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## Editorial Editorial: Special issue on "Complex fluids in Biological Systems"



This special issue of the Journal of Non-Newtonian Fluid Mechanics includes a series of papers based on work presented at the Banff International Research Station for Mathematical Innovation and Discovery (BIRS) during a workshop on "Complex Fluids in Biological Systems," held in July 22–27, 2018. BIRS is a collaborative Canada–US–Mexico venture that provides an environment for creative interaction as well as the exchange of ideas, knowledge, and methods within the Mathematical Sciences, with related disciplines and with industry. The research station is located at The Banff Centre in Alberta and is supported by Canada's Natural Science and Engineering Research Council (NSERC), the U.S. National Science Foundation (NSF), Alberta's Advanced Education and Technology, and Mexico's Consejo Nacional de Ciencia y Tecnología (CONACYT).

The workshop was focused at the intersection of three areas: rheology (the study of the deformation and flow of matter), biolocomotion (swimming and crawling through biological fluids and tissues), and active matter (large systems of active particles and their collective dynamics) largely mirroring a recent edited volume in this area [1]. The participants consisted of early career, mid career and established scientists across departments of engineering, physics and mathematics in Canada, the United States, the United Kingdom and Israel.

The list of participants of the workshop were (in alphabetical order): Alexander Alexeev, Georgia Institute of Technology; Arezoo Ardekani, Purdue University; Paulo Arratia, University of Pennsylvania; Sujit Datta, Princeton University; Joern Dunkel, Massachusetts Institute of Technology; Jonas Einarsson, Stanford University; Gwynn Elfring, University of British Columbia; Lisa Fauci, Tulane University; James Feng, University of British Columbia; Henry Fu, University of Utah; Eric Furst, University of Delaware; Michael Graham, University of Wisconsin-Madison; Robert Guy, University of California at Davis; Christel Hohenegger, University of Utah; Gabriel Juarez, University of Illinois; Eva Kanso, University of Southern California; Aditya Khair, Carnegie Mellon University; Enkeleida Lushi, Simons Foundation & New York University; Tom Montenegro-Johnson, University of Birmingham; Vivek Narsimhan, Purdue University; On Shun Pak, Santa Clara University; Thomas Powers, Brown University; Arun Ramchandran, University of Toronto; David Saintillan, University of California San Diego; Saverio Spagnolie, University of Wisconsin-Madison; David Stein, Flatiron Institute; Jean-Luc Thiffeault, University of Wisconsin-Madison; Becca Thomases, University of California, Davis; Patrick Underhill, Rensselaer polytechnic institute; Wen Yan, Flatiron Institute, Simons Foundation; Ehud Yariv, Technion - Israel Institute of Technology; Yuan-Nan Young, NJIT; Roseanna Zia, Stanford University (Fig. 1).

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This special issue includes eleven papers that reflect a number of the problems discussed at the BIRS workshop. Most of these papers may be categorized under the theme of fluid-body interactions in fluids or flows that are non-Newtonian with a variety of applications relevant to biological systems.

Many biological processes feature the interaction of long flexible objects and fluids. In their paper, LaGrone et al. [2] focus on fast methods to compute the dynamics of long flexible fibres in Newtonian shear flows using a regularized Stokeslet framework coupled with a fast multipole method. They present numerical evidence that nearly-rigid fibers rotate simply in a shear flow, while semi-flexible fibers can buckle, and yet softer filaments can transition to "snaking" and curling dynamics. The degree of detail in these simulations, which couple elastic and viscous stresses, would not have been feasible without the use of new computational techniques. The study of fluid-structure interactions in viscoelastic flows, meanwhile, has long presented other numerical challenges, so much so that the International Workshop on Numerical Methods for Non-Newtonian Flows [3], which was created to aid in ameliorating these problems, has now seen its 19th iteration. For example, the Immersed Boundary (IB) method, widely used in the study of fluid-body interaction problems, suffers from a lack of convergence of viscoelastic stresses at boundaries with the Stokes/Oldroyd-B model of viscoelastic flow. In their paper in this special issue, Stein et al. [4] analyze the root of the failure of the IB method and propose a modification which provides convergent stresses on the boundary. Termed the "Immersed Boundary Smooth Extension" (IBSE) scheme, the authors show that this modified scheme produces convergent polymeric stresses through the whole domain, including on embedded boundaries, and their results compare favorably with known benchmarks.

The presence of constitutive nonlinearities in model viscoelastic fluids offer insight into why flows generated by fluid-body interactions substantially different than with Newtonian fluids. In their paper, Vishwanathan and Juarez [5] investigate steady-streaming flows, which are rectified flows generated by a periodically oscillating body in a fluid. Traditionally these flows arise due to weak inertial effects in Newtonian fluids (in Stokes flow the mean flow field would be zero) but here Vishwanathan and Juarez [5] demonstrate that viscoelasticity leads to qualitative differences arising from the competition between constitutive and inertial nonlinearities. Similarly, Dehghani and Narsimhan [6] show that in the presence of interfacial linear viscoelasticity, traditional forces acting on a translating droplet retain their functional form but are endowed with a frequency dependent viscosity. Aramideh et al. [7] consider the effects of complex fluid rheology in the presence of an array of cylinders, as a model of porous media. They find that fluid elasticity can both decrease resistance at low Deborah numbers and dramatically



Fig. 1. Group photo at the Banff International Research Station for Mathematical Innovation and Discovery (BIRS) during a workshop on "Complex Fluids in Biological Systems," held July 22-27, 2018.

increase resistance at high Deborah numbers. A different view of flows through porous media is described in the paper by Stoop et al. [8], who derive an elegant way to categorize the topological state of spatial disorder of the flow, and combine microfluidic experiments with large-scale, pore-resolved simulations.

A classical system in biological fluid dynamics which has seen tremendous interest for the last few decades is the self-propulsion of microorganisms. This problem has a long literature when the fluid is Newtonian (see Lauga and Powers [9] for a comprehensive review), but when the fluid is non-Newtonian significant complications arise due to the nonlinearity of the consitutive equations and foundational understanding of these active body and fluid interactions is still being developed [10,11]. This issue includes a number of fundamental papers on swimming in complex fluids. Pietrzyk et al. [12] study the motion of a canonical model swimmer, the squirmer, as it moves through a shearthinning fluid. This study details how complex fluid rheology leads to changes of stress on the boundary of the swimmer and a flow modification in the bulk; both these modify the motion of the swimmer with the latter effect often dominating. Datt and Elfring [13] also use the squirmer model but to investigate higher-order viscoelastic effects and show that the details of the constitutive relationship matter. Thomases and Guy [14] explore in detail the viscoelastic stresses that often lead to changes in swimming dynamics of microorganisms, particularly those that oscillate slender appendages that see stress concentrated at the tips. Krieger et al. [15] investigate swimming in a different complex fluid, a liquid crystal, and show that confinement can significantly affect the rheological response of the fluid. Their theory and numerics suggest that bodies swimming with undulatory waves may swim in the direction of wave propagation, opposite what is observed for swimming in a Newtonian fluid, depending on the liquid crystalline properties. They also show that this strange behavior may be suppressed when the body is in the presence of a nearby boundary. Finally, Alonso-Matilla and Saintillan [16] investigate a suspension of swimmers in a thin film on a substrate and, with a coarse-grained kinetic theory to describe the active fluid, examine the effect of active stresses from the swimmers on the stability of the liquid-air interface.

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