

# Modeliranje širjenja svetlobe vzdolž ograjenih tekočekristalnih defektnih linij

Avtor Miha Čančula

Mentor prof. dr. Slobodan Žumer

Somentor doc. dr. Miha Ravnik

3. september 2013

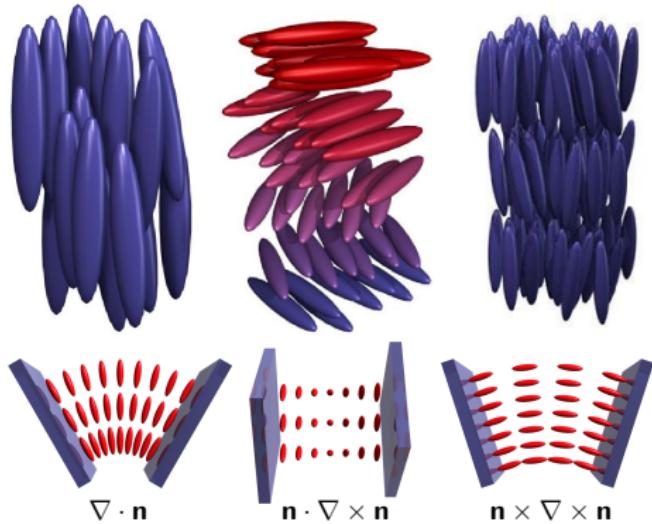
# Tekoči kristali

- Lastnosti tekočin in kristalov
- Orientacijski red
  - Direktor  $\mathbf{n}$
  - Stopnja reda  $S$
  - Simetrija  $\mathbf{n} \leftrightarrow -\mathbf{n}$
- Delni pozicijski red



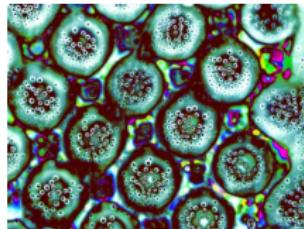
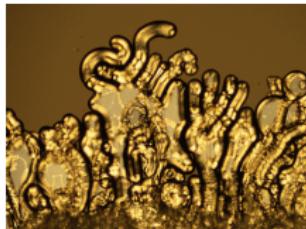
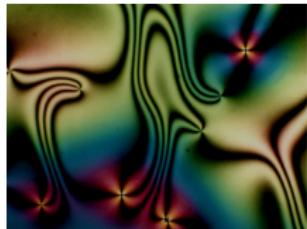
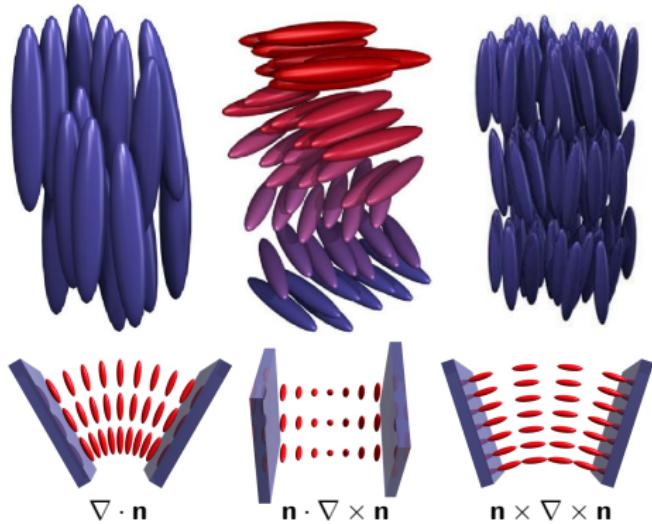
# Tekoči kristali

- Lastnosti tekočin in kristalov
- Orientacijski red
  - Direktor  $\mathbf{n}$
  - Stopnja reda  $S$
  - Simetrija  $\mathbf{n} \leftrightarrow -\mathbf{n}$
- Delni pozicijski red
- Dvolomnost
- Nadzor z zunanjimi polji
- Elastične deformacije direktorja



