Au plus près de la cochlée. Certitudes et questions

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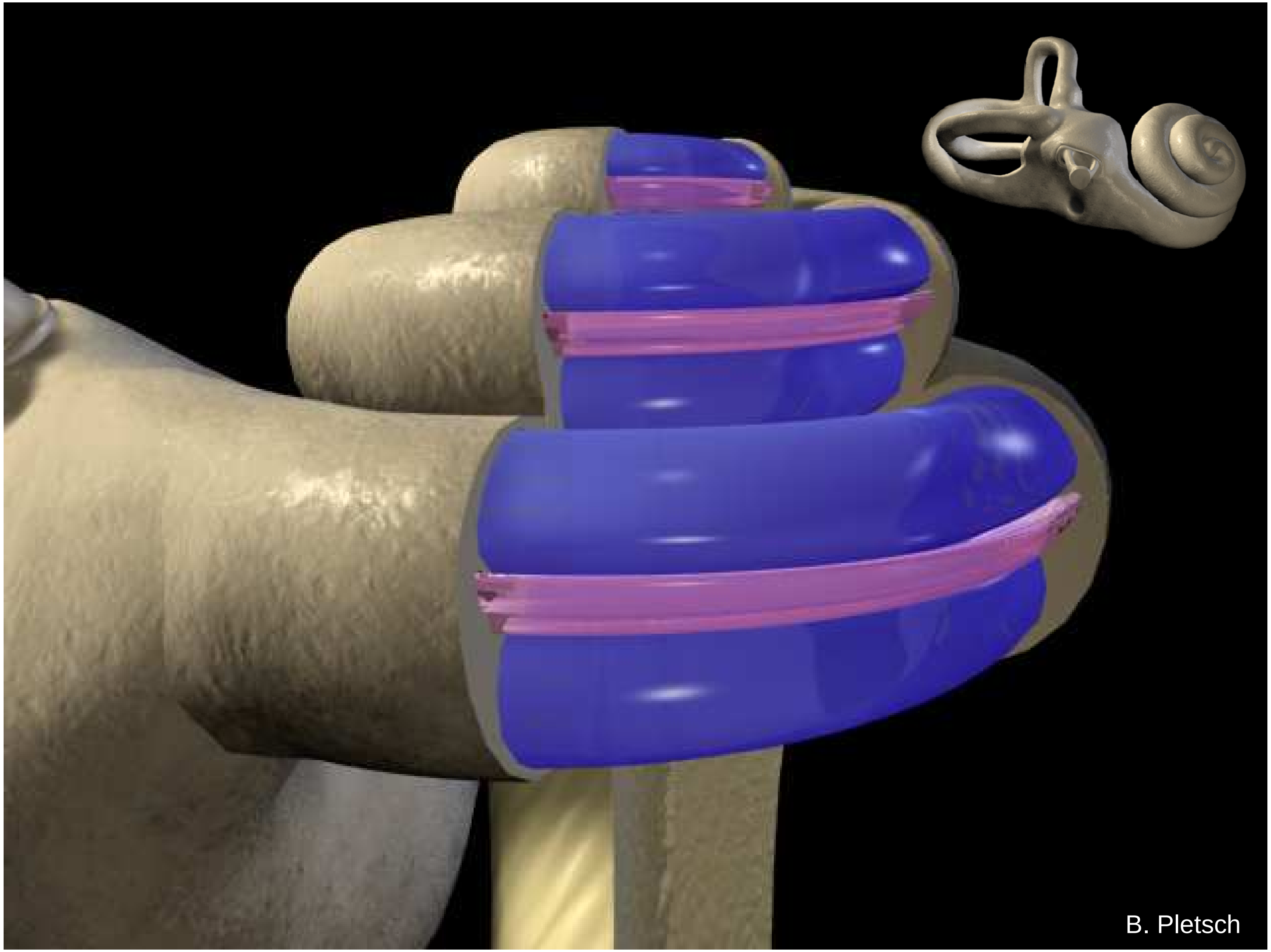
