Active matter
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A crowd of marine embryos self-assembles into a living solid

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Marine embryos are usually studied in isolation. But when starfish embryos are in a crowd, they self-assemble into living solids with unexpected dynamics, revealing how simple organisms can help understand physics far from equilibrium.

Collective biological systems such as bird flocks and fish schools have long served as a testbed for active matter physicists[1,2]. By contrast, developmental biologists almost always study early marine animal embryos in isolation[3]. In the ocean, starfish embryos disperse freely with currents, and in the lab they are deliberately cultured at low densities to ensure normal development[4]. However, in a recent *Nature Physics* study, Yu-Chen Chao and colleagues overturned this convention by studying dense populations of swimming starfish embryos[5]. They showed that crowded embryos self-assemble into living solids that switch between fluctuating and oscillatory states, revealing remarkable nonequilibrium dynamics.

Active matter physics seeks to understand how collections of energy-consuming units generate collective motion and material-like behaviour. Many well-known examples come from biology, including flocks, schools, swarms and cytoskeletal assemblies, where interactions among individuals or components lead to emergent order[1,2]. These systems have been especially valuable because they combine rich dynamics with experimental accessibility. In addition, several biological model systems used in active matter physics are not whole animals, but simplified cell-free extracts (for example, cytoskeletal assays[6]) or reduced living systems (for example, cell monolayers[7]). Against this backdrop, early animal embryos have rarely been considered as candidates for revealing new active-matter phenomena.

Marine invertebrates have been central to modern cell and developmental biology, with echinoderms such as starfish and sea urchins in particular providing some of the clearest experimental windows into early embryogenesis[3,4]. More recently, the starfish *Patiria miniata* has gained prominence in biophysics, including studies of cellular biophysics[8] and larval fluid dynamics[9]. Despite this long history, starfish embryos are almost always examined one at a time, rather than as interacting collectives, leaving their collective dynamics largely unexplored.

This perspective shifted with a systematic study of interacting starfish embryos under crowded conditions near an air–water interface[10]. Rather than disrupting development, these conditions instead led embryos to self-assemble into living chiral crystals with emergent material properties. The living chiral crystals exhibited odd elasticity — a nonreciprocal mechanical response in which deformation along one direction produces forces in another, arising from embryo spinning and hydrodynamic interactions. This discovery reframed a classic

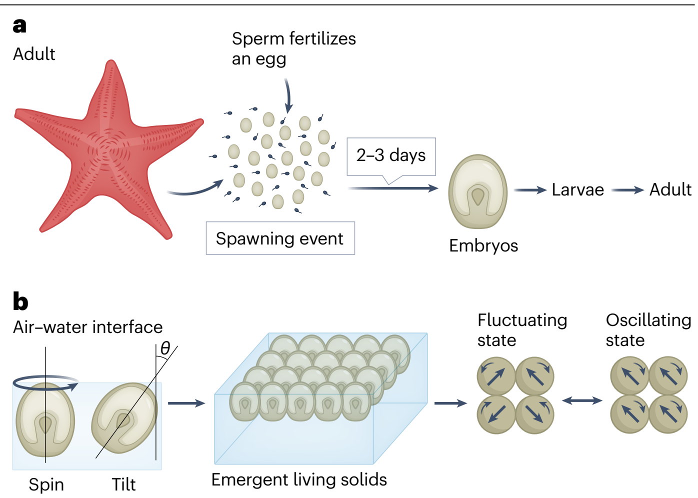

Fig. 1 | Marine embryos become materials. a, Starfish embryos form when sperm fertilizes an egg during a spawning event, and they are traditionally studied as isolated, developing organisms, with a focus on individual development rather than interaction. **b**, When embryos are brought into close proximity with each other under crowded laboratory conditions, they interact and self-assemble into an emergent living solid with material-like properties. Microscopic asymmetries, such as embryo spinning and slight tilts (θ) of the swimming axis with respect to the perpendicular at the air–water interface, enable collective modes and nonreciprocal responses. At the macroscopic scale, the living solid can switch between a fluctuating state, characterized by disordered motion, and a coherent oscillatory state, characterized by ordered, periodic motion (arrows show spinning directions of the embryos).

developmental system as a platform for studying living materials far from equilibrium. The work by Chao and colleagues moves beyond structure to dynamics, revealing a class of behaviour in which living chiral crystals switch between fluctuating and oscillatory states[5].

The authors showed that living chiral crystals do not occupy a single steady state but instead exhibit two distinct nonequilibrium regimes[5]. The crystals displayed a fluctuating state characterized by small fluctuations consistent with ciliary-driven hydrodynamic interactions. Under mechanical compression, however, the system transitioned into a coherent oscillatory state, marked by large-scale, periodic deformations that persisted over long timescales. These behaviours arise from chirality at the level of individual embryos: spinning generates odd elasticity and nonreciprocal mechanical responses; on the other hand, a slight tilt of the swimming axis introduces slow precession, supporting long-wavelength collective vibrational modes across the living crystal (Fig. 1).

Importantly, the authors showed that this oscillatory state can be selectively excited by mechanical compression, revealing the system as an excitable living solid. Under these conditions, the embryos collectively generate sustained deformation cycles that perform mechanical work without externally imposed cyclic driving. Together, these findings position living chiral crystals as a class of active material whose mechanical properties emerge dynamically from the interactions of developing organisms rather than being prescribed by engineered components.

Beyond active matter physics, this work suggests design principles for living and bio-inspired materials. The ability to switch between fluctuating and oscillatory states and to generate work without cyclic driving echoes long-standing goals in soft robotics and programmable matter. At the same time, the specificity of the system, that is, swimming embryos interacting through hydrodynamics near an interface, has many constraints. Whether similar excitable dynamics arise in other biological collectives or can be engineered in synthetic systems with comparable robustness remains an open and exciting question.

Perhaps most striking is how this work emerged by revisiting a classic biological system from an unconventional perspective. Starfish embryos have been studied extensively, yet allowing them to interact under crowded conditions in the laboratory revealed surprising collective behaviours. This underscores a broader lesson: living systems may harbor rich physical phenomena that remain hidden simply because we have not looked under the right conditions.

By blurring the boundary between organism and material, the works on interacting starfish embryos[5,10] yield insights that span active matter physics, materials science, and robotics. Starfish and other marine organisms are full of secrets still waiting to be uncovered. It seems that these secrets are not only biological, but physical, with the potential to inspire biomaterial design and alternative ways of thinking about nonequilibrium matter.

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Competing interests

The author declares no competing interests.