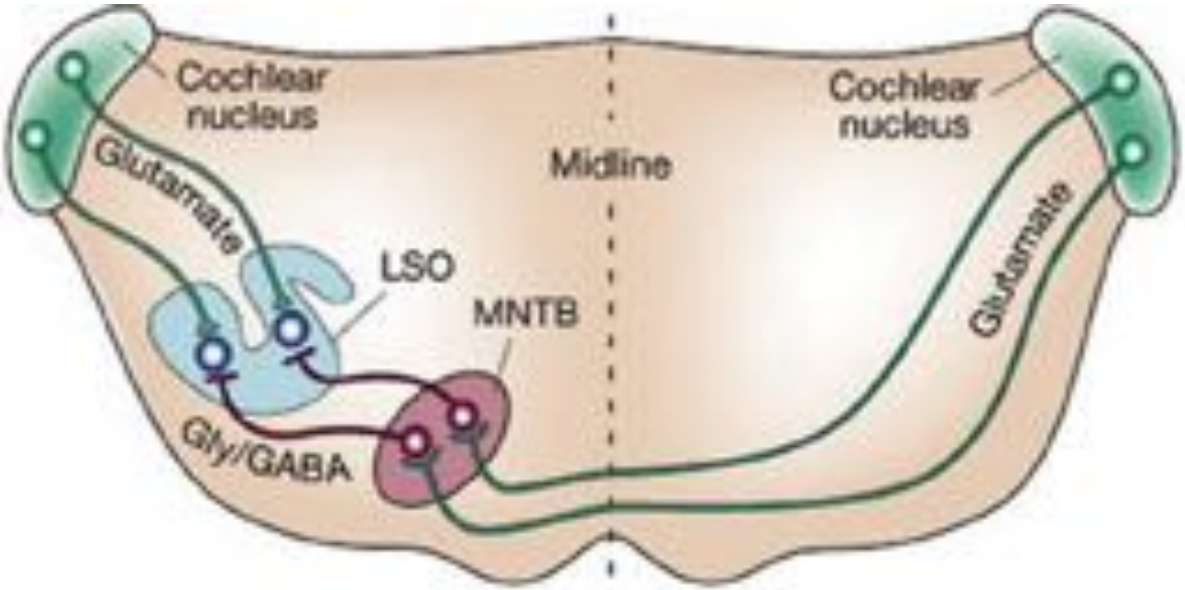
The MSO

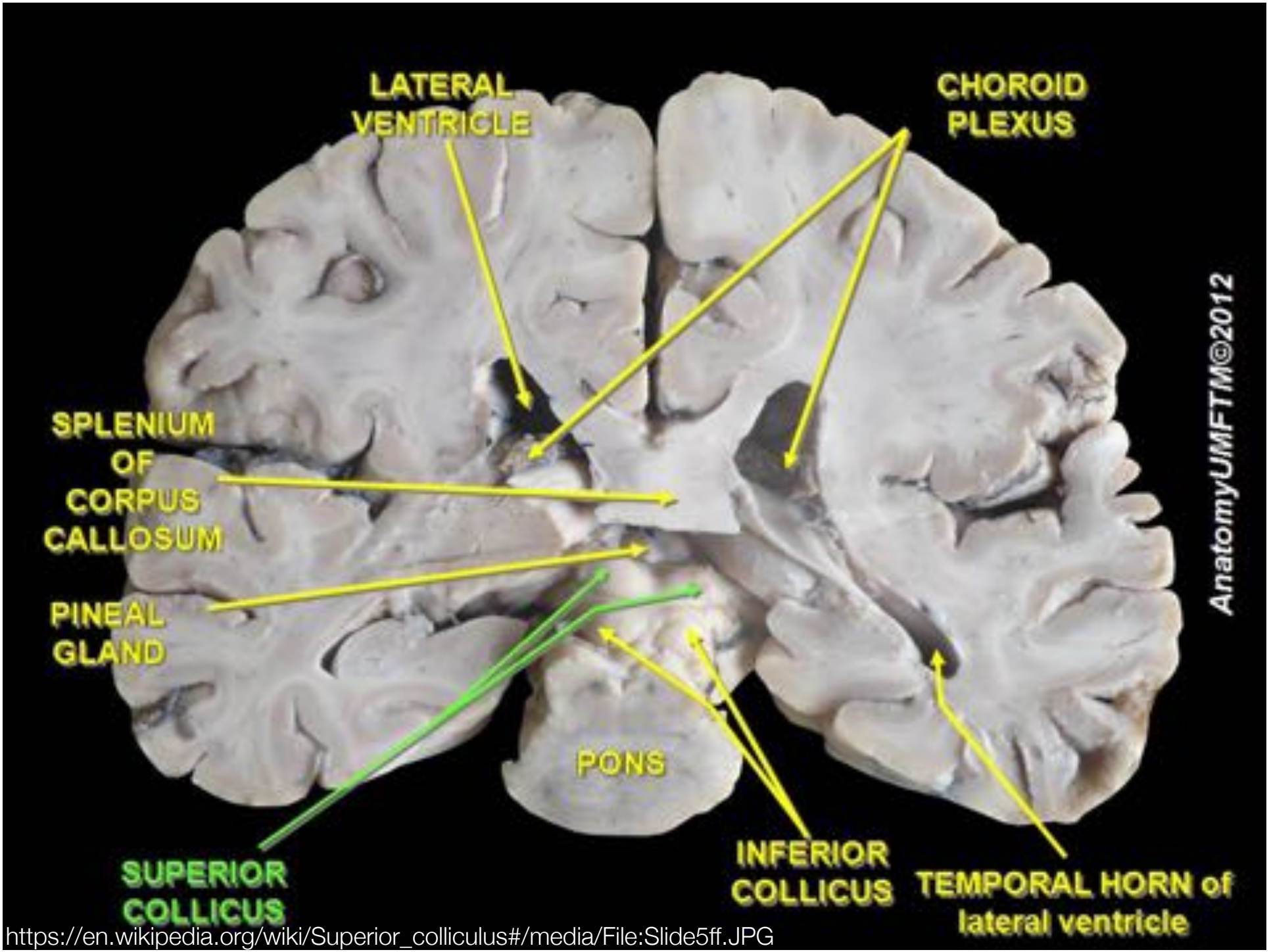

To midbrain
Phase-locked excitation
MSO
Phase-locked excitation
Phase locked inhibition
Phase locked inhibition
Phase-locked excitation
LNTB
MNTB
Phase-locked excitation
SBC
GBC
GBC
SBC
Phase-locked excitation
VCN
Phase-locked excitation
Phase-locked excitation
Phase-locked excitation
Left cochlea
Right cochlea

Gigantic synapses in the MNTB (calyx of Held)

