Curvature-growth interplay in the morphogenesis of the sea urchin skeleton microstructure

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The context:

Echinoderms, like sea urchins, sea stars and sea cucumber build a calcite skeleton whose porous microstructure, called *stereom*, bears a characteristic saddle-shaped curvature signature[1,2] (Fig. **a**) which provides optimal mechanical properties[3]. Stereom growth has been addressed at different levels[4–6] and was shown to rely on the progressive addition of small bids of mineral (~100 nm) at the tips of micro-spines, successively branching and looping to form a complex meshwork of much larger characteristic scale (10-50 µm). Very recently it was also shown that cytoskeleton may guide localised skeletal growth in sea urchin larvae[7] and sea cucumber juveniles[8]. Despite these findings **many fundamental questions remain**: how tip growth happens in the first place? how and when branching happens? Why the final structure bears such a peculiar geometry? Do stereom growth relies on a simple and robust self-organised mechanism?

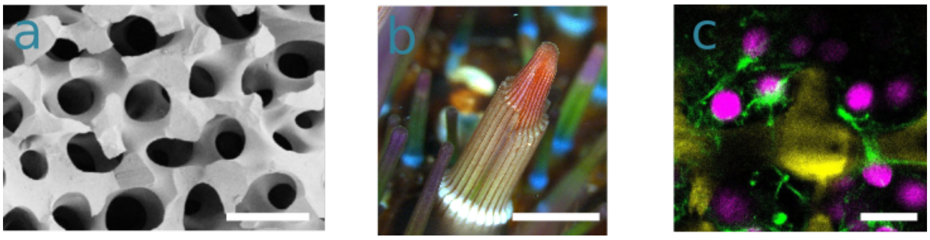

*Figure a: sea urchin stereom2 , b: sea urchin regenerating spine (MSC), c: confocal image of regenerating stereom (yellow), surrounded by cell nuclei (magenta) and cytoskeleton (green), MSC. Scale bars are 50 µm (**a**), 500 µm (**b**) and 10 µm (**c**).*

The internship:

We believe that surface curvature plays a major role in organising this morphogenetic process, similarly to my previous work on termites nests[9], and coherently with many recent discoveries pointing curvature as a strong biological morphogenetic cue[10].

This is a **highly interdisciplinary** project in close collaboration with LBDVM laboratory at the Marine station of Villefranche-sur-mer. According to the skills, curiosity and motivations of the candidate the internship may be more or less oriented in one of the two directions:

1- **Investigate experimentally** the curvature-growth interplay characterising stereom growth and cytoskeleton organisation in the stereom of sea urchin spines (Fig. **b**). The candidate will learn a variety of techniques, including fixing samples, confocal microscopy (Fig. **c**), image analysis, and in vivo observations working on regenerating spines of sea urchin adults. Possible fieldworks in Villefranche working with sea urchin juveniles.

2- **Build** a minimal **numerical model** able to reproduce the complexity of the final structure starting from very simple interactions rules. Different options will be considered like adapting our previous model on termites[9] and modifying a classical DLA particle attaching model to take in account the effect of cytoskeleton which may enforce the observed wavelength.

Keywords: morphogenesis, self-organisation, 3D structures, mechanobiology

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