LadHyX Seminar – November 5, 14:00

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Multi-scale hydrodynamics of mucus transport in human lungs: some experimental, theoretical and numerical insights.

Human airways are protected by mucus, a complex fluid transported along the epithelial surface by the coordinated beating of millions of microscopic cilia. From the dynein motor activity on ciliary microtubules to the long-range mucus transport at the tissue scale, a series of multiscale self-organized processes are at play, involving active fluid-filament interactions, collective beating synchrony and long-range directional organization. These mechanisms have been investigated in an inter-disciplinary framework on the basis of experimental, theoretical and numerical approaches. To investigate the system dynamics at the cilium scale, a three-dimensional fluid-structure simulation approach is first setup based on recent developments on the lattice-Boltzmann, immersed-boundary, and finite-element methods. Several ciliary activation models are considered; their singular and collective flow-structure dynamics and their efficiency in propelling Newtonian and pseudo-plastic fluids are explored. At the multi-cellular level, ciliary-beating metachrony is observed to vary as a function of mucus conditions in in vitro cultures of reconstituted bronchial epithelium. This phenomenon is examined in the light of a minimal physical model and 3D simulations. Finally, the tissue-scale ciliary dynamics observed in vitro exhibits active directional self-organization closely related to the mucus flow. This coupled muco-ciliary system undergoes a transition from swirly mucus flow to global mucus transport as a function of the ciliary density and mucus properties. A two-dimensional hydrodynamic model suggests that this transition is governed by the variation of the hydrodynamic length scale related to the competition between planar momentum diffusion and friction on the substrate, emphasizing the complex role of mucus viscosity in the muco-ciliary dynamics.