

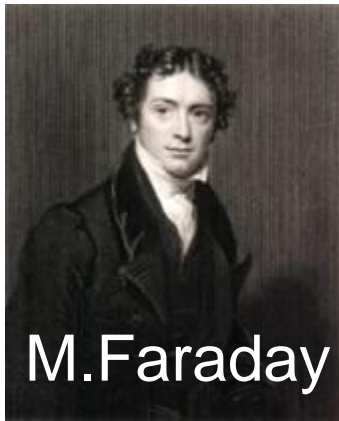
Tekoči kristali in fotonika

Igor Muševič

Institut J. Stefan in Fakulteta za matematiko
in fiziko, Univerza v Ljubljani

Vsebina:

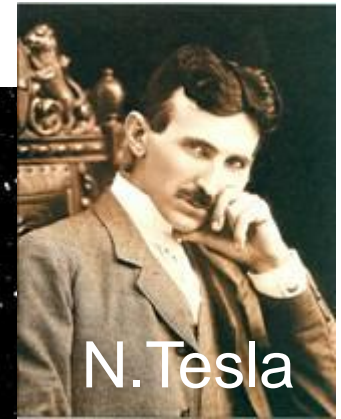
- Zakaj fotonika?
- Uvod v tekoče kristale
- Mikrolaserji s tekočimi kristali
- 3D mikrolaser
- Tekočekristalna vlakna
- Zaključek



M.Faraday



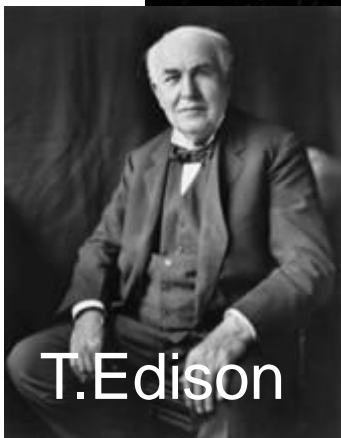
J.C.Maxwell



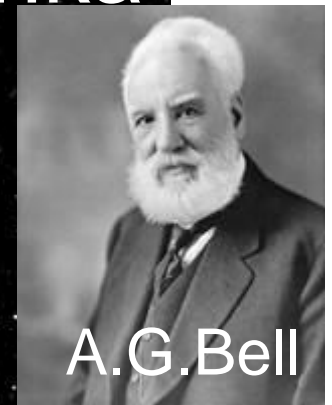
N.Tesla



našo civilizacijo poganja elektrika



T.Edison



A.G.Bell

vir: Sunita Williams, NASA, Slideshare

pr

mikročip-integrirano vezje

vir: Wikipedia Commons



FOTONIKA

Podoben razvoj lahko pričakujemo

na področju svetlobe

znanost o svetlobi, njenem pridobivanju,
širjenju, preoblikovanju in zaznavanju



KUNGL.
VETENSKAPS-
AKADEMIEN

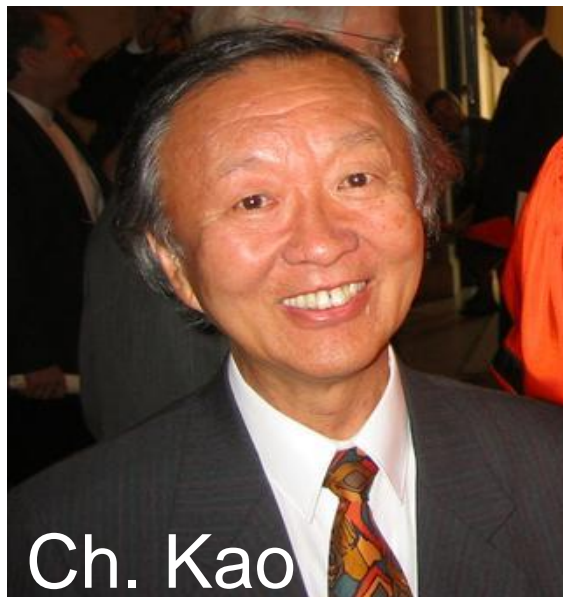
THE ROYAL SWEDISH ACADEMY OF SCIENCES



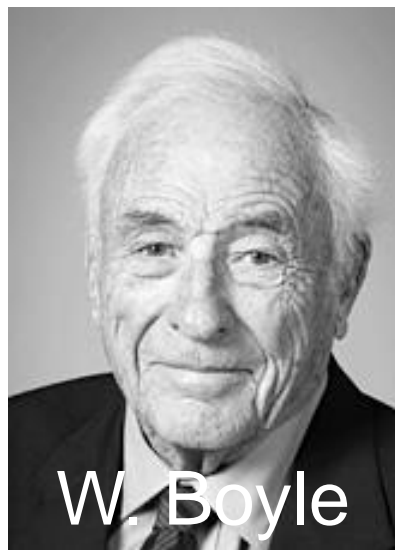
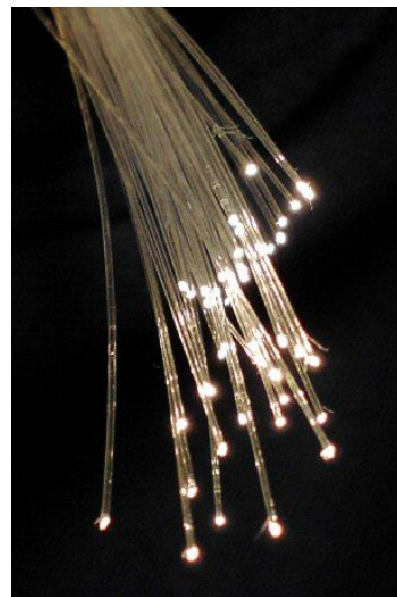
Scientific Background on the Nobel Prize in Physics 2009

TWO REVOLUTIONARY OPTICAL TECHNOLOGIES

compiled by the Class for Physics of the Royal Swedish Academy of Sciences



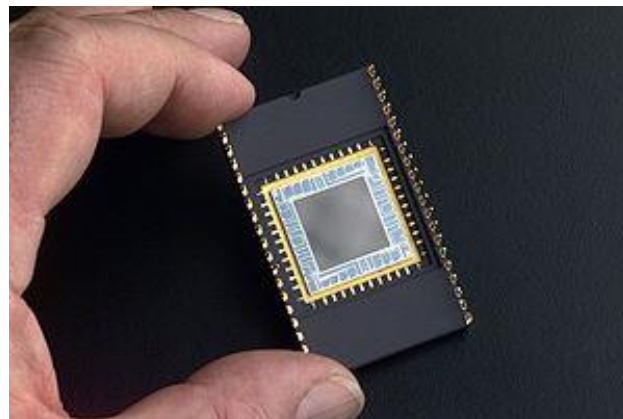
Ch. Kao



W. Boyle



G.E. Smith





Nobel Prize in Physics 2014

„Za izum modre LED diode“



Isamu Akasaki



Hiroshi Amano

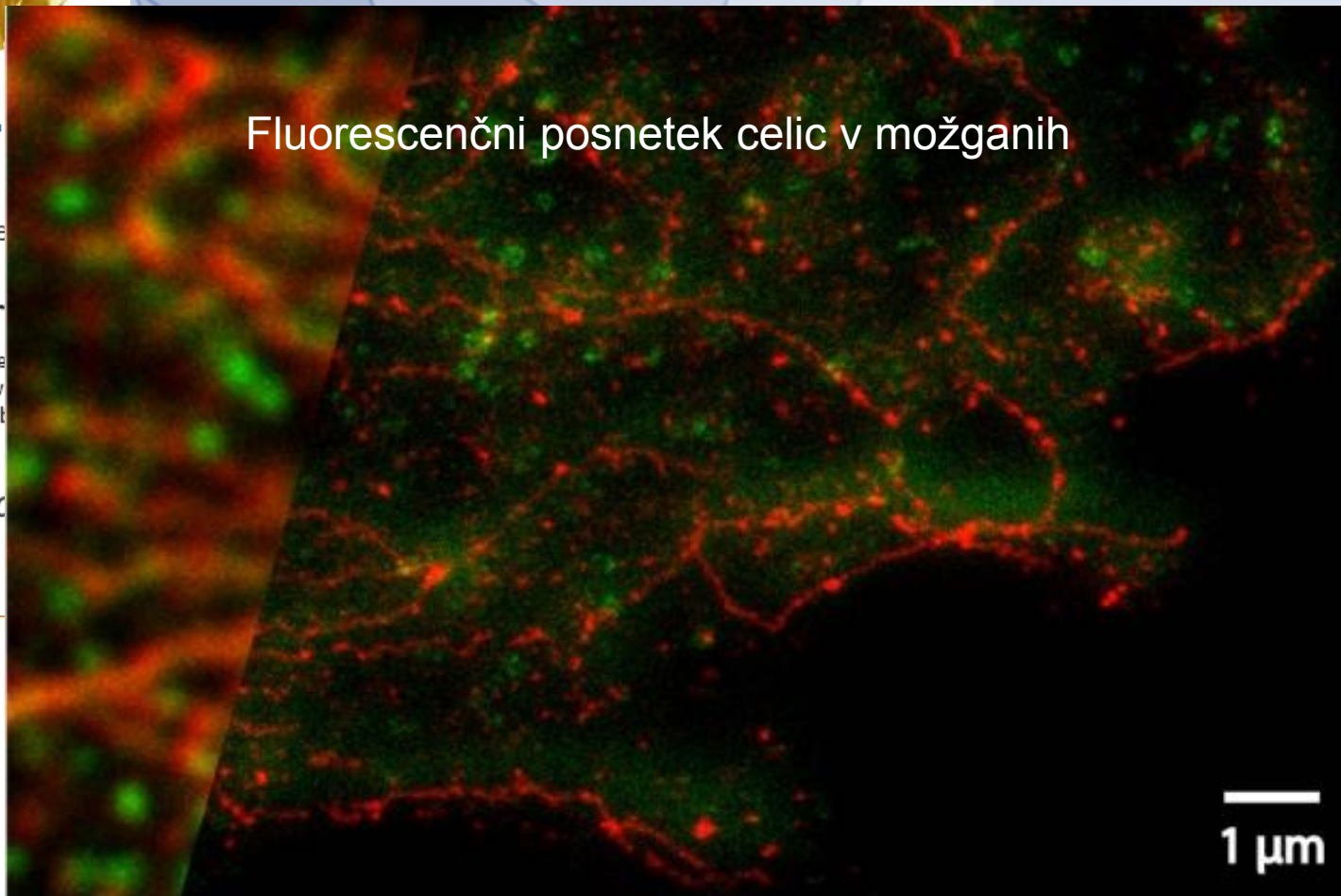


Shuji Nakamura



October 2014

Fluorescenčni posnetek celic v možganih



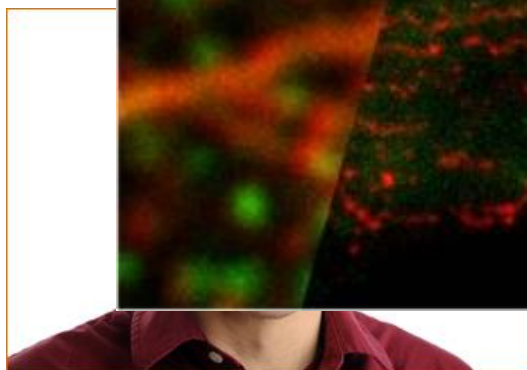
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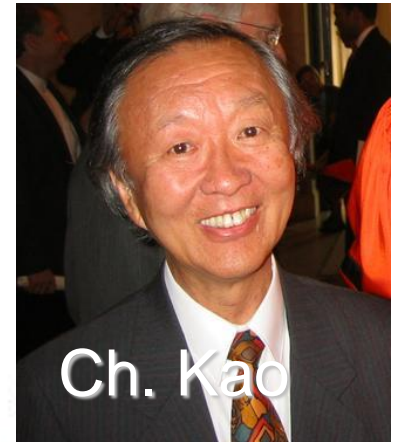
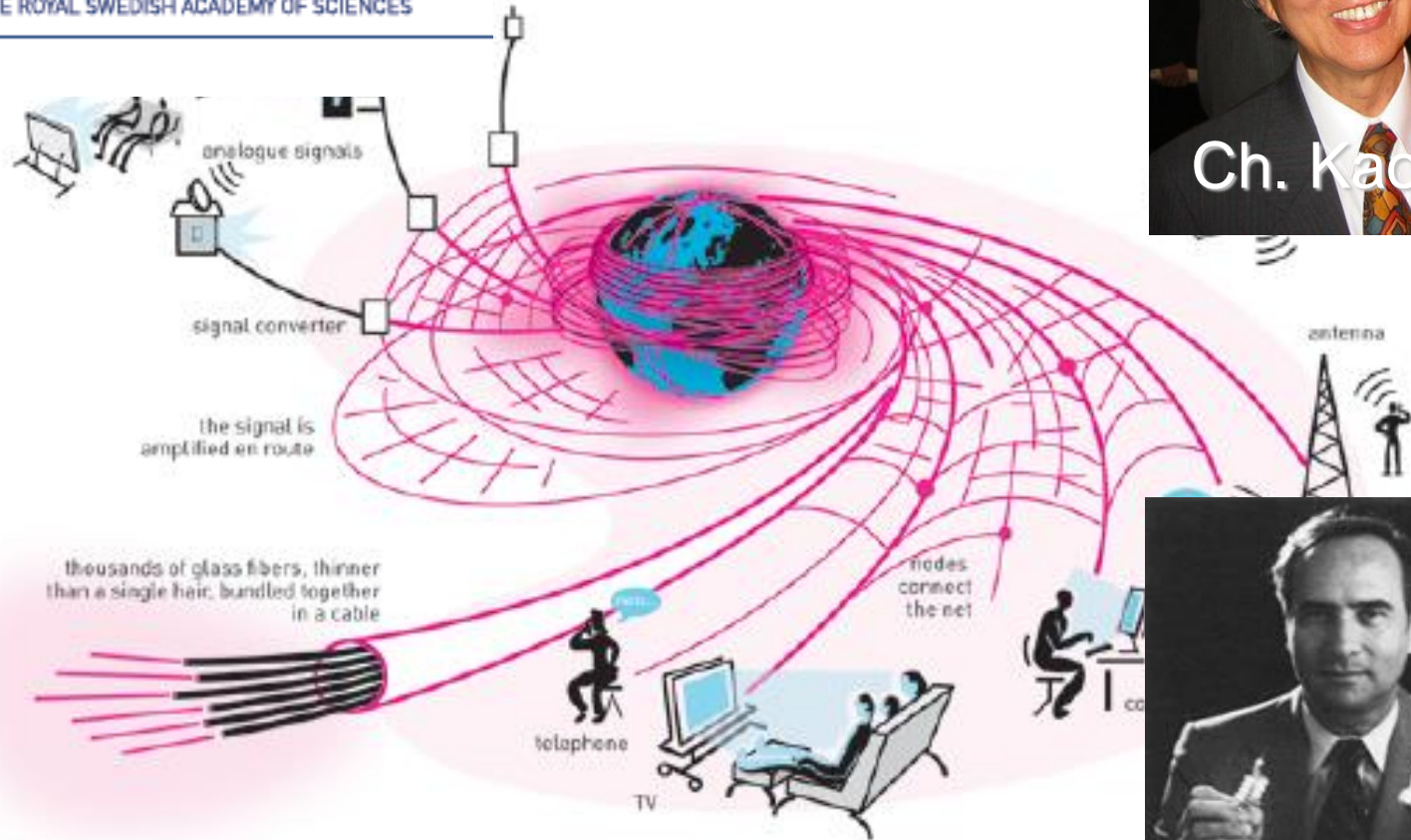
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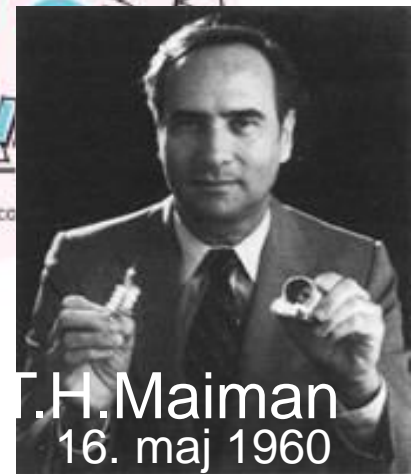


KUNGL. VETENSKAPS-
AKADEMIEN

THE ROYAL SWEDISH ACADEMY OF SCIENCES



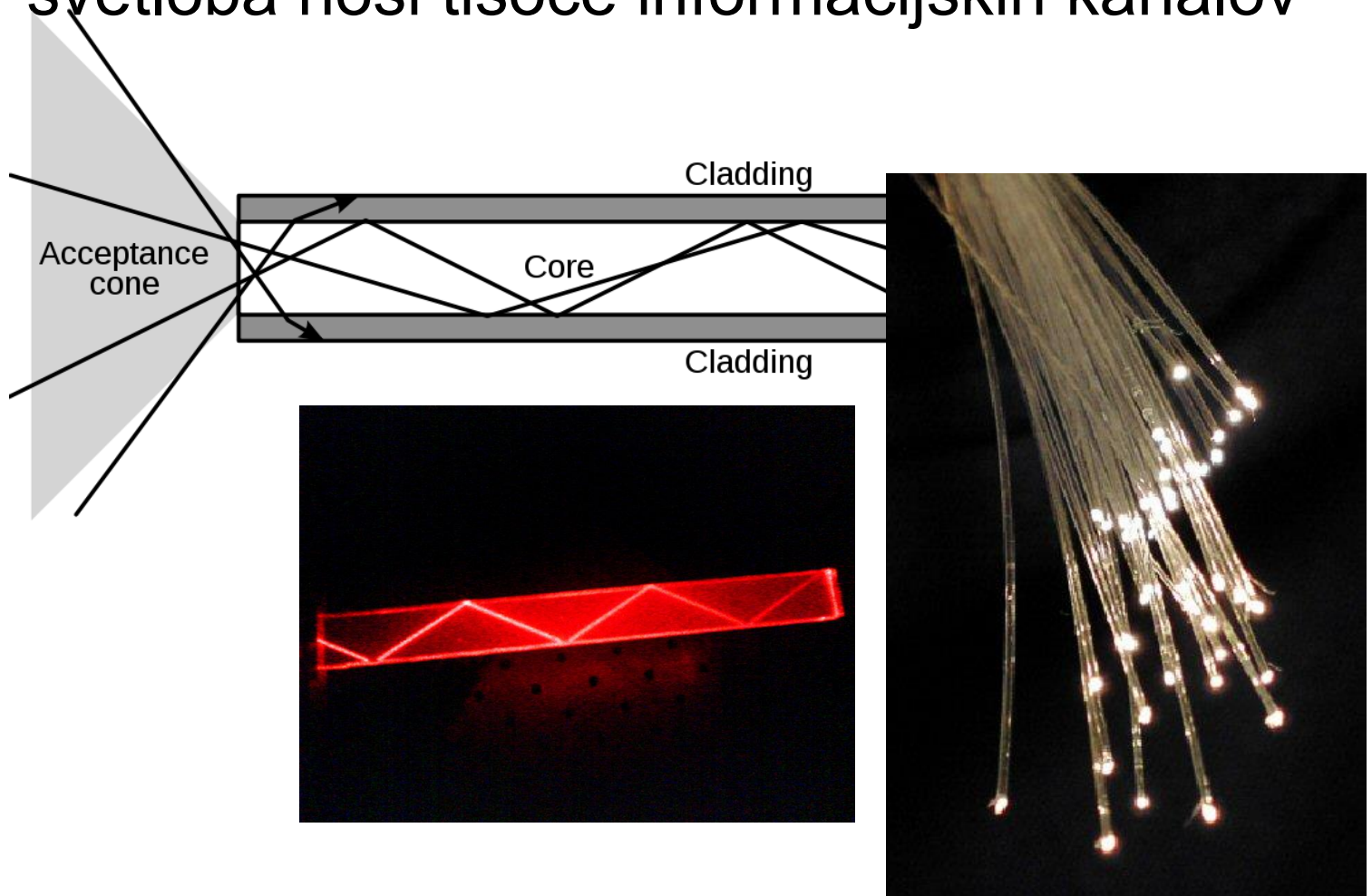
Ch. Kao



T.H. Maiman
16. maj 1960

Figure 5: Artistic view of global communication

Širjenje svetlobe po optičnih vlaknih: svetloba nosi tisoče informacijskih kanalov



„visokofrekvenčno“ borzno trgovanje om

RICHARD DREW/AP

FAST TRADING HOTSPOTS

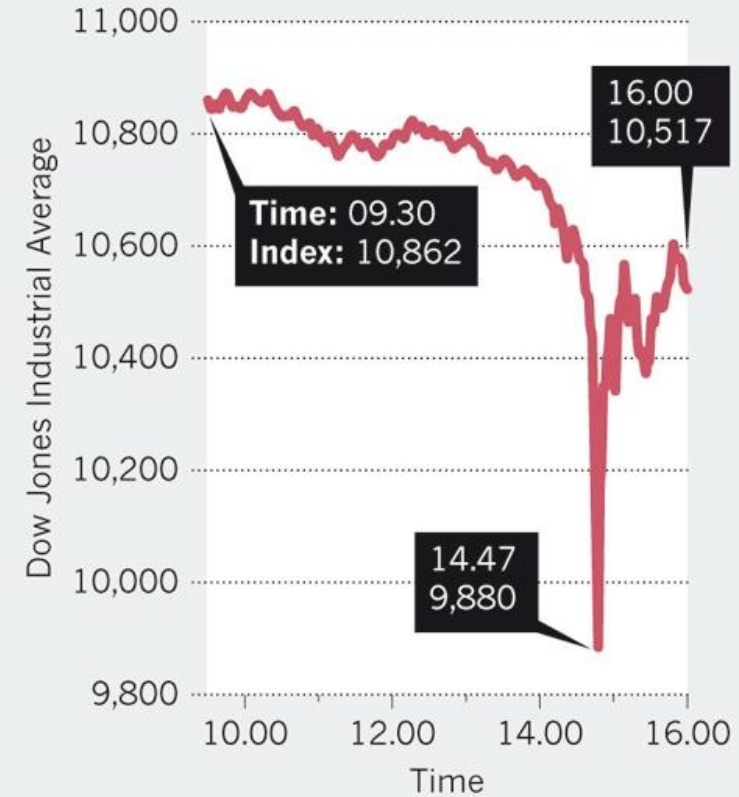
The speed of light is the ultimate limit to how rapidly trades can be made between exchanges (●) — it would take signals travelling at this speed 67 milliseconds to travel half the distance between New York and London. The midpoints between exchanges (•) are the best places to site high-frequency trading firms because they access information from both simultaneously and with the minimum delay.



A software glitch at trading firm Knight Capital caused losses of US\$440 million in a single day in 2012.

FLASH CRASH

On 6 May 2010, the market value of the Dow Jones Industrial Average index fell by 9%, but recovered in minutes. High-speed trading algorithms were in part to blame.



Trading at the speed of light

obstoječe naprave za uravnavanje toka svetlobe med vlakni:

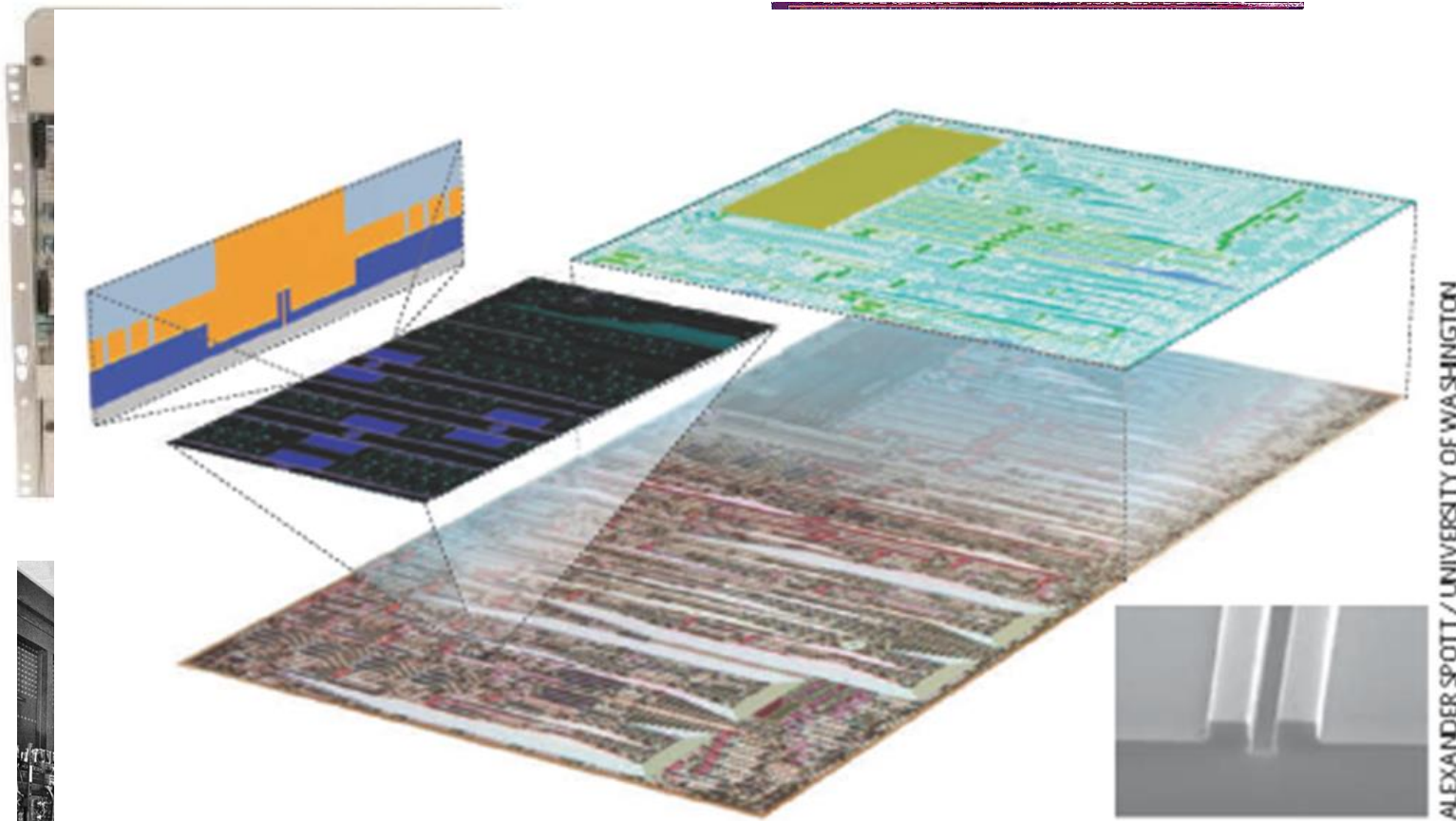


Figure 1 | Complexity in silicon photonics. It is already possible to lay out and fabricate silicon photonic-electronic integrated circuits containing thousands of components. Such circuits are extremely complex, with critical features down to the scale of a few nanometres. Shown here is a dark-field macro photograph of a recently fabricated $\sim 1 \text{ cm} \times 2 \text{ cm}$ photonic die, demonstrating its high component

o
a toka

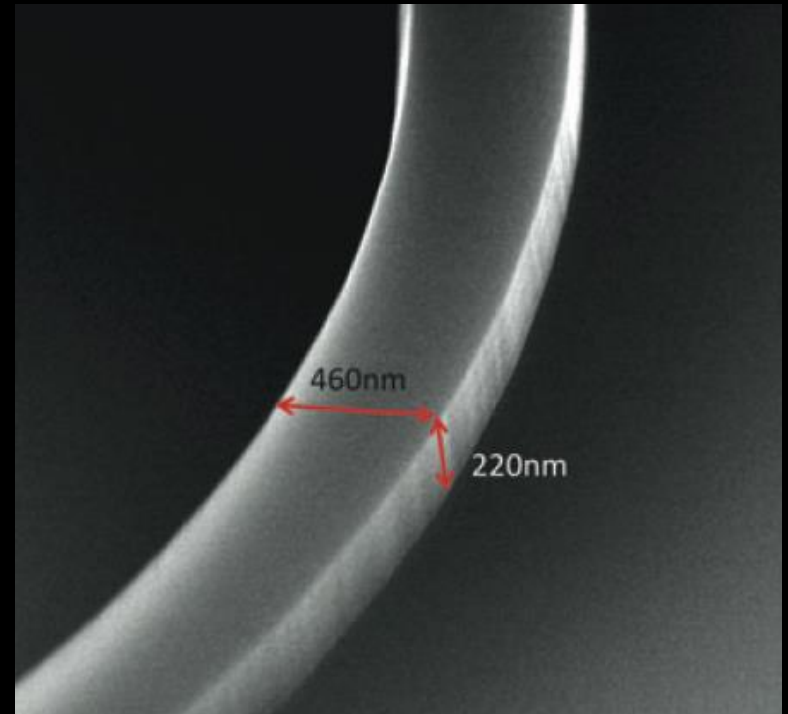
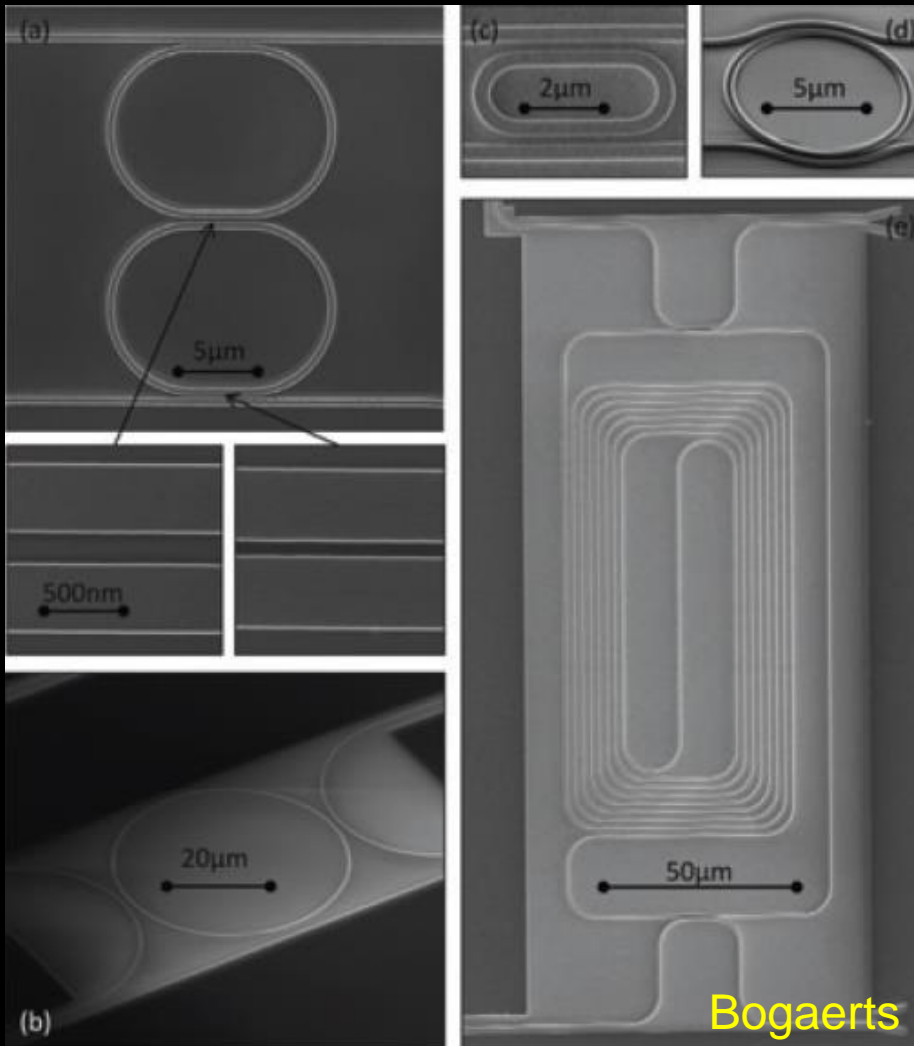
Zakaj fotonika?

Zakaj bi raje uporabili fotone kot elektrone?

- Količina podatkov raste hitreje kot računska moč.
- Silicijevi procesorji so dosegli svojo največjo hitrost takta 3 do 4 GHz
- Težave s hlajenjem nanostruktur: procesorji se „talijo“
- Težave z zakasnitvami električnih signalov in latenco,
- Poraba energije: serverji in računalniki v ZDA porabijo 2-3% skupne električne moči!
- leta 2050 bodo podatkovni centri v EU porabili toliko energije, kot jo sedaj porabi celotna EU!
- Povečujejo se potrebe po številu optičnih komunikacijskih kanalov.



Integrirana fotonska vezja na osnovi trdne snovi:



Bogaerts et al. Laser Photonics Review 6, 47(2012)

Prednosti fotonike na osnovi trdne snovi:

- Silicijeva tehnologija, CMOS kompatibilna
- 50+ let razvoja, predvidljiv in zanesljiv napredek v majhnih korakih.

Slabe strani fotonike na osnovi trdne snovi:

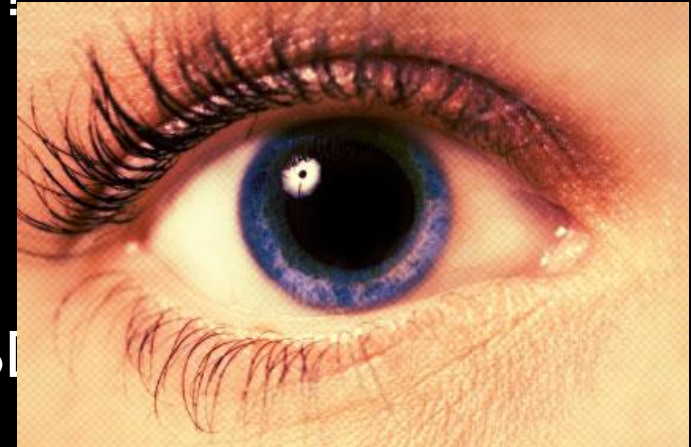
- 2D planarna tehnologija, težak prehod v 3D arhitekturo
- Poraba električne moči: električni tok
- Velike svetlobne izgube zaradi „grobe“ tehnologije izdelave

Ali je kakšna radikalna alternativa?

1. Ali lahko uporabimo mehko snov in kompleksne tekočine za izdelavo fotonских vezij?
2. Ali lahko izdelamo mikrolaserje, mikrovlakna in hitra optična stikala iz mehke snovi-tekočih kristalov?

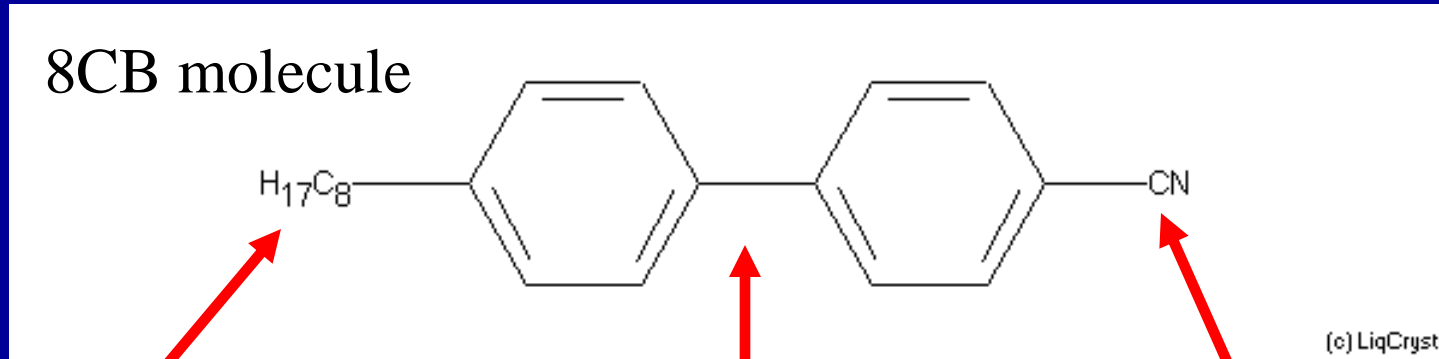
Zakaj?

1. Mehka snov je samo-sestavljiva v 3D
2. Mehka (biološka) snov lahko raste, se celi in sama popravi
3. Mehka snov tvori osupljivo kompleksne ftonske strukture



Tekoči kristali

Molekularna struktura tipičnega tekočega kristala



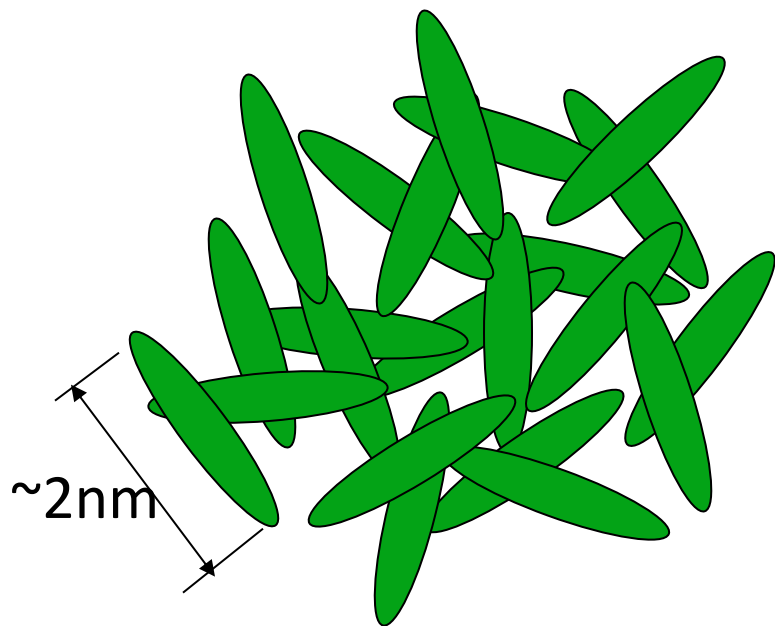
Giblivi rep

Trdna sredica

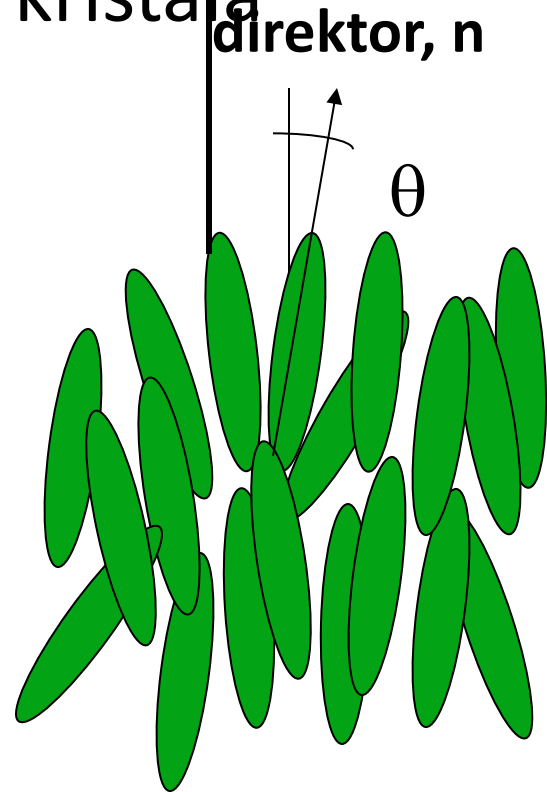
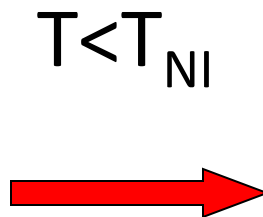
Polarna glava

- običajna tekočina nad $40^{\circ}C$
- tekoči kristal (nematik) med $40^{\circ}C$ in $34^{\circ}C$

Nematska faza tekočega kristala

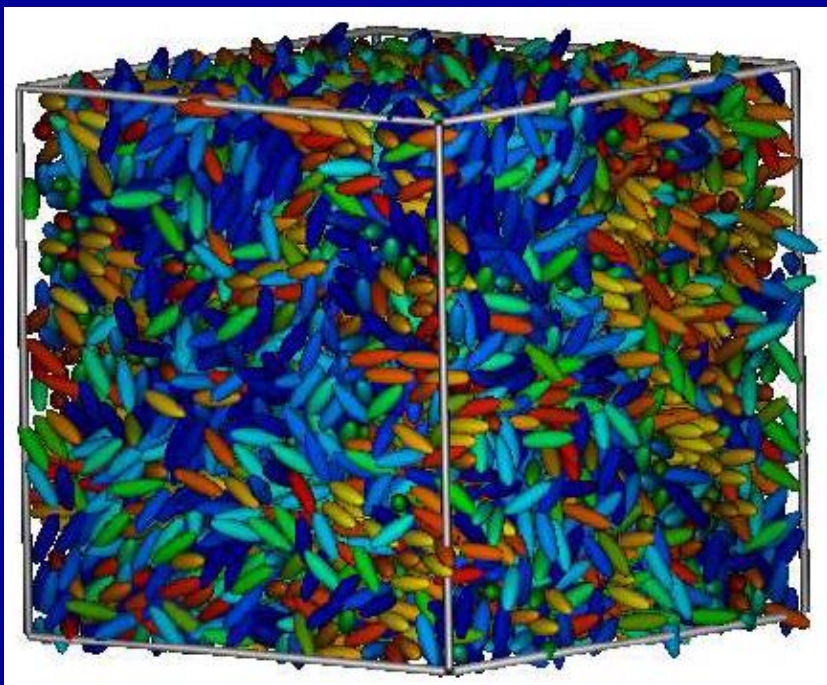


Orientacijski in pozicijski nered.
Običajna tekočina.

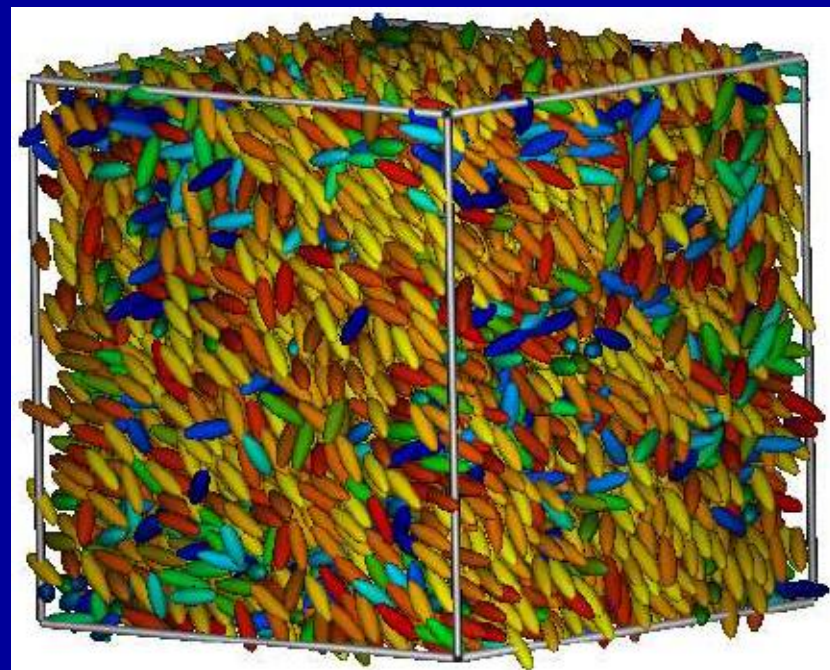


Orientacijski red,
pozicijski nered.
Tekočina je urejena

Računske simulacije



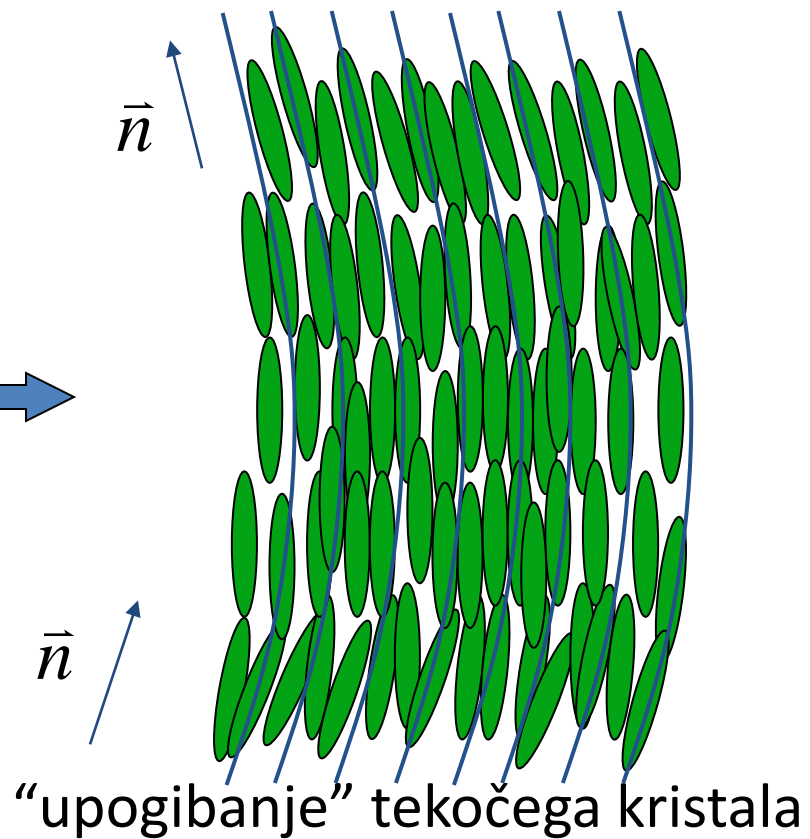
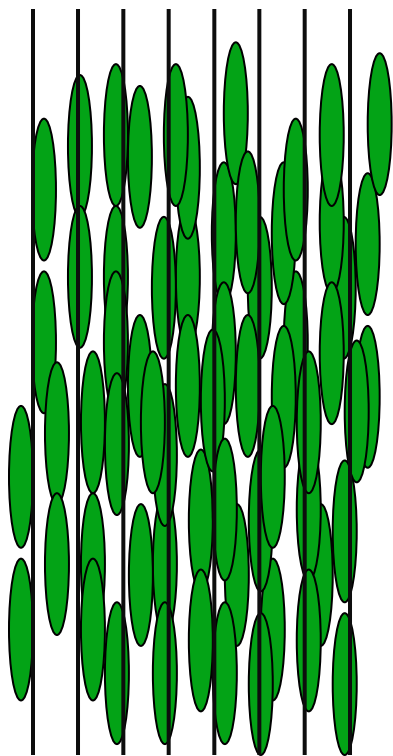
Izotropna faza



Nematska faza

(foto P.Allen)

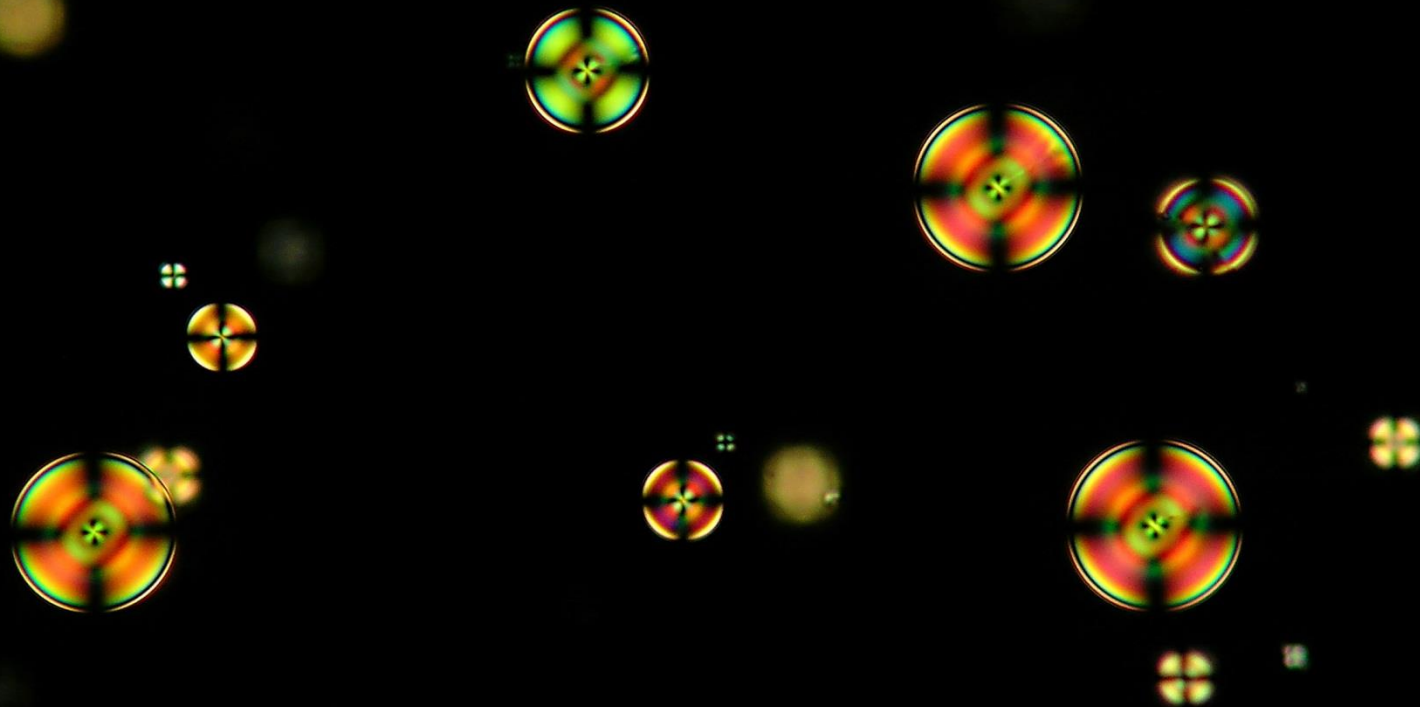
Orientacijski red povzroči "elastičnost"



"upogibanje" tekočega kristala

Emulzije s tekočimi kristali:
mešanica tekočega kristala in nezmesljive tekočine
voda, polimer,

Milijoni kapljic nematskega tekočega kristala v vodi



Uglasljivi optični rezonatorji in laserji

Optični rezonator:
ujame svetlobo zaradi popolnega odboja

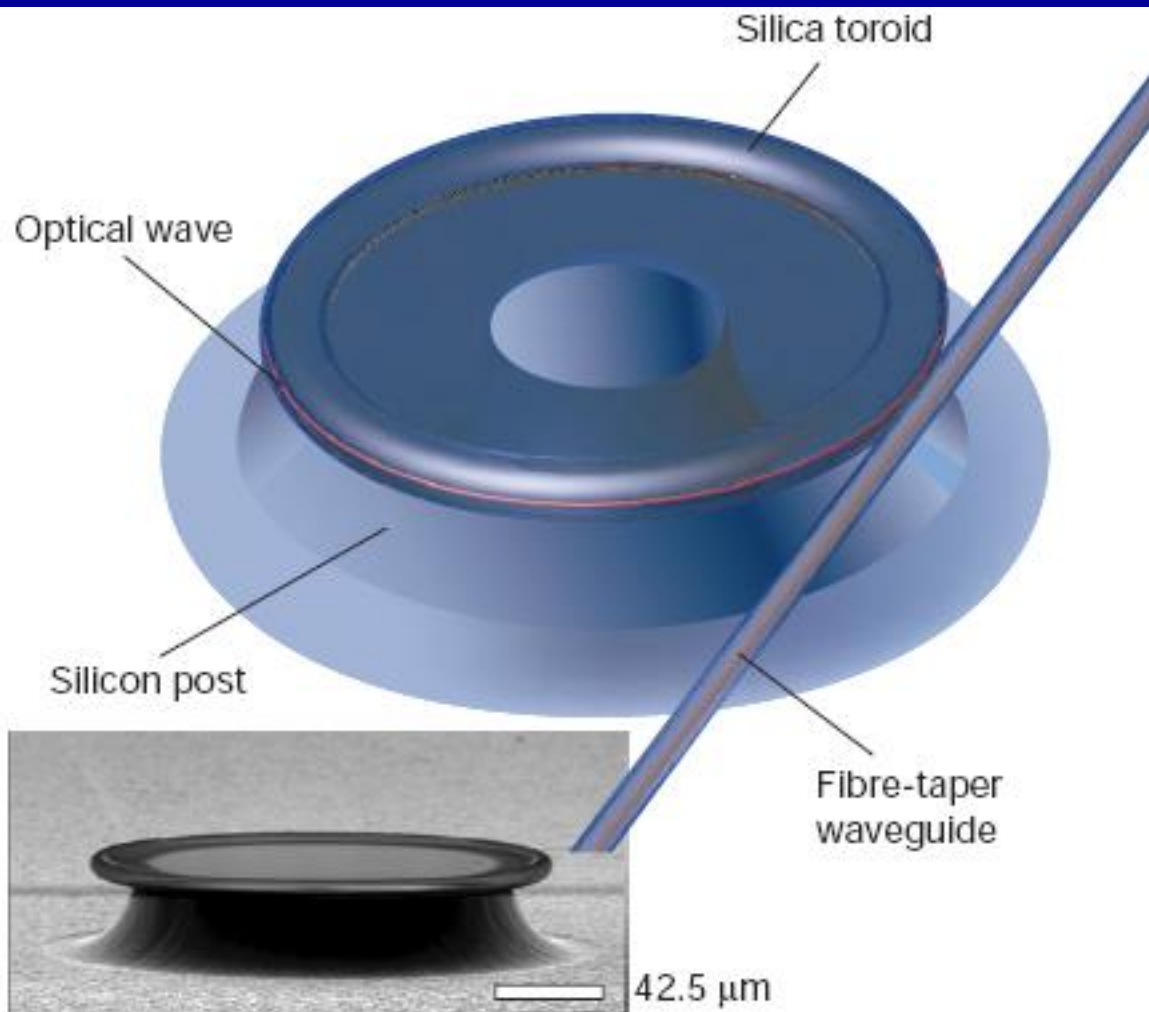


Nizek lomni količnik

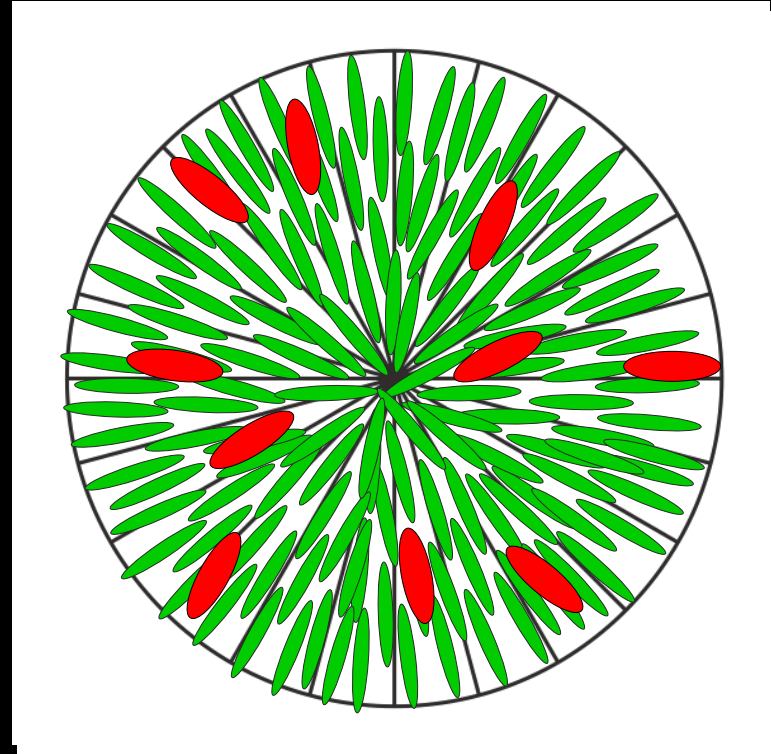
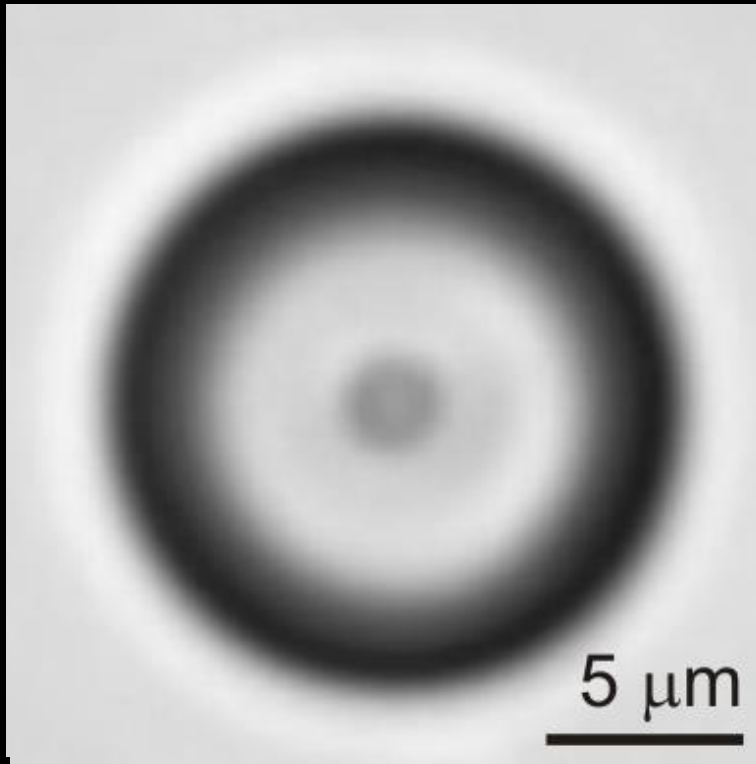
"whispering gallery modes", WGMs

Popolni odboj

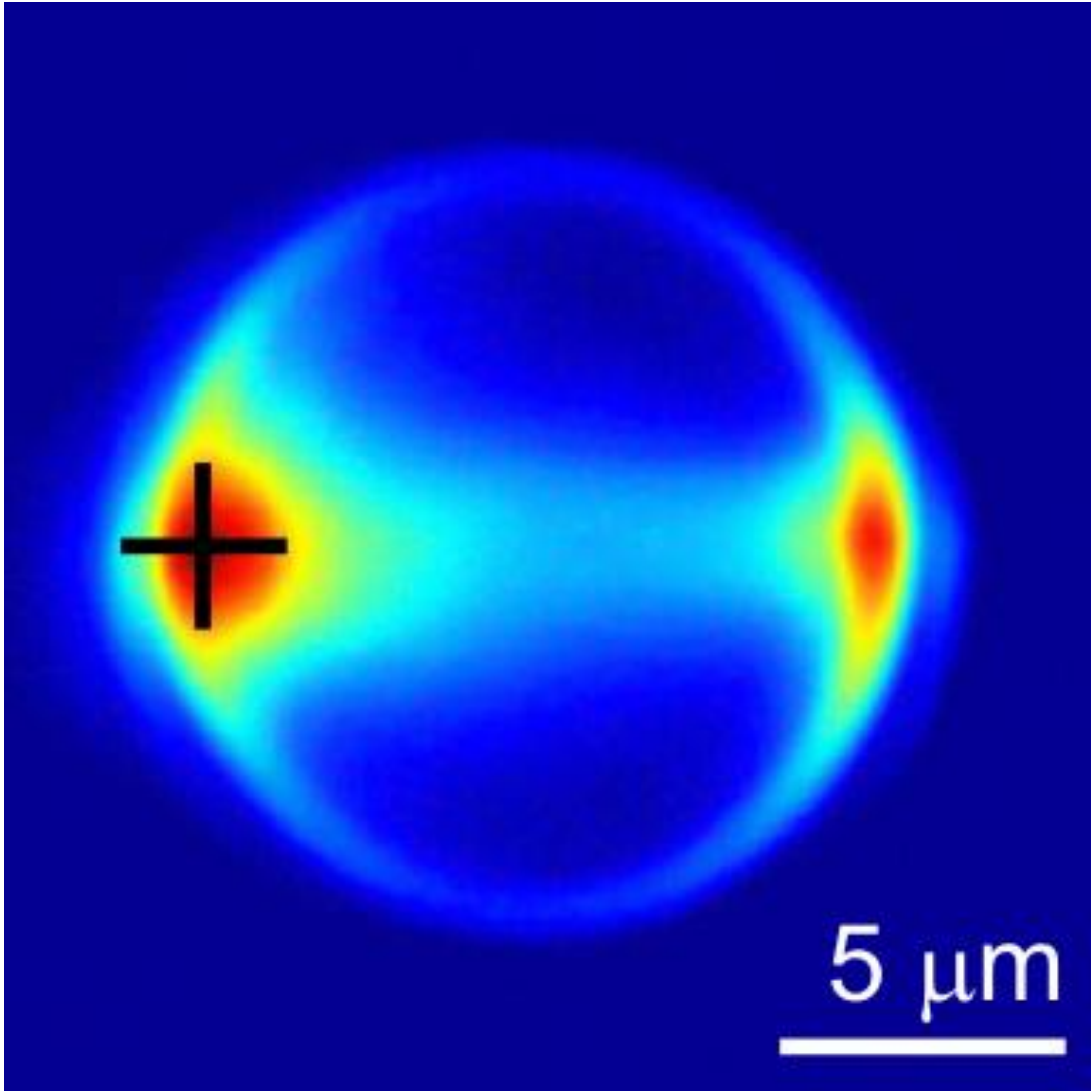


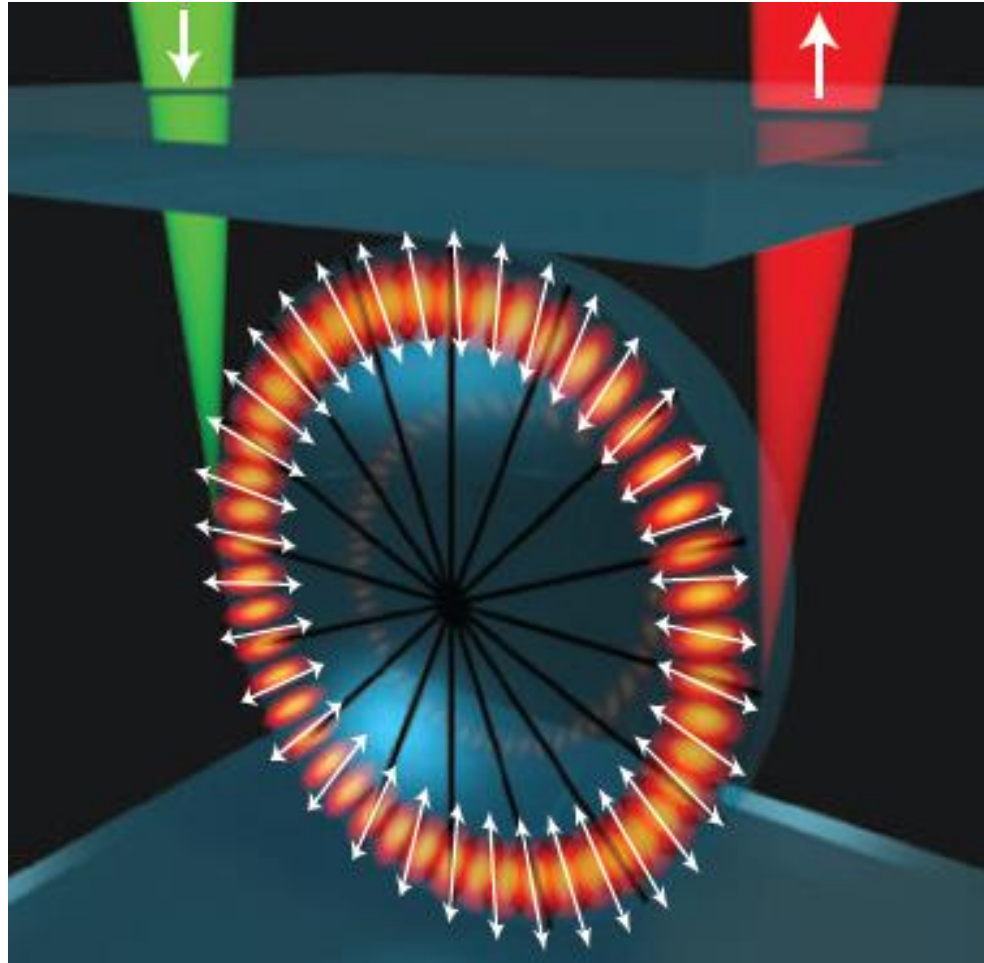


Kapljico osvetlimo z zelenim laserjem:



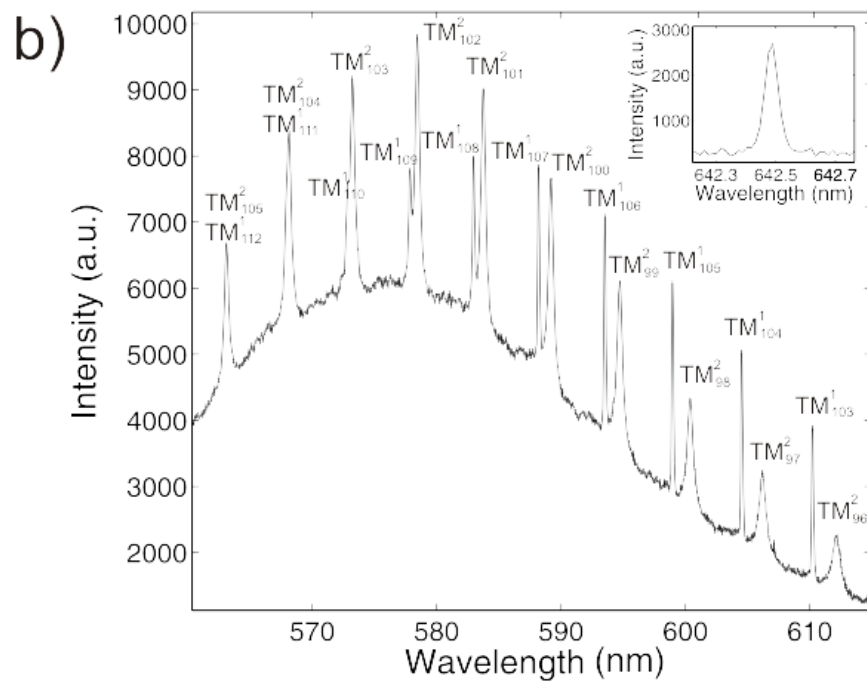
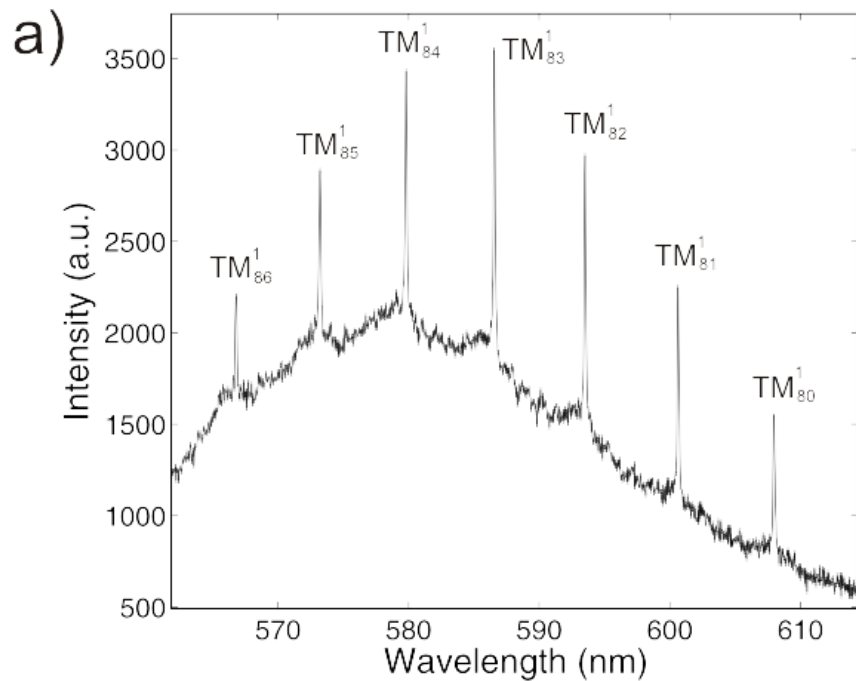
Tekočemu kristalu dodamo fluorescenčno barvilo



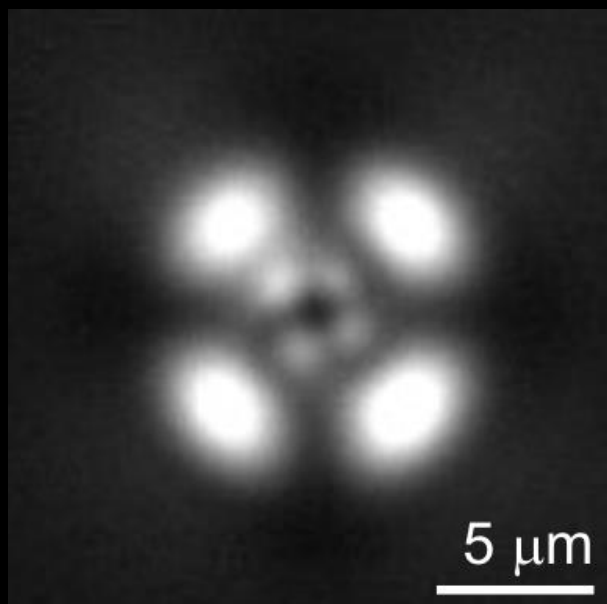


Photonics West, San Francisco, 5th
February 2014

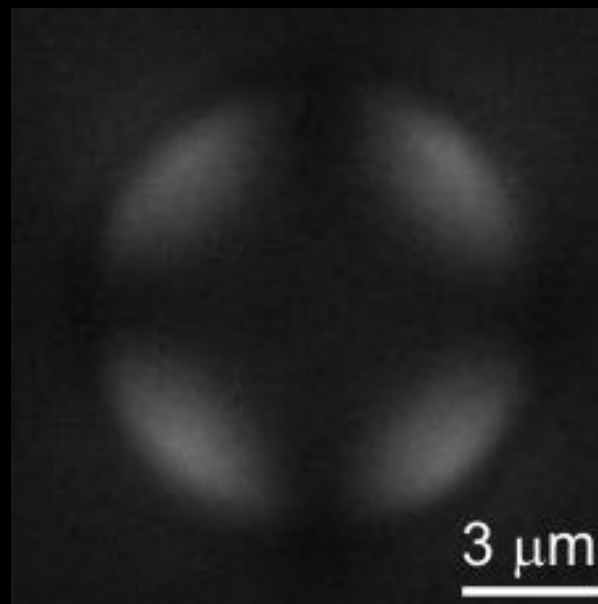
Spekter izsevane svetlobe vsebuje ostre črte: WGM rezonance



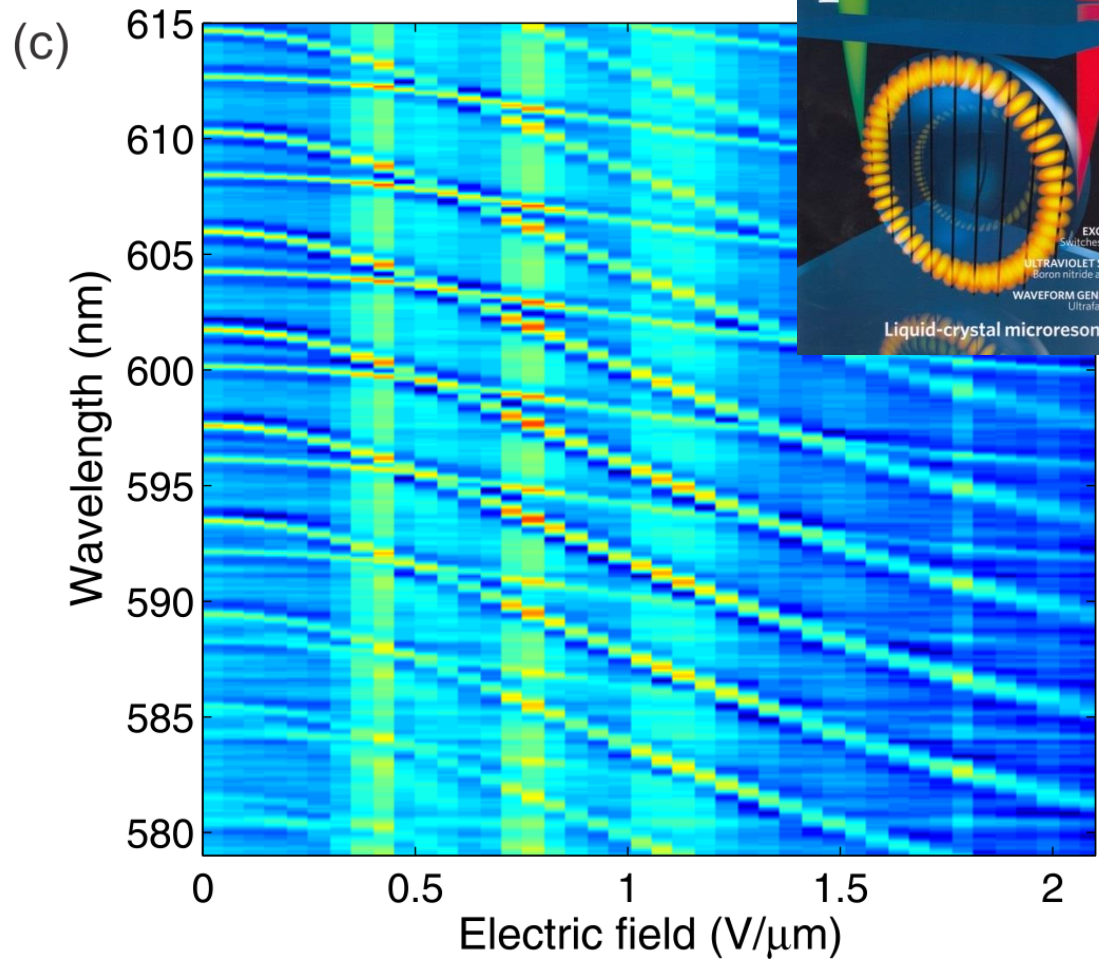
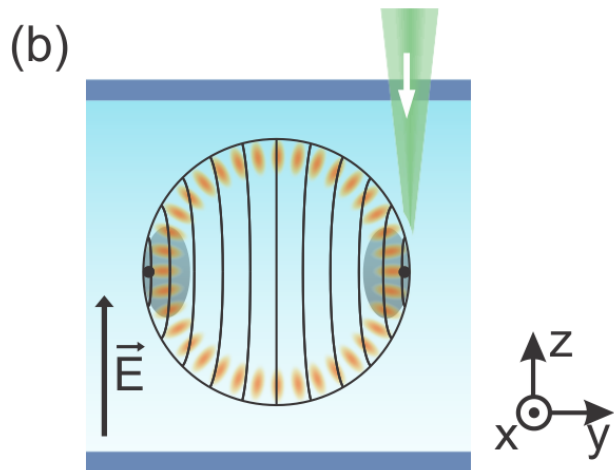
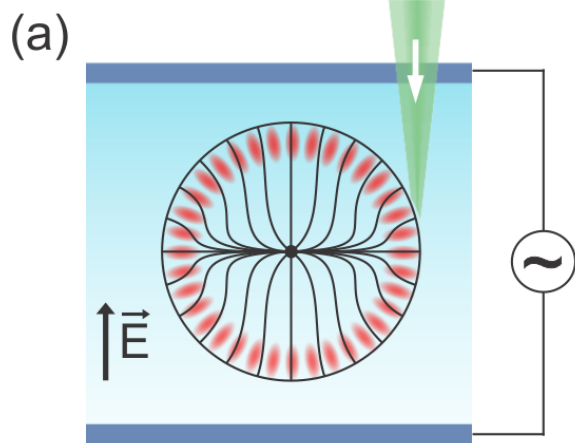
WGM rezonance lahko uglasimo z električnim poljem



Brez polja



S poljem

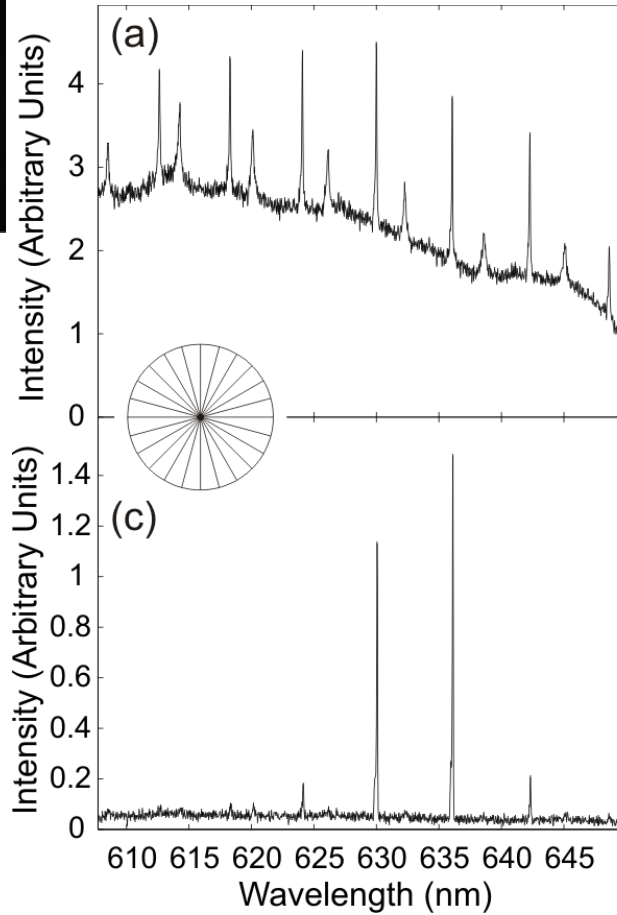


~100 x večja uglasljivost glede na trdno snov

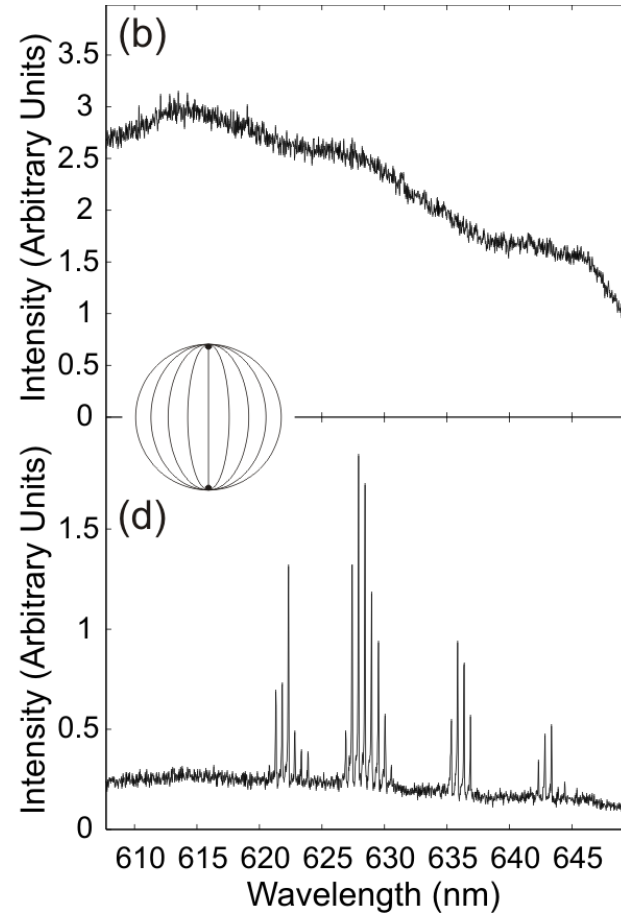
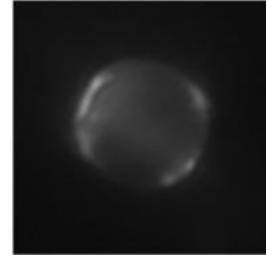
Humar, Ravnik, Pajk, Musevic, *Nature Photonics* **3**, 595(2009)

WGM mikrolaserji:

radial

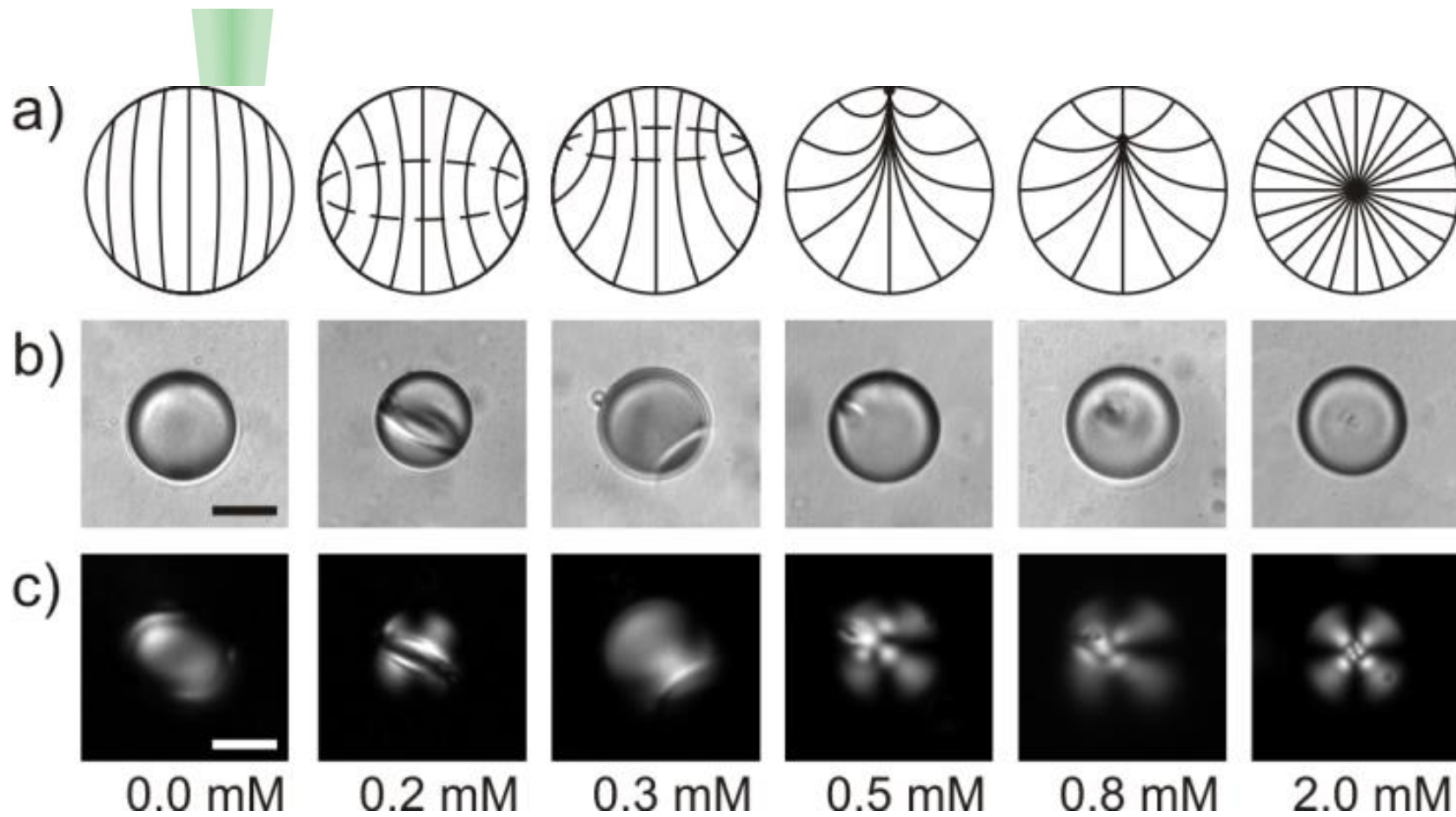


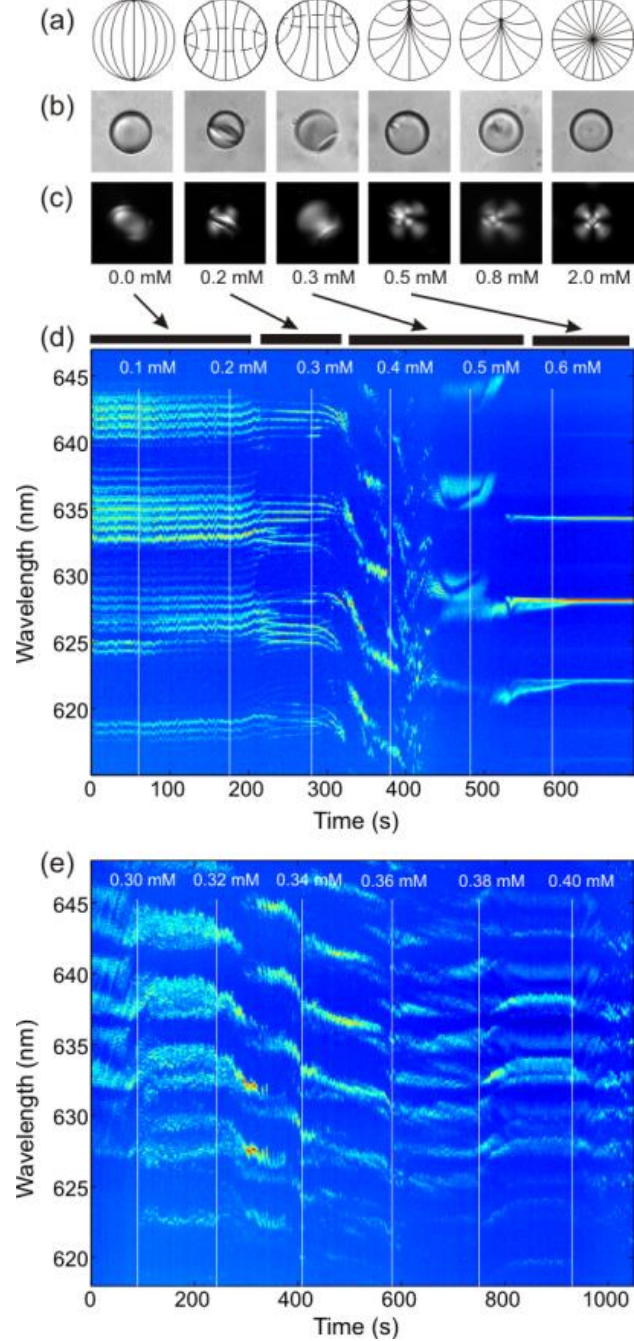
bipolar



WGM mikrolaser v delovanju

Takšen laser se odziva na okolico:

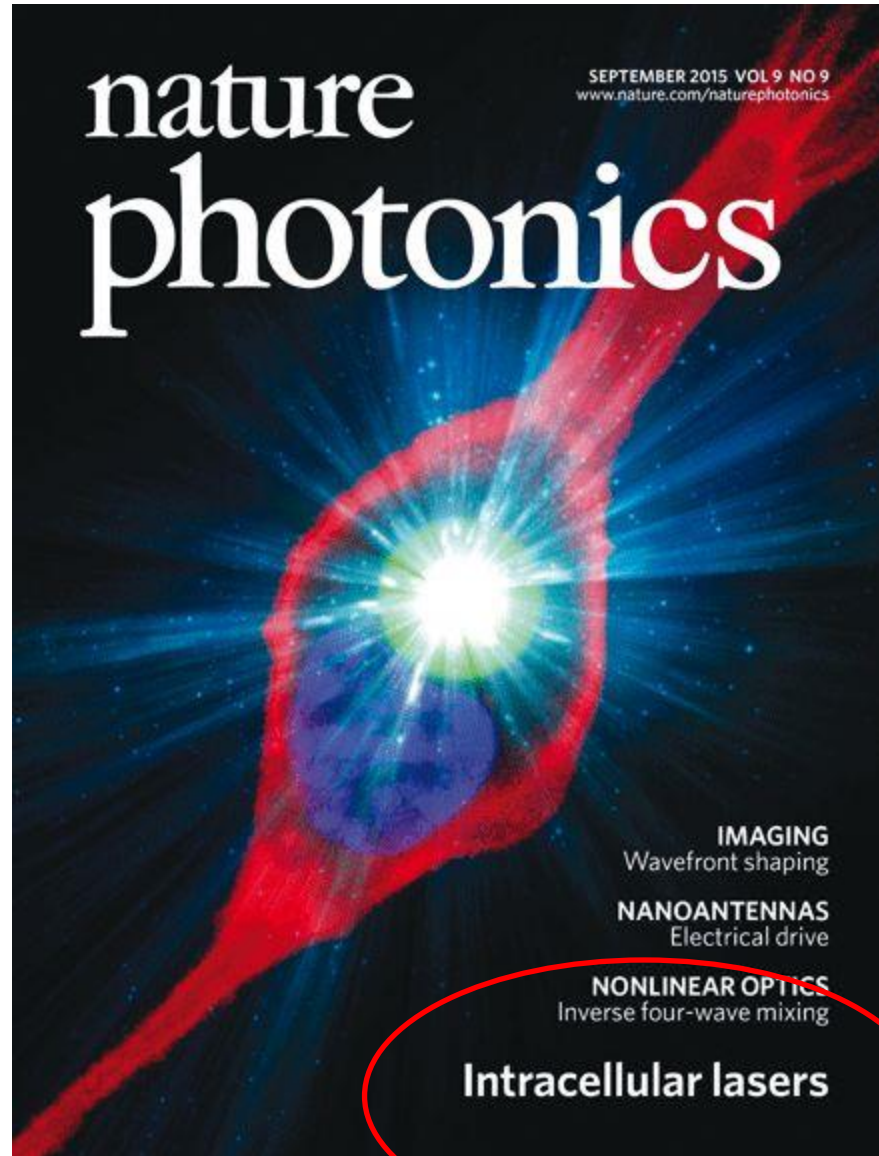




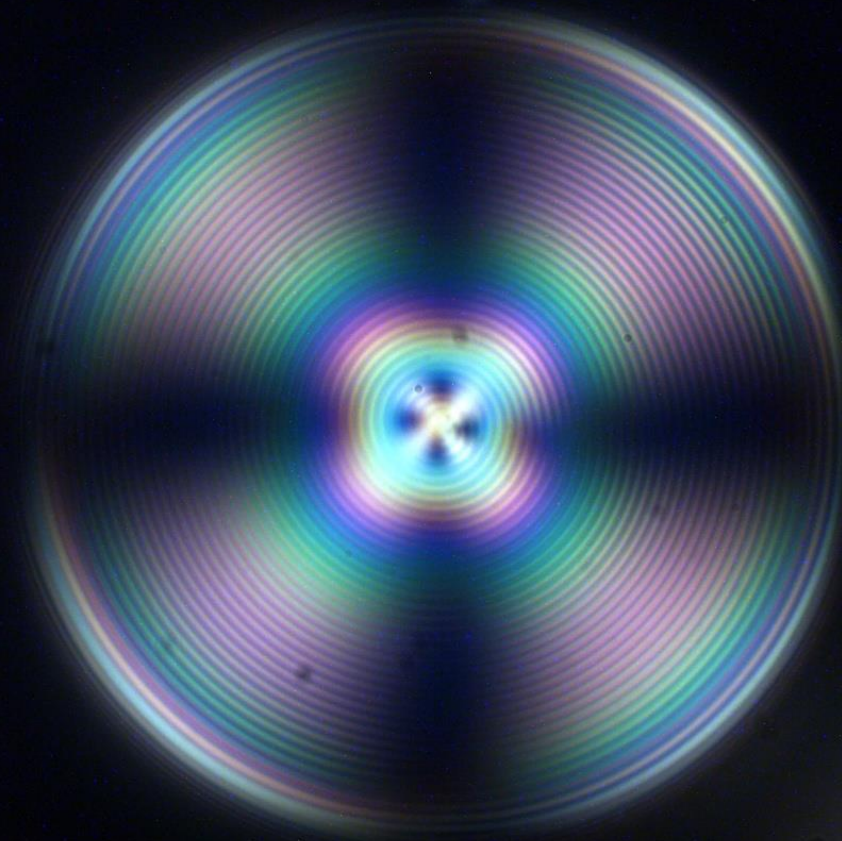
Humar and Musevic. Opt. Express 19, 19836-19844 (2011)



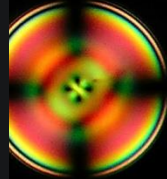
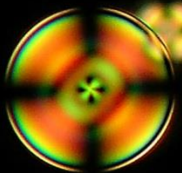
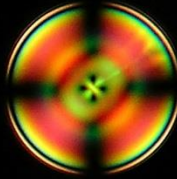
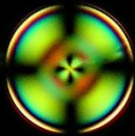
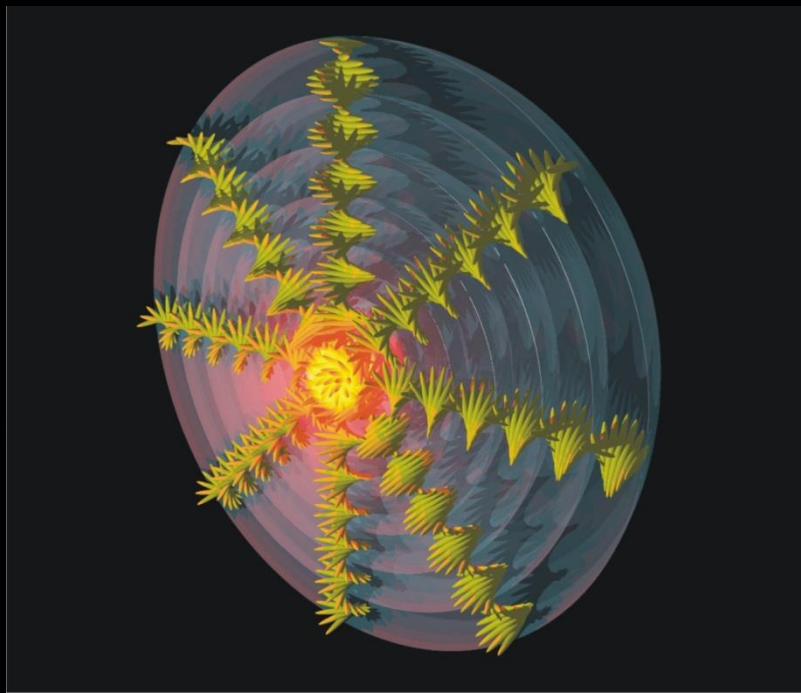
Matjaž Humar



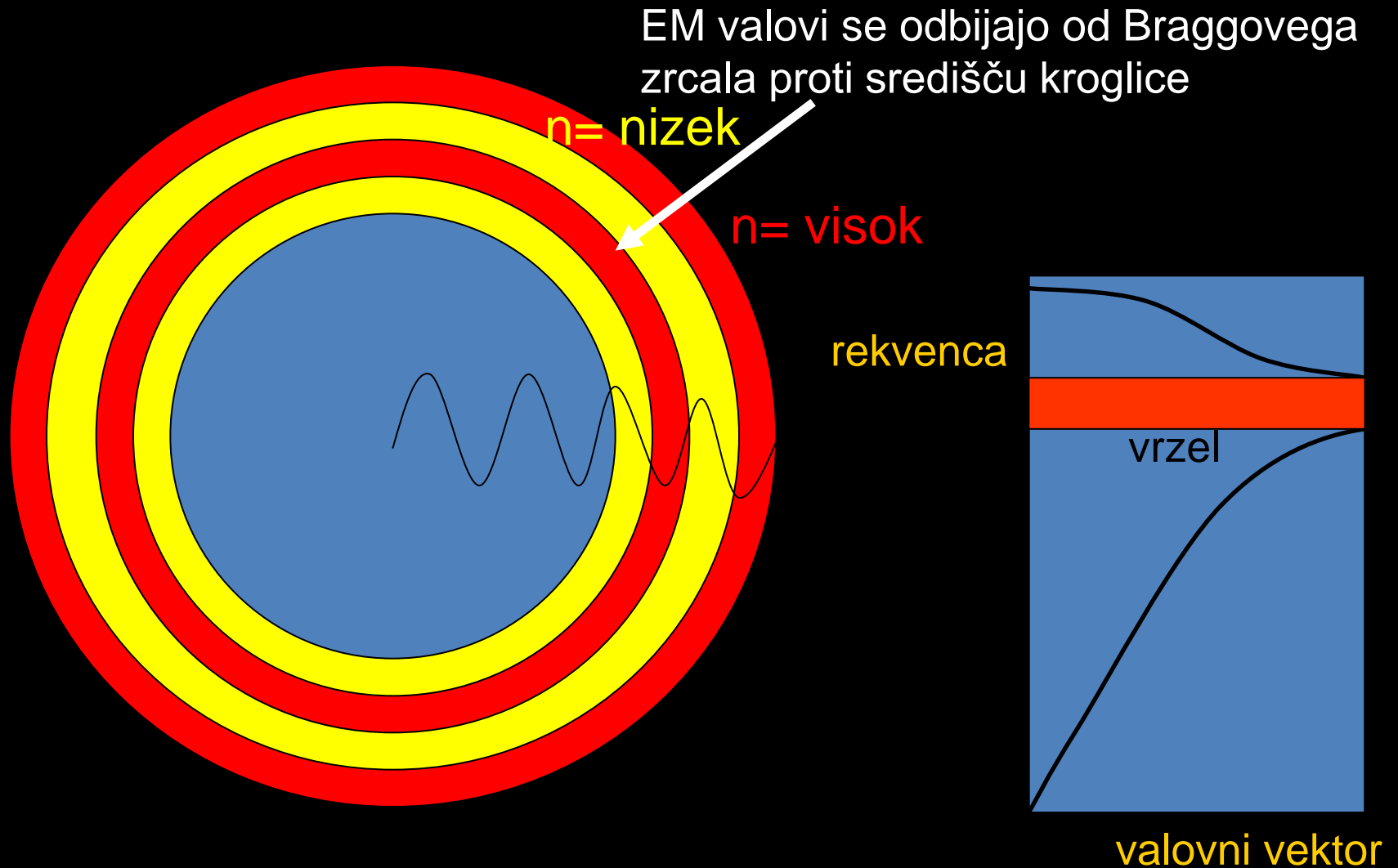
Prav poseben mikrolaser izdelamo iz vijačnih tekočih kristalov

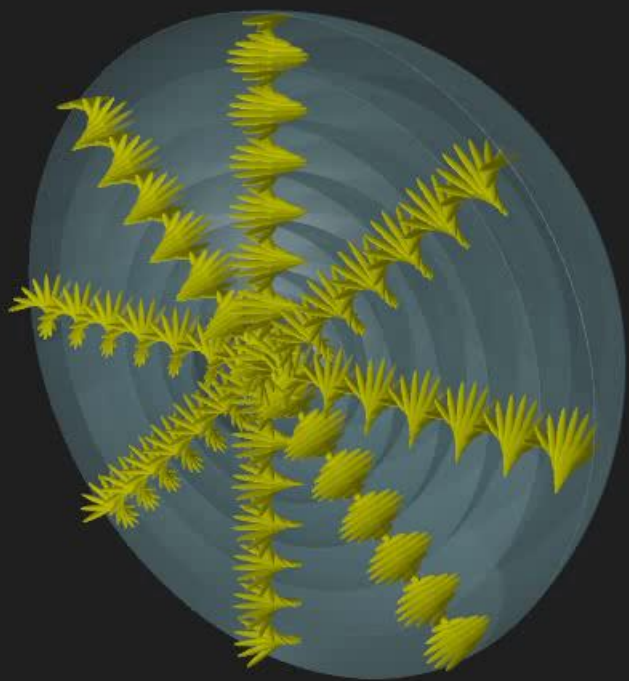


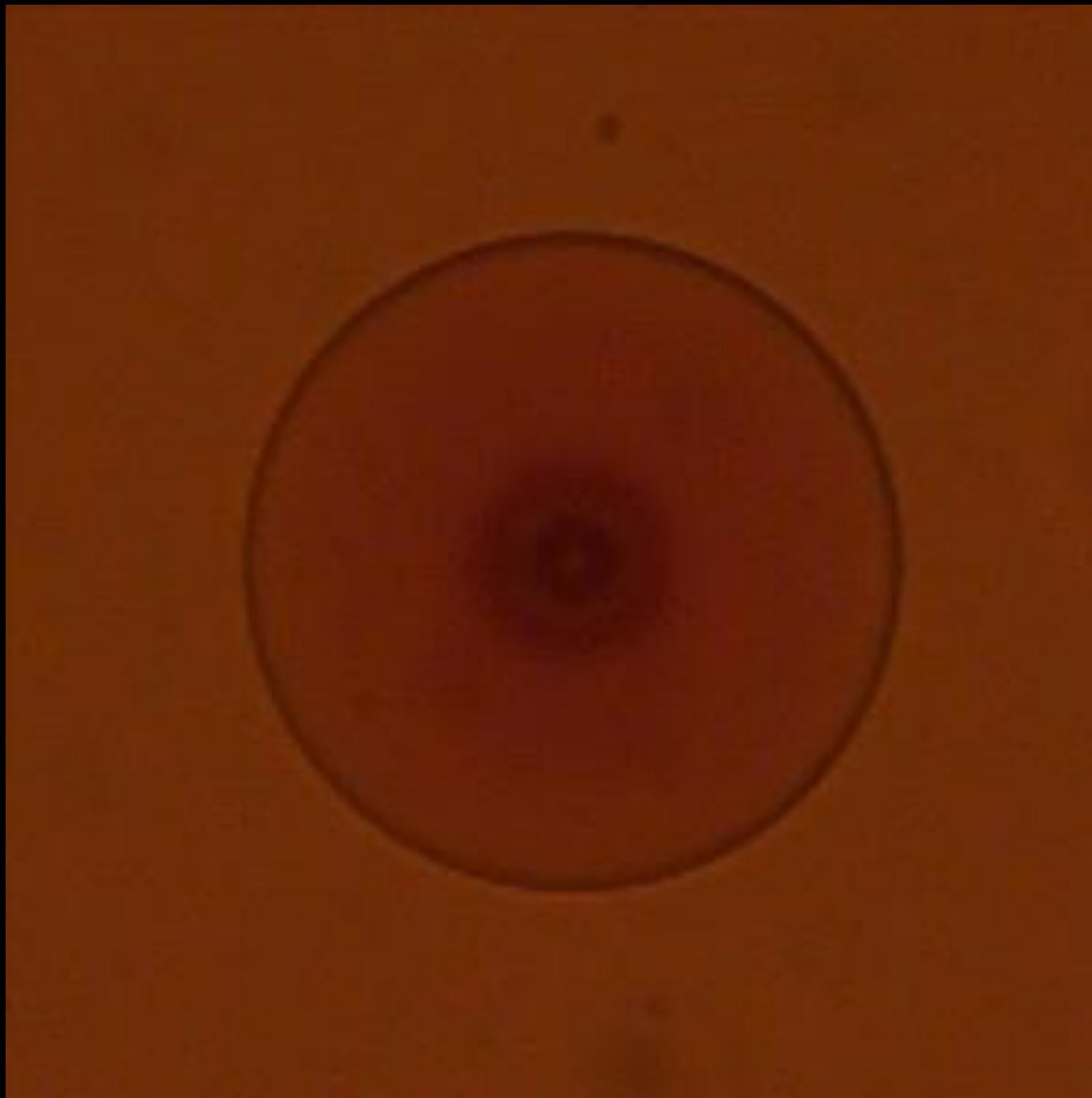
„lamelna“ struktura vijačnega tekočega kristala



Okroglo Braggovo zrcalo: "čebulni rezonator"



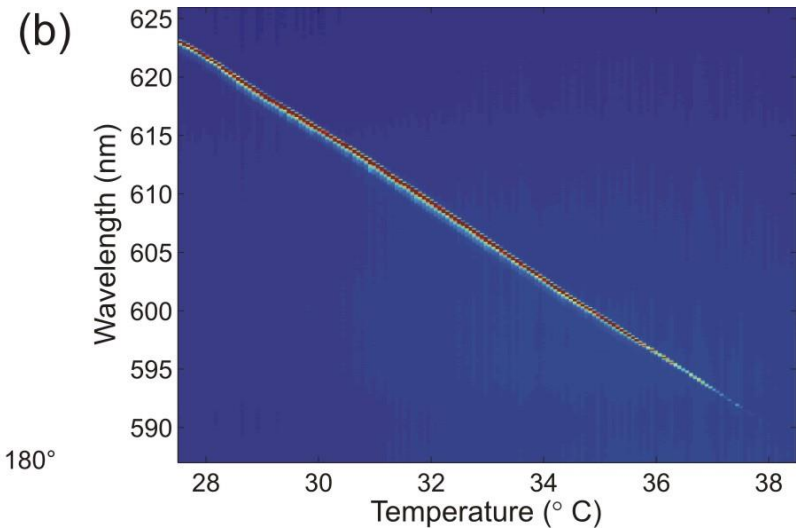
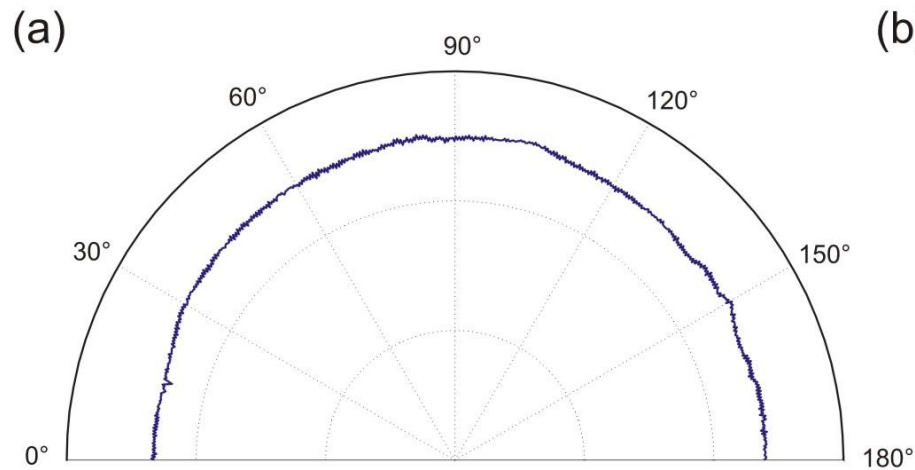




3D mikrolaser v delovanju

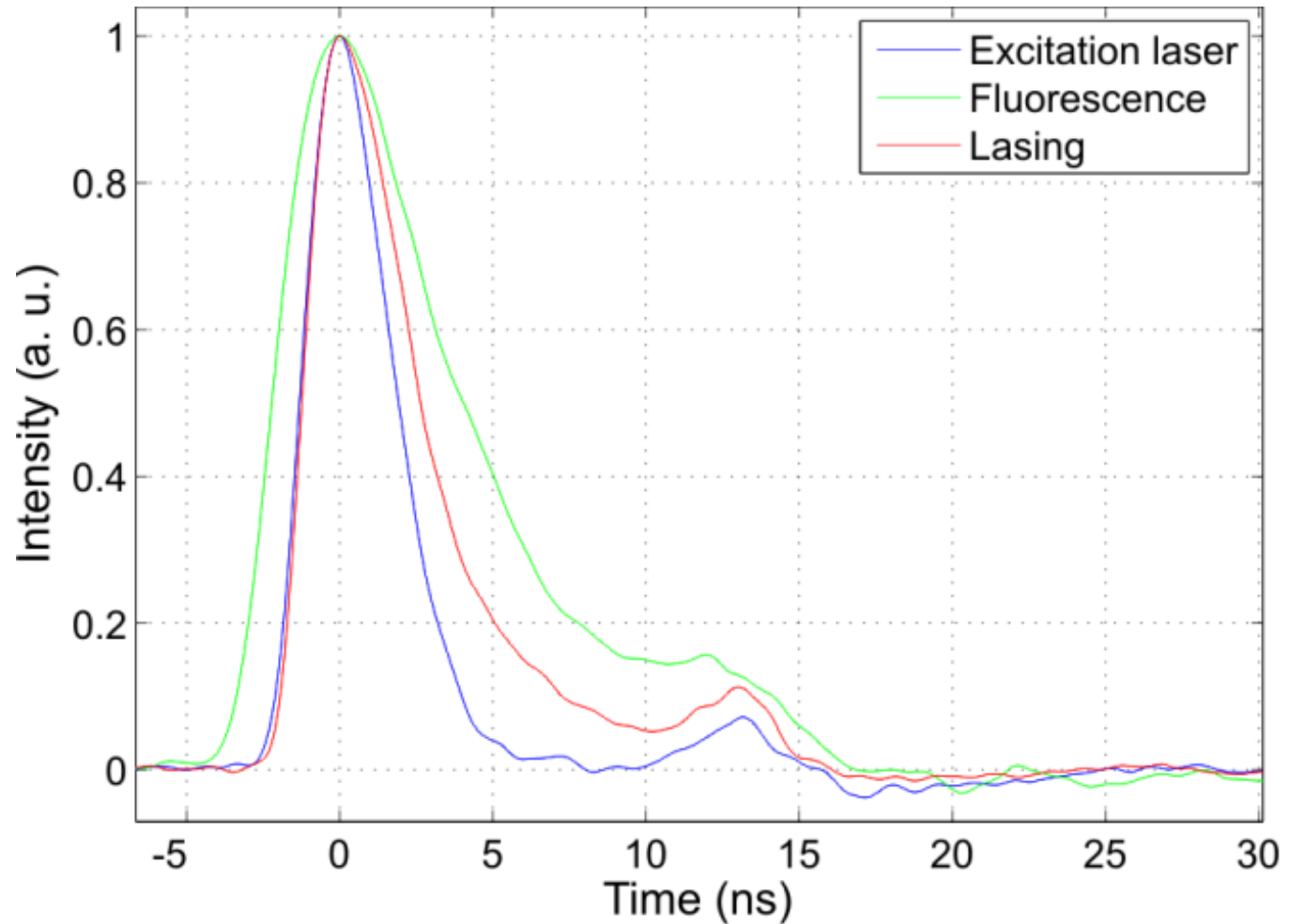
Humar and Musevic, *Optics Express* **18**, 26996(2010)

Laser seva svetlobo enekomerno v vse smeri v prostoru uglasimo ga s temperaturo

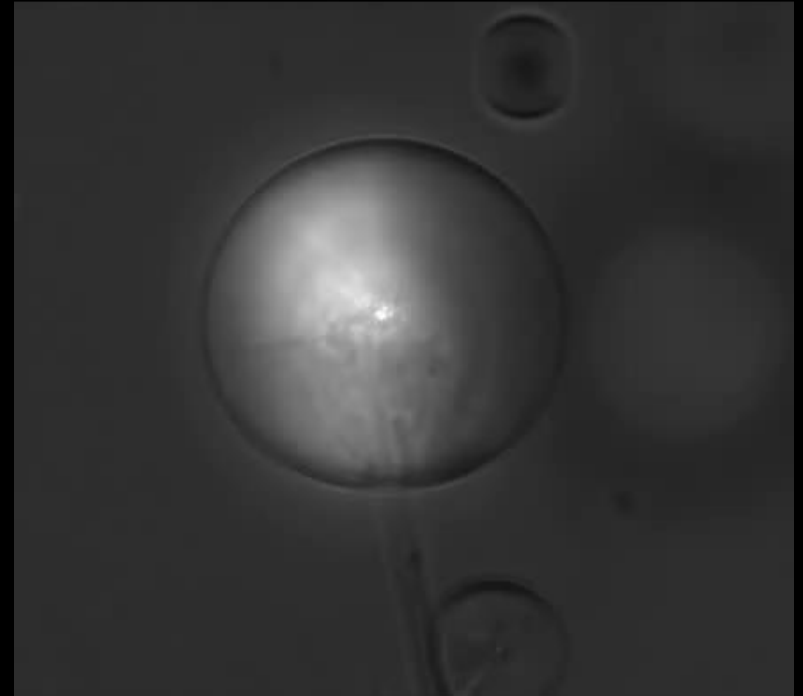


Največja izhodna moč okoli 0.05 mW, 200Hz

Laser je hiter, deluje v GHz, pulzi ~ ns



Laser zlahka povežemo z optičnim vlaknom



..... in je presenetljivo trdoživ

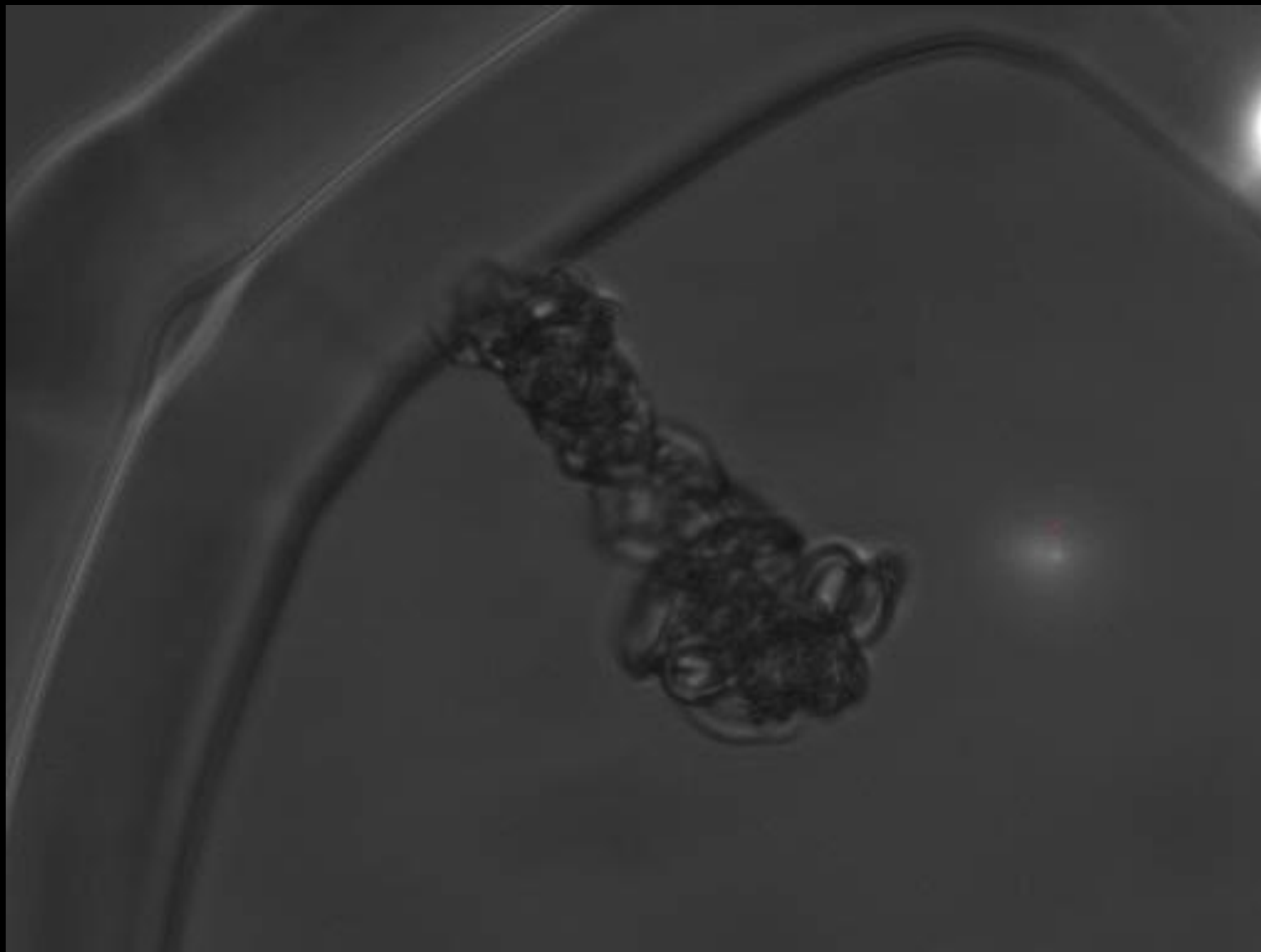
S tekočimi kristali lahko naredimo tudi vlakna

Tekoči kristal + voda + detergent



K. Peddireddy, et al. *Langmuir* **28**, 12426--12431 (2012)

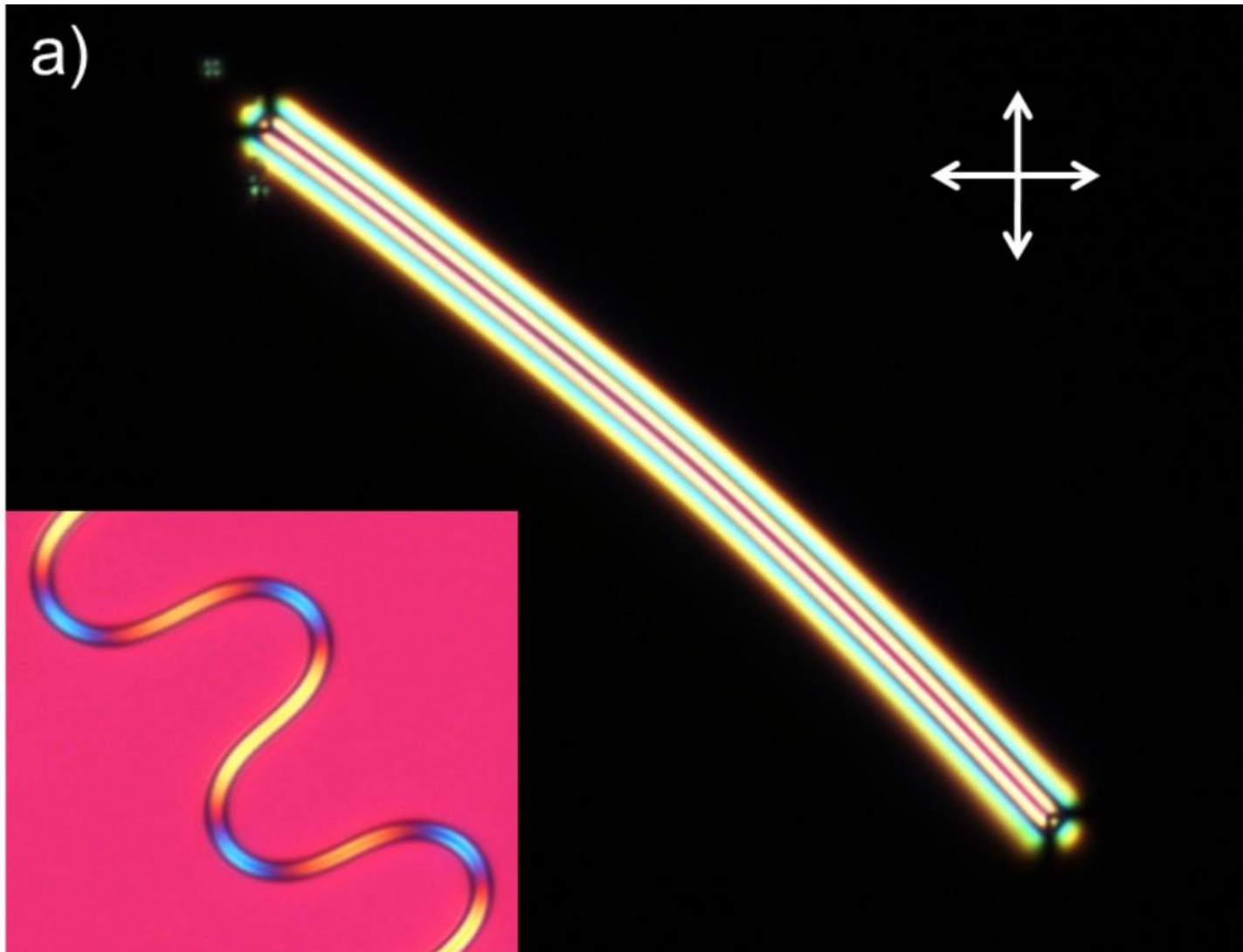
Tekoča vlakna „prebodemo“ s svetlobo



Vlakna oblikujemo s svetlobo

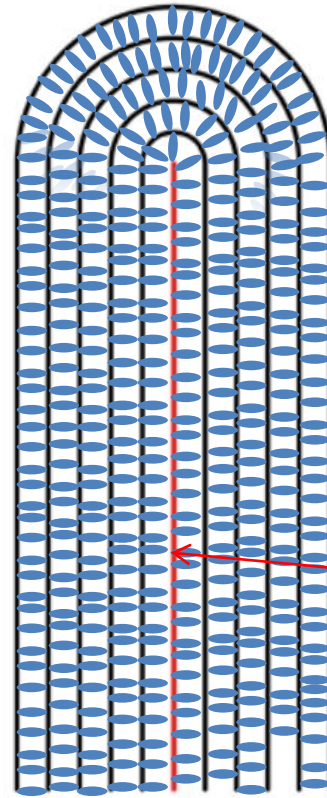


Vlakna so dvolomna in zelo enakomerna:



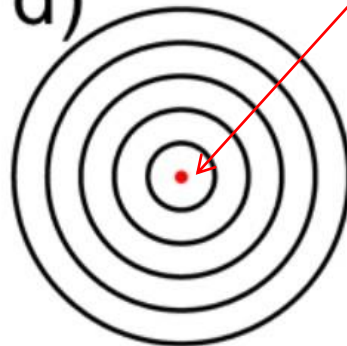
Njihovo strukturo razložimo s fluorescenčno mikroskopijo





Topološki defekt v jedru vlakna

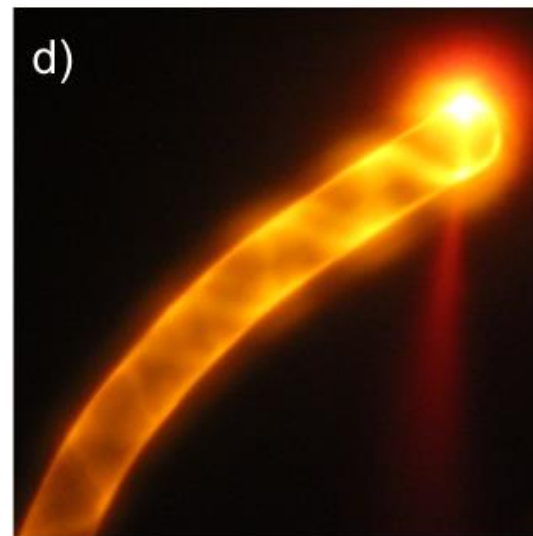
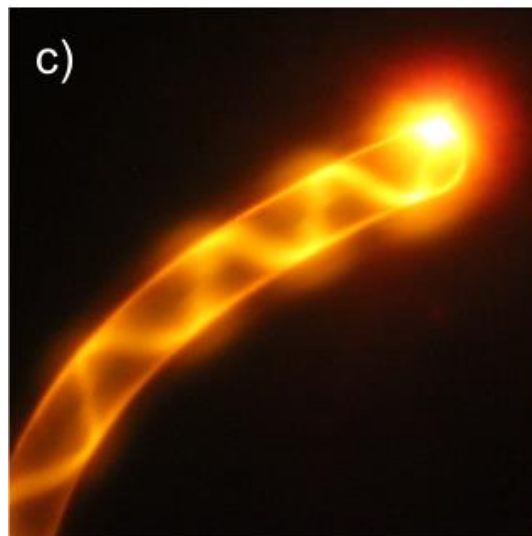
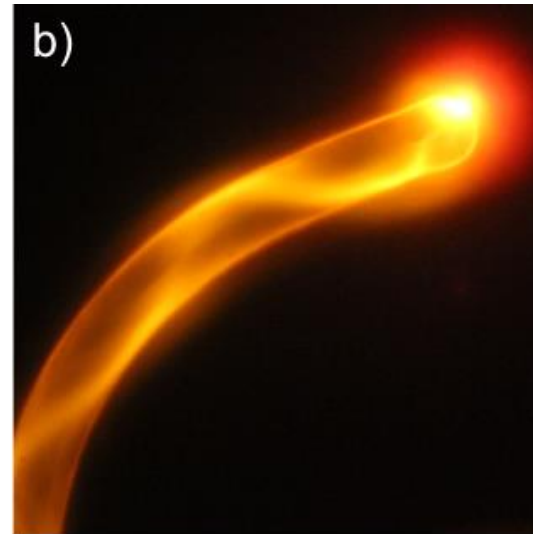
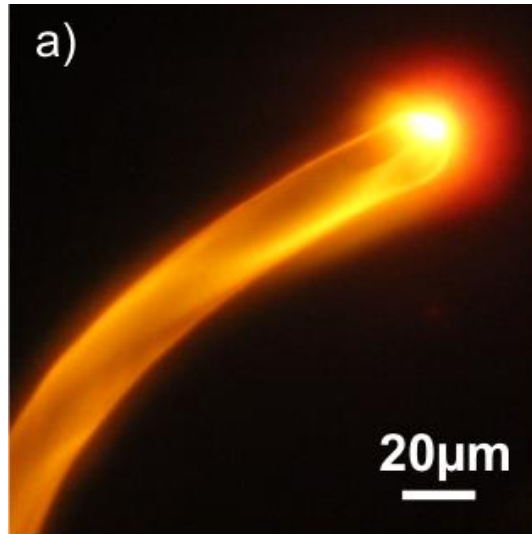
d)



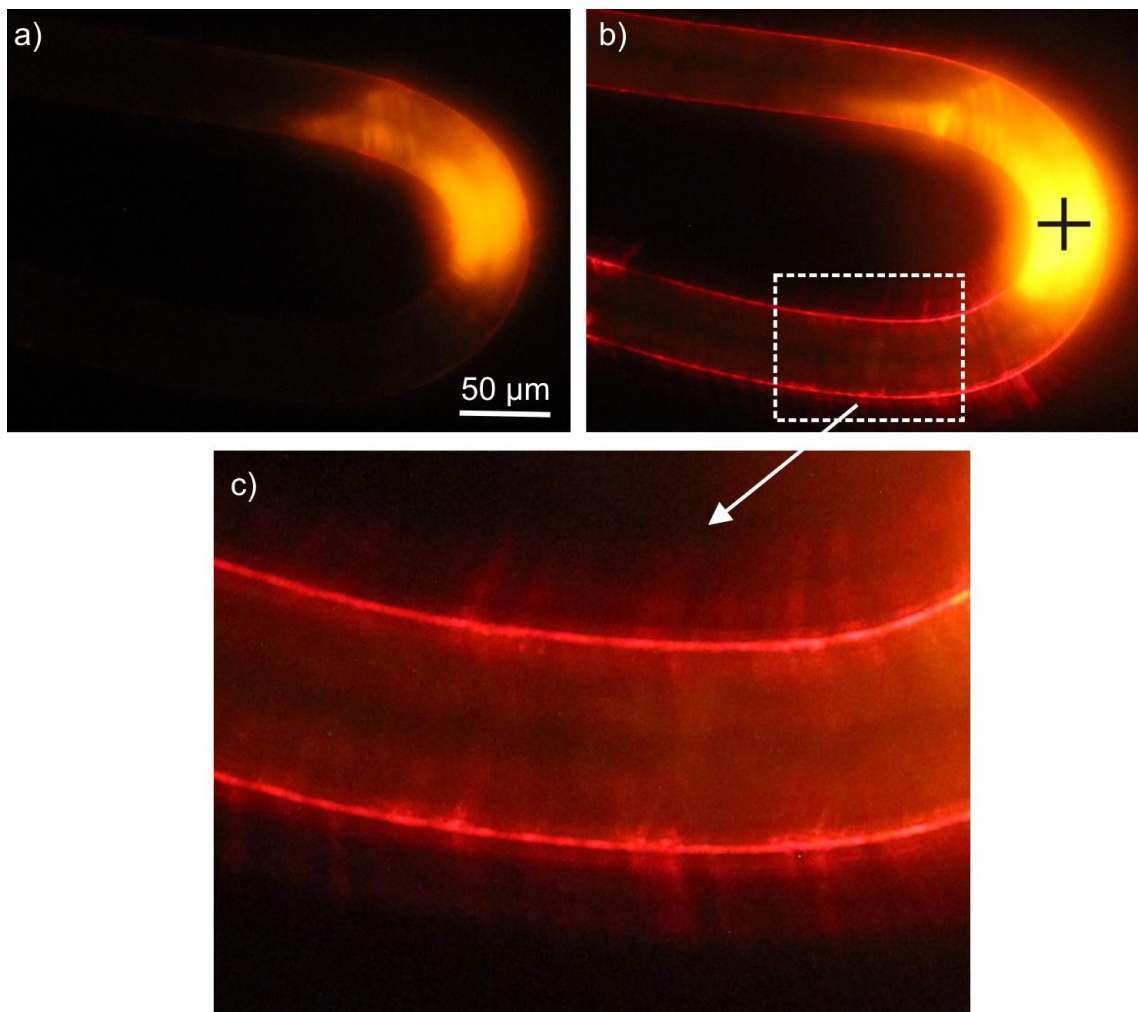
Vlakna lepo vodijo svetlobo s totalnim odbojem

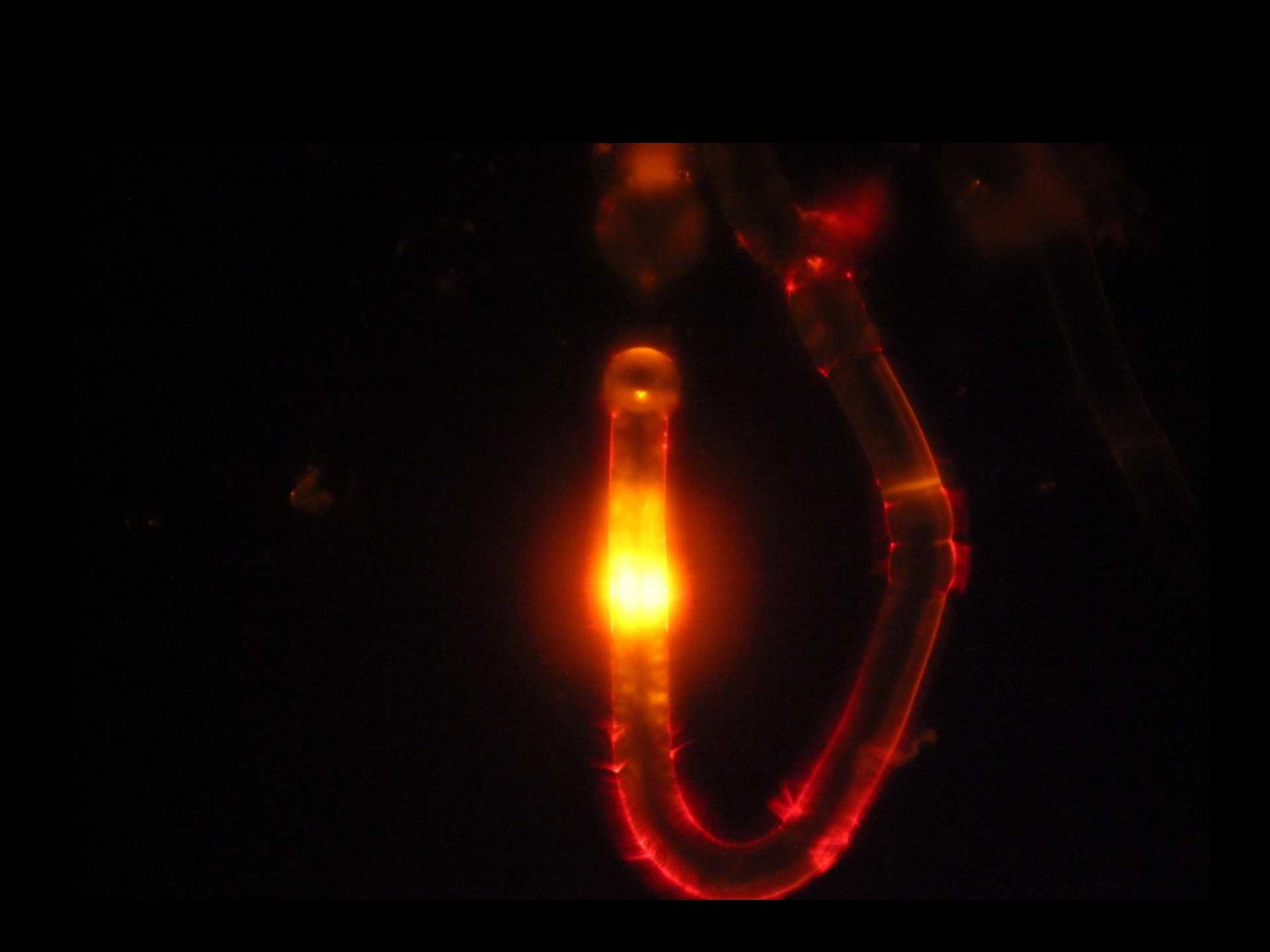






Iz vlaken lahko dobimo tudi lasersko svetlobo:





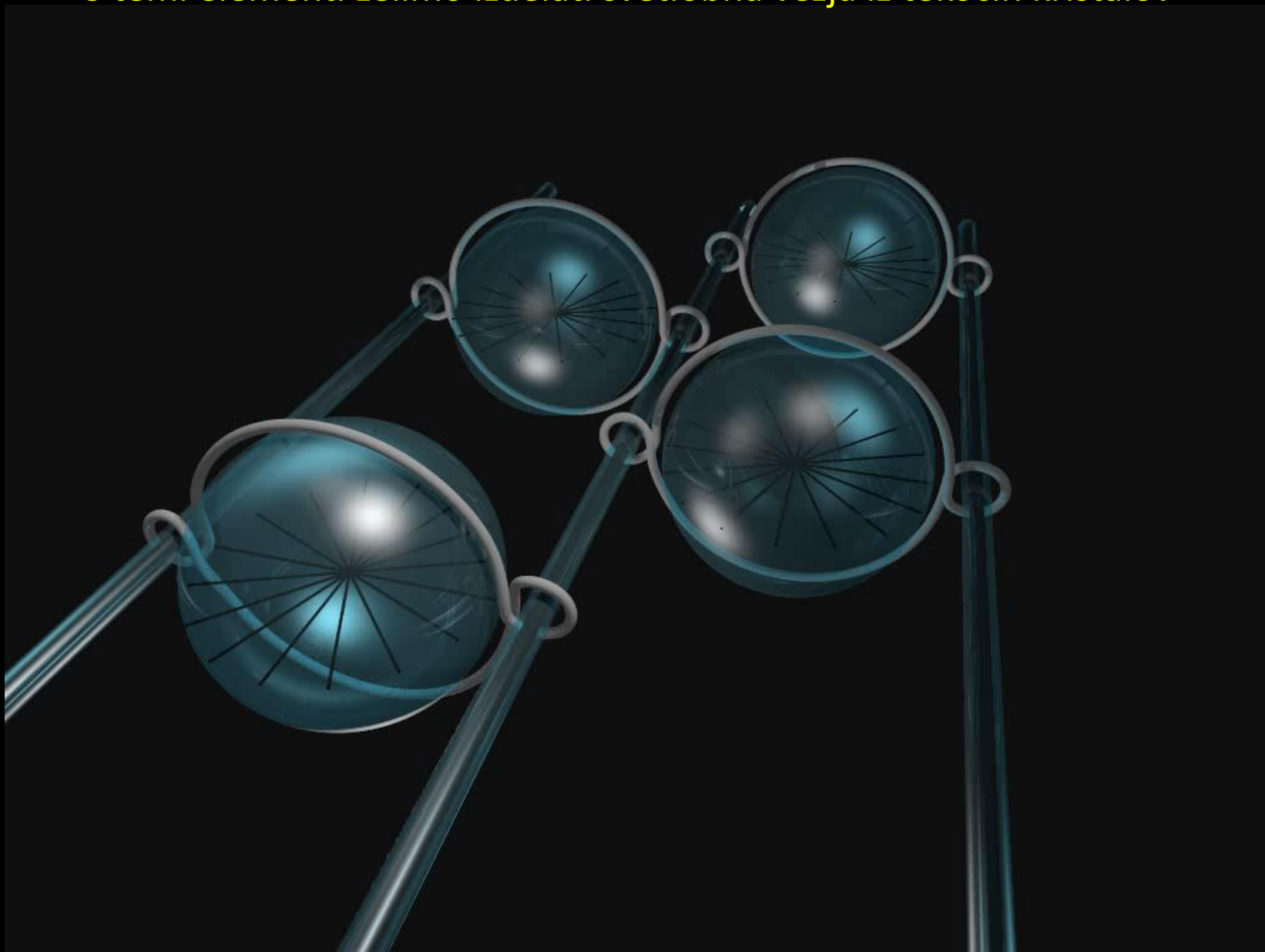
Lasing and waveguiding in smectic A liquid crystal optical fibers

Karthik Peddireddy,¹ V. S. R. Jampani,² Shashi Thutupalli,¹ Stephan Heringhaus,¹ Christian Bahr,¹ and Igor Mušević^{2,3,*}

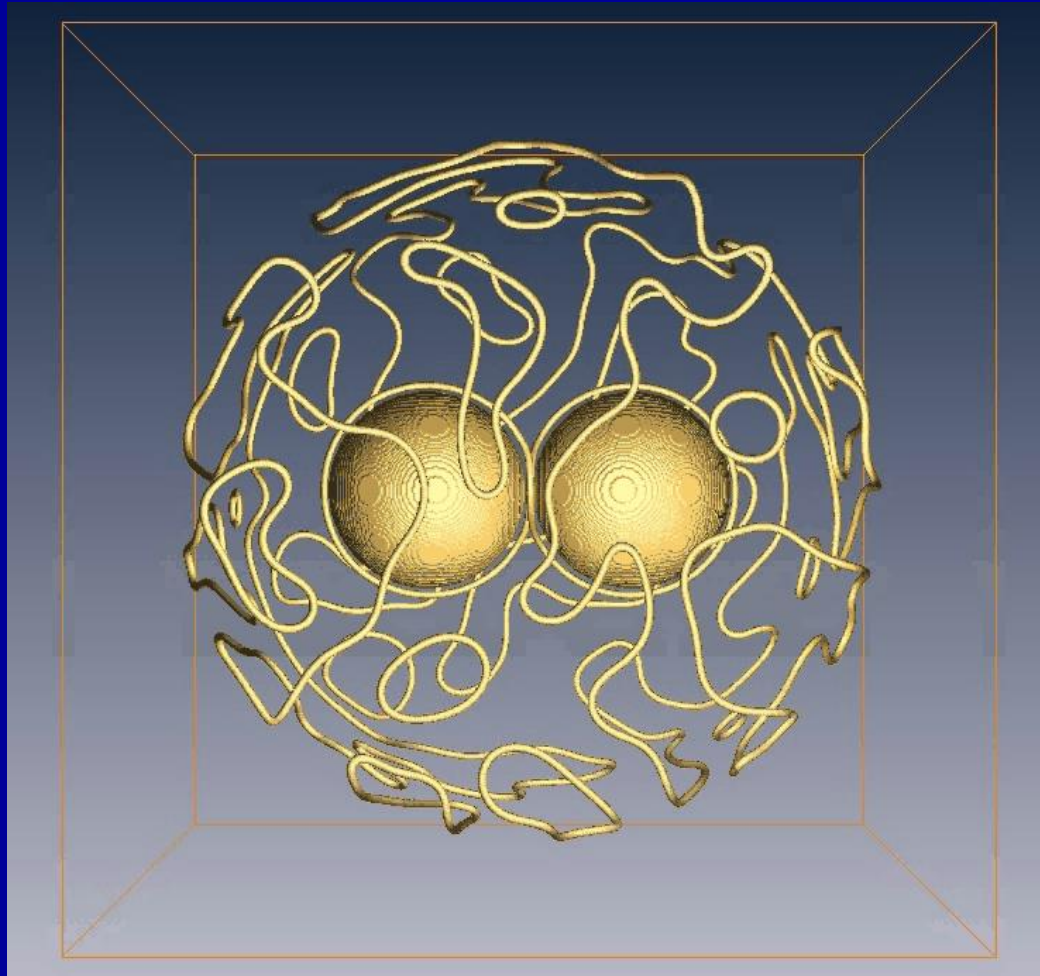
16 December 2013 | Vol. 21, No. 25 | DOI:10.1364/OE.21.030233 | OPTICS EXPRESS 30233

The screenshot shows the Optics InfoBase website interface. At the top, there is a navigation bar with links for 'Contact Us', 'Login', 'Login Benefits', and 'My InfoBase'. The main header features the 'Optics InfoBase' logo and a dropdown menu for 'Select Another Publication'. Below the header is a 'Spotlight on Optics' banner for December 2013. On the left, a sidebar menu includes 'Home', 'Previous Spotlights', 'About', 'Using Optics InfoBase', 'Authors', 'Librarians', and 'Subscribe'. The main content area displays the article title 'Lasing and waveguiding in smectic A liquid crystal optical fibers' with a small image of a fiber. Below the title, it states the article was published in Optics Express, Vol. 21 Issue 25, pp. 30233-30242 (2013) by Karthik Peddireddy, V. S. R. Jampani, Shashi Thutupalli, Stephan Heringhaus, Christian Bahr, and Igor Mušević. Source links for 'Abstract', 'HTML', and 'PDF' are provided. On the right, there is a search box with 'Journal Search' and 'Article Lookup' tabs, a search input field, and a 'Go' button. Below the search box is a 'Previous Spotlights' section for the year 2013.

S temi elementi želimo izdelati svetlobna vezja iz tekočih kristalov

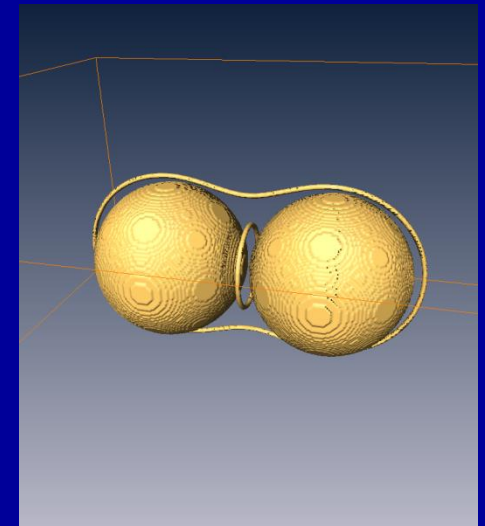
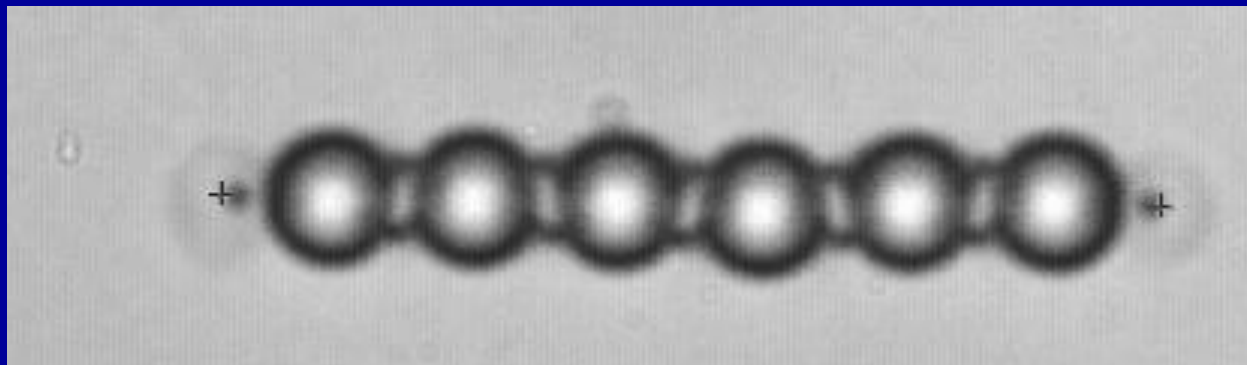
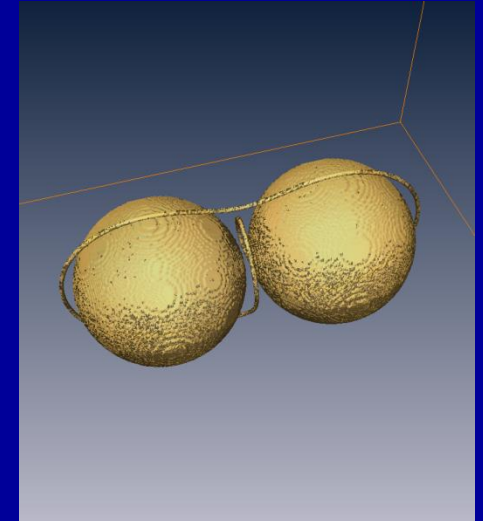
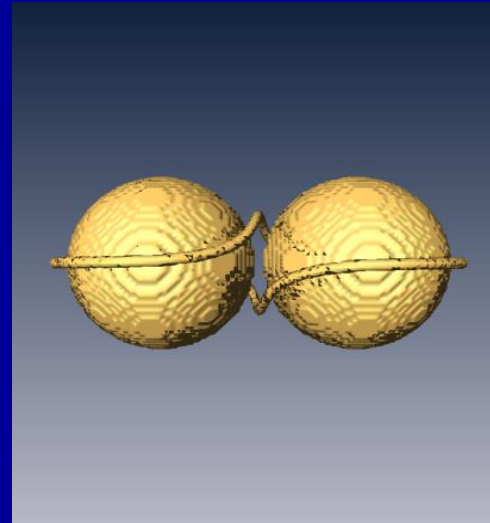
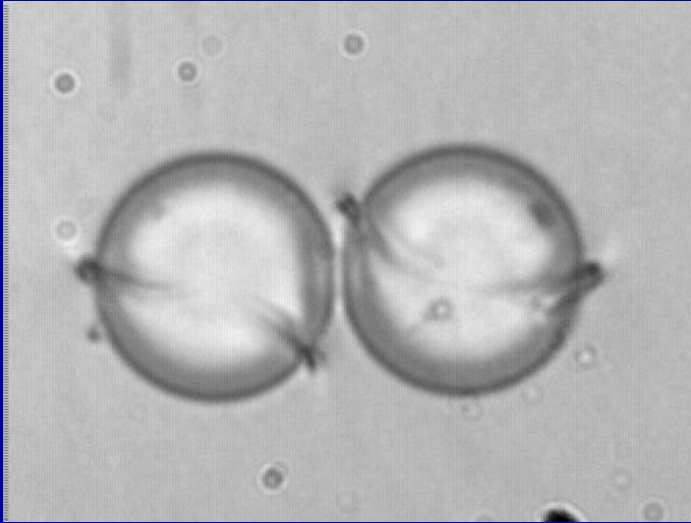


Teorija: hitro ohlajanje tekočega kristala okoli koloidnih delcev

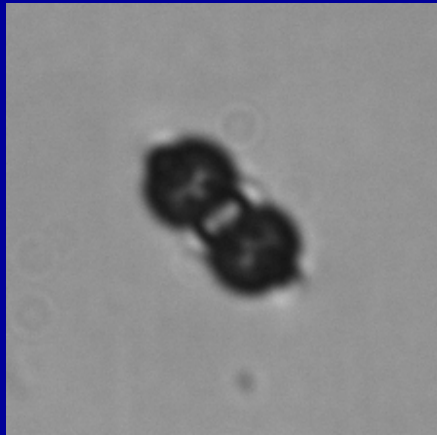


Landau de Gennes simulacije M.Ravnik, S.Žumer

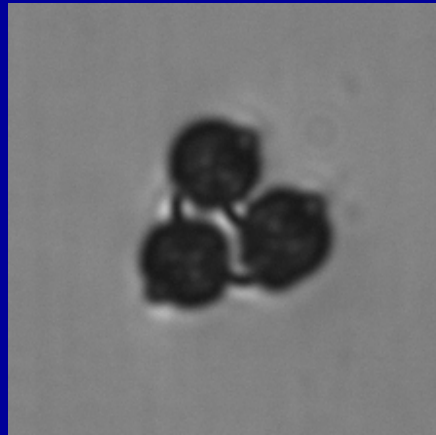
Spleteni koloidni delci:



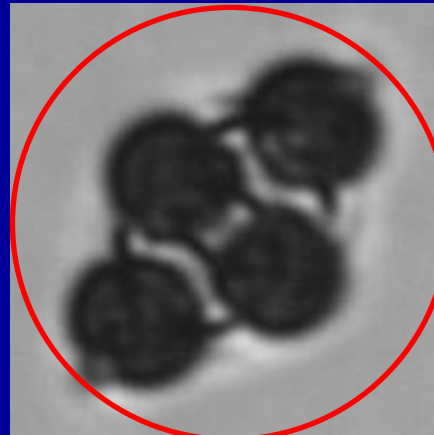
Napoved Araki and Tanaka, PRL 2006; S. Zumer ILCC 2006
Eksperimenti M.Ravnik et al., PRL 99, 247801(2007)



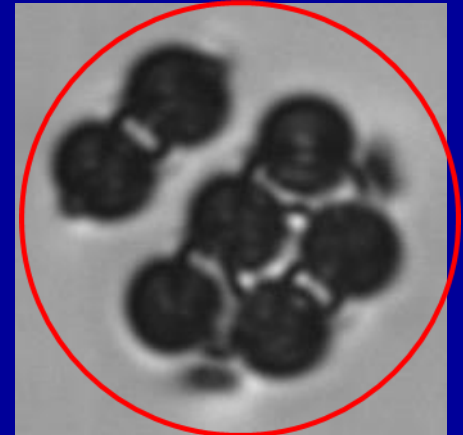
N=2



N=3

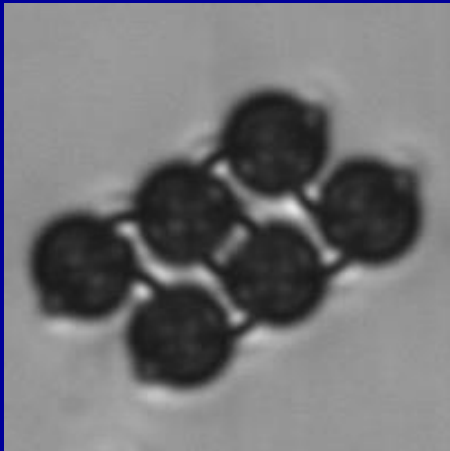


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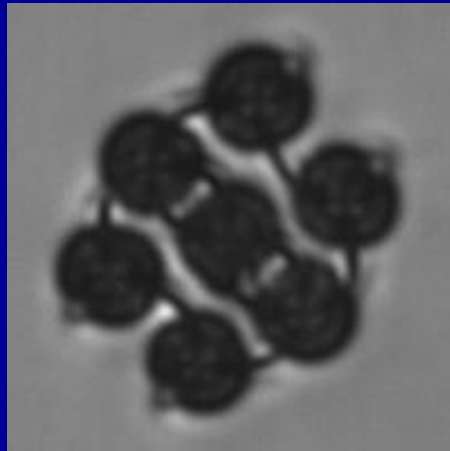


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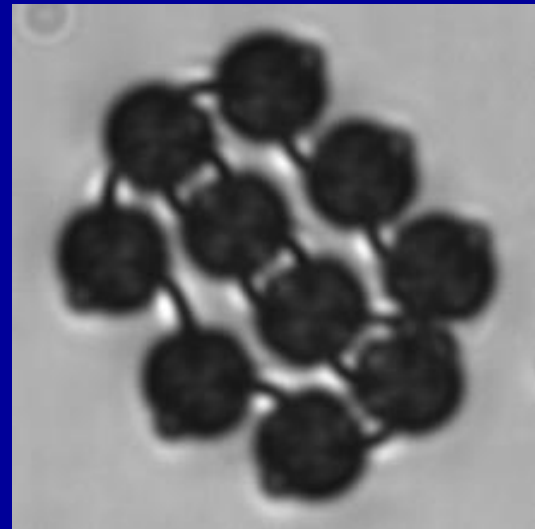
Spleti in vozli?



N=6

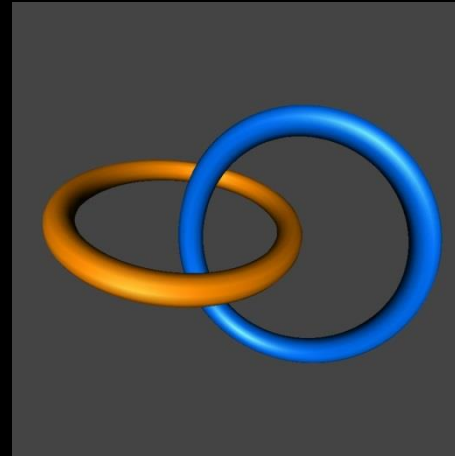


N=7

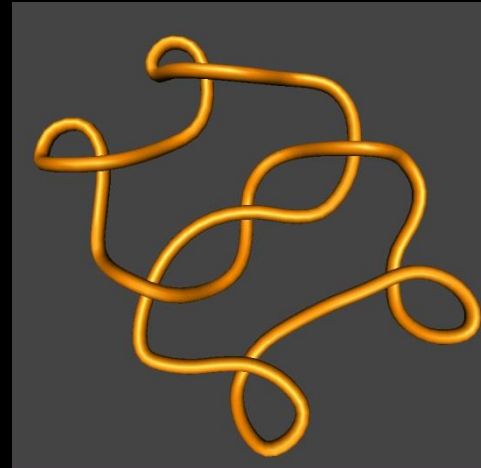
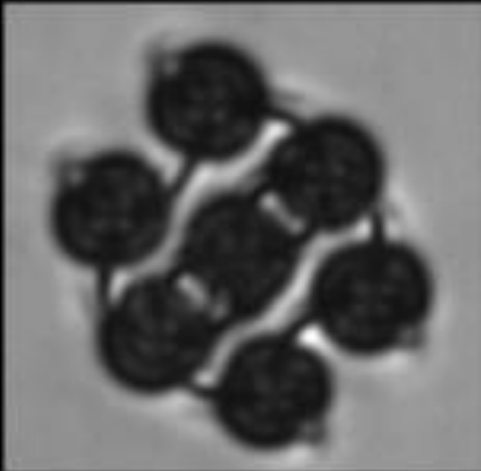


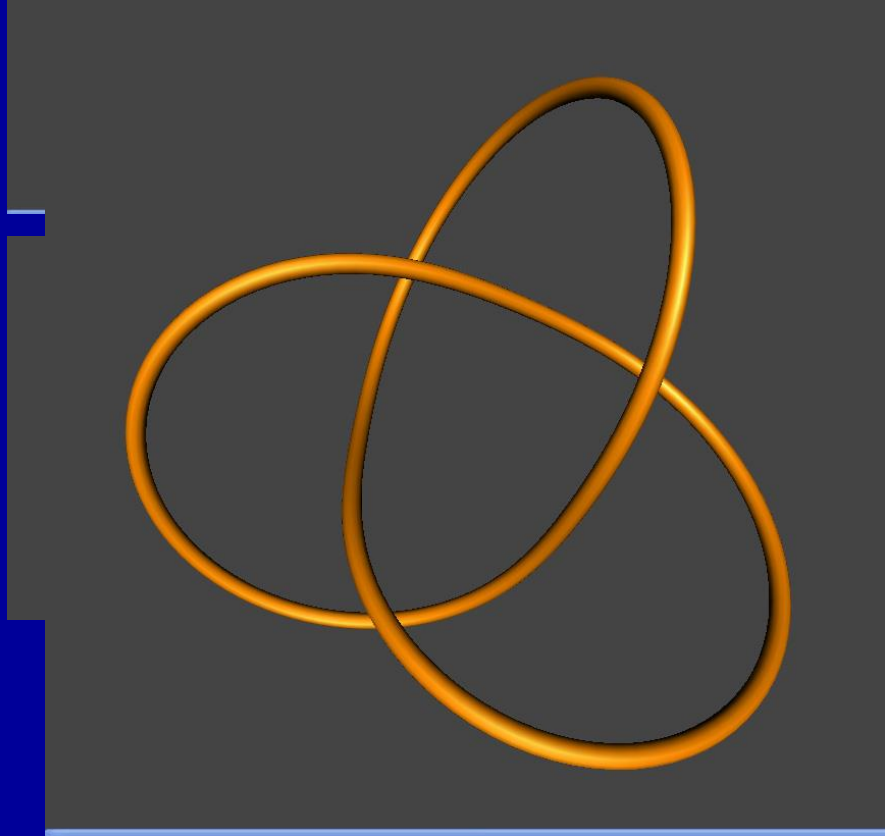
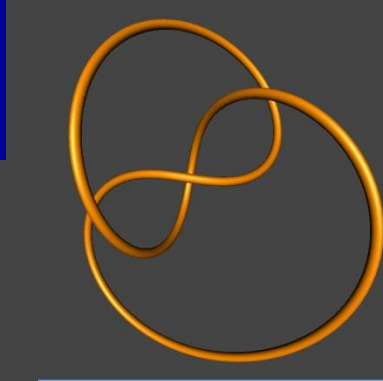
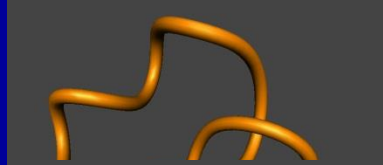
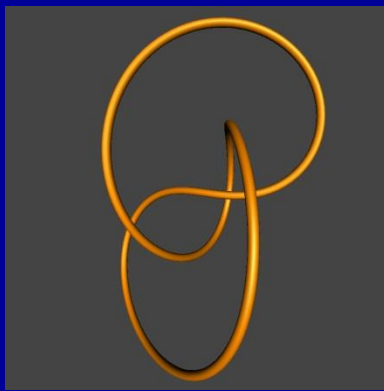
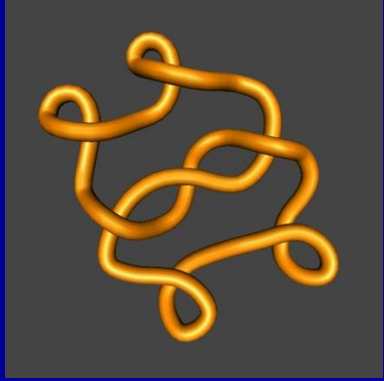
N=8

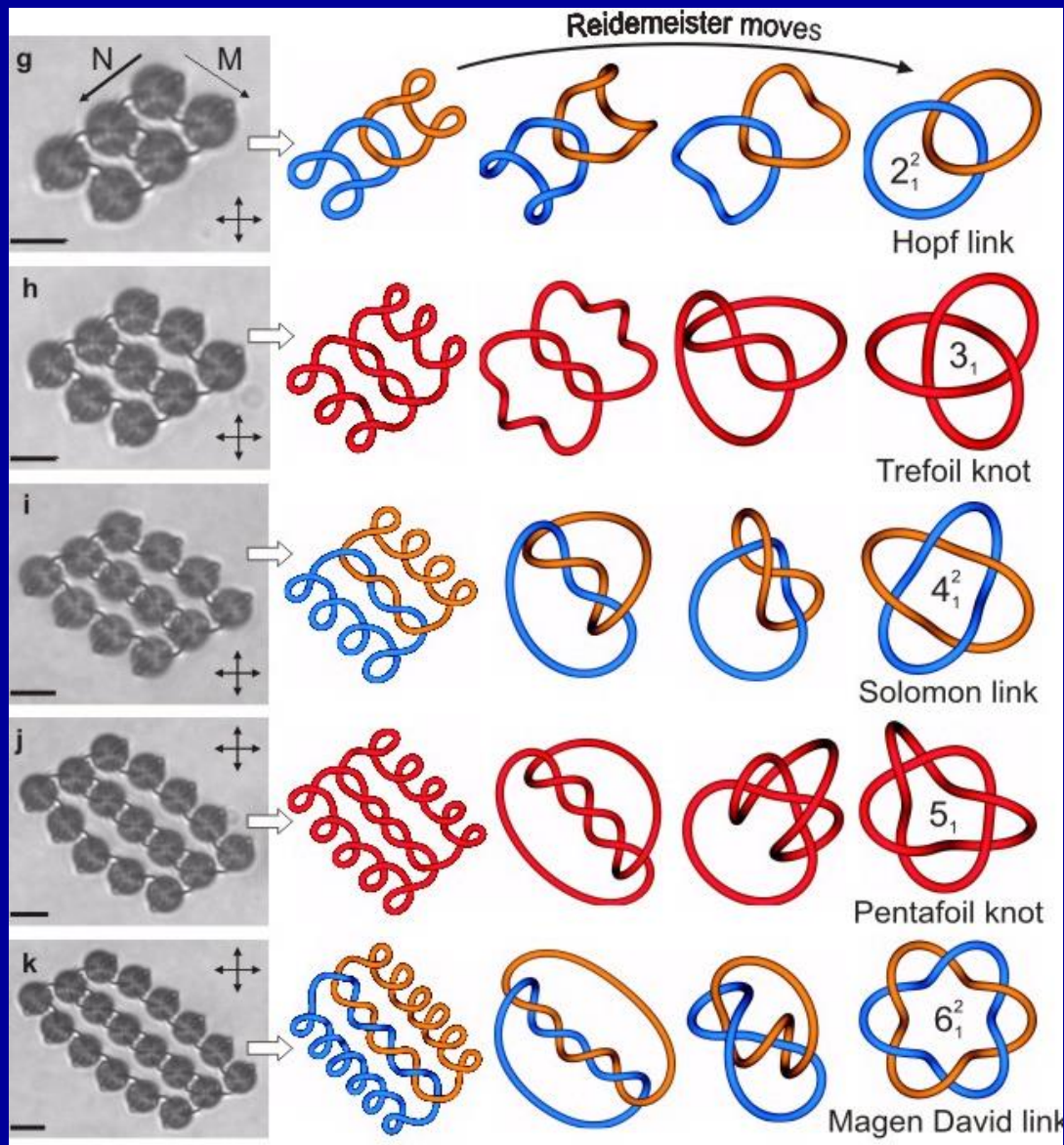
Primer spleta: "Hopfov" splet



Primer vozla: "trefoil,, trilst

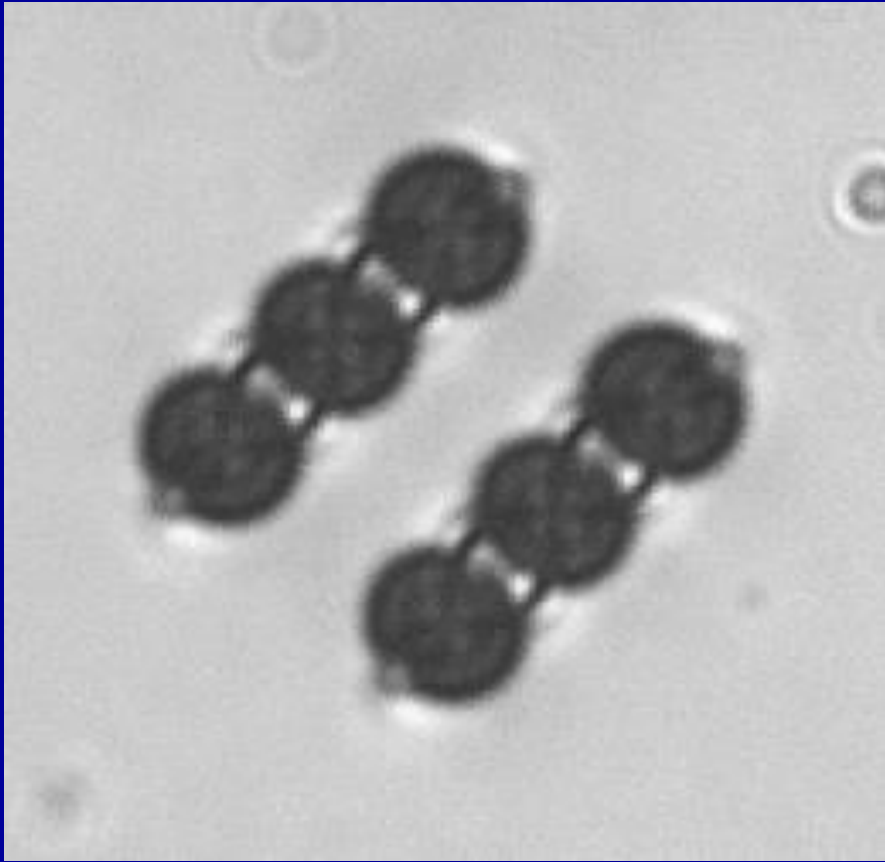




