Ribbon Formation in Twist-Nematic Elastomers

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Introduction

Nematic Elastomers (NEs) have both the elastic properties of rubbers and the orientational properties of liquid crystals. Those two properties makes the shape of NEs very sensitive to isotropic-nematic phase transition. Our goal is to replicate with numerical experiments the phenomena of shape formation in slender bar made of **twist-nematic elastomers** (TNEs), where **chirality** plays a critical role.

Physical Model

Elastomeric distortions are sensible to both solvent evaporation (v) and temperature (ϑ) and can be described by uniaxial stretches $\mathbf{U}_o$ aligned with the nematic orientation $\mathbf{N}$:

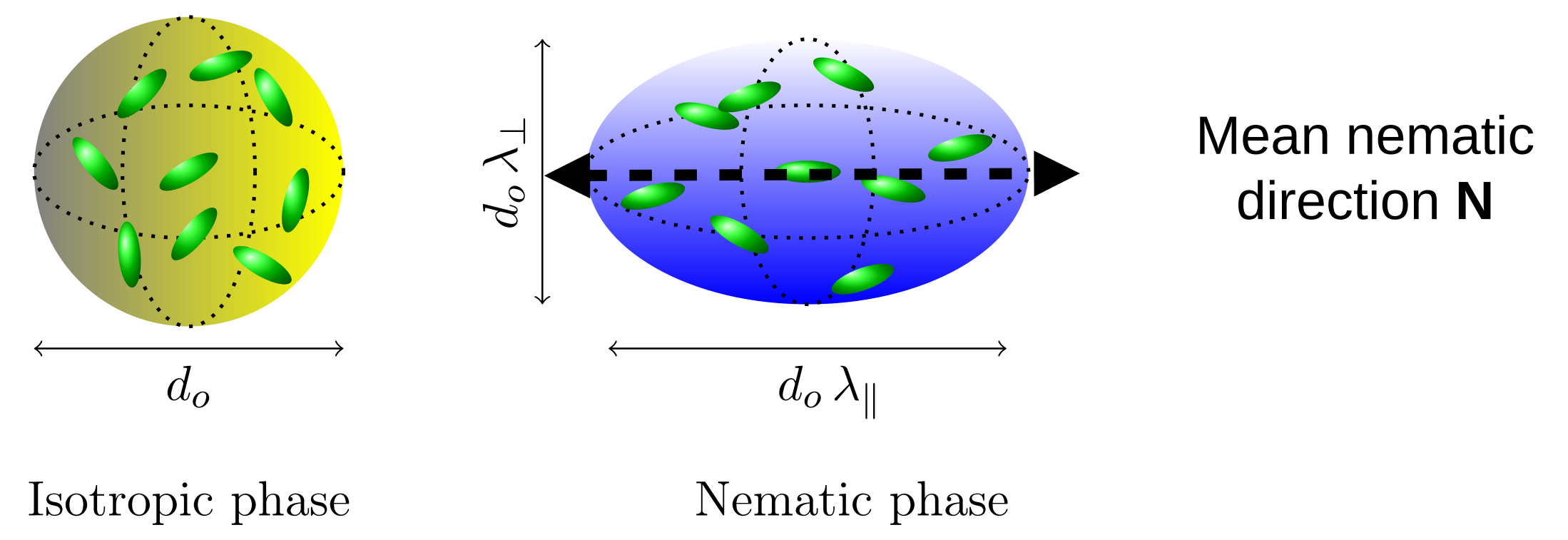
$$\mathbf{U}_o(\vartheta, v) = \Lambda_\parallel(\vartheta, v)\,\mathbf{N} + \Lambda_\perp(\vartheta, v)\,(\mathbf{I} - \mathbf{N})$$

A key role is played by the resultant stretches:

$$\Lambda_\parallel(\vartheta, v) = \frac{\lambda_\parallel(\vartheta)\,\alpha_\parallel(v)}{\lambda_\parallel(\vartheta_o)}, \quad \Lambda_\perp(\vartheta, v) = \frac{\lambda_\perp(\vartheta)\,\alpha_\perp(v)}{\lambda_\perp(\vartheta_o)}$$

