Lensing and deflection of light with soft topological solitons

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Univerza *v Ljubljani*
Fakulteta za *matematiko in fiziko*

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MARIE CURIE ACTIONS

Outline

1 Introduction

2 Interaction with line-like solitons

3 Interaction with point-like solitons

4 Summary

The cholesteric phase

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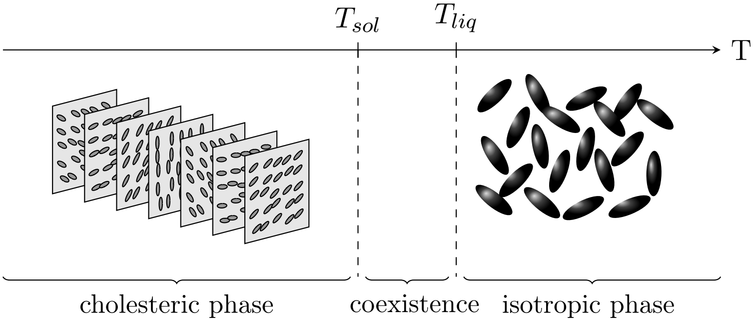

Two classes of soft topological solitons in confined homeotropic samples

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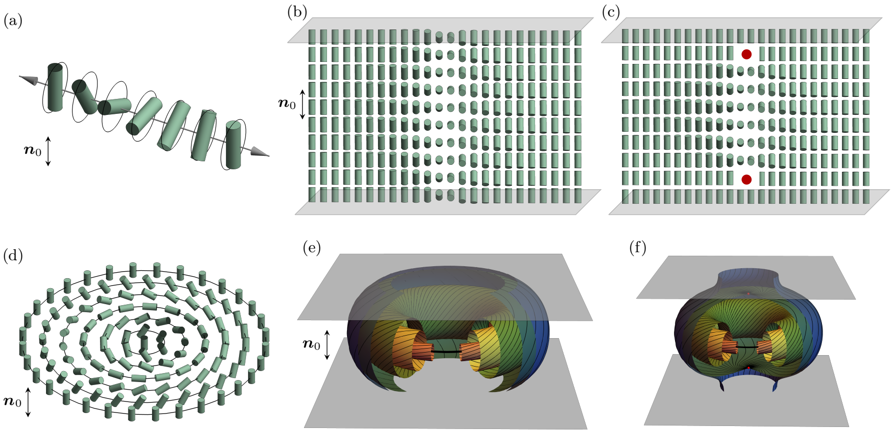
- At intermediate sample thickness:



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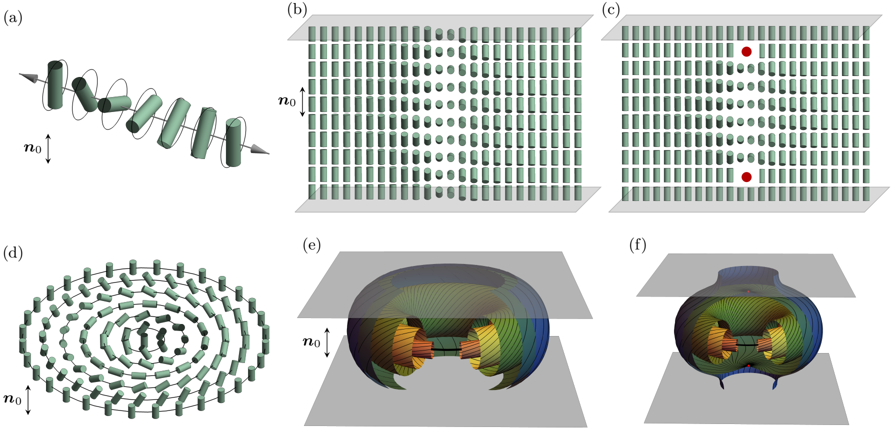

Localized robust birefringent structures ⇒ interesting interaction with light?

Light propagation tools in birefringent media

Experimental work in the group of Prof. Smalyukh, modeling work in Ljubljana.

G. Poy and S. Žumer. *Optics Express*, 28:24327, 2020

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- Custom-built beam propagation code:
  - ⋆ Wave-equation in anisotropic media: $\left[\partial_k\partial_k\delta_{ij} - \partial_i\partial_j + k_0^2\epsilon_{ij}\right] E_j = 0$

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  - ⋆ After eliminating E_z and keeping only forward modes:

$$i\partial_z \boldsymbol{E}_\perp = -\boldsymbol{\mathcal{P}}\boldsymbol{E}_\perp$$

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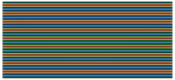
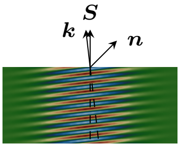
  - ⋆ What's inside $\boldsymbol{\mathcal{P}}$?



