Optical solitons and chirality-enhanced nonlinear optical response in frustrated liquid crystals

Guilhem Poy

Faculty of Mathematics and Physics, Ljubljana

September 8, 2021

Univerza v Ljubljani
Fakulteta za matematiko in fiziko

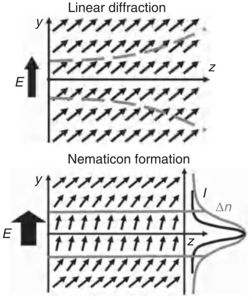
arrs
JAVNA AGENCIJA ZA RAZISKOVALNO DEJAVNOST REPUBLIKE SLOVENIJE

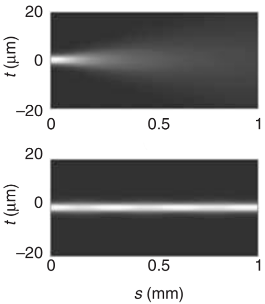
MARIE CURIE ACTIONS

Outline

Motivations

Spatial light solitons in liquid crystals: nematicons



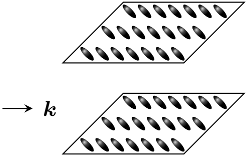


Increasing beam power

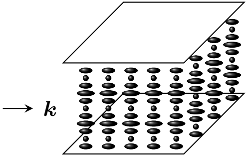
G. Assanto. *Nematicons.* John Wiley & Sons, 2013

Motivations

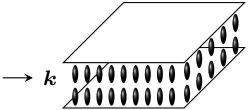
Studied systems in the past 20 years:



thick samples
with planar $\boldsymbol{n}$



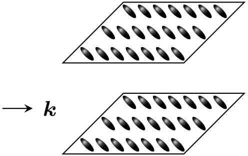
thick samples with
cholesteric helix



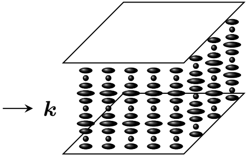
thin samples with
homeotropic $\boldsymbol{n}$

Motivations

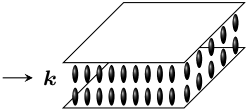
Studied systems in the past 20 years:



thick samples
with planar $\boldsymbol{n}$



thick samples with
cholesteric helix

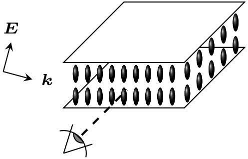


thin samples with
homeotropic $\boldsymbol{n}$

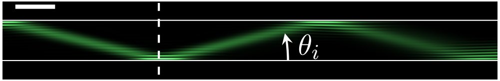
What about confined chiral systems? Can we amplify the optical response with chirality?

Outline

Our first approach: unwound cholesteric with homeotropic anchoring



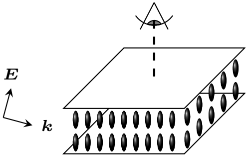
Side slice of beam intensity (simulation):



Side slice of 3PF signal (experiment):

G. Poy *et al.*, *Physical Review Letters* **125** (2020)

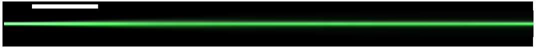
Our first approach: unwound cholesteric with homeotropic anchoring



Top view of the thickness-averaged laser intensity (simulation):

Linear optical regime

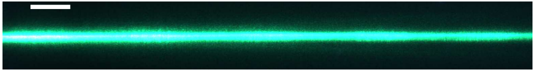
Non-linear optical regime



Top view of the scattered laser light (experiments):

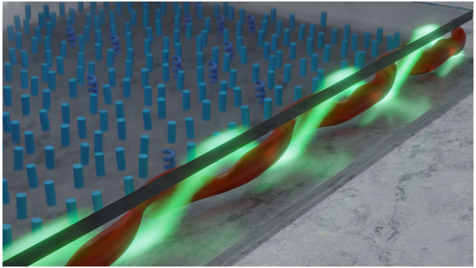
Linear optical regime

Non-linear optical regime



G. Poy *et al.*, *Physical Review Letters* **125** (2020)

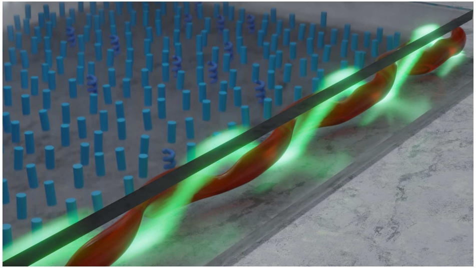
Summary of first approach



- Possibility of generating solitons at a power ~ 2 times smaller than in achiral media.