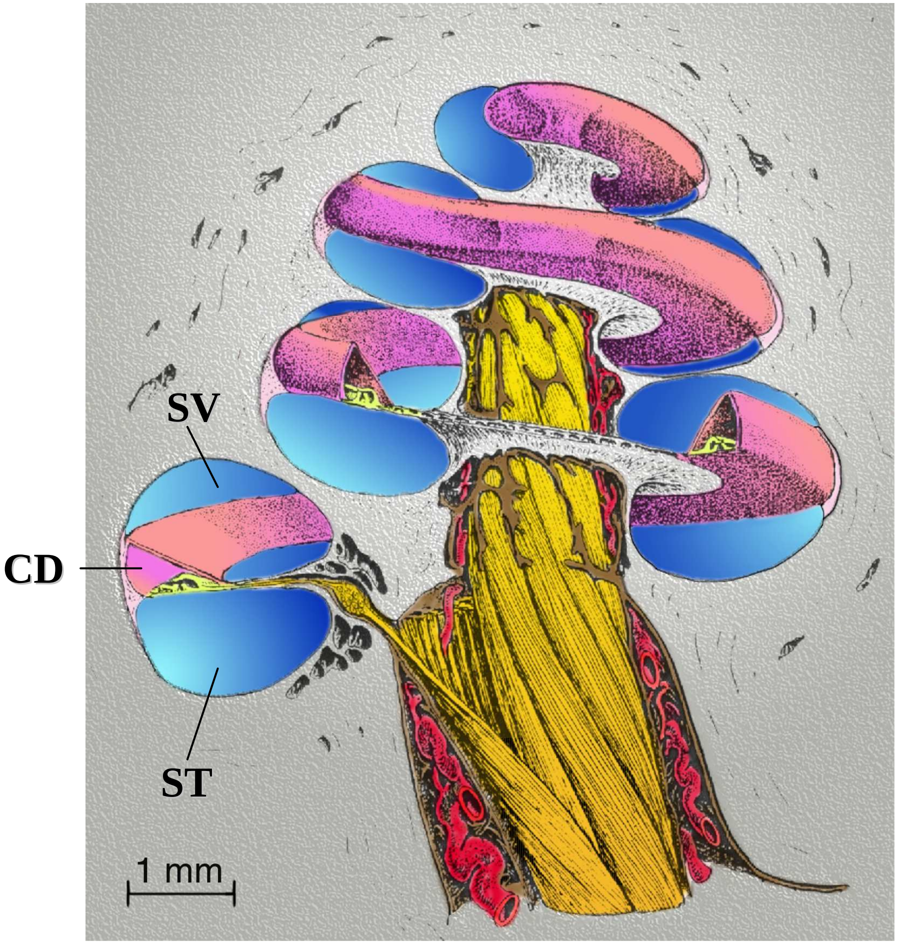
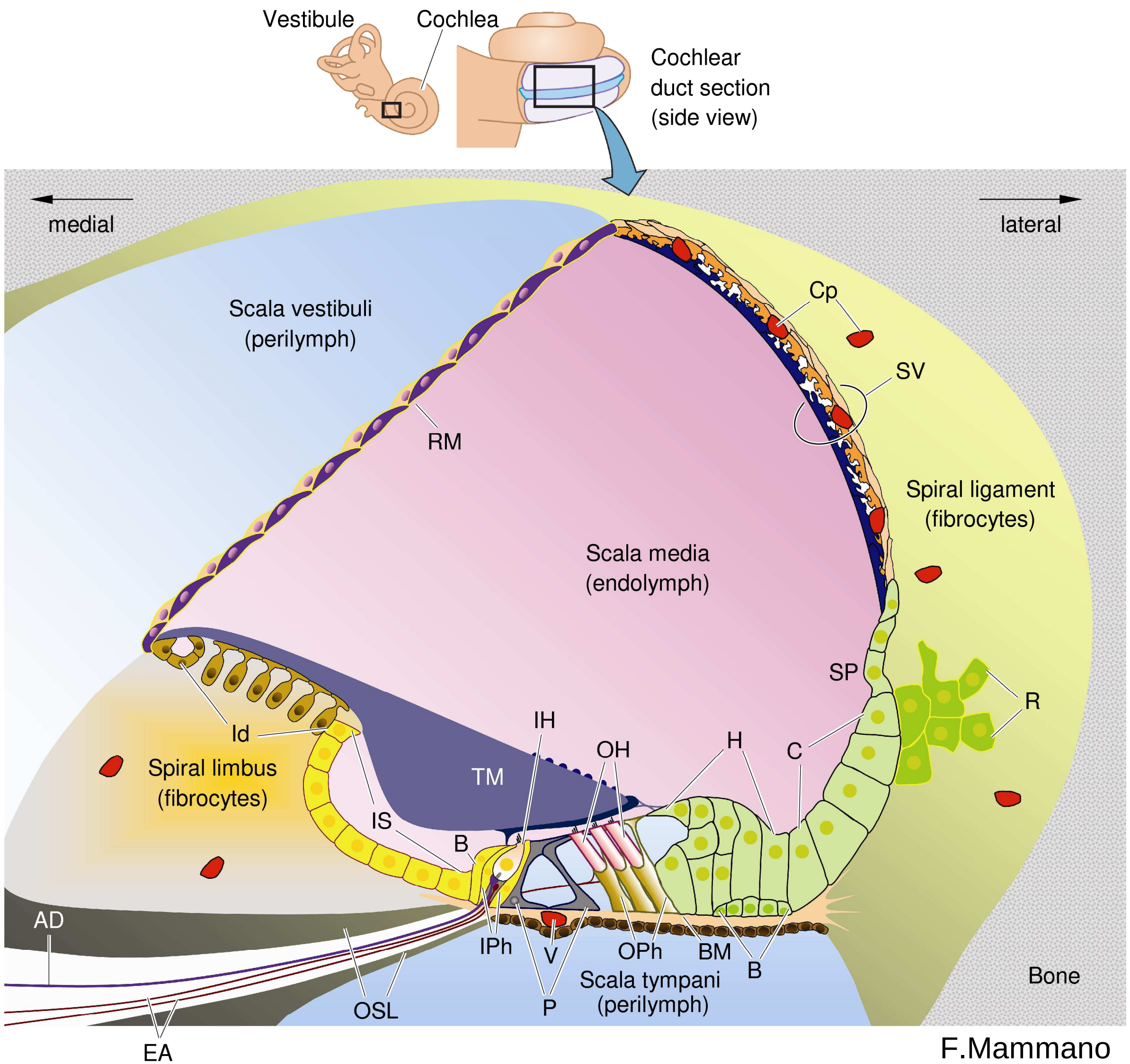
The cochlea is a fluid-filled tube which contains the cochlear duct