Phase op. $\boldsymbol{K} \sim k_0^2\boldsymbol{\epsilon}$



Walkoff op. $\boldsymbol{W} \sim (\boldsymbol{\epsilon}\,\boldsymbol{u}_z) \otimes \boldsymbol{\nabla}_\perp$

Diffraction op. $\boldsymbol{D} \sim \boldsymbol{\Delta}_\perp$

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- Applications:
  - ⋆ Open-source code for polarized optical micrograph simulation (google search: Nemaktis)
  - ⋆ Closed-source code for wide-angle simulations (or non-linear optics)

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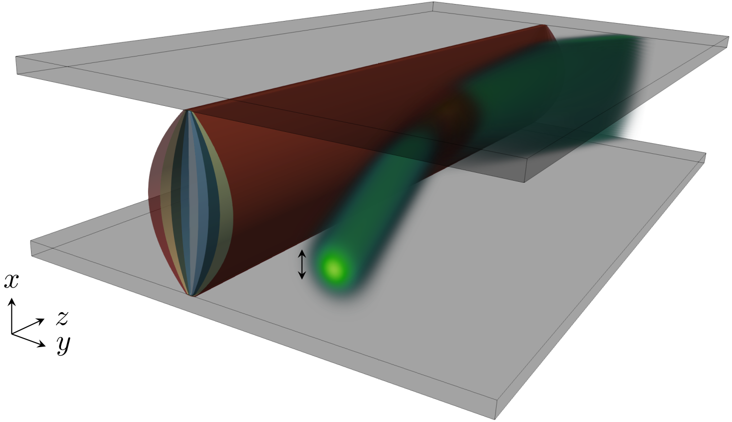
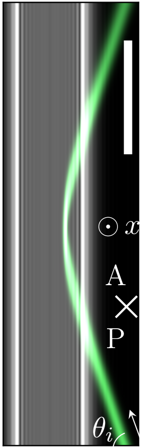
Transmission and/or reflection

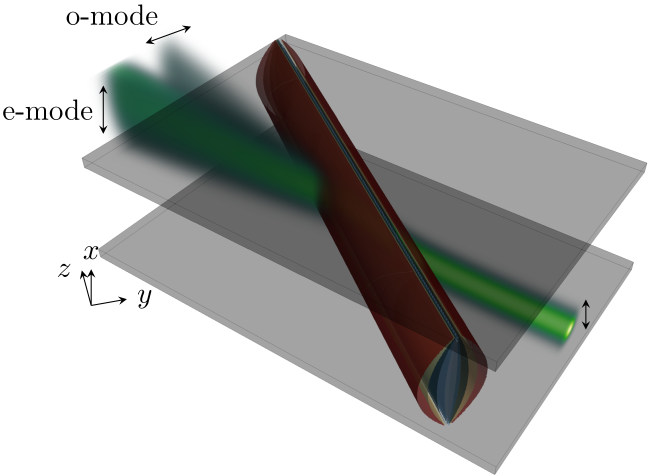
Reflection of incident extraordinary beam ($\theta_i = 70°$):

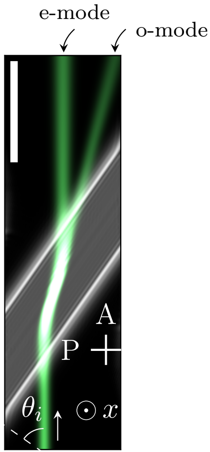




Transmission and/or reflection

Transmission of incident extraordinary beam ($\theta_i = 55°$):





Description with a generalization of Snell's law

From an exact eigenmode decomposition of Maxwell equations:

$$n^{(\alpha,m)} \sin\theta^{(\alpha,m)} = n_i \sin\theta_i$$

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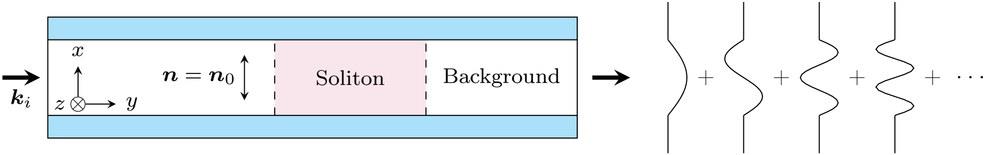
- In our system, $n^{(\alpha,m)}$ = effective index of eigenmode $\{\alpha, m\}$ far from the soliton
  - ⋆ $\alpha = e, o$: polarisation state
  - ⋆ $m = 1, 2, \ldots$: mode index