G. Poy *et al.*, *Physical Review Letters* **125** (2020)

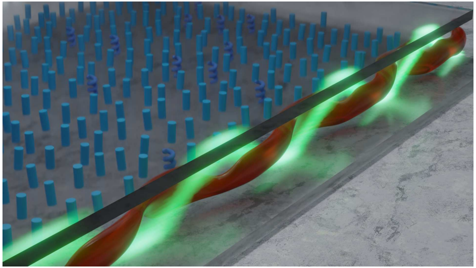
Summary of first approach



- Possibility of generating solitons at a power ~ 2 times smaller than in achiral media.
- Basic mechanism: for a given optical power, the amplitude of molecular reorientation is boosted by the chiral molecules.

G. Poy *et al.*, *Physical Review Letters* **125** (2020)

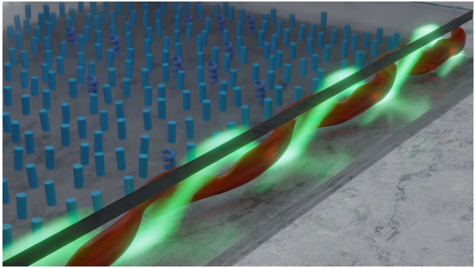
Summary of first approach



- Possibility of generating solitons at a power ~ 2 times smaller than in achiral media.
- Basic mechanism: for a given optical power, the amplitude of molecular reorientation is boosted by the chiral molecules.
- Advanced theoretical analysis very difficult because of the complex bouncing pattern of the beam.

G. Poy *et al.*, *Physical Review Letters* **125** (2020)

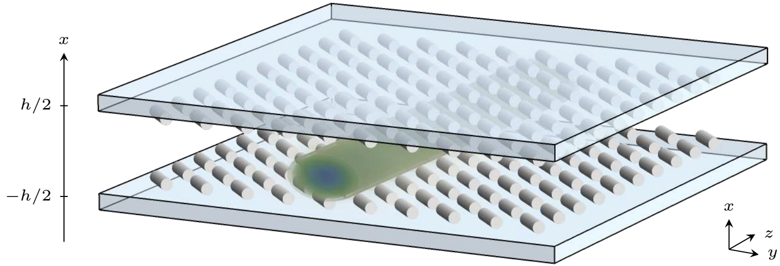
Summary of first approach

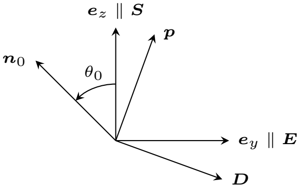


- Possibility of generating solitons at a power ~ 2 times smaller than in achiral media.
- Basic mechanism: for a given optical power, the amplitude of molecular reorientation is boosted by the chiral molecules.
- Advanced theoretical analysis very difficult because of the complex bouncing pattern of the beam.

G. Poy *et al.*, *Physical Review Letters* **125** (2020)

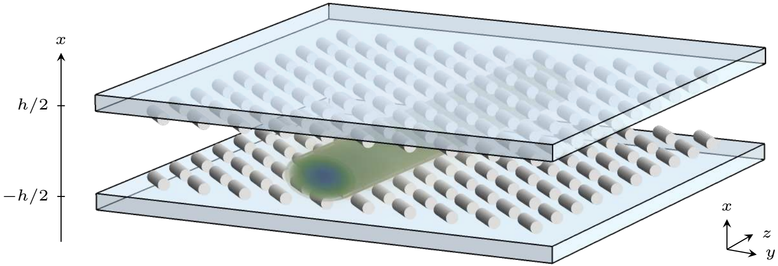
New approach: unwound cholesteric with planar anchoring

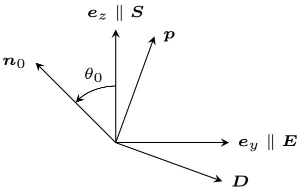




- Control parameter: spontaneous twist $q = 2\pi/P$, with P periodicity of cholesteric helix.
- When $q < q_c \approx \pi/h$, the unwound cholesteric is stable.

New approach: unwound cholesteric with planar anchoring





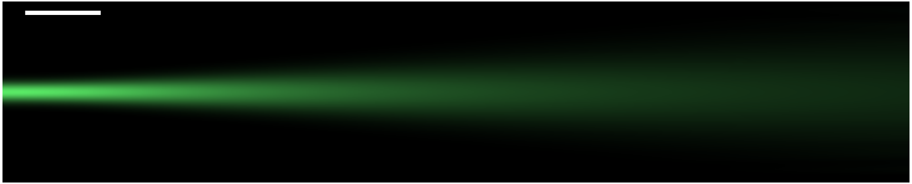
- Control parameter: spontaneous twist $q = 2\pi/P$, with P periodicity of cholesteric helix.
- When $q < q_c \approx \pi/h$, the unwound cholesteric is stable.