SV: scala vestibuli
ST: scala tympani
CD: cochlear duct





The **cochlear duct** or **scala media** is a canal shut off between the scala tympani below and the scala vestibuli above. It is triangular on transverse section, its roof being formed by **Reissner's membrane (RM)**, its outer wall by the **stria vascularis** (SV), and its floor by the **basilar membrane** (BM) and the outer part of the **osseous spiral lamina** (OSL). The basilar membrane supports the **organ of Corti**, where **sensory hair cells** are located.

Basilar membrane

The **basilar membrane** stretches from the tympanic lip of the osseous spiral lamina to the basilar crest and consists of two parts. The inner is thin, and is named the **pars arcuata.** The outer is thicker and striated, and is termed the **pars pectinata.** The under surface of the membrane is covered by a layer of vascular connective tissue; one of the vessels in this tissue is somewhat larger than the rest, and is named the **vas spirale;** it lies below Corti's tunnel.

162 *L. M. Cabezudo*

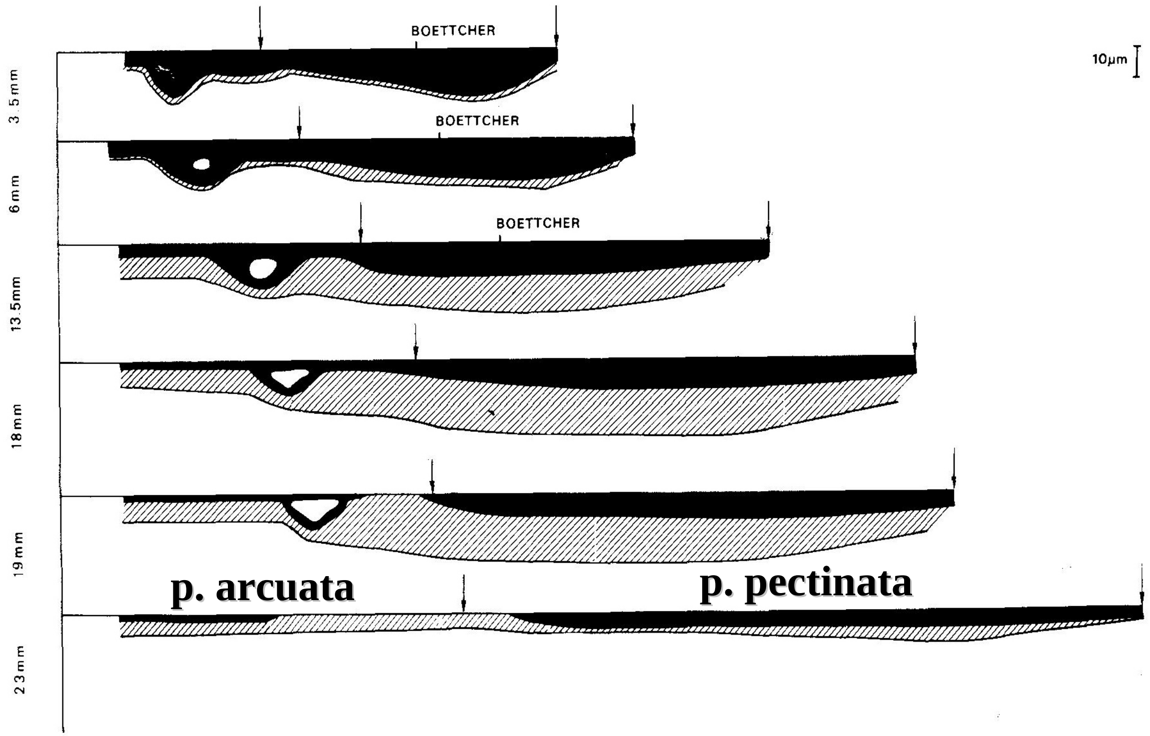


Fig. 2. Schematic drawing showing the variation in thickness of the basilar membrane along the cochlear duct at six different points in the same cat. The black and shaded portions represent the outline of the homogeneous ground substance with the filaments included and the area occupied by the mesothelial cells, respectively. The vertical axis corresponds to the distance from the base in mm. In each case the arrow on the right side indicates the basilar crest and the left arrow indicates the demarkation between the pars tecta and the pars pectinata.

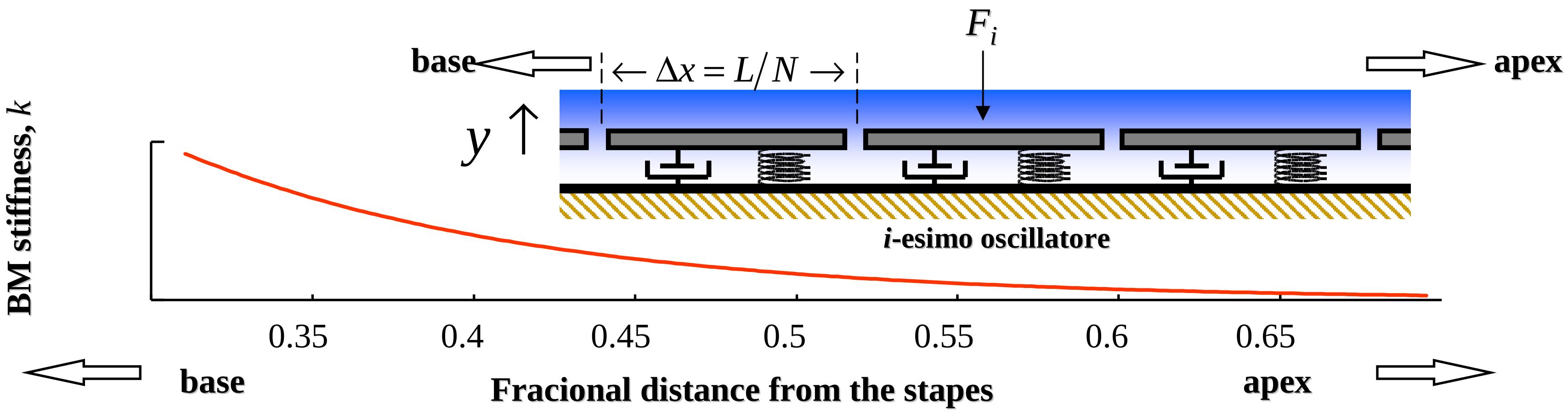
A mechanical model for the basilar membrane

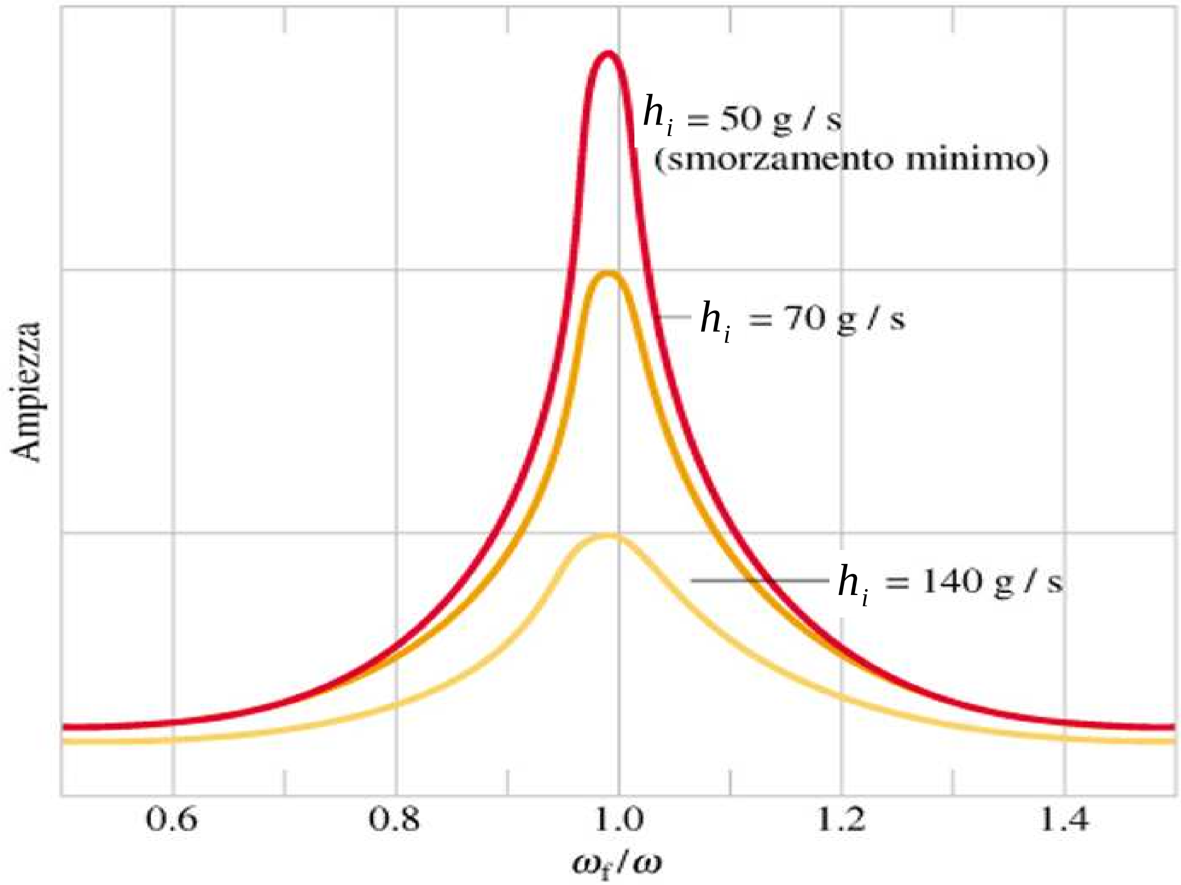
The elastic basilar membrane supports the spiral organ of Corti that, in humans, can be subdivided into approximately $N = 3600$ transversal segments.

