

Description of Additional Supplementary Files:

Supplementary Movie 1: **Orientational transitions in a pressure-driven nematic flow.** In a weak flow, the uniformly aligned homeotropic nematic (black colour) is bowed toward the flow direction (grey-to-orange-to-reddish birefringent colours). With an increasing flow velocity the nematic undergoes a continuous symmetry-breaking transition into a chiral state of left- and right-handed domains (blue-greenish colour) that flow separated by a soliton-like structure between them. Eventually, the chiral state is replaced by a flow-aligned state (green colour) whose interface is distinguished by a disclination line. Terminal flow velocity is close to $110\text{ }\mu\text{ms}^{-1}$. Recorded under crossed polarizers at 25 fps. The channel width is $100\text{ }\mu\text{m}$ and the channel depth is $12\text{ }\mu\text{m}$.

Supplementary Movie 2: **Symmetric formation of two oppositely-twisted chiral domains in an accelerating nematic flow.** The orientational transition can also start from the sides of the channel and propagate to the middle, where growing chiral domains collide in a flexible soliton that is prone to long-wavelength undulations. The distinct orientational order is reflected in different birefringent colours. The flow velocity is close to $90\text{ }\mu\text{ms}^{-1}$. Recorded under crossed polarizers at 25 fps. The view field size is $450\text{ }\mu\text{m} \times 150\text{ }\mu\text{m}$.

Supplementary Movie 3: **Formation of chiral flow state in weakly chiral nematic.** Gradual continuous transition from bowed to chiral nematic state occurs at relatively low flow velocity and typically starts from the middle of the channel. A small amount of a chiral dopant triggers growth of a single chiral domain with no soliton. Terminal flow velocity is close to $80\text{ }\mu\text{ms}^{-1}$. Recorded under crossed polarizers at 25 fps. The view field size is $450\text{ }\mu\text{m} \times 120\text{ }\mu\text{m}$.