Can we get additional insight in this simpler sample geometry?

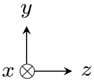
Outline

Simulated self-focused intensity profiles

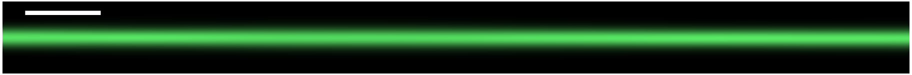
Vanishingly small power



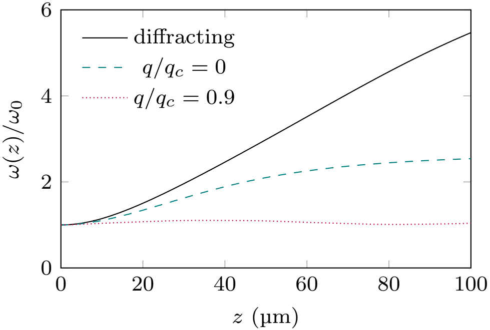
$P = 3.76\ mW$, achiral sample ($q/q_c = 0$)

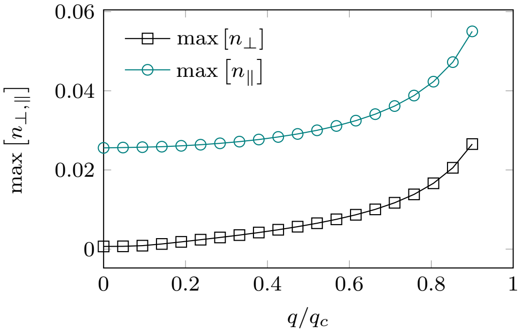


$P = 3.76\ mW$, chiral sample ($q/q_c = 0.9$)



Waist evolution and chirality-enhancement effect

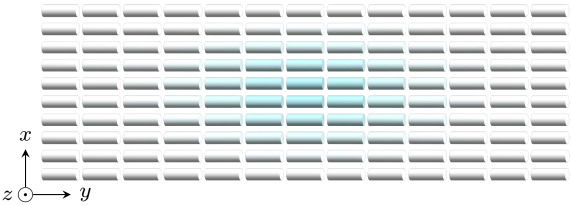




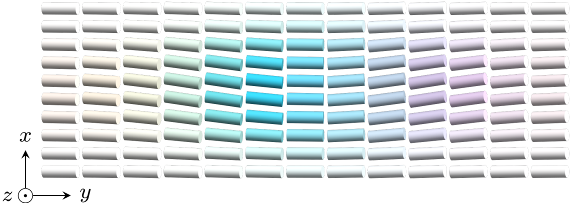
Amplification of nonlinear optical response due to chirality: almost $\times 3$ (higher than in homeotropic cells)

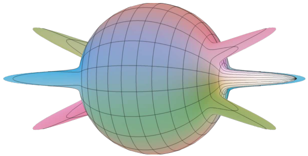
Transverse cross-section of the director field

Achiral sample ($q/q_c = 0$)



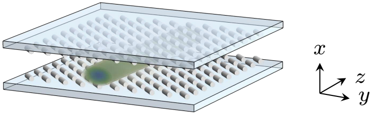
Chiral sample ($q/q_c = 0.9$)





Outline

(1+1)D effective nonlinear beam propagation model



Light fully confined by the plates of the sample:

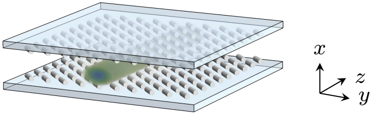
$$A_y \approx A(y,z)\psi(x,z)\exp\{i\boldsymbol{p}\cdot\boldsymbol{R}\}$$

Waveguide mode along x

Amplitude profile along y

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

(1+1)D effective nonlinear beam propagation model



Light fully confined by the plates of the sample:

$$A_y \approx A(y,z)\psi(x,z)\exp\{i\boldsymbol{p}\cdot\boldsymbol{R}\}$$

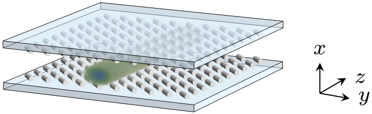
Waveguide mode along x

Amplitude profile along y

- Simplified x-averaged wave equation: $$\left[2ip_z\partial_Z + \partial_Y^2 + \frac{2P}{P_0}\Gamma_{\text{eff}}\right]A = 0$$
  - ⋆ ∂_Y^2: diffraction.
  - ⋆ Γ_{eff}: effective nonlinear photonics potential.

