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Thermomechanics of active fluids

Active matter describes systems whose fundamental constituents dissipate energy to exert self-propelling forces on the environment. This mechanical driving out of equilibrium alters not only the steady-state distribution of active systems but also their mechanical interactions with their environment. Consider the gas that fills the room in which you are reading this project. The gas molecules push with the same strength on your skin, the glass window or the wall rooms because the pressure of any passive systems satisfies an equation of state. For an ideal gas, $P = \rho RT$ states that the force per unit area exerted on a container's wall can be evaluated by bulk quantities (the density ρ and the temperature T) far away from the boundaries.

Few years ago, we conjectured that the pressure exerted by active systems generically does not obey an equation of state [1], something which has been verified experimentally using self-propelled grains [2]. In addition to being a theoretical peculiarity, this has strong consequences such as the impossibility of universal pressure gauges for active systems. Take an assembly of cells crawling on a 2D substrate and confined by a metalic plate at one end of the system and by a soft gel at the other end: the forces exerted by the cells on these two boundaries will be different (See Fig 1, left). It thus does not make sense to speak about 'the' pressure of the system.

Crawling cells and vibrating grains fall into the class of 'dry active matter'. They exchange momentum with a hard substrate whose role in the mechanical balance with the confining boundaries is negligible. The situation is very different for swimmers like bacteria or cells in developing embryo, which push on a surrounding, momentum-conserving fluid. The mechanical properties of such active suspensions remain to be explored. In particular, if a semi-permeable membrane confine the active particles, it has been conjectured that it is now the *osmotic* pressure exerted by the particles that does not satisfy an equation of state (See Fig 1, center).

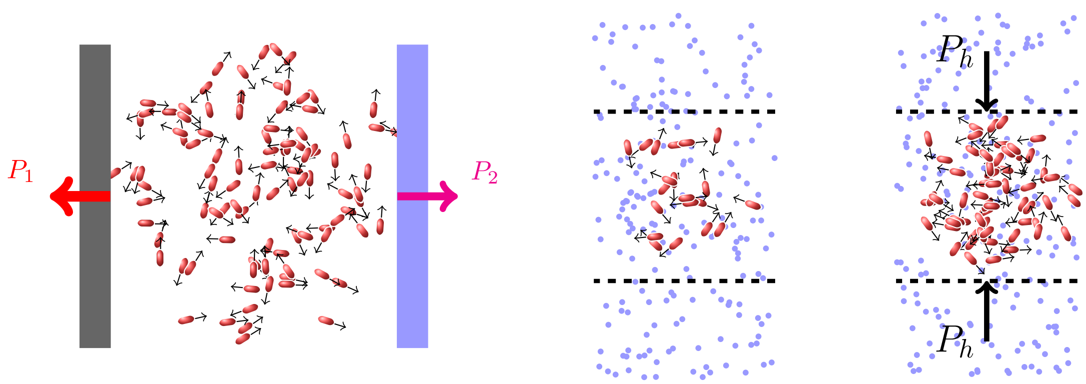

FIG. 1. **Left**: Schematic top view of active particles crawling on a substrate, confined by two different boundaries on the left and on the right. The pressures exerted by the active fluid at the two ends will generically be different. **Center:** active particles in red self-propel by pushing on passive particles in blue. A semi-permeable membrane (black dashed line) confines the active particles, which exert in return an osmotic pressure on the membrane. **Right:** If an external pressure P_h is exerted on the membrane and active particles mimic dividing cells, the latter are allowed to divide until they exert a pressure P_h on the confining membrane. Does P_h depend on the properties of the confining membranes? If so, what are the implications for growing tissues?

The goal of this project will be to model such a suspension of swimmers in an analytically tractable way to compute the force exerted on confining boundaries. Both active and passive particles will be modelled and the statistics of the forces exerted on potentials confining either both types of particles or solely the active ones will be considered. In a second time, the active particles will be allowed to divide, to model the dynamics of growing tissues. It has been conjectured that tissues grow until their osmotic pressure match that exerted by the environment [3]. In the absence of an equation of state, how to describe this homeostatic pressure becomes an interesting, open question (See Fig 1, left).

Beyond these two precise problems, there are many open questions regarding the anomalous thermomechanics of active systems. For instance, it has been shown that some active systems exhibit an equation of state for their pressure [1] due to some hidden symmetry [4]. This, however, does not extend to the question of surface tension [5] and the wetting properties of active systems thus constitute uncharted territory.

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