

# Entangled active matter: from ants to living cells

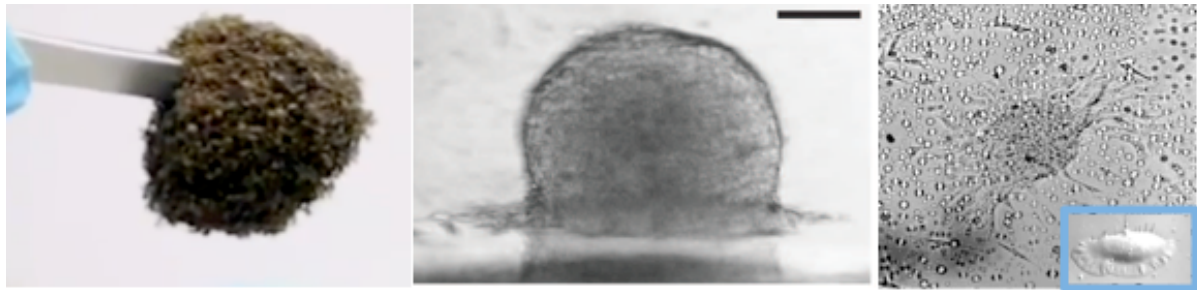
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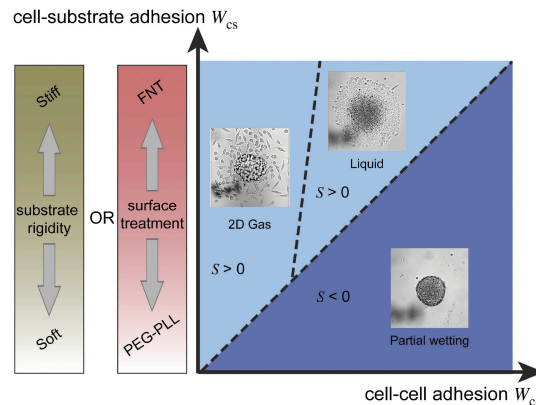
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We introduce the broad field of entangled active matter, a novel class of non-equilibrium materials composed of many interacting units that individually consume energy and collectively generate motion or mechanical stresses. Unlike swarms of fish and flocks of birds, both ants and cells can support static loads. This is because both cells and ants are also entangled, so that the individual units (cell, ant) are bound by transient links. We explore and establish analogies between aggregates of both ants and cells in analogy with soft matter physics [1].



a) Aggregate of Ants, b) Aggregate of cells spreading and c) migrating

We first describe the mechanical properties of this entangled active matter (surface tension, elastic modulus, viscosity). We use parallel-plate compression and pipette aspiration technique for tissue and ants [2] [3] [4]. Both aggregates of cells and ants exhibit a viscoelastic response. For cells, we observe aggregate reinforcement with pressure, which may result in pulsed contractions or “shivering”. We interpret this reinforcement as a mechano-sensitive active response of the actomyosin cortex.



We then describe the spreading of cellular aggregates on rigid and soft substrates, varying both intercellular and substrate adhesion. We find both partial and complete wetting, with a precursor film forming a cellular monolayer in a liquid or gas state [5]. We show that the spreading of aggregates of ants is very similar, with a dense precursor film on water and a gas state on a solid substrate [6]. We model the dynamics of spreading from a balance between active cellular driving forces and permeation of cells to enter into the film [7].

Finally we study the motility of aggregates induced by chemical or rigidity gradients, or

spontaneous: on soft substrate, the precursor film is unstable, leading to a symmetry breaking and a global motion of the aggregate as a giant keratocytes. We describe the shapes of migrating aggregates, the flow and the force field responsible of the motion. We monitored the center of mass motion and we observe stick-slip.

We hope that our models applied to active entangled matter will spur further investigations into ants and cells as active materials, and inspire the fabrication of synthetic analogs.

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- [4] Guevorkian, K., et al., (2010) *Aspiration of biological viscoelastic drops*. Physical review letters. **104**(21): p. 218101.
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- [6] NJ Mlot, CA Tovey, DL Hu (2011).*Fire ants self-assemble into waterproof rafts to survive floods*. PNAS, **108**.19
- [7] Gregory Beaune et al. (2014) *How cells flow in the spreading of cellular aggregates*. PNAS **111**.22.