# Tekoči kristali

- Lastnosti tekočin in kristalov
- Orientacijski red
  - Direktor  $\mathbf{n}$
  - Stopnja reda  $S$
  - Simetrija  $\mathbf{n} \leftrightarrow -\mathbf{n}$
- Delni pozicijski red
- Dvolomnost
- Nadzor z zunanjimi polji
- Elastične deformacije direktorja



# Elektromagnetno valovanje

## Maxwellove enačbe

$$\nabla \cdot \mathbf{D} = \rho_f \quad \nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad \nabla \times \mathbf{H} = \mathbf{J}_f + \frac{\partial \mathbf{D}}{\partial t}$$

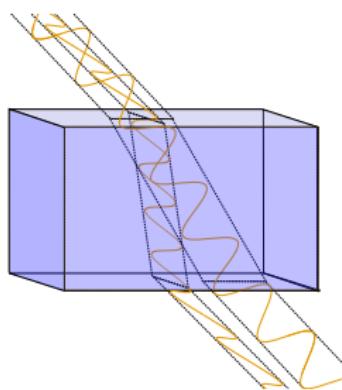
## Konstitutivni zvezi

$$\mathbf{D} = \epsilon \epsilon_0 \mathbf{E} \quad \mathbf{B} = \mu \mu_0 \mathbf{H}$$

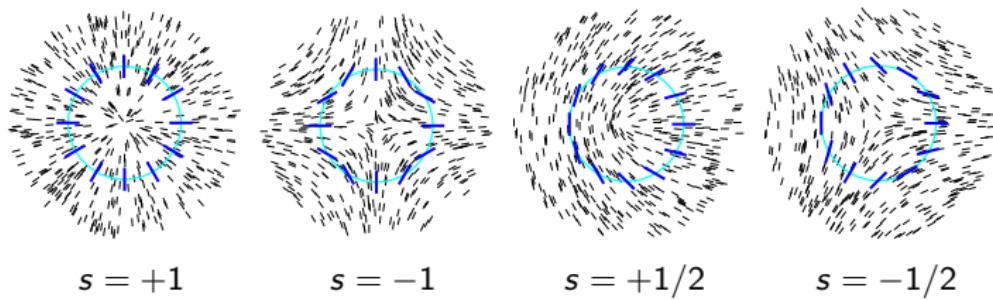
- $\epsilon$  in  $\mu$  sta anizotropna tenzorja
- V vzorcu ni prostih nabojev ali tokov
- Izredna os in dvolomnost  $\Delta n$   
v TK krajevno odvisna

## Dvolomnost

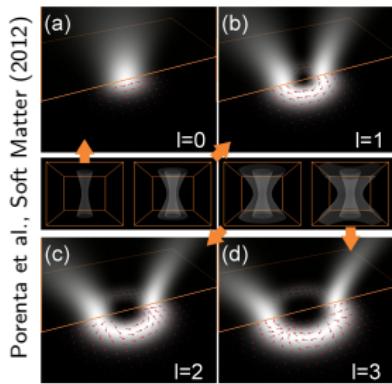
- Lomni količnik odvisen od polarizacije svetlobe
- Ena izredna os z  $n_e$  pravokotne smeri  $n_o$



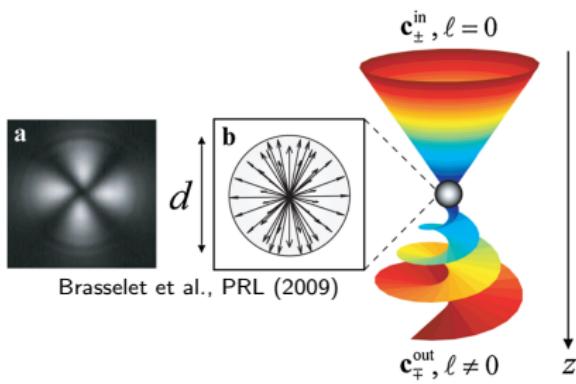
# Topološki defekti



- Točka z nedefinirano smerjo direktorja ali električnega polja
- Ovojno število – celo za vektorska polja, polcelo za direktor