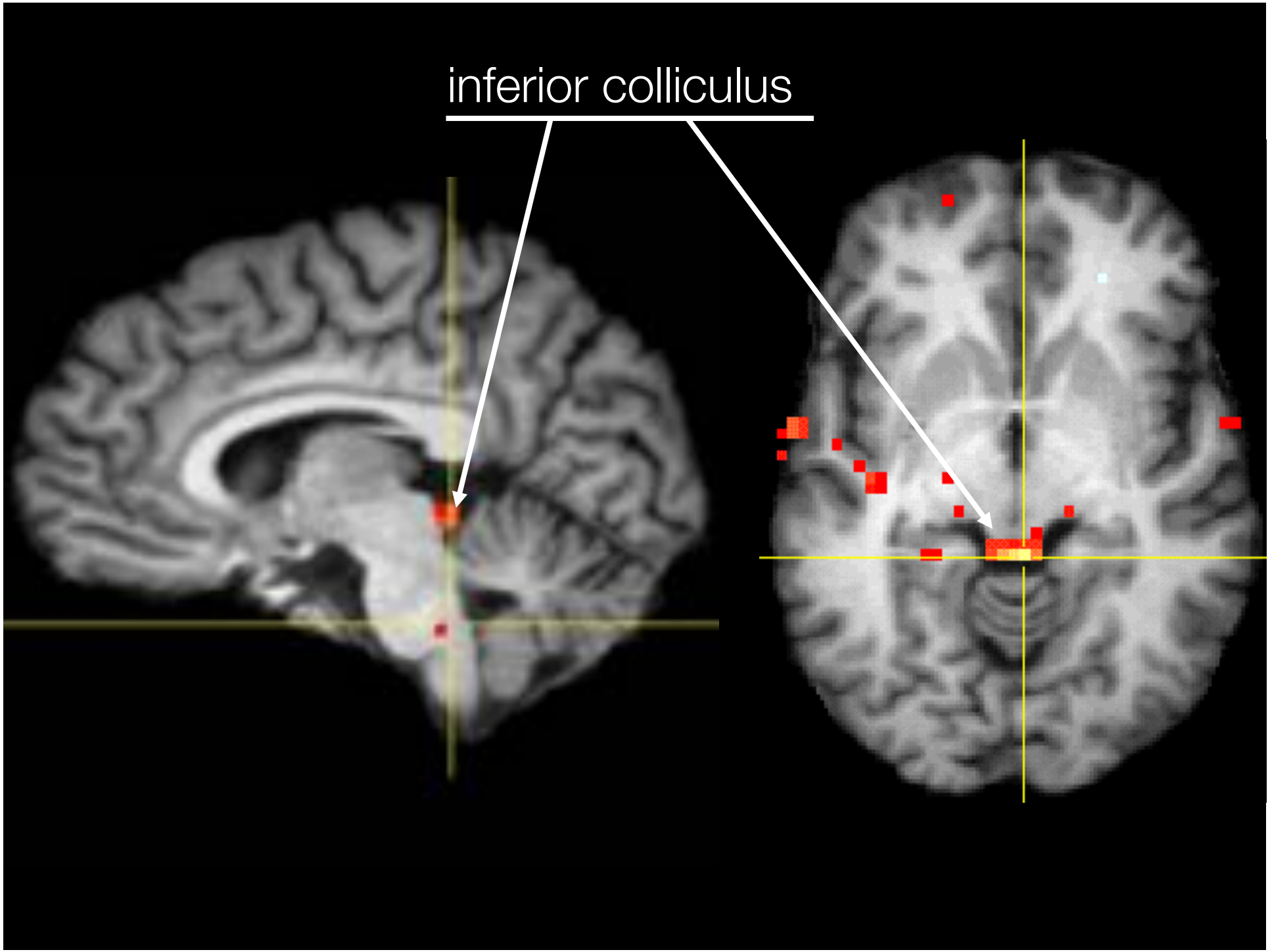


The LSO

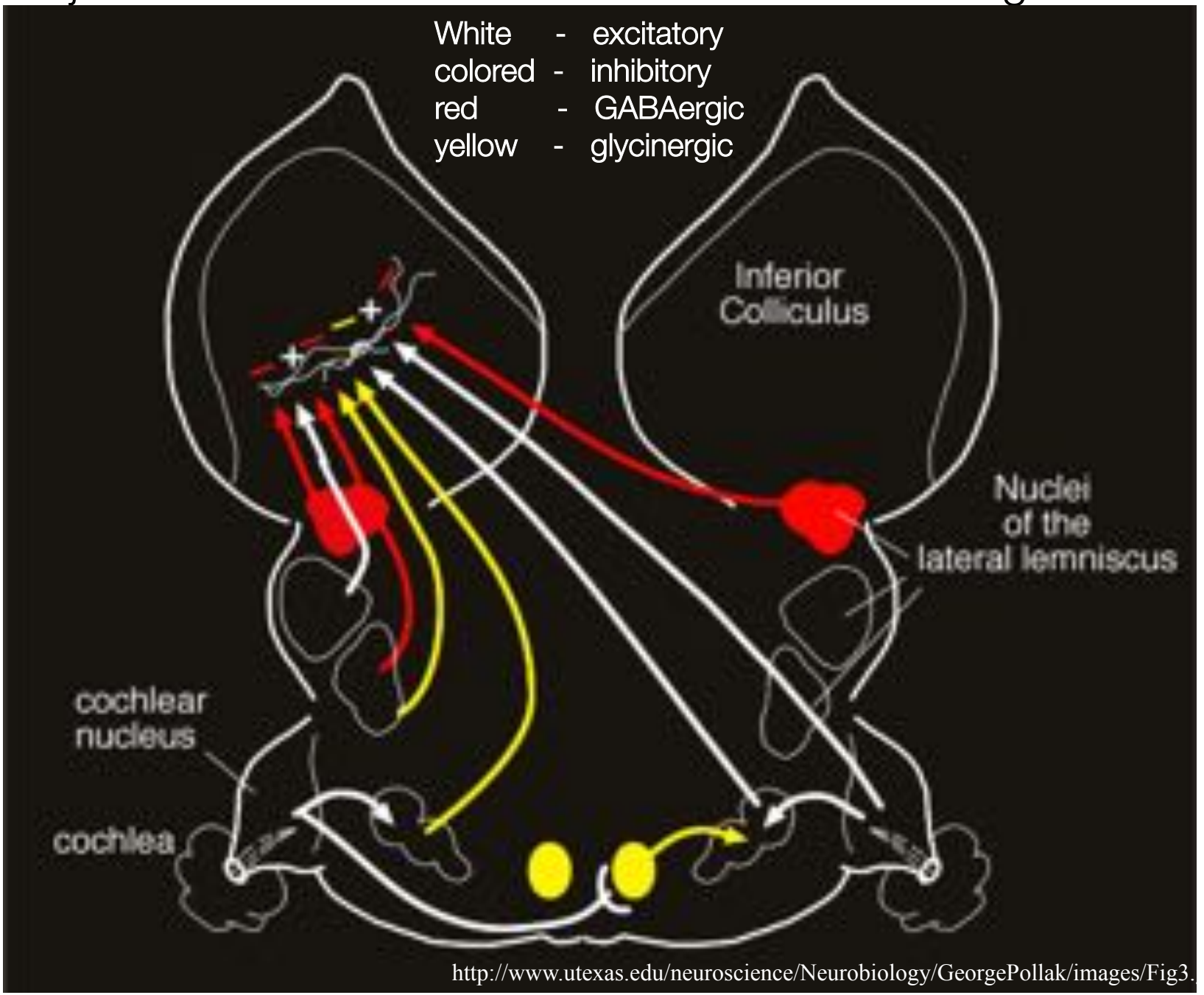

Cochlear nucleus
Midline
Cochlear nucleus
Glutamate
LSO
MNTB
Gly/GABA
Glutamate



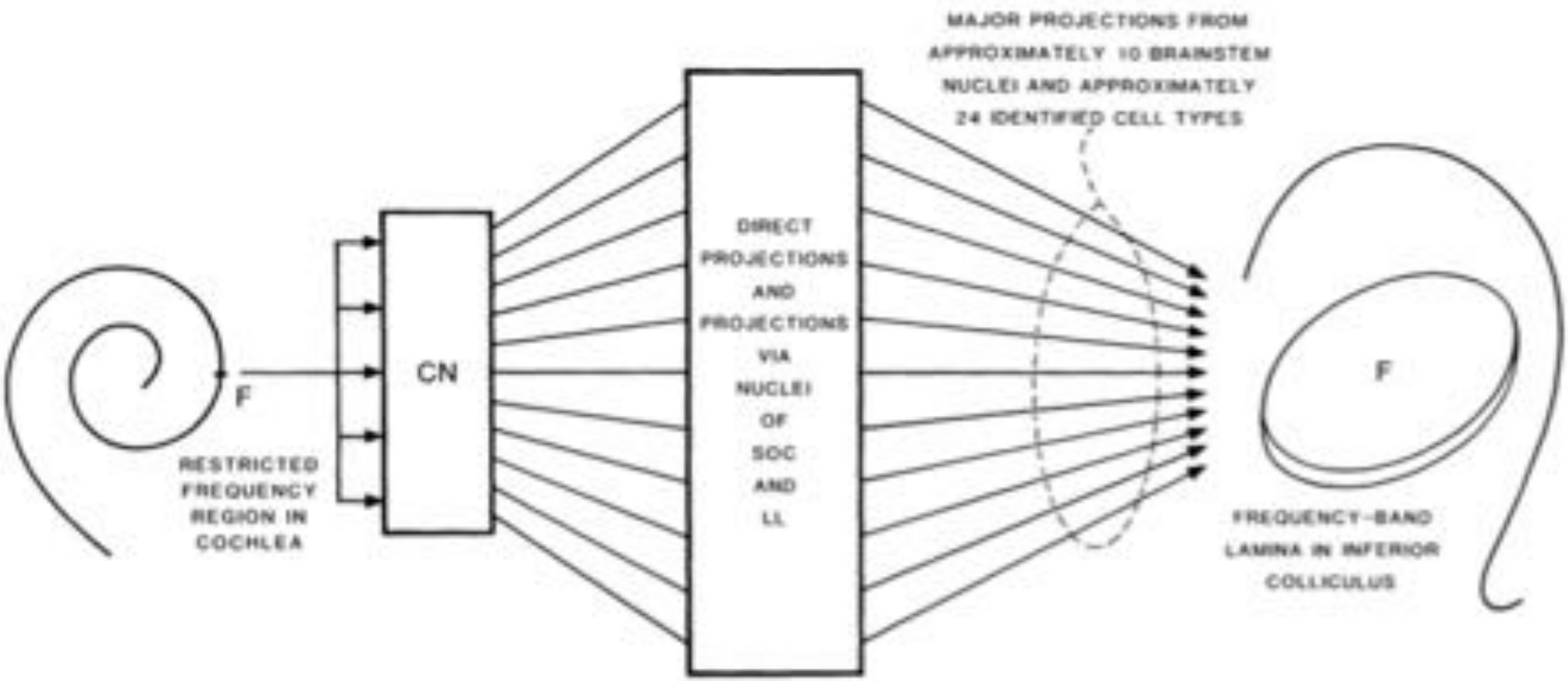
