I use minimal mechanistic mathematical models to understand processes in cellular biology. In particular, I am interested in the physical regulation and consequences of cellular heterogeneity in shaping the emergent dynamics and material properties of cell collectives in the context of cell development and cancer. To do so, I use a range of mathematical techniques from the non-linear dynamics of partial differential equations. My research includes applications to tumour growth, collective cell migration, and biomolecular condensates. Where possible, I integrate theory and experimental data through close collaboration with experimental collaborators.

You can find out more about my past and current research on my website.

Do not hesitate to contact me for any questions.

The impact of fluctuating environment on the cancer cell fate transitions

Oxygen levels in solid tumours fluctuate due to their complex and immature vasculature, exposing cancer cells to intermittent periods of oxygen deprivation and reoxygenation—a process known as cyclic hypoxia. These fluctuations can profoundly affect cancer cell behaviour and have been linked to the epithelial-to-mesenchymal transition (EMT), a process associated with increased invasiveness and metastasis. While the effects of sustained hypoxia (i.e., low oxygen levels) on EMT have been extensively studied, the impact of temporal fluctuations in oxygen availability remains poorly understood, despite growing evidence linking cyclic hypoxia to poorer treatment outcomes.

In this project, we aim to investigate how fluctuations in oxygen availability influence EMT gene-regulatory networks, in collaboration with Mohit Jolly's lab at IISc Bangalore. The project will combine asymptotic analysis and numerical techniques for nonlinear dynamical systems to develop a theory of single-cell fate transitions in fluctuating environments. By revealing how fluctuating microenvironments influence cancer cell behaviour, we ultimately aim to gain insight into the role of cyclic hypoxia in disease progression. Possible extensions include introducing spatial variability in oxygen levels using partial differential equations, investigating the role of noise in EMT dynamics under fluctuating conditions, or developing population-level models of epithelial and mesenchymal cells to capture the effects of cell movement.

The biophysics of invasion of chemoresistant cancer cells

The evolution of resistance to chemotherapy is often associated with rapid progression to metastasis—the spread of cancer from its primary site to other parts of the body. Metastasis has been linked to cancer cells and tumors acquiring new biophysical properties, such as increased motility and invasiveness; yet, the connection between these physical traits and underlying changes in gene expression remains poorly understood.

In this project, we aim to bridge this gap by linking the genetic and biophysical determinants of cancer invasion through a combination of continuum mathematical modelling and experimental data (in collaboration with Ramray Bhat's lab, IISc Bangalore). This work will involve extending classical active matter theories to incorporate intratumour cellular heterogeneity and determine how cell-level behaviours affect the emergent physics of collective invasion. In parallel, statistical techniques will be employed to calibrate and validate the models against experimental observations.

Self-organisation of biomolecules via phase separation

Biomolecular condensates are dynamic, liquid-like compartments composed of macromolecules, *i.e.*, proteins and RNAs. Evidence suggests that these structures form within cells through liquid–liquid phase separation (LLPS), analogous to the demixing of oil in water, and that this process plays a key role in cellular organization and disease.

This project will investigate the electrochemical regulation of LLPS by developing multiscale phase-field models that extend classical nonequilibrium theories of phase separation based on the Cahn–Hilliard formalism. The goal is to understand how molecular-level processes, such as the

protonation and deprotonation of ionizable groups on proteins, affect the phase behaviour and spatial organization of biomolecules. Using tools from nonequilibrium thermodynamics, nonlinear dynamics, and computational modelling, this work aims to reveal how intracellular and environmental factors regulate condensate formation, providing new insights into the physical principles underlying cell organization.