Porenta et al., Soft Matter (2012)



Brasselet et al., PRL (2009)

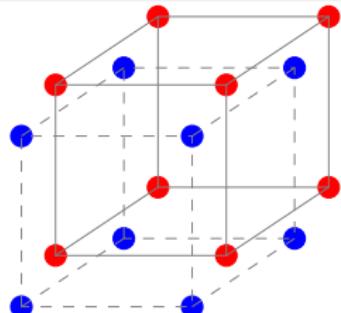
## Metoda končnih diferenc v časovni domeni – FDTD

- Časovni razvoj vseh 6 komponent  $\mathbf{E}$  in  $\mathbf{B}$
- Dinamični Maxwellovi enačbi na diskretni mreži

$$\frac{\partial \mathbf{B}}{\partial t} = -(\nabla \times \mathbf{E}) \quad \frac{\partial \mathbf{E}}{\partial t} = \epsilon^{-1} (\nabla \times \mathbf{B})$$

## Diskretizacija na mreži

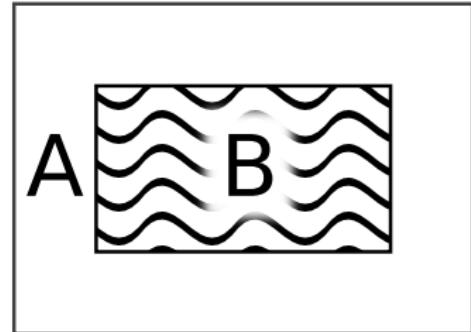
- Komponente polj znane na različnih krajih ob različnih časih
- Izvor in absorpcija valovanja na robu



# Simulacijska celica

## Izvor valovanja

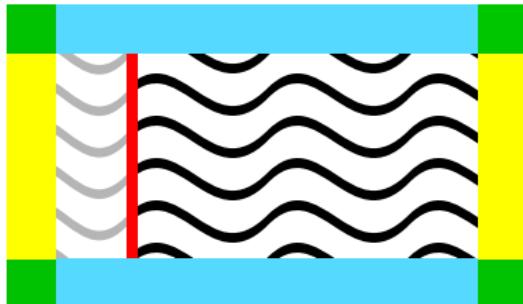
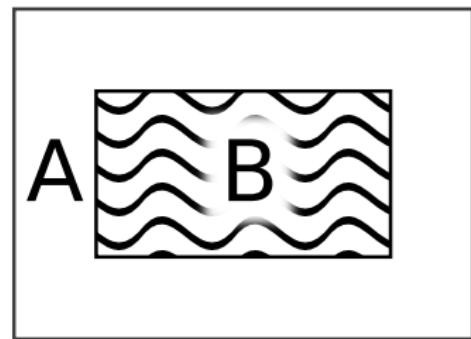
- Delitev na dve območji
- Linearne enačbe →  
vpadno + sipano valovanje
- Zunaj samo sipano valovanje
- Izvor modeliran na meji



# Simulacijska celica

## Izvor valovanja

- Delitev na dve območji
- Linearne enačbe → vpadno + sipano valovanje
- Zunaj samo sipano valovanje
- Izvor modeliran na meji

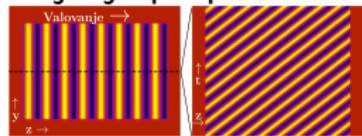


## Absorpcija na robu

- Električna prevodnost in magnetne izgube
- Nefizikalnen material – dodatne prostostne stopnje