https://en.wikipedia.org/wiki/Superior_colliculus#/media/File:Slide5ff.JPG


inferior colliculus

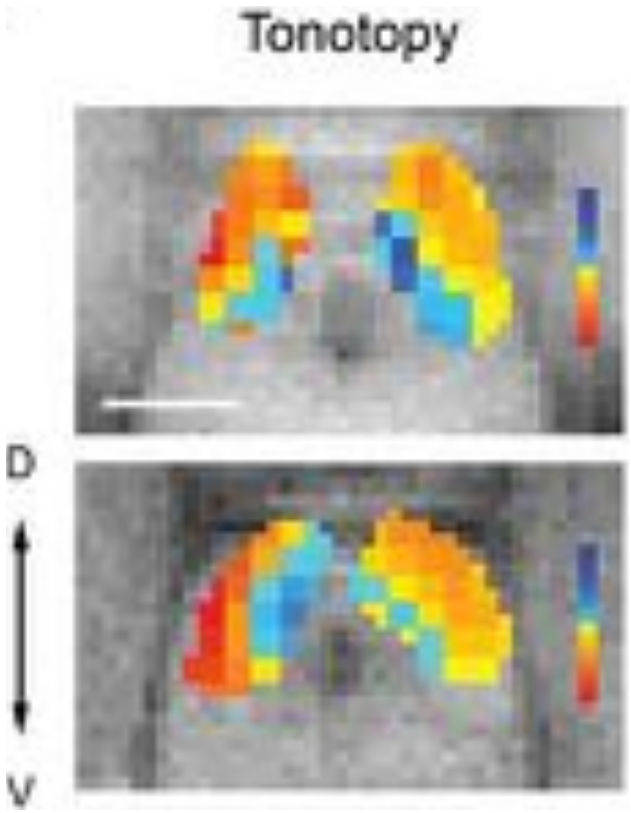
Projections from all lower brainstem nuclei converge in IC



