

**Video S1 | File: Betterton\_SVid1.mov. Type: video. Title: Constant-volume simulation of an equilibrium system with no motors.** Legend: Red lines show the outline of the periodic simulation box. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). Parameters are the reference parameter set of table EDII and the system contains 4000 filaments. The system shows filament alignment and diffusive motions characteristic of an equilibrium nematic liquid crystal.

**Video S2 | File: Betterton\_SVid2.mov. Type: video. Title: Constant-volume simulation of an active system with motors.** Legend: Red lines show the outline of the periodic simulation box. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors. Parameters are the reference parameter set of table EDII and the system contains 4000 filaments. The system shows motor-driven active transport of filaments and formation of fluctuating polar lanes.

**Video S3 | File: Betterton\_SVid3.mov. Type: video. Title: Constant-pressure simulation of a system with motors.** Legend: System is also shown in fig. 1g. Red lines show the outline of the periodic simulation box, which is adjusted to achieve a constant isotropic pressure. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors. Parameters are the reference parameter set of table EDII and the system has 500 filaments. Persistent extensile stress leads to continuous elongation of the simulation box as the system attempts unsuccessfully to reach a constant isotropic pressure.

**Video S4 | File: Betterton\_SVid4.mov. Type: video. Title: Constant-volume simulation of a system with 1 flipped filament.** Legend: Red lines show the outline of the periodic simulation box. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors. Parameters are the reference parameter set of table EDII and the system has 100 filaments. Most filaments have plus ends pointed up (red); a single filament has plus end down (blue). The blue filament undergoes motor-driven sliding toward its minus end, leading to collisions with the minus ends of red filaments.

**Video S5 | File: Betterton\_SVid5.mov. Type: video. Title: Constant-volume simulation of a system with motors with a reversed force-velocity relation.** Legend: Red lines show the outline of the periodic simulation box. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors. Parameters are the reference parameter set of table EDII and the system has 4000 filaments. The system shows extensive bundling and motor-driven active transport of filaments.

**Video S6 | File: Betterton\_SVid6.mov. Type: video. Title: Constant-pressure simulation of an system with motors with a reversed force-velocity relation.** Legend: Red lines show the outline of the periodic simulation box, which is adjusted to achieve a constant isotropic pressure. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors. Parameters are the reference parameter set of table EDII and the system has 500 filaments. Persistent contractile stress leads to continuous shortening of the simulation box as the system attempts unsuccessfully to reach a constant isotropic pressure.

**Video S7 | File: Betterton\_SVid7.mov. Type: video. Title: Constant-volume simulation of a system with motors and static crosslinkers.** Legend: Red lines show the outline of the periodic simulation box. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors and crosslinkers. Parameters are the reference parameter set of table EDII and the system has 4000 filaments. The system shows bundling and motor-driven active transport of filaments.

**Video S8 | File: Betterton\_SVid8.mov. Type: video. Title: Constant-pressure simulation of an system with motors and crosslinkers.** Legend: System is also shown in fig. 3g. Red lines show the outline of the periodic simulation box, which is adjusted to achieve a constant isotropic pressure. Filaments are colored according to orientation as shown in the color wheel in fig. 1f: red (plus end up), green (left), blue (down), and purple (right). White lines indicate motors and crosslinkers. Parameters are the reference parameter set of table EDII and the system has 500 filaments. Persistent contractile stress leads to continuous shortening of the simulation box as the system attempts unsuccessfully to reach a constant isotropic pressure.