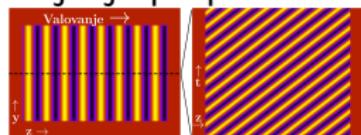
# Primeri uporabe metode

- Širjenje po praznem prostoru

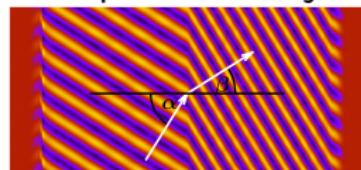


# Primeri uporabe metode

- Širjenje po praznem prostoru

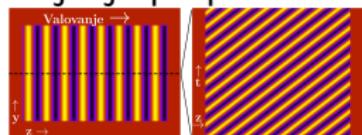


- Lom pri Brewsterjevem kotu

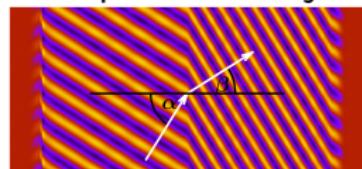


# Primeri uporabe metode

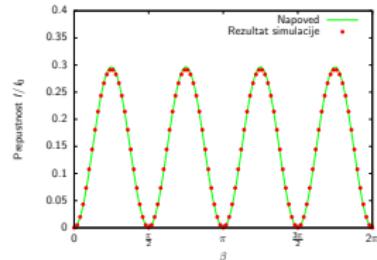
- Širjenje po praznem prostoru



- Lom pri Brewsterjevem kotu

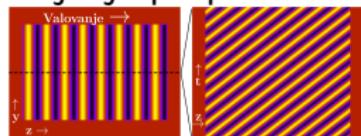


- Dvolomni kristal med prekrižanima polarizatorjema

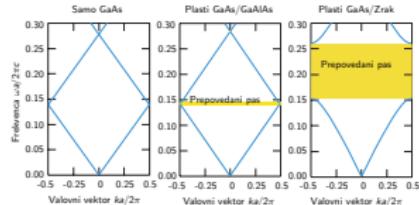


# Primeri uporabe metode

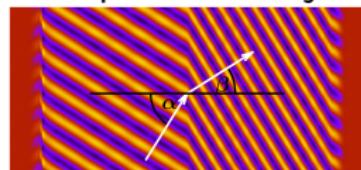
- Širjenje po praznem prostoru



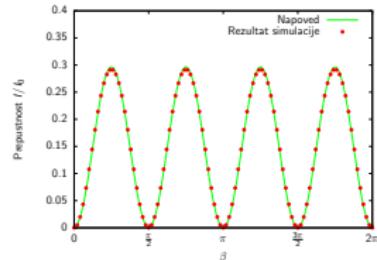
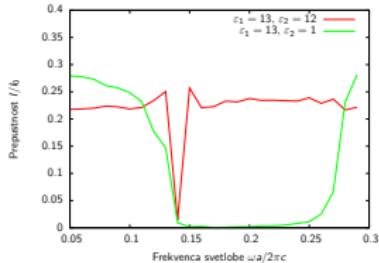
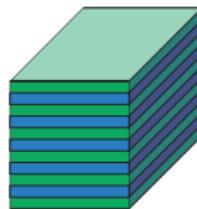
- Fotonski prepovedani pas



- Lom pri Brewsterjevem kotu

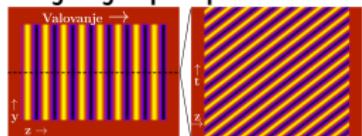


- Dvolomni kristal med prekrižanima polarizatorjema

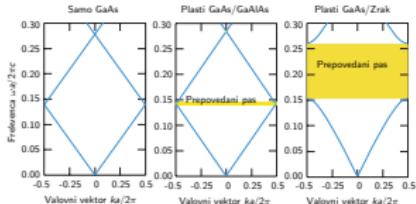


# Primeri uporabe metode

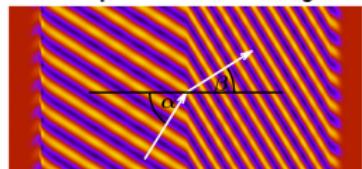
- Širjenje po praznem prostoru



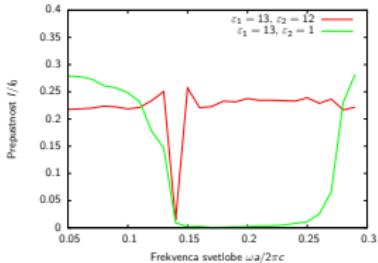
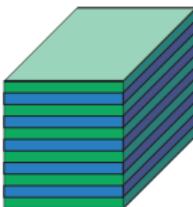
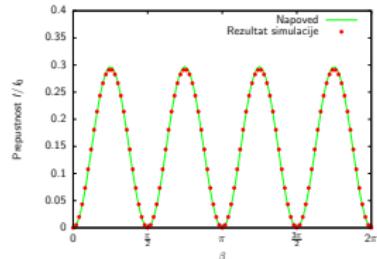
- Fotonski prepovedani pas