The i-th segment may be further schematized as a damped harmonic oscillator driven by **fluid pressure forces**

$$m_i a_i + h_i v_i + k_i y_i = F_i$$

Motion equation for the i-th oscillator driven by the force F_i

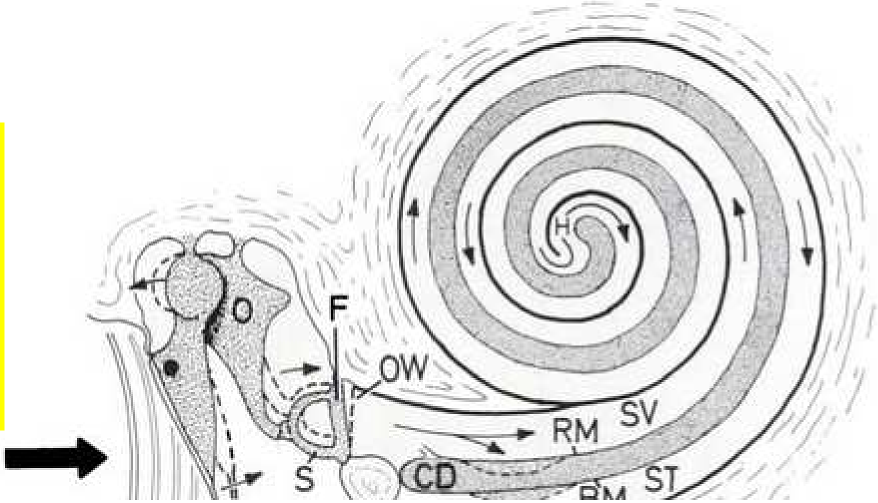


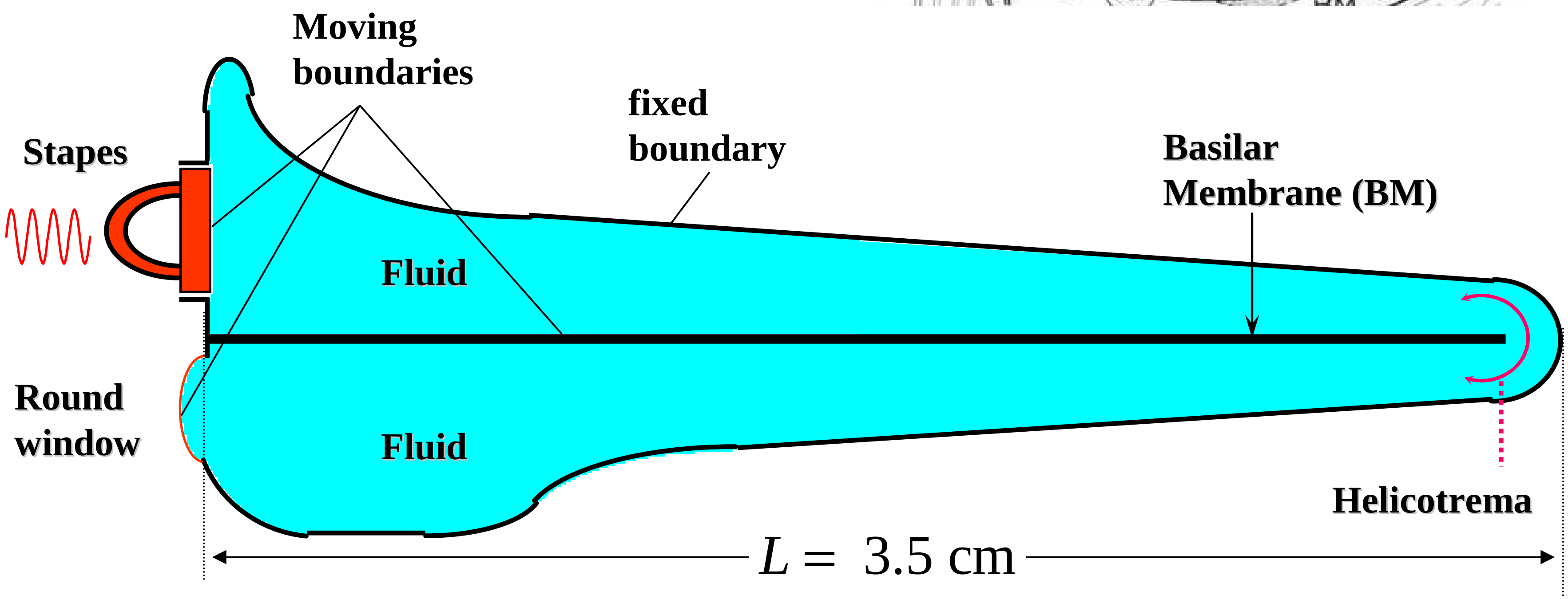


Resonance curves

To compute the forces F_i we need to know how the fluid moves within the cochlea

Fluid motion is driven by the piston action of the stapes bone in the oval window.





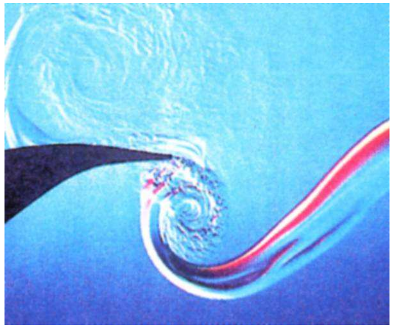
Known parameters:

u (max fluid velocity) $\sim 4.5\times10^{-3}$ m s^{-1} [T.Ren, a 90 dB SPL]

η (viscosity) ~ 1.5 kg m^{-1} s^{-1} [von Békésy]

ρ (density) ~ 1000 kg m^{-3} [water]

D (pipe diameter) ~ 1 mm = 10^{-3}m [on average]

