M2 INTERNSHIP PROPOSAL

Laboratory name: Physics of Cells and Cancer
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Thesis possibility after internship: YES

TITLE: Entropy production and fluctuation-response relations underlying active mechanosensitivity by the inner ear's hair cells.

SUMMARY: Sounds are detected and amplified in the inner ear by active mechano-sensory hair cells (see Figure). Hearing starts with the deflection of the hair bundle, a cohesive tuft of cylindrical protrusions that works as the hair cell's mechanical antenna. Hair-bundle vibrations produce an electrical signal that is then transmitted to the brain. Importantly, the hair bundle can oscillate spontaneously, enhancing the sensitivity and frequency selectivity of auditory detection. Active (but noisy) oscillations and response of the hair bundle are not only relevant for hearing but also provide a paradigmatic case study of nonequilibrium physics in biology. Here, we propose to (i) to experimentally estimate the power dissipated by a hair cell to drive active oscillations of its hair bundle (Roldán et al., 2021) and (ii) to probe relations between response and fluctuations in this active system (Dinis et al., 2012). To reach these goals, the trainee will combine force application (1-100 pN) to single hair bundles (using flexible microfibers) and electrophysiological measurements (patch clamp) of the transduction currents. We will use the electric potential across the sensory tissue that houses the hair cells as a control parameter of active hair-bundle motility, as recently demonstrated by our group (Joliot and Martin, 2024). These experiments will be interpreted using recent theories from stochastic thermodynamics and out-of-equilibrium physics to shed light on the energy requirements associated with active mechanosensitivity by the hair cell, as well as on the fundamental limits imposed by fluctuations on mechanosensitivity. The work will benefit from on-going collaborations with Edgar Roldan (ICTP, Trieste) and Frank Jülicher (MPIPKS, Dresden).

KEYWORDS: sensory systems, mechanosensitivity, out-of-equilibrium physics, micromanipulation, electrophysiology, oscillations, amplification, fluctuations.

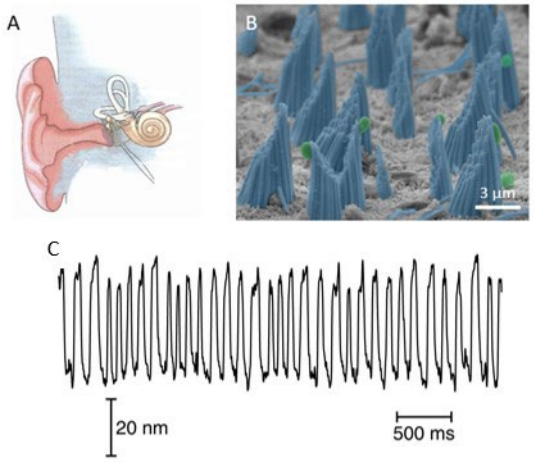

Figure 1: A: schematic of the human inner ear. B: electron micrograph of hair bundles protruding from the apical surface of the sensory epithelium in a frog's ear. C: Spontaneous oscillations of a hair bundle.

REFERENCES:

Dinis L, Martin P, Barral J, Prost J, Joanny JF (2012) Fluctuation-Response Theorem for the Active Noisy Oscillator of the Hair-Cell Bundle. Phys Rev Lett 109:160602.

Roldán É, Barral J, Martin P, Parrondo JMR, Jülicher F (2021) Quantifying entropy production in active fluctuations of the hair-cell bundle from time irreversibility and uncertainty relations. New J Phys 23:083013.

Joliot A, Martin P (2024) The Endolymphatic Potential Can Control the Gating Force of the Hair Cell's Transduction Channels. Available at: https://zenodo.org/doi/10.5281/zenodo.13336409.