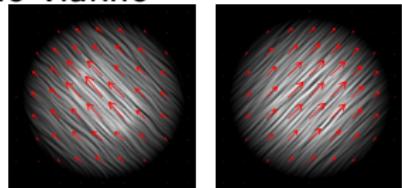
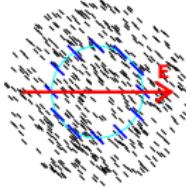
- Lom pri Brewsterjevem kotu



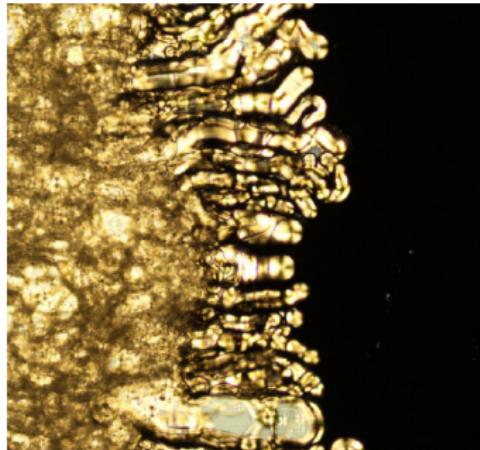
- Dvolomni kristal med prekrižanima polarizatorjema



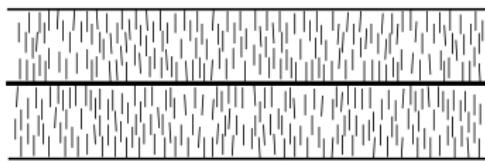
- Dvolomno vlakno



# Vlakno z radialnim direktorskim profilom

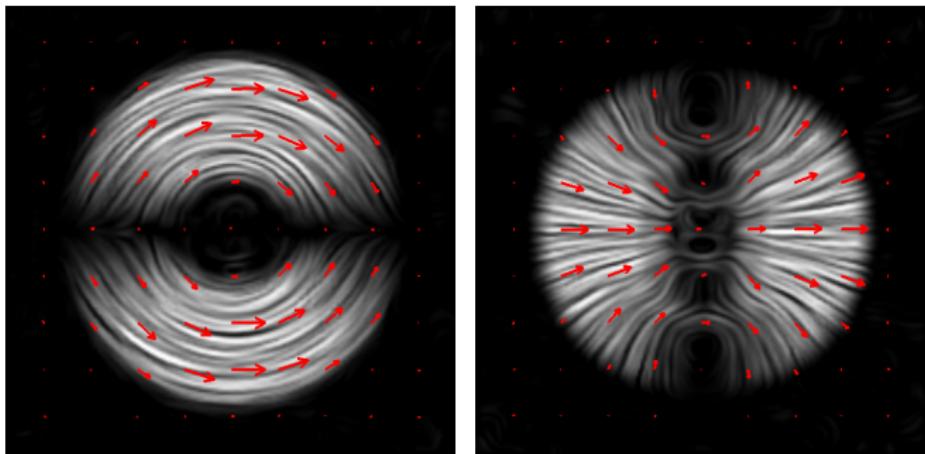
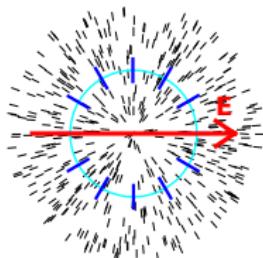


Peddireddy et al., Langmuir (2012)