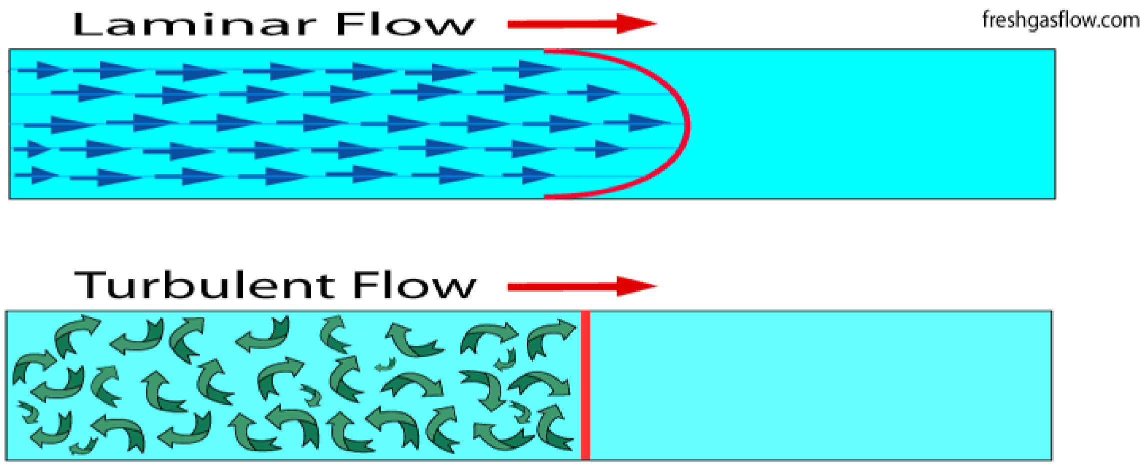


$N_R > 2000$

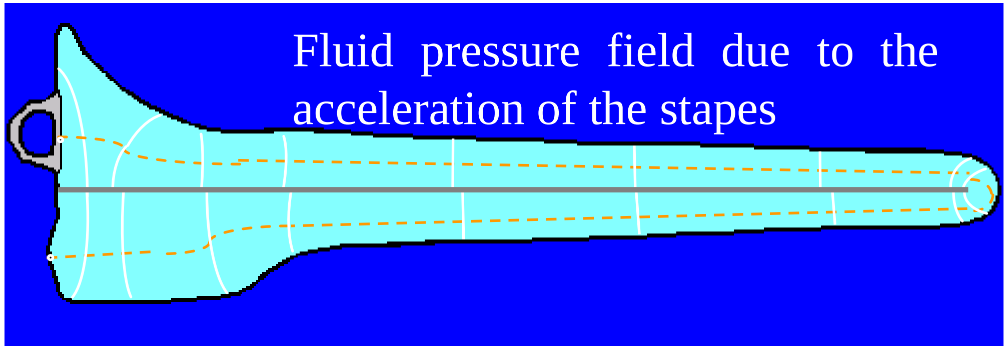
Reynolds number

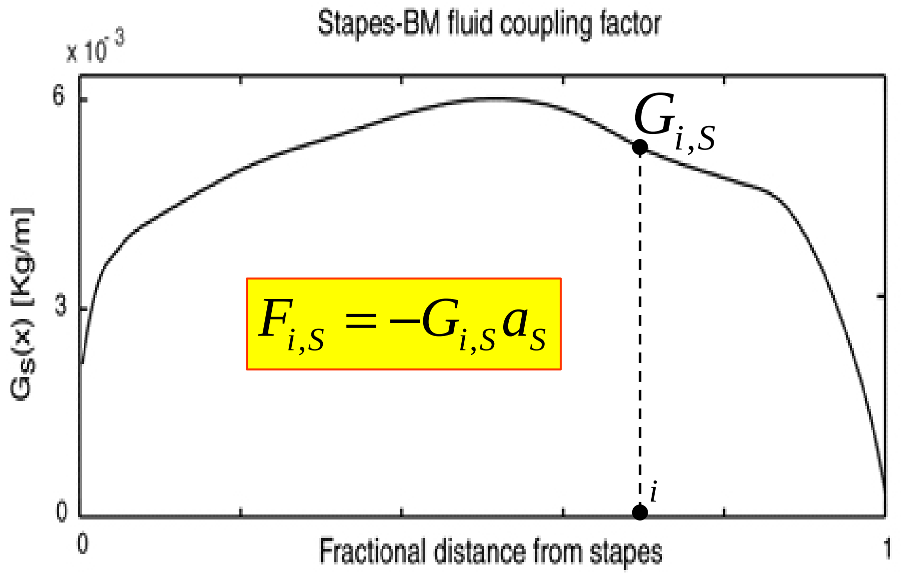
$$N_R = \frac{\rho\ \mathrm{v}\ D}{\eta} \approx \frac{(1000)\ (4.5\times10^{-3})\ (10^{-3})}{1.5\times10^{-3}} = \mathbf{3}$$

The small value of N_R guarantees that fluid motion is laminar



Fluid pressure forces due to the acceleration of the stapes



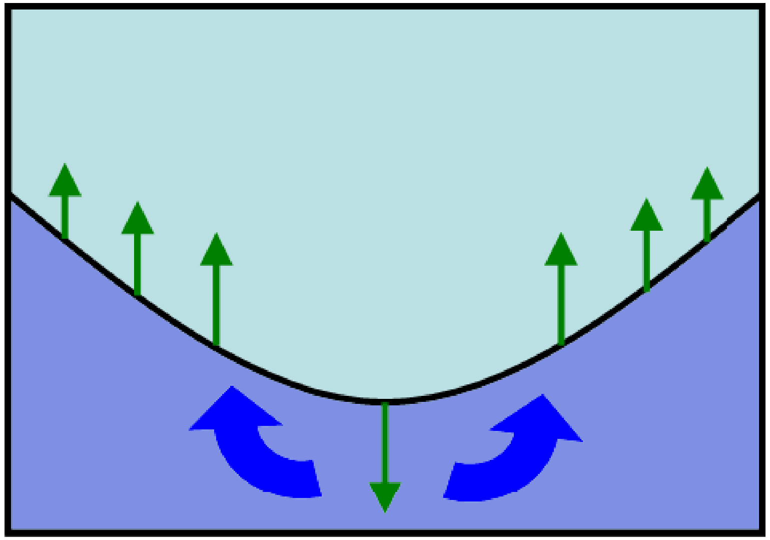


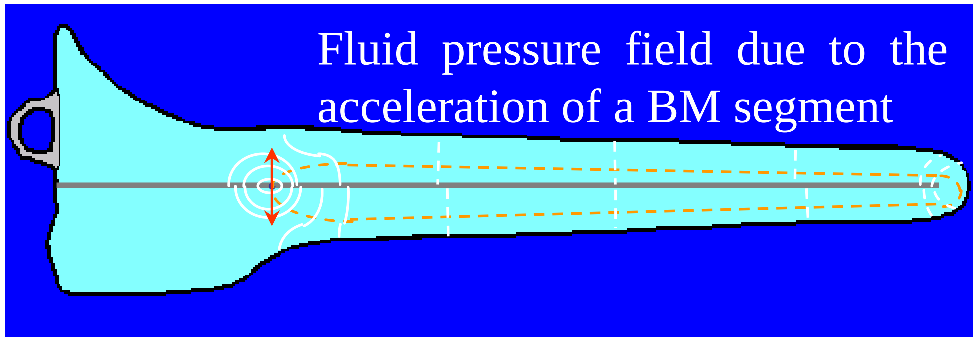
Plot of the stapes-BM coupling factor for the **human cochlea**.