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

(1+1)D effective nonlinear beam propagation model



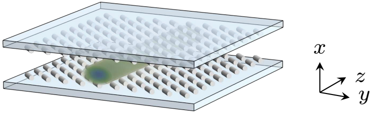
Light fully confined by the plates of the sample:

$$A_y \approx \underbrace{A(y,z)}_{\text{Amplitude profile along } y}\underbrace{\psi(x,z)}_{\text{Waveguide mode along } x} \exp\{i\boldsymbol{p}\cdot\boldsymbol{R}\}$$

- Simplified x-averaged wave equation: $$\left[2ip_z\partial_Z + \partial_Y^2 + \frac{2P}{P_0}\Gamma_{\text{eff}}\right]A = 0$$
  - ⋆ ∂_Y^2: diffraction.
  - ⋆ Γ_{eff}: effective nonlinear photonics potential.
- In Fourier space: $\tilde{\Gamma}_{\text{eff}} = \tilde{G}_{\text{eff}}\tilde{\mathcal{J}}_{\text{eff}}$, with $\mathcal{J}_{\text{eff}}$ the rescaled intensity profile associated with A.

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

(1+1)D effective nonlinear beam propagation model



Light fully confined by the plates of the sample:

$$A_y \approx A(y,z)\psi(x,z)\exp\{i\boldsymbol{p}\cdot\boldsymbol{R}\}$$

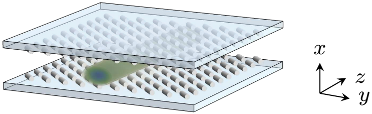
Waveguide mode along x

Amplitude profile along y

- Simplified x-averaged wave equation: $\left[2ip_z\partial_Z + \partial_Y^2 + \frac{2P}{P_0}\Gamma_{\text{eff}}\right]A = 0$
  - ⋆ ∂_Y^2: diffraction.
  - ⋆ Γ_{eff}: effective nonlinear photonics potential.
- In Fourier space: $\tilde{\Gamma}_{\text{eff}} = \tilde{G}_{\text{eff}}\tilde{\mathcal{J}}_{\text{eff}}$, with $\mathcal{J}_{\text{eff}}$ the rescaled intensity profile associated with A.
- Effective Green function of the LC's reponse: $\tilde{G}_{\text{eff}} \sim \frac{|\boldsymbol{k}|^2}{|\boldsymbol{k}|^4 - \eta^2 q^2 k_y^2}$ increases when q increases.

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

(1+1)D effective nonlinear beam propagation model



Light fully confined by the plates of the sample:

$$A_y \approx \underbrace{A(y,z)}_{\text{Amplitude profile along } y}\underbrace{\psi(x,z)}_{\text{Waveguide mode along } x} \exp\{i\boldsymbol{p}\cdot\boldsymbol{R}\}$$

- Simplified x-averaged wave equation: $\left[2ip_z\partial_Z + \partial_Y^2 + \frac{2P}{P_0}\Gamma_{\text{eff}}\right]A = 0$
  - ⋆ ∂_Y^2: diffraction.
  - ⋆ Γ_{eff}: effective nonlinear photonics potential.
- In Fourier space: $\tilde{\Gamma}_{\text{eff}} = \tilde{G}_{\text{eff}}\tilde{\mathcal{J}}_{\text{eff}}$, with $\mathcal{J}_{\text{eff}}$ the rescaled intensity profile associated with A.
- Effective Green function of the LC's reponse: $\tilde{G}_{\text{eff}} \sim \frac{|\boldsymbol{k}|^2}{|\boldsymbol{k}|^4-\eta^2q^2k_y^2}$ increases when q increases.
- Estimation of the power of a fundamental soliton with waist ω_0:

$$P = \frac{P_0}{k_0^2\omega_0^4\left[-\Gamma''_{\text{eff}}(0)\right]}$$

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

Outline

Concluding remarks

Take-home message

Chirality allows to boost the response of frustrated liquid crystals to external fields, and therefore to generate optical solitons at a lower power than in achiral media.

- Experimental implementation: need to avoid π-twisted domains, only keeping the unwound phase inside the LC sample.
- Beyond solitonic science: chirality-enhanced optomechanical manipulation of LC patterns with laser, relevance in spin-orbit interactions, etc.

G. Poy *et al.*, *Proc. SPIE 11807, Liquid Crystals XXV* (2021)

Thank you for your attention!