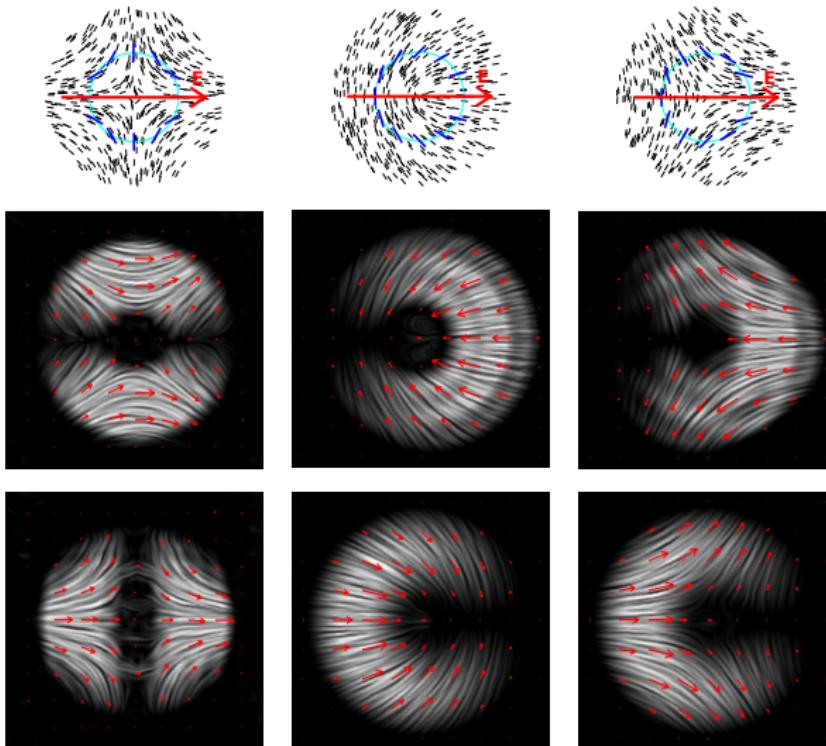
- Rast vlaken iz 8CB v vodi
- Delujejo kot valovodi

# Sunek v vlaknu z radialnim direktorskim profilom



- Sunek razpade na dva stacionarna načina – redni in izredni
- “Neprava” defekta v **E** z ovojnim številom +1
- Temna območja zaradi vpadne polarizacije

# Sunek v vlaknih z različnimi defekti



## Parametri

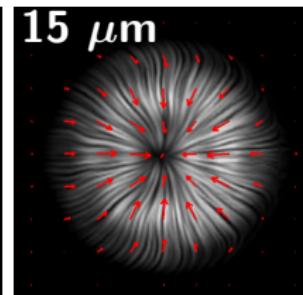
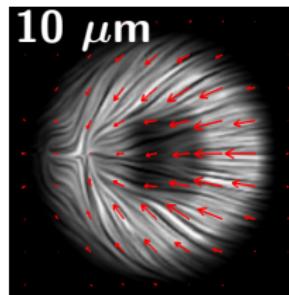
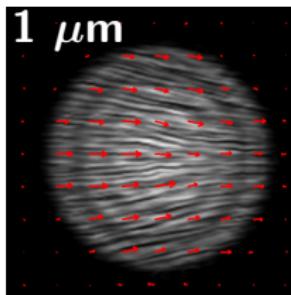
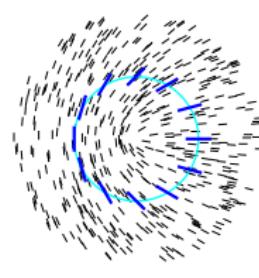
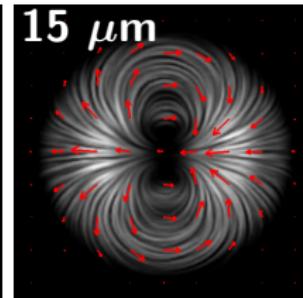
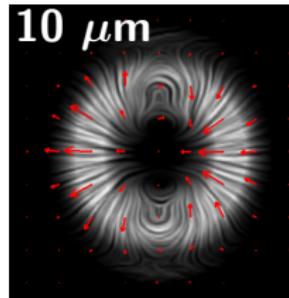
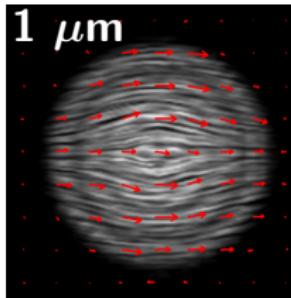
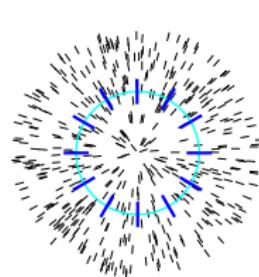
- $\lambda = 480 \text{ nm}$
- $\Delta n = 0,16$
- Premer vlakna  $5 \mu\text{m}$
- Pot sunka  $\sim 40 \mu\text{m}$