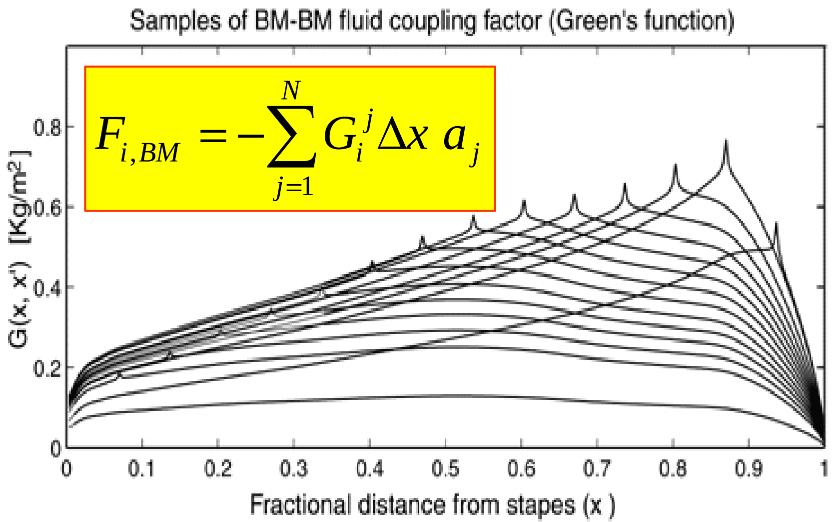
Additional pressure forces are generated by the basilar membrane reaction

Each segment of the basilar membrane that is set into motion by the pressure field generated by the stapes generates an additional pressure field.

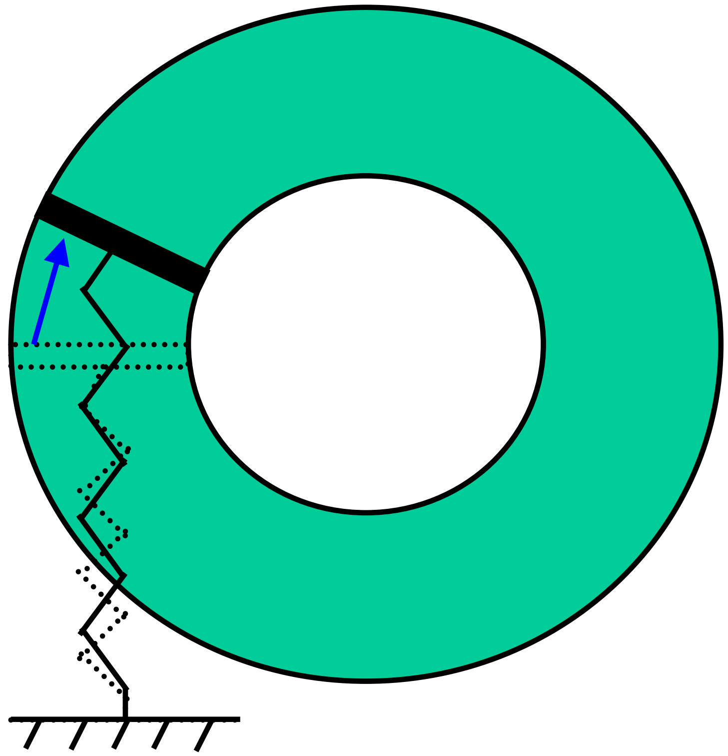
While moving e.g. downward, the segment must displace the surrounding fluid **instantaneously generating pressure forces in the opposite (upward) direction** on all other basilar membrane segments.







The **diagonal terms** G_i^i represent the inertial reaction of fluid mass that the *i*-th moving segment of the basilar membrane must displace. The situation is similar to that of a piston in a closed fluid circuit.



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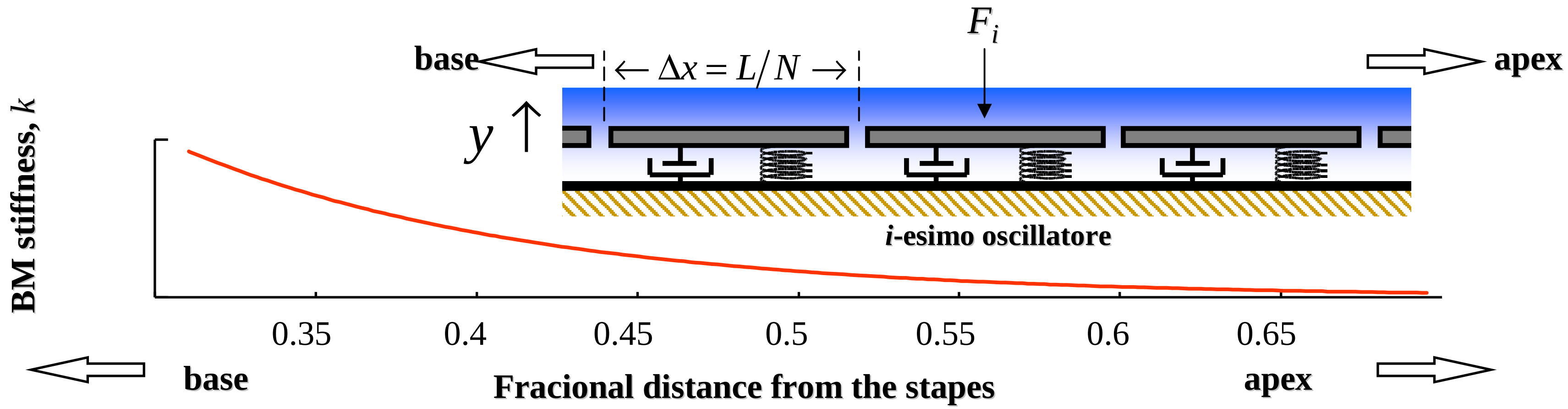
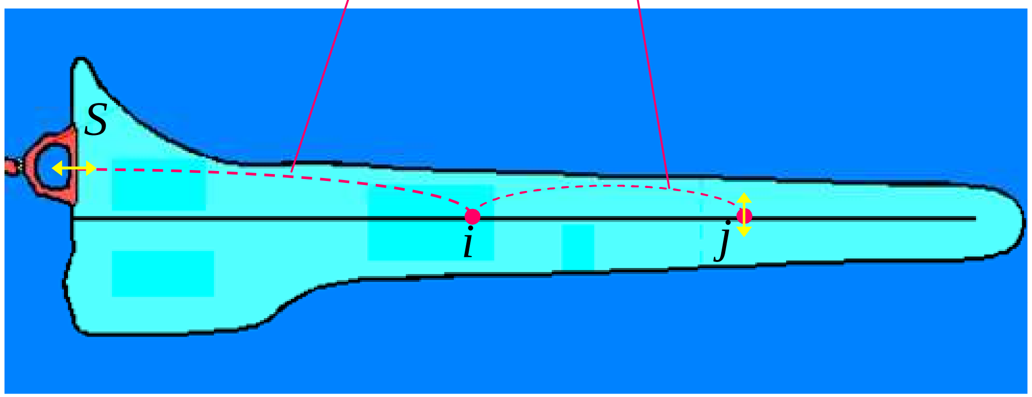
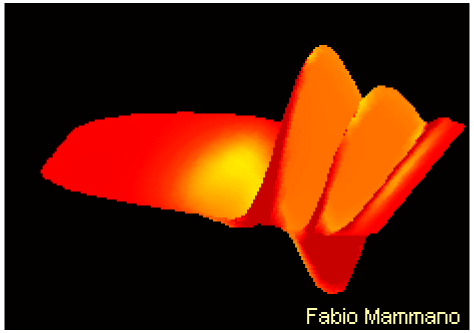