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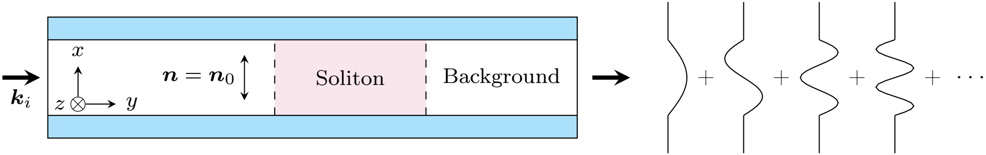
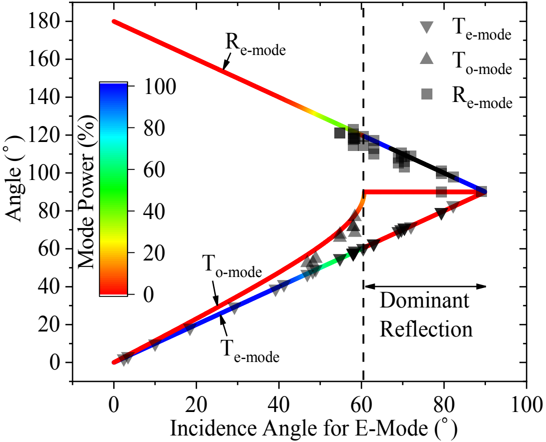
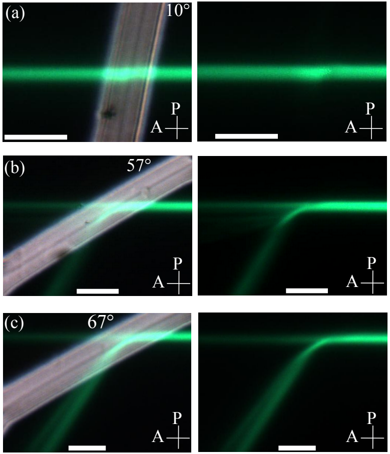


$\theta^{(\alpha,m)}$ does not depends on the choice of topological soliton!
(but Fresnel coefficients do)

Comparison with experiments

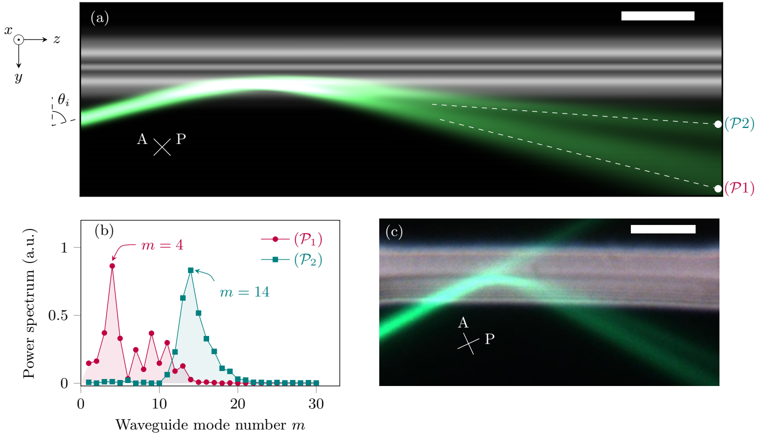
Small mode index approximation in thick samples: $n^{(\alpha,m)} \approx n_\alpha \sqrt{1-(m/m_0)^2} \approx n_\alpha$





Comparison with experiments

Splitting of eigenmode packets (strongly depends on x-profile): $n^{(\alpha,m_1)} \neq n^{(\alpha,m_2)}$



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Ray-tracing description

Hamiltonian reformulation of century-old Fermat-Grandjean theory:

$$\begin{aligned}\frac{\mathrm{d}\boldsymbol{r}}{\mathrm{d}\bar{s}} &= \frac{\partial\mathcal{H}^{(\alpha)}}{\partial\boldsymbol{p}}\\ \frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}\bar{s}} &= -\frac{\partial\mathcal{H}^{(\alpha)}}{\partial\boldsymbol{r}}\end{aligned}$$

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- Canonical variables $\{\boldsymbol{r}, \boldsymbol{p}\}$: position and momentum of "light bullets".

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- Canonical variables $\{\boldsymbol{r},\boldsymbol{p}\}$: position and momentum of "light bullets".
- Hamiltonian for ordinary and extraordinary rays:

$$\mathcal{H}^{(o)} = \frac{|\boldsymbol{p}|^2}{2\epsilon_\perp}$$

$$\mathcal{H}^{(e)} = \frac{\epsilon_\perp |\boldsymbol{p}|^2 + \epsilon_a \left|\boldsymbol{n}(\boldsymbol{r}) \cdot \boldsymbol{p}\right|^2}{2\epsilon_\perp \epsilon_\parallel}$$