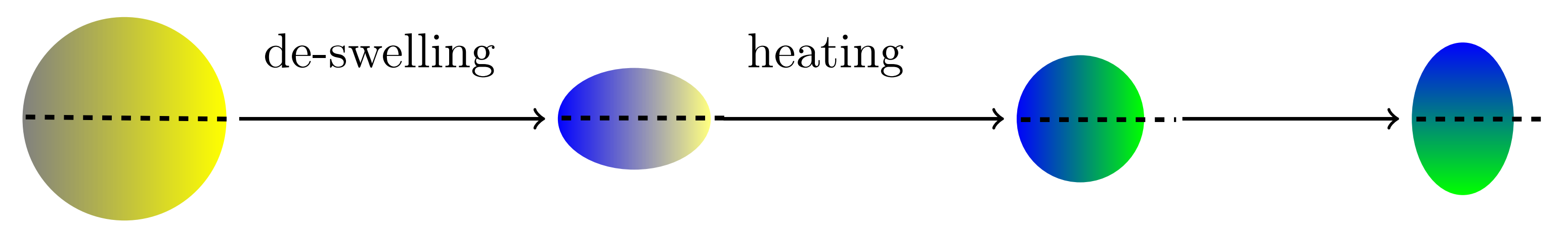
The temperature-induce stretches are highlighted in red, the de-swelling-induced ones in blue. The uniaxial stretches $\mathbf{U}_o$ enter the elastic energy of the system as a pre-strain.

Nematic Elastomer



Disordered, isotropic phase (left, $T>T_{NI}$), ordered, nematic phase (right, $T<T_{NI}$); RVE is a spheroid whose polar axis is aligned with the mean mesogen direction.

Phase Transformations at Microscopic Scale



preparation state $v = 1,\ \vartheta = \vartheta_p$

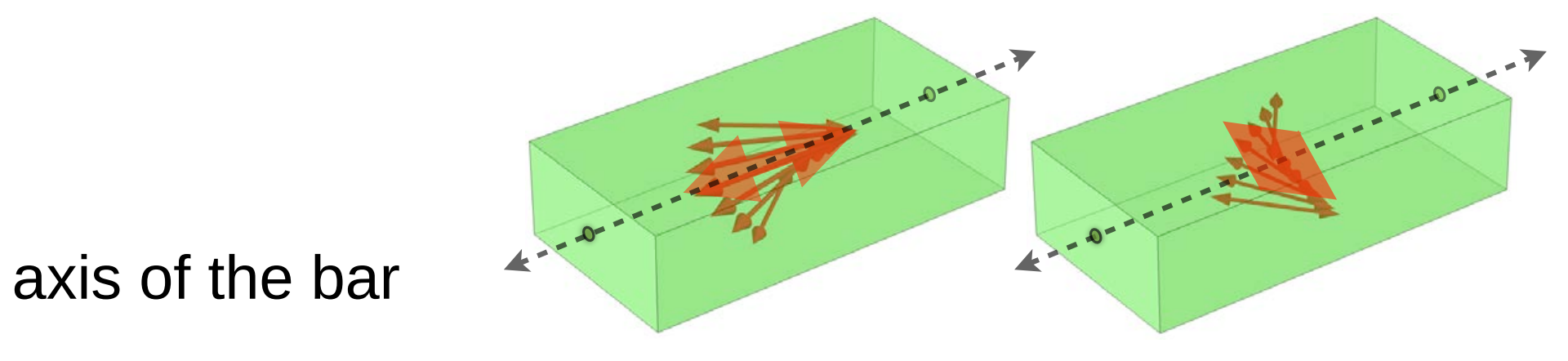
$\sim 50\%$ volume reduction $v = v_d,\ \vartheta = \vartheta_p$