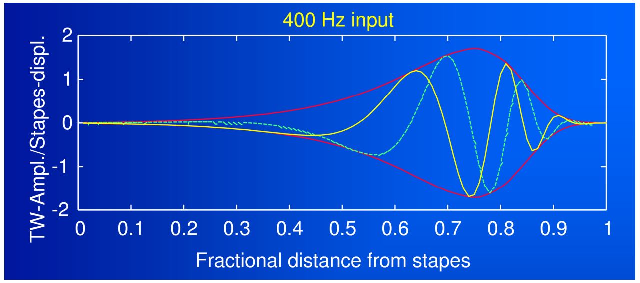
$$F_i = -G_{i,S}\, a_S - \sum_{j=1}^{N} G_i^j \Delta x\, a_j$$

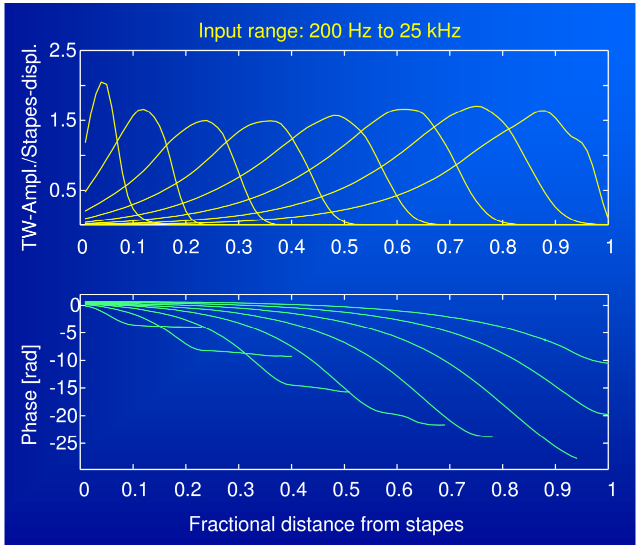


Results: traveling waves on the basilar membrane

400 Hz input





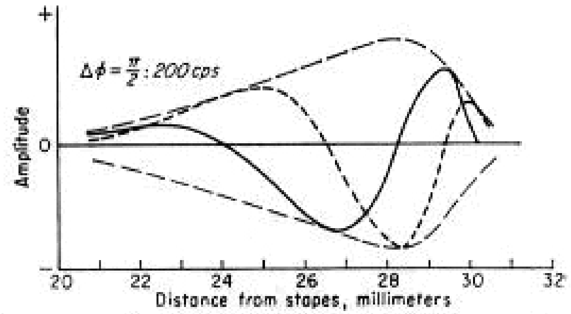


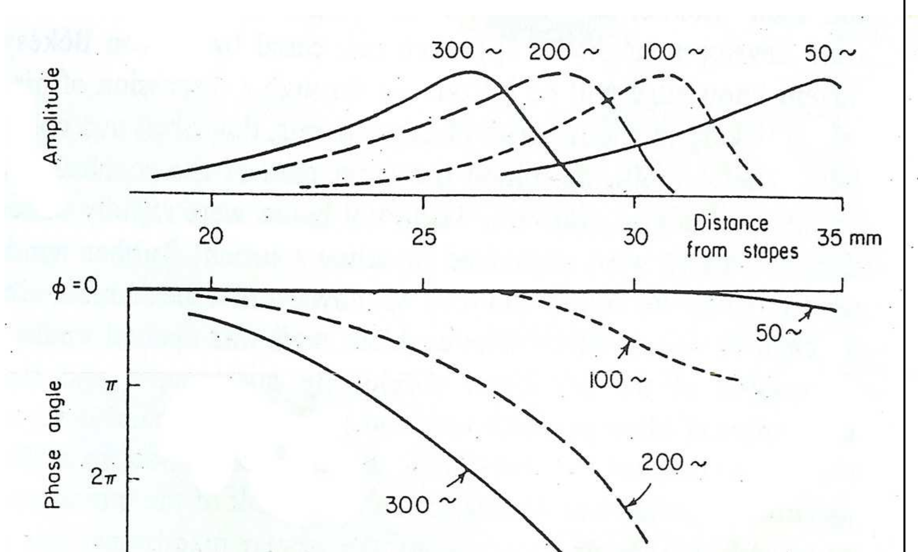
Solutions of the basilar membrane motion equation

The Nobel Prize in Physiology or Medicine 1961

"for his discoveries of the physical mechanism of stimulation within the cochlea"