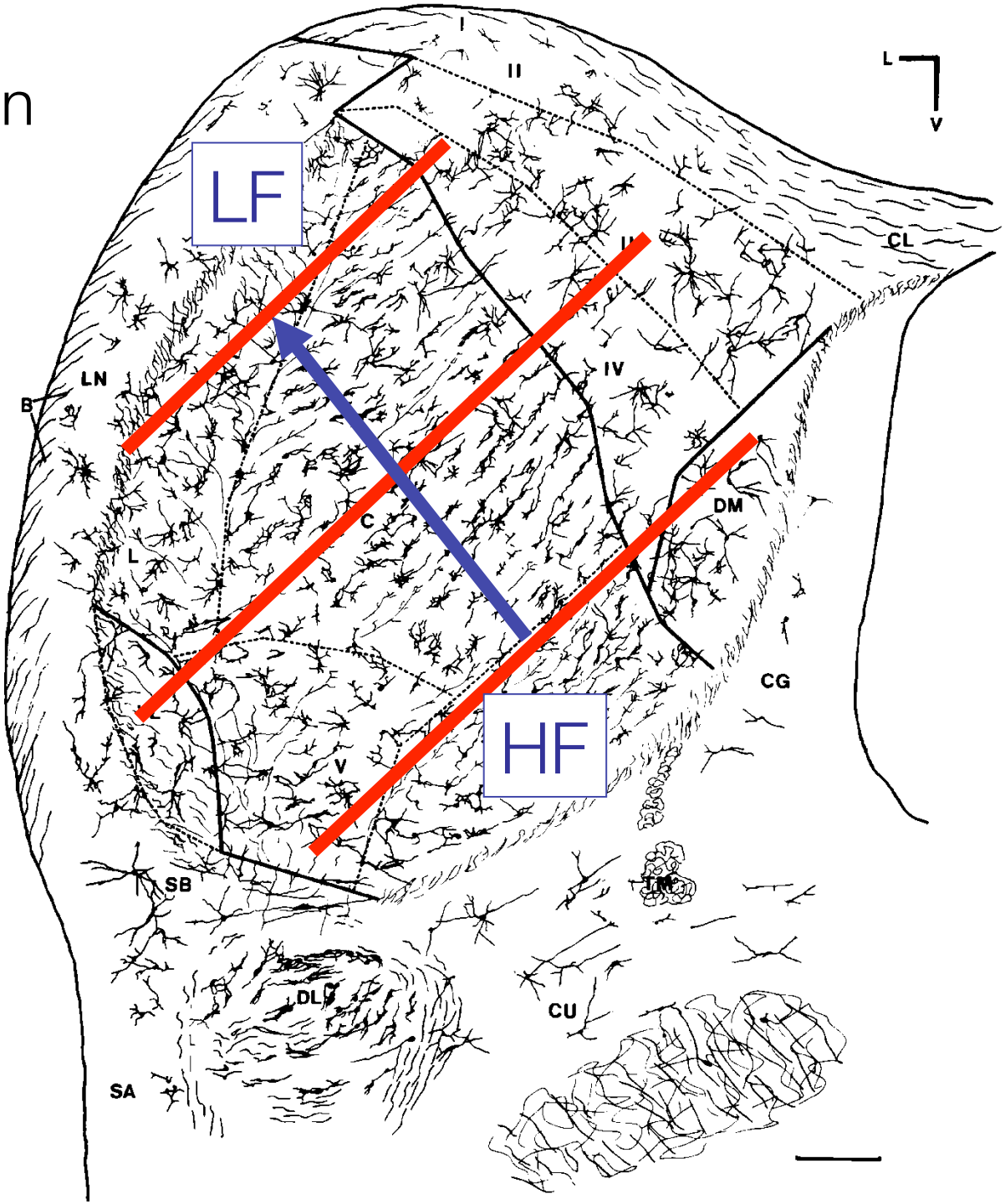
Projections from all lower brainstem nuclei converge in IC



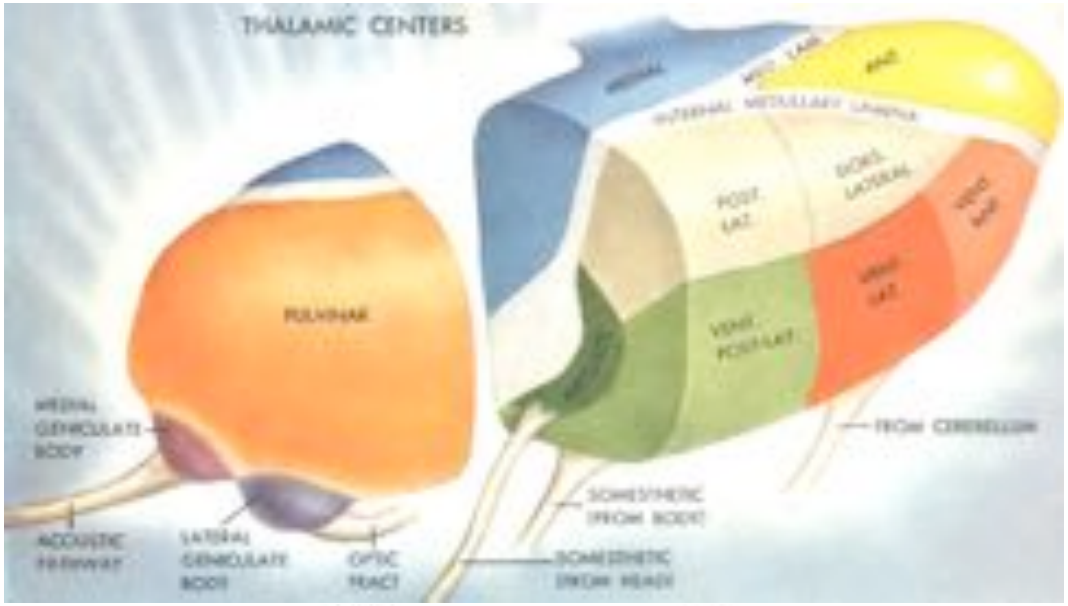
Internal organisation of the inferior colliculus