flat $v = v_d,\ \vartheta = \vartheta_f$

isotropic state $v = v_d,\ \vartheta = \vartheta_{NI}$

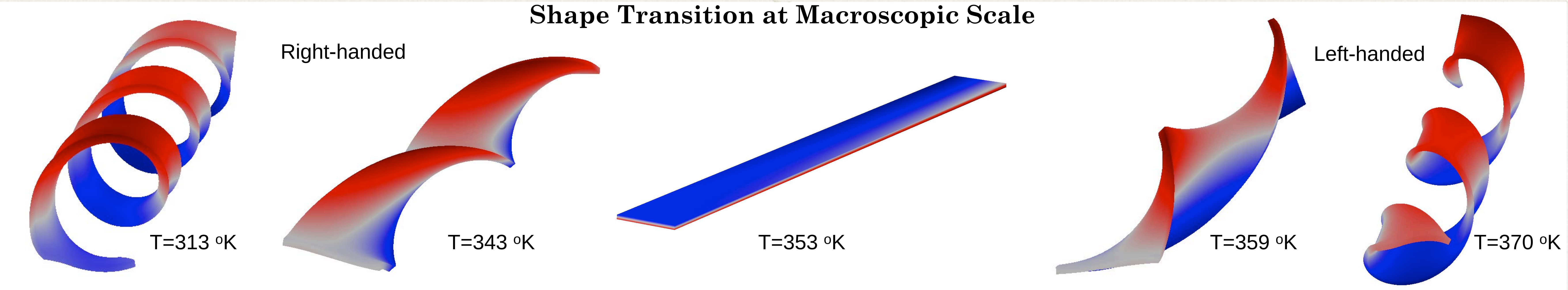
Specimens are prepared in the nematic & swollen state ($\theta=\theta_o$, v=1), and are initially flat. Then, they undergo two transformations: deswelling at constant temperature θ_o (irreversible); nematic-to-isotropic phase transition (reversible).

Chirality

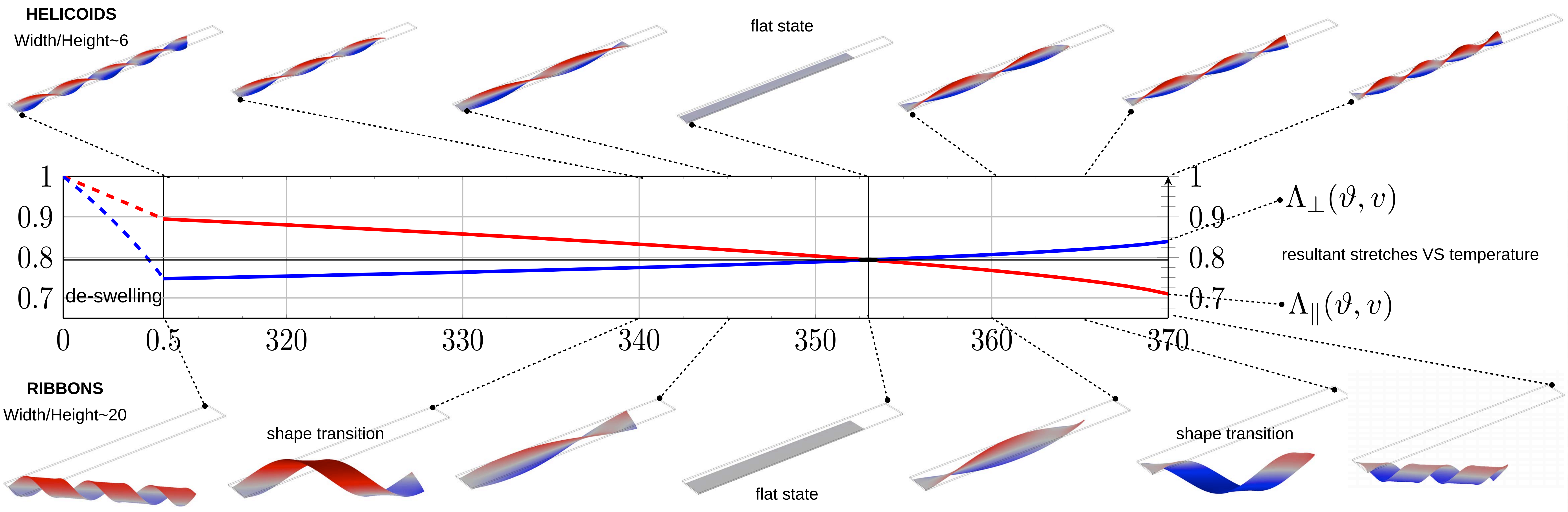


The nematic axis at mid plane may be parallel to the axis of the bar (left, L-geometry), or orthogonal (right, S-geometry). The nematic axis varies linearly from top to bottom with an overall twist of Pi/2, thus inducing a chiral microstructure.

Shape Transition at Macroscopic Scale



Results: shape-temperature dependence



Computational Model

We model the TNEs in the framework of 3D incompressible non-linear elasticity with large pre-strains, and we account for both chirality, de-swelling and temperature changes. We use three nested Parametric Sweep nodes to solve the model; the first Sweep generates a parametric geometry, the second and the third ones simulate de-swelling and temperature variation.

References:

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