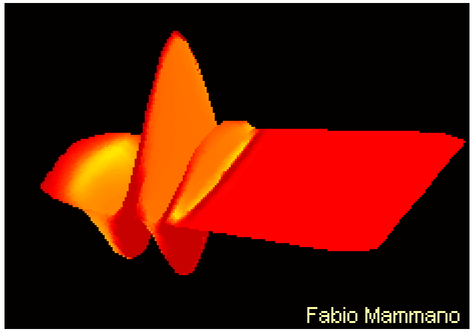
Georg von Békésy



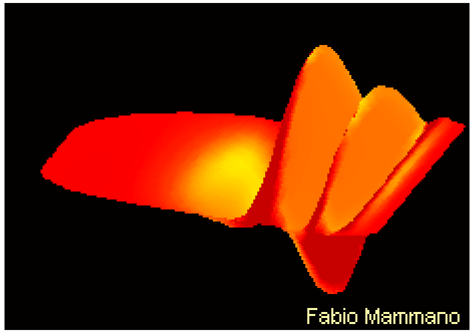


Experimental results

High frequency



Low frequency



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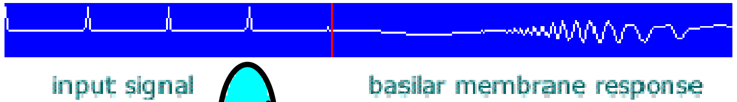
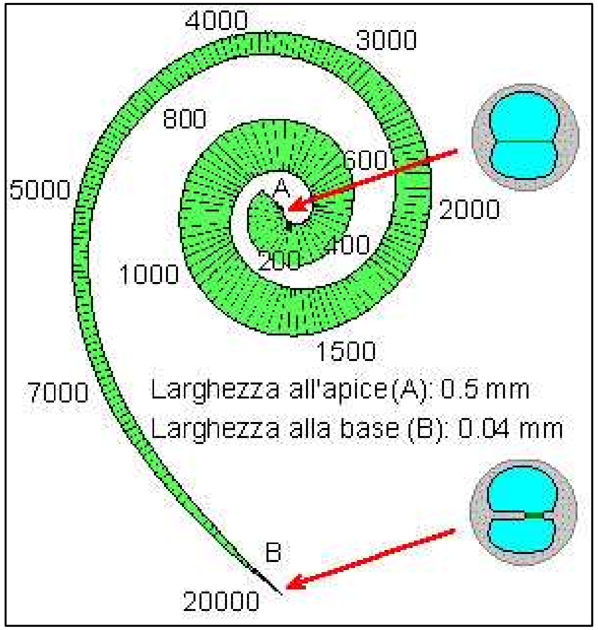
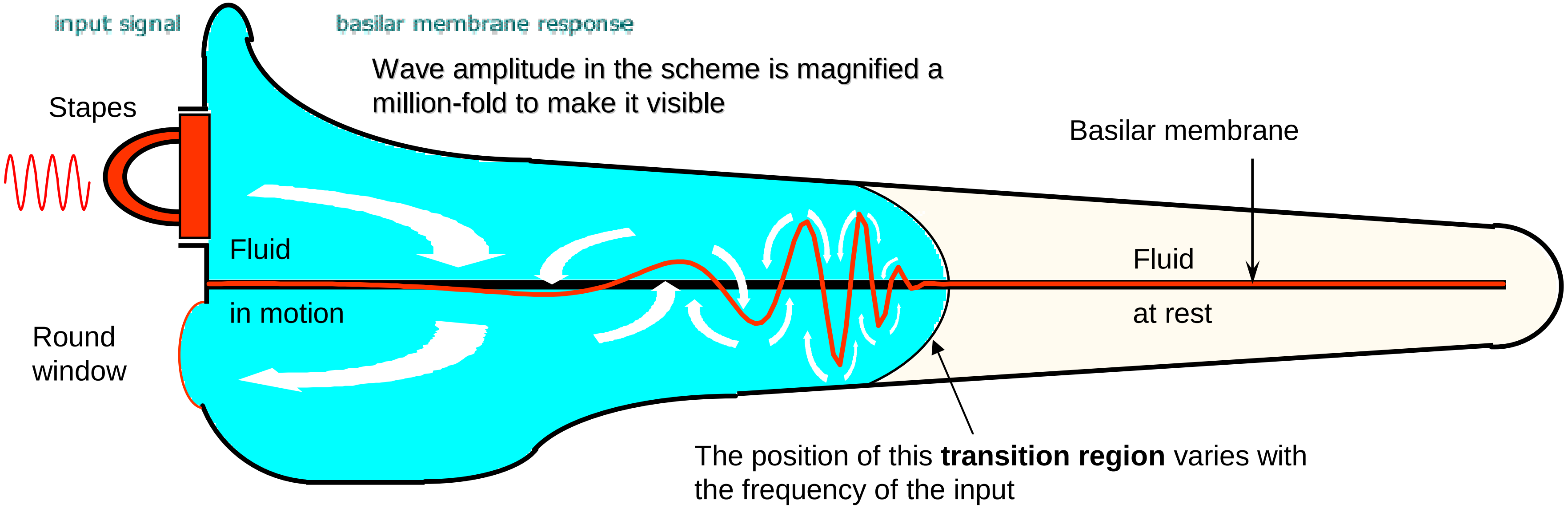
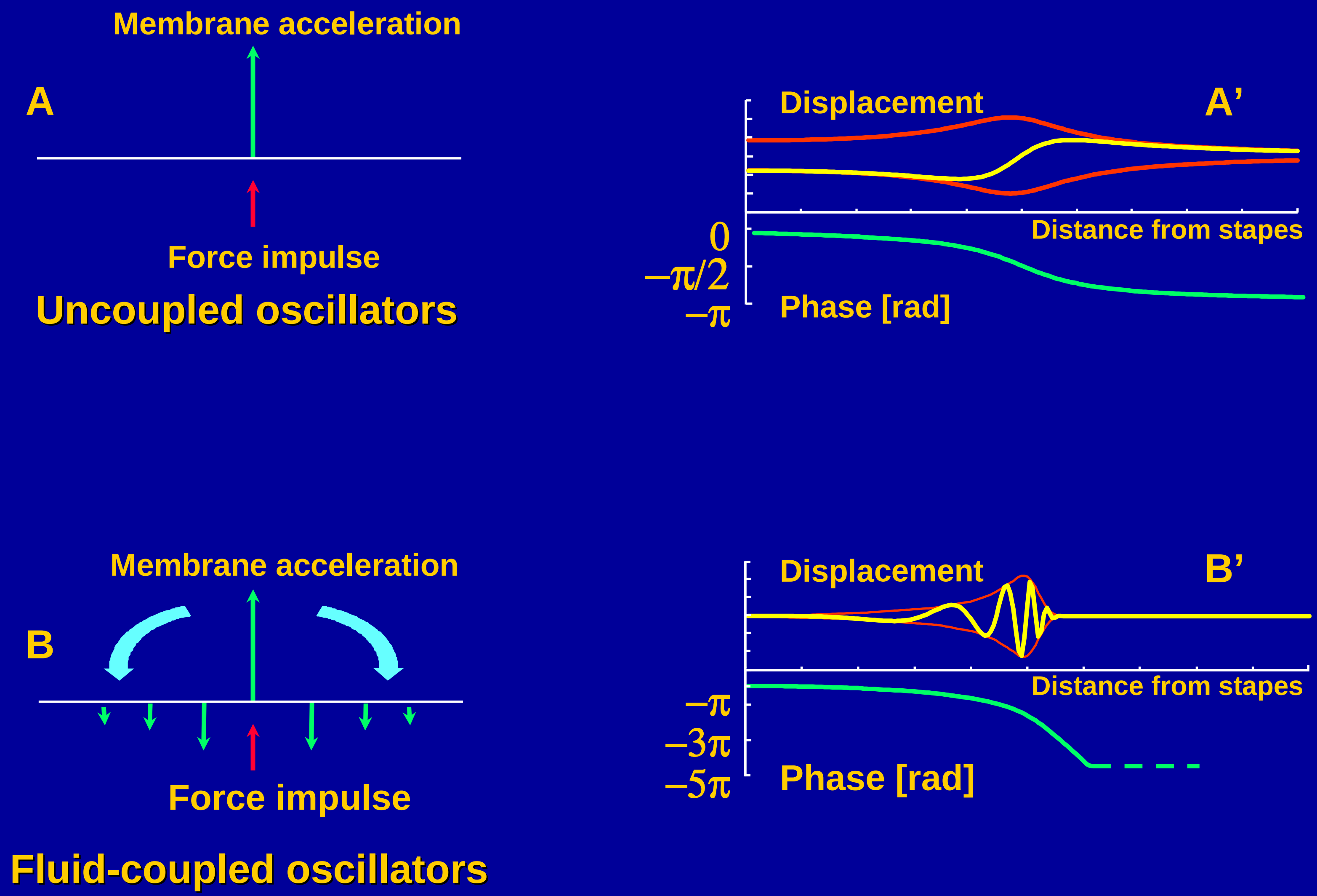




Basilar membrane frequency map



Key role played by fluid coupling



Get the whole story at http://vimm.it/cochlea