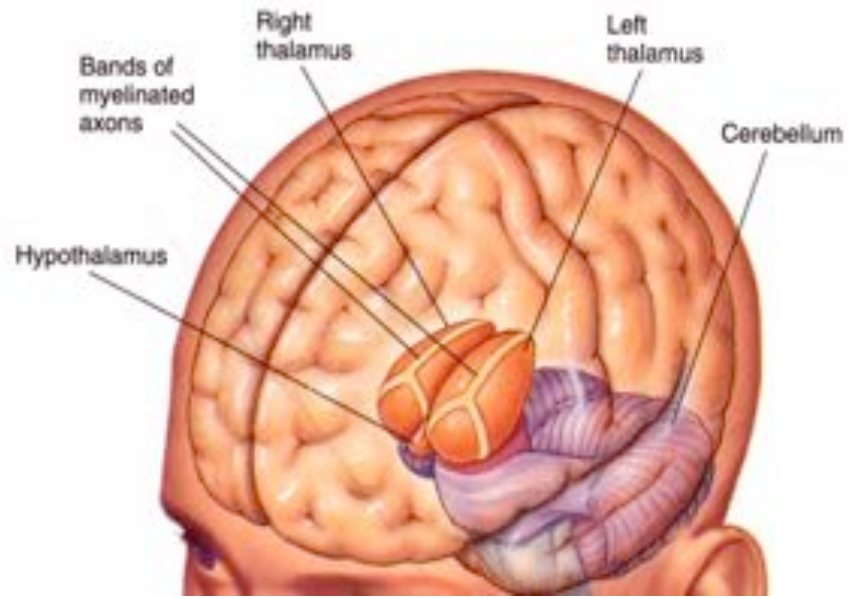


Baumann (2011) Na Neurosci



Thalamus

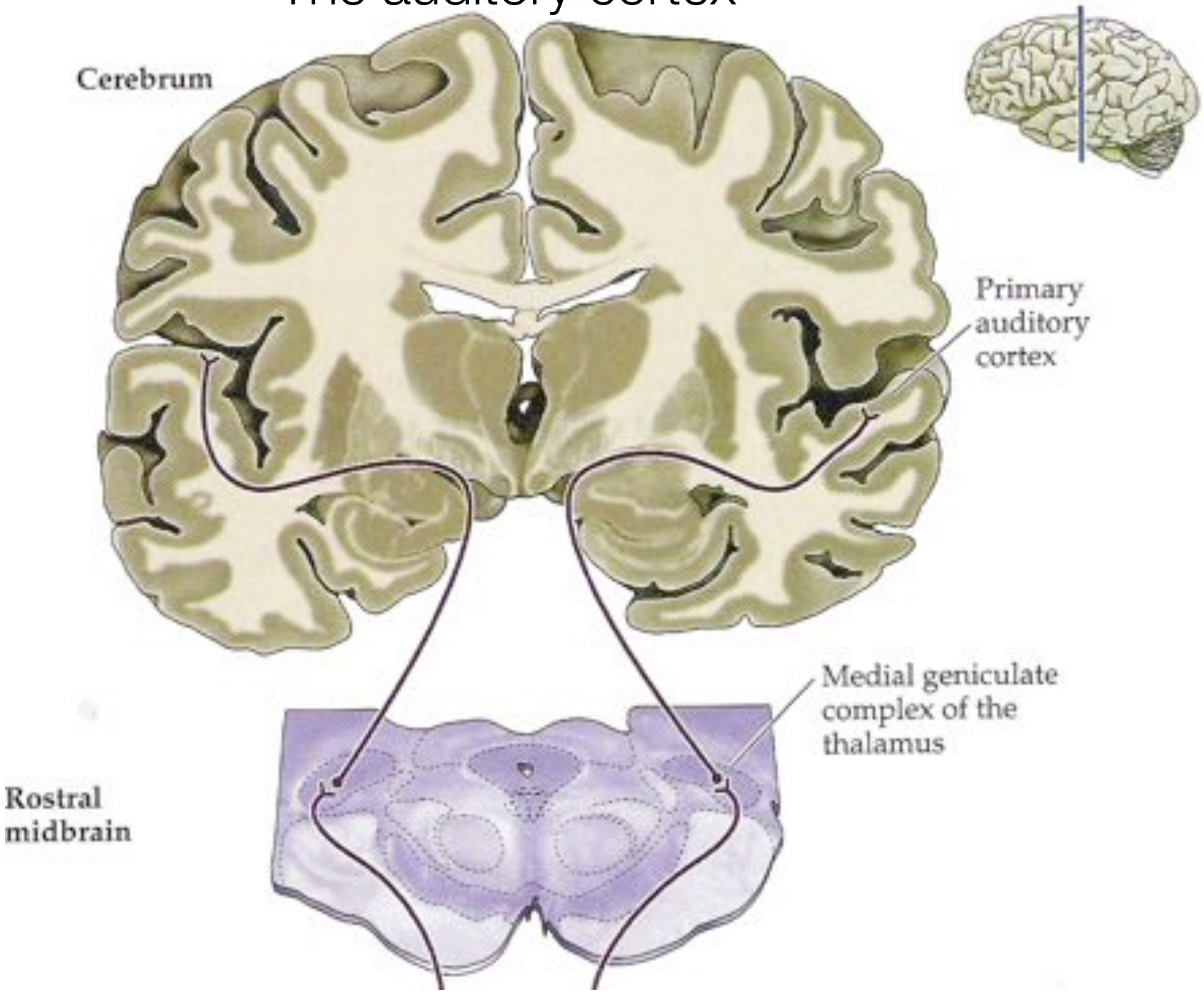


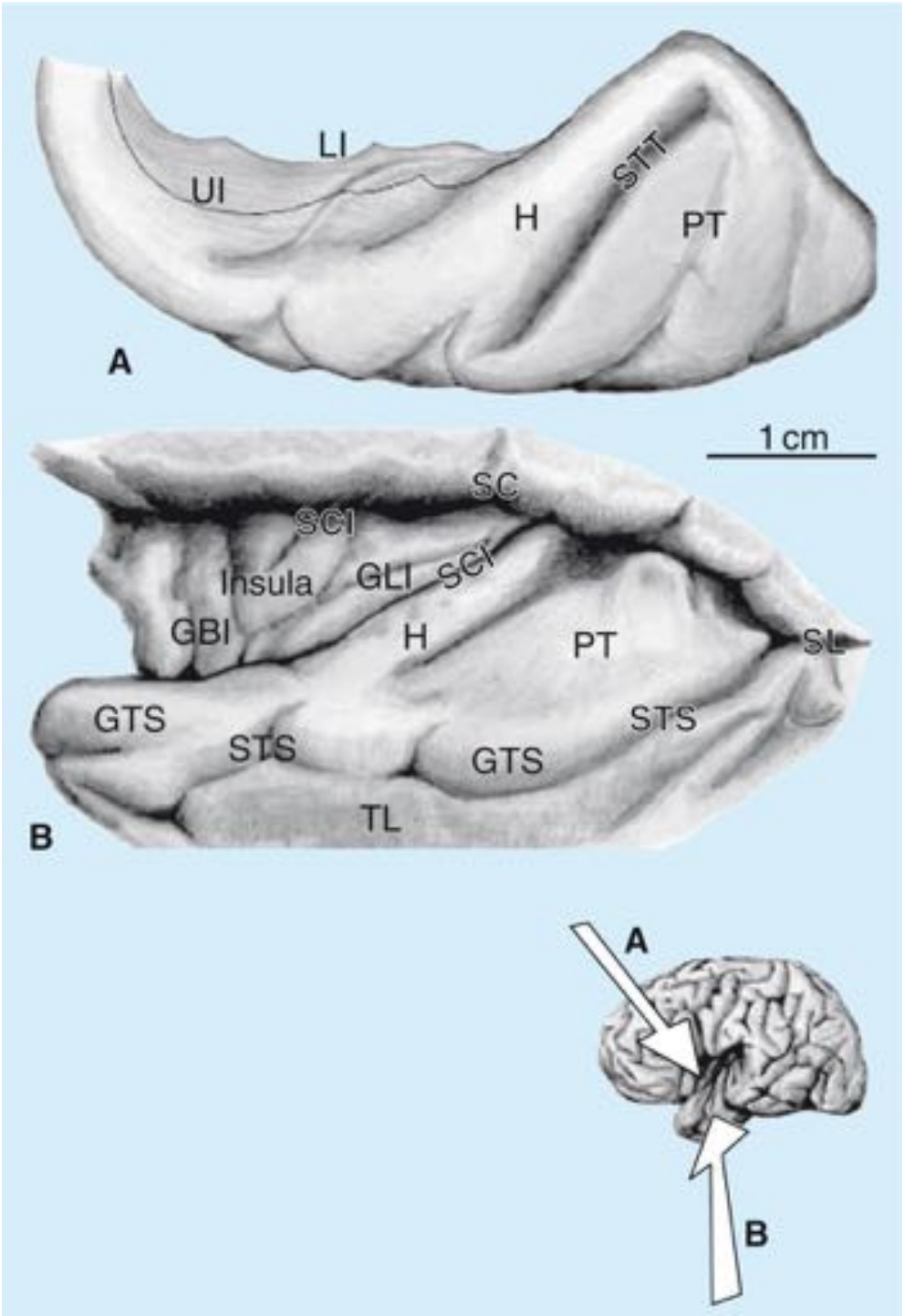


Sensory relay

- lateral geniculate → V1
- medial geniculate → A1
- ventral posterior → S1