## Opažanja

- 2 stacionarna načina
- Enako ovojno število kot defekt v TK
- Temna pega v osi
- Temne ravnine

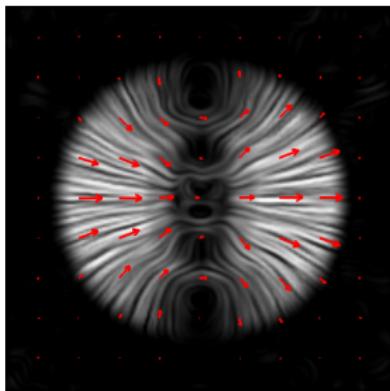
# Stalna laserska svetloba

- Dvolomnost  $\Delta n = 0,01 \Rightarrow$  večja značilna dolžina pojavov
- Stacionarno stanje s krajevno odvisnostjo polarizacije
- Defekt z dvakratnim ovojnim številom

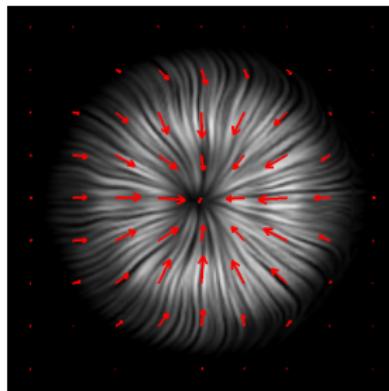


# Stalna laserska svetloba

- Kombinacija dveh stacionarnih načinov, različni hitrosti
- Stacionarno stanje, polje na vsakem mestu niha
- Pretvorba v radialno polarizirano svetlobo
- Brez temnih ravnin – obrat polarizacije za  $90^\circ$



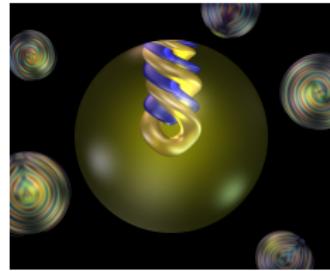
sunek



stalna svetloba

## Tekočekristalne strukture

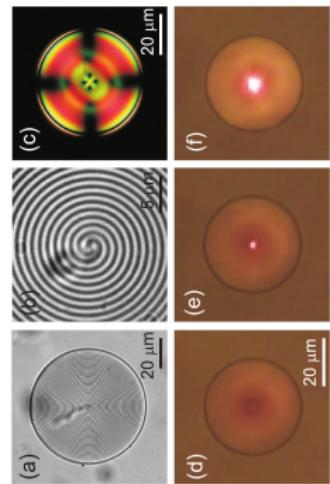
- Natančne transmisijske slike
- Povezava med teorijo in eksperimenti
- Pretvorba polarizacije svetlobe
- Tekočekristalne kapljice in vlakna kot laserji
- Mikroskopija z bližnjim poljem (*near-field*)
- Metamateriali, fotonski kristali, ...



Seč et al., Soft Matter (2012)

## Razširitev metode

- Sklopitev med svetlobo in tekočim kristalom
- Stimulirana emisija, fluorescenza



Humar, Muševič, Optics Express (2010)