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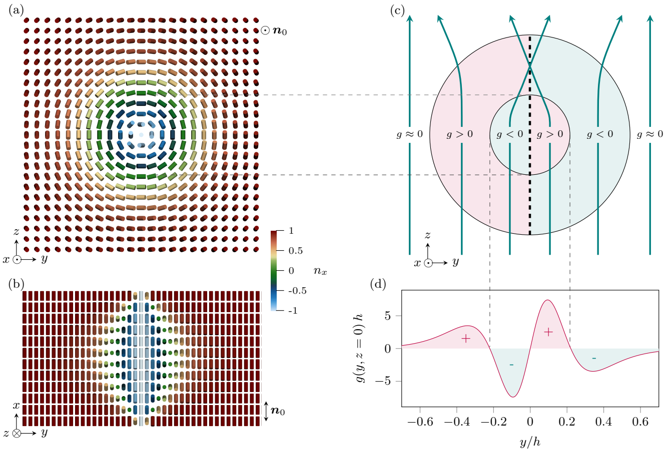
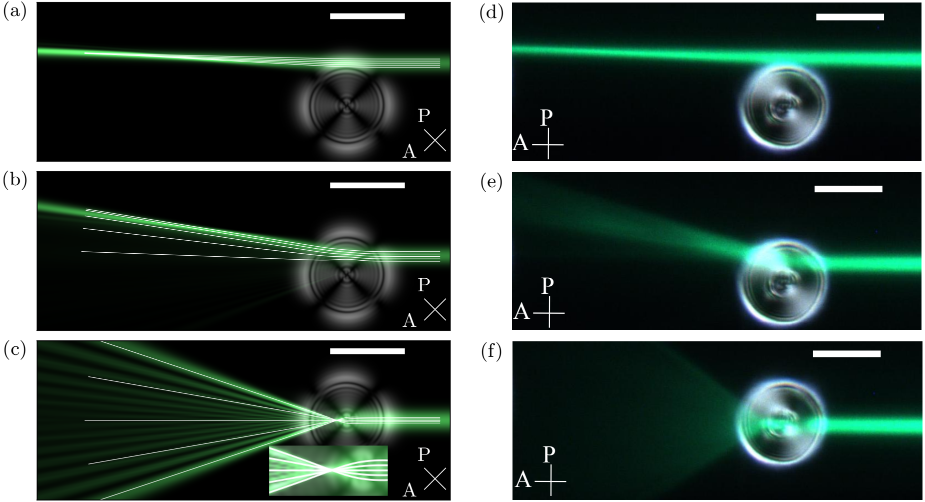
Ray-tracing description

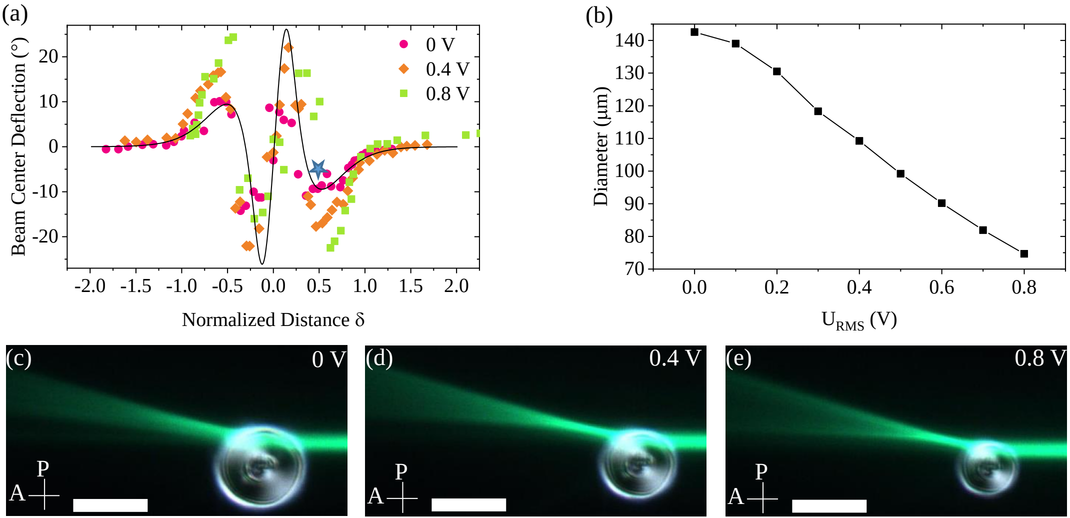
Simplification with 2D rays: $\mathrm{d}p_y/\mathrm{d}z \approx -(\epsilon_a/2n_0)\, g$, where $g \equiv \partial n_z^2/\partial y$



Comparison with simulation and experiments



Tunable deflection and lensing



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Take-home message

Soft topological solitons can reliably control the flow of light at the microscopic level

A. J. Hess, G. Poy, J.-S. B. Tai, S. Žumer, and I. I. Smalyukh. *Physical Review X*, 10:031042, 2020

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- Future developments: non-linear optical regime

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