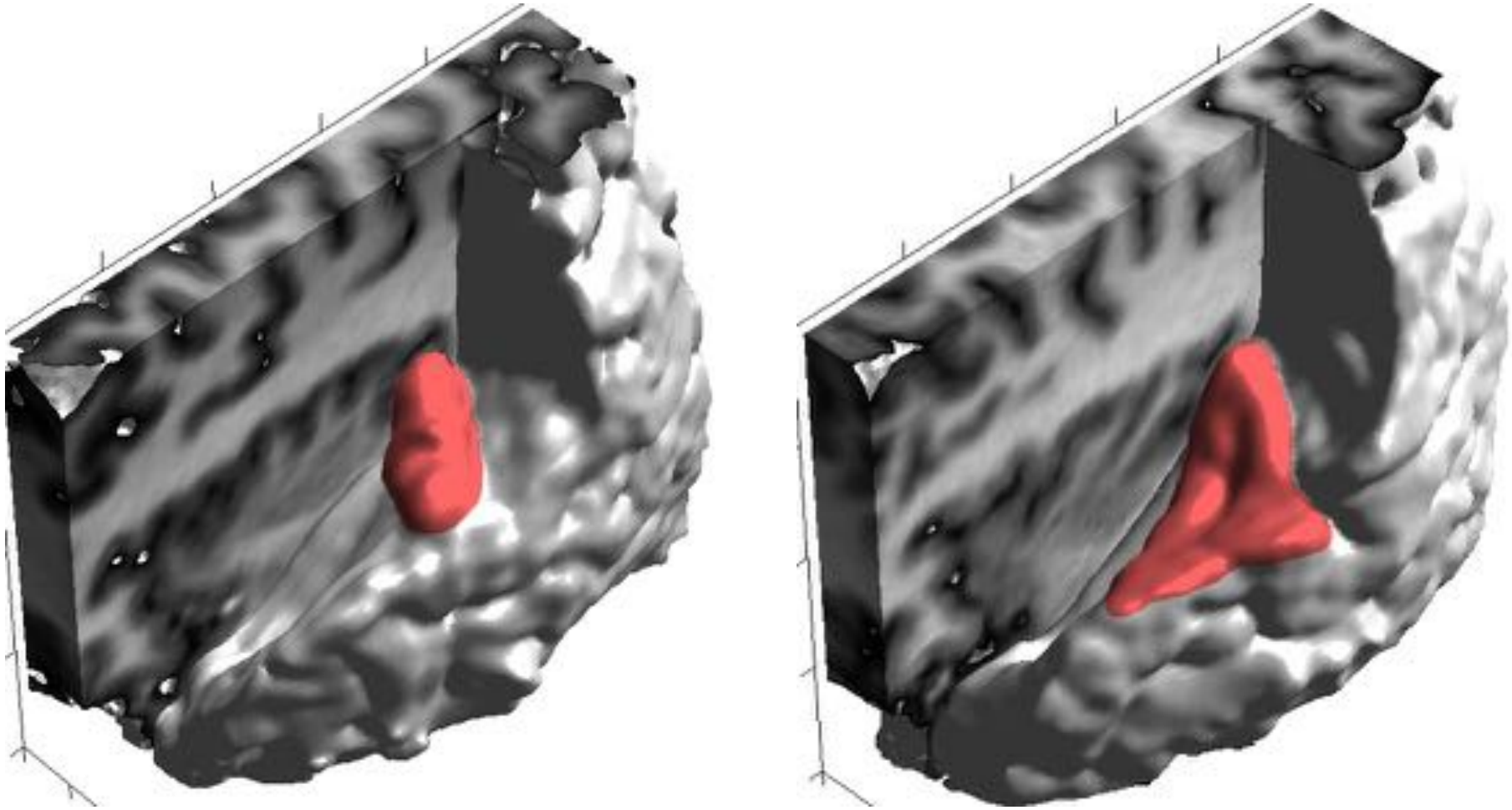
The auditory cortex

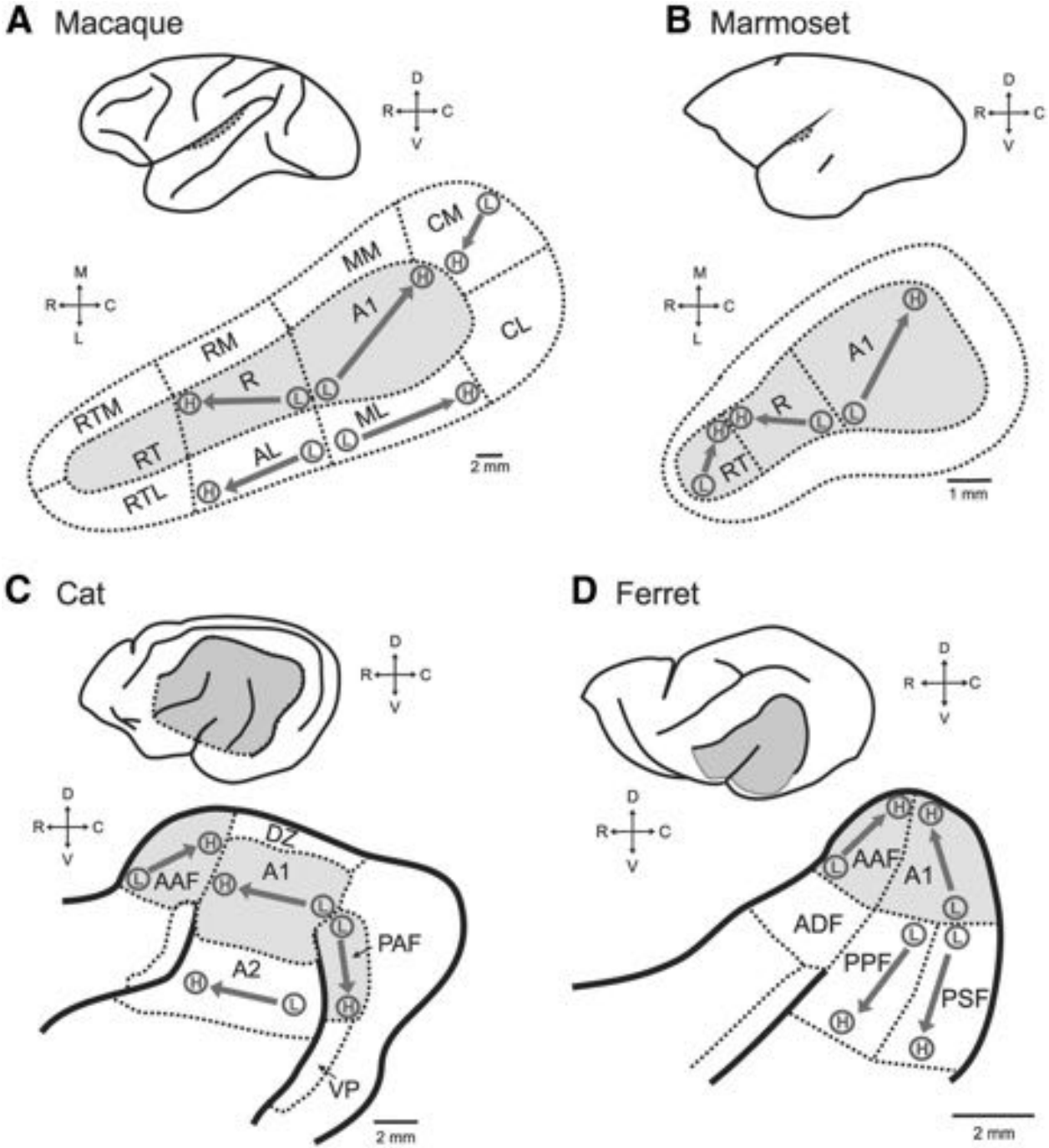


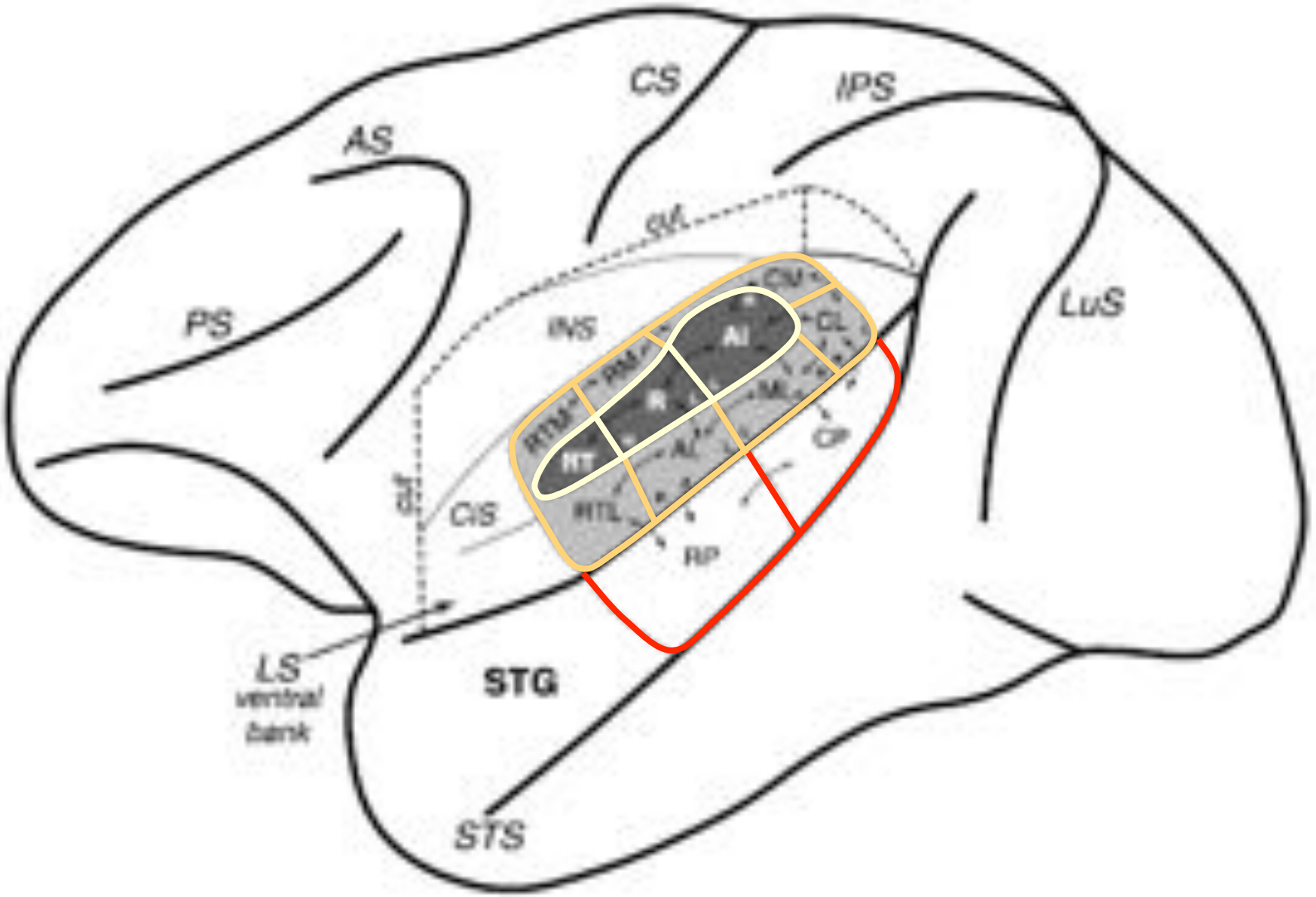


H	Heschl's gyrus
PT	Planum temporale

The shape and size of Heschl's gyrus is highly variable

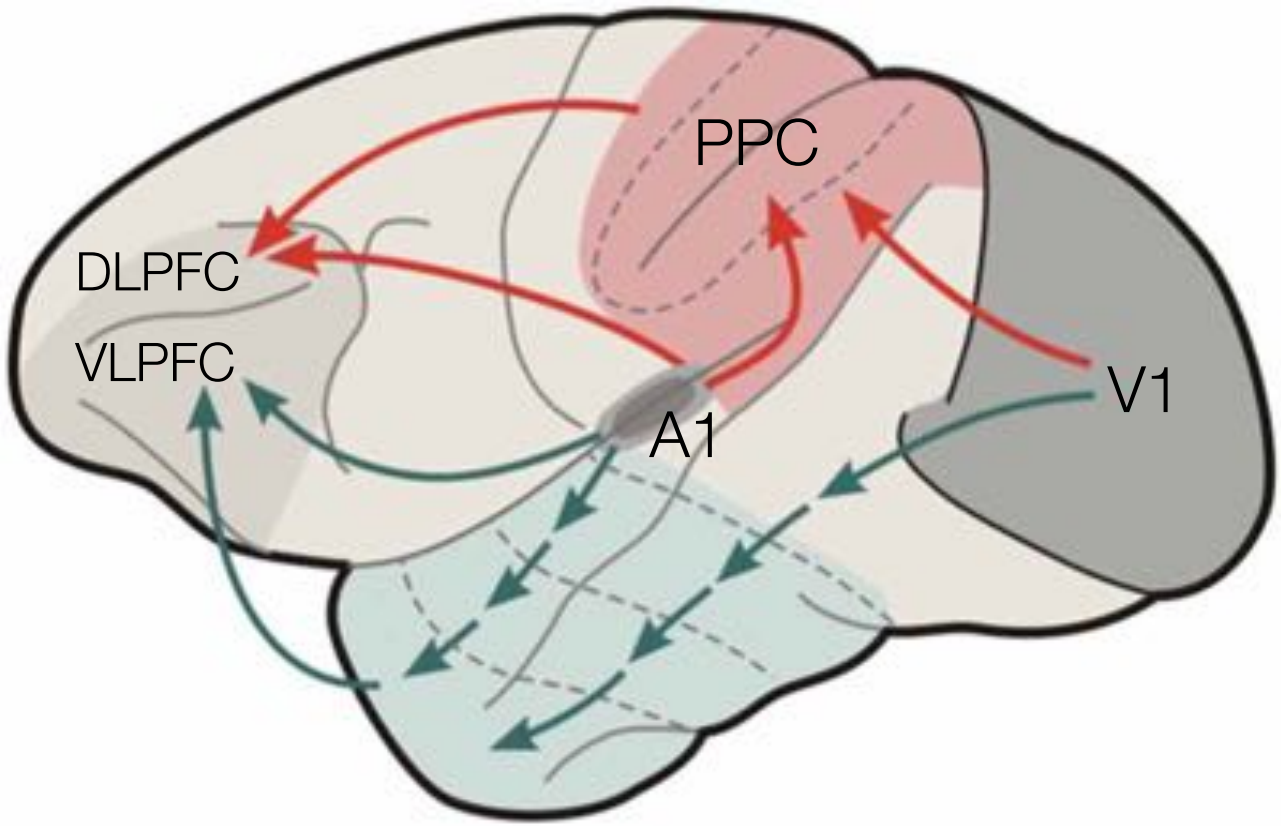



A Macaque
D
R
C
V
M
L
CM
MM
A1
CL
RM
R
RTM
RT
RTL
AL
ML
2 mm
B Marmoset
1 mm
C Cat
DZ
AAF
A1
PAF
A2
VP
2 mm
D Ferret
AAF
A1
ADF
PPF
PSF
2 mm


CS
IPS
AS
SM
PS
INS
LuS
CM
CL
AI
RM
R
ML
RTM
RT
AL
CP
RTL
RP
ctf
CIS
LS
ventral
bank
STG
STS

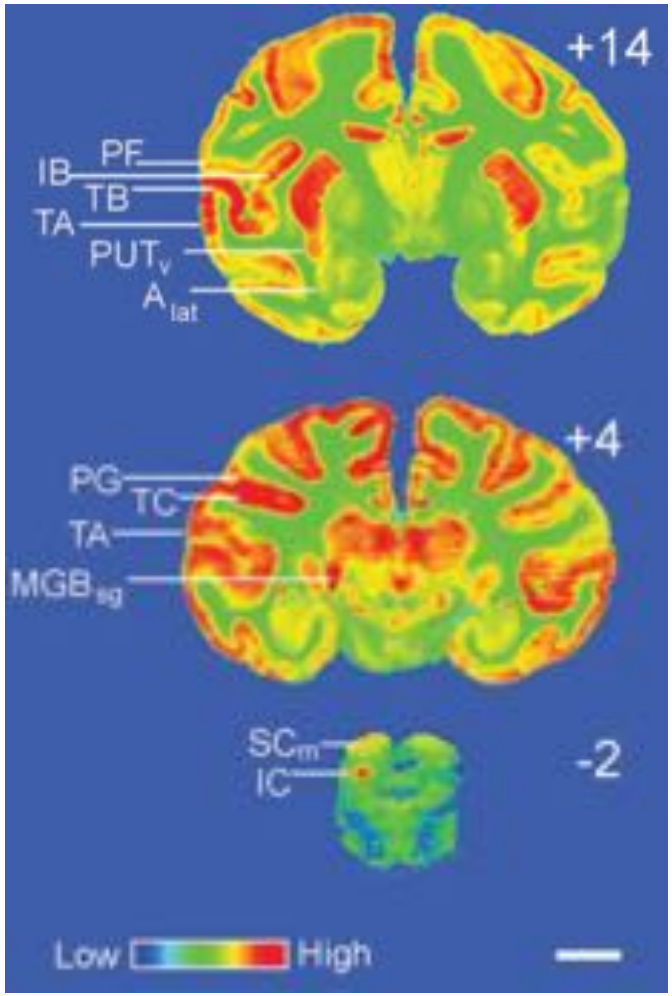
‘What’ and ‘where’ pathways

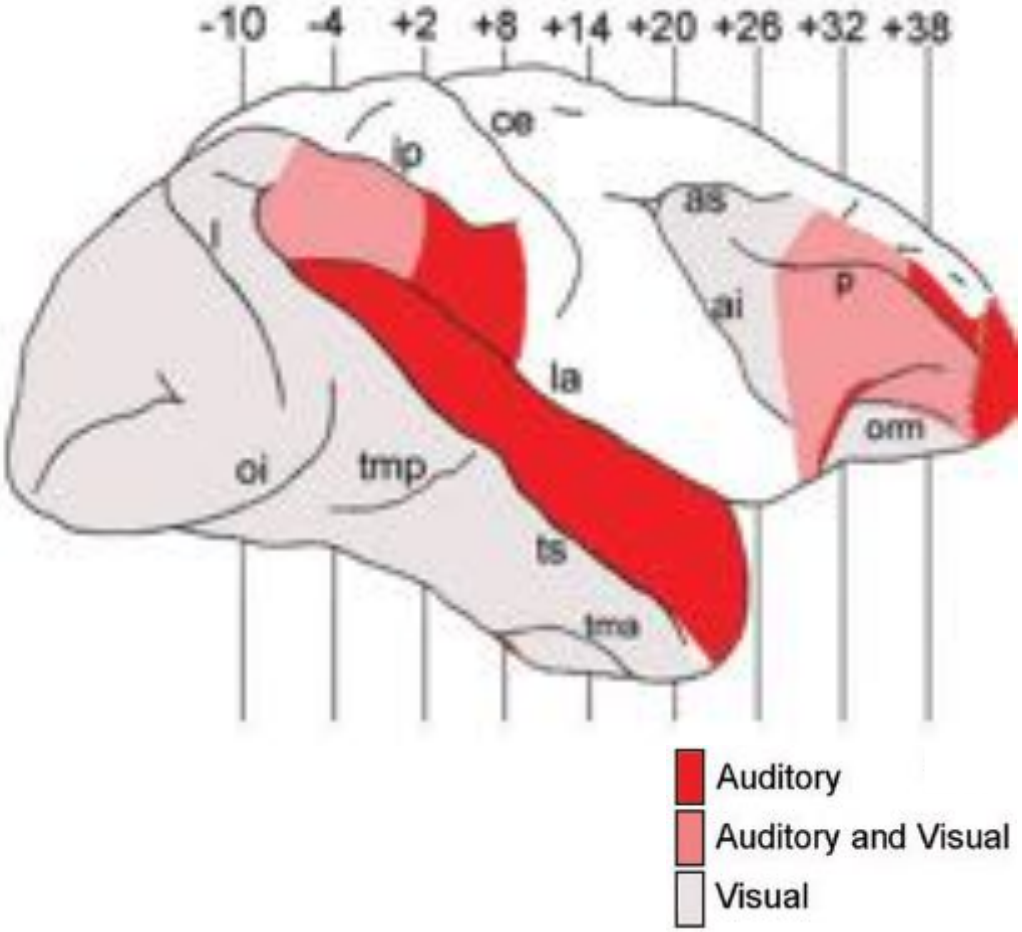
Parietal lobe: ‘where’



Temporal lobe: ‘what’

The Primate Cortical Auditory System





Poremba 2003, Science