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Geometrically frustrated filament assemblies: Unravelling the connection between bundle shape and inter-filament order

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From steel cables and textile fibers to filamentous protein bundles in cells and tissues, densely-packed assemblies of filaments are vital structural elements of the worlds around us and inside of us. Despite the ubiquity and utility of dense-filament assemblies in such diverse materials (across 7 orders of magnitude in size!) surprisingly little is known about the fundamental rules that govern their structure. This talk will discuss recent progress in our understanding of the non-linear relationship between the geometry of a rope-like assembly and the structure and energetics of inter-filament packing. In particular, we focus on mathematical models of the geometric frustration between twist – as in macroscopic cables or chiral biofilament bundles – and the preference for isometric, or "constant spacing," packing of filaments in the cross section. Any measure of twist makes it geometrically impossible to evenly space filaments in bundles, begging the question what is the optimal packing of a twisted bundle? We show that geometry of interfilament contact can be mapped formally onto a problem of packing on a 2D non-Euclidean surfaces, whose intrinsically-curved geometry points to the necessity of a complex spectrum defects in the ground-state packing. We confirm the existence of defects and their sensitivity to bundle twist and radius through simulations of energy-minimizing assemblies of cohesive filaments.