Introduction

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One contribution of 13 to a Theme Issue ‘Biophysics of active systems: a themed issue dedicated to the memory of Tom Duke’.

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Theme Issue in memory of Tom Duke

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This Theme Issue is dedicated to the memory of Tom Duke, who passed away in 2012 at the age of 48. Tom made lasting contributions to a broad range of topics and was highly regarded for his very elegant approaches that unravel key physical principles underlying the function of biological systems. Himself being a theoretician, Tom’s work was always motivated by experiments and he often worked closely with experimentalists. Tom had an extraordinary talent to communicate with biologists, which led him to develop simple and original theories for important biological processes. His way of approaching the physics of biological systems was highly regarded by his colleagues and friends, who sadly miss him.

His early work brought the innovation to use micro-fabricated sieves together with electric fields for the segregation of polymers such as DNA in electrophoresis. Other highlights of his pioneering contributions include a theory for the collective interactions of myosin motors in muscles, and the suggestions that the critical behaviours in receptor clusters on bacterial membranes provide high sensitivity for chemotactic sensing. A similar theme occurs in his works on the amplifier underlying the extraordinary sensitivity of hearing based on critical dynamic oscillators. For his contributions to biophysics, Tom was awarded the Franklin Medal in 2010.

The contributions of this issue span a wide arc on research areas that Tom was passionate about. Sturm et al. [1] review the basic physics of microfluidic ratchets and the mechanisms by which particles move through arrays of obstacles. This leads to particle separation by their physical properties. The authors highlight, in particular, the original contributions of Tom Duke and co-workers to this fascinating field. Several contributions deal with the physics of bacteria and chemotaxis. Fan & Endres [2] present a model for chemotaxis, which depends on the cell metabolic state. In the case of metabolism-dependent chemotaxis, cells possess two types of receptors: (i) on the membrane to detect outside chemicals, and (ii) in the cytoplasm to detect metabolite levels in the cell. Interestingly, in such a system, certain chemicals can dynamically change their role from being attractants to becoming repellents. Wettmann et al. [3] study principles underlying the spatial distribution of proteins inside rod-shaped bacteria. Many proteins are not distributed homogeneously. The authors present a general mechanism based on the cooperative assembly on the bacterial membrane that can give rise to polarized protein distributions. The symmetry of these distributions is broken spontaneously, and the system can switch polarity in a characteristic time that increases exponentially with molecular number. The collective behaviour of many bacteria in thin biofilms is studied in the contribution by Dervaux et al. [4]. The authors show that heterogeneities and a rough surface morphology of the film arise from bacterial growth pressure together with the material properties and mechanics of the film consisting of bacteria and secreted matrix material.

Tom Duke and co-workers made original contributions to the field of mechanosensing and the physics of hearing. The role of dynamic oscillators in the detection of weak signals by auditory hair cells is the theme of the contribution by Shlomovitz et al. [5]. The authors present a beautifully simple model, the noisy Adler equation, to understand spontaneous spiking and phase locking of hair cells, which permits detection of very weak mechanical stimuli. West & Ashmore [6] present a model of ionic transport and cell volume control in outer hair cells that can explain observed slow cell-length changes and is relevant to the amplifier in the mammalian cochlea.

Moving to the physics of molecular motors and the cytoskeleton, Vilfan [7] discusses the velocity of large ensembles of non-processive molecular motors. Considering a general model, he demonstrates that the ensemble velocity
can have an interesting ATP dependence that reveals features of the underlying chemical scheme. The contribution by Reese et al. [8] studies the principles of microtubule length regulation by proteins that interact with the growing tip. They investigate the interplay of microtubule depolymerases and polymerases and suggest scenarios in which length is either tightly regulated or in which strong length fluctuations occur.

Three contributions are collaborations with Tom that he co-authors and which thus reflect his recent interests. Lewalle et al. [9] investigate the dynamics of the actin cytoskeleton in the lamellipodia of migrating cells. Their work reveals the spatial distribution of actin assembly and disassembly rates in two different cell lines and presents a simple kinetic model that can account for the main features of observed actin dynamics. Holmes et al. [10] present a microfluidic method to separate blood cells with high throughput according to their mechanical properties using micro-fabricated structures. This method is inspired by the microfluidic separation techniques pioneered by Tom. Moving from cells to multicellular systems, the contribution by Strandkvist et al. [11] discusses a kinetic mechanism by which groups of cells with different motility can segregate in a tissue in different domains. This is an interesting example of collective cell behaviour giving rise to coarsening dynamics and domain formation. The biophysics of tissues is also the subject of the final contribution together with Delarue et al. [12]. The mechanics of spherical cell aggregates is discussed in a general continuum description, taking into account cell polarity and active cell stresses. Interestingly, cell volume drops rapidly in the interior of the spheroid after a sudden pressure increase.

The contributions to this issue show nice examples of current progress in the broad field of molecular and cellular biophysics that Tom stimulated early with his work.

References