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

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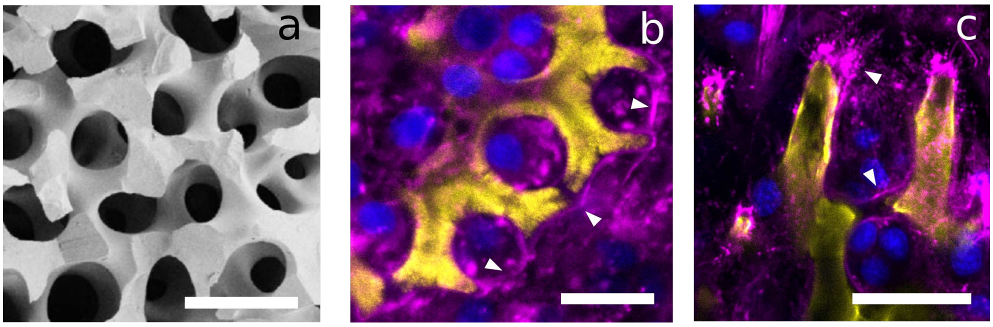
The context: Echinoderms, like sea urchins and sea stars, and sea cucumbers build a calcite skeleton whose porous microstructure, called ***stereom***, bears a characteristic saddle-shaped curvature signature[1,2] (Fig. **a**) that provides optimal mechanical properties[3]. Stereom growth has been addressed 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). Recently, it was also shown that the cytoskeleton may guide localized skeletal growth in sea urchin larvae[7] and sea cucumber juveniles[8]. Despite these findings, **many fundamental questions remain**: how does tip growth happen in the first place? how and when does branching take place? Why is the final structure bearing such a peculiar geometry? Does stereom growth relies on a simple and robust self-organized mechanism?



Caption: a *: sea urchin spine electron micrograph (Yang et al. 2020);* ***b*** *: close-up on a J2 juvenile shell plate, newly formed stereom in yellow, actin in magenta nuclei in blue;* ***c*** *: close-up on a 10-days regenerating adult spine, labeling as in b. Scale bars are 100 µm (a), 10 µm* (b,c). White symbols denote actin structures.

The internship: We will study the origin of the special surface signature of the stereom and model its emergence, similarly to our previous work on termite nests[9], and coherently with many recent discoveries pointing to curvature as a strong biological morphogenetic cue[10]. In particular we will investigate the role of the cytoskeleton, and explore how its spatial organisation (i) depends on the shape of the pre-existing skeleton and (ii) determine the shape of the skeleton that is built successively.

The candidate will **characterise experimentally** the spatial organization of the cytoskeleton (arrows in Fig. **b,c**) in the vicinity of the growing stereom (yellow, Fig. **b,c**) in sea urchin spines . The internship will be an opportunity to learn a variety of experimental techniques, including immunochemistry, confocal microscopy (Fig. **b, c**) and *in vivo* observations, working on regenerating spines of sea urchin adults. The intern will also develop a numerical workflow to analyse and quantify experimental images.

This is a **highly interdisciplinary** project and the candidate will interact with different scientific profiles spanning from Physiscs to Biology. This is an **experimental internship** but according to the skills, curiosity, and motivations of the candidate, the internship may be more or less oriented towards experiments, data analysis or numerical modelling (see also, related theoretical internship).

[**1**] Smith, A. B. *Spec. Pap. Palaeontol.* 1–81 (1980); [**2**] Yang, T. *et al. Acta Biomater.* **107**, 204–217 (2020); [**3**] Yang, T. *et al. Science* **375**, 647–652 (2022); [**4**] Heatfield, B. M. *J. Morphol.* **134**, 57–89 (1971); [**5**] Politi, Y. *Science* **306**, 1161–1164 (2004); [**6**] Gorzelak, P. *et al. J. Struct. Biol.* **176**, 119–126 (2011); [**7**] Hijaze, E. *et al. eLife* **12**, (2024); [**8**] Vyas, P. *et al. bioRxiv* (2024); [**9**] Facchini, G. *et al. J. R. Soc. Interface* **17**, 20200093 (2020); [**10**] Schamberger, B. *et al. Adv. Mater.* **35**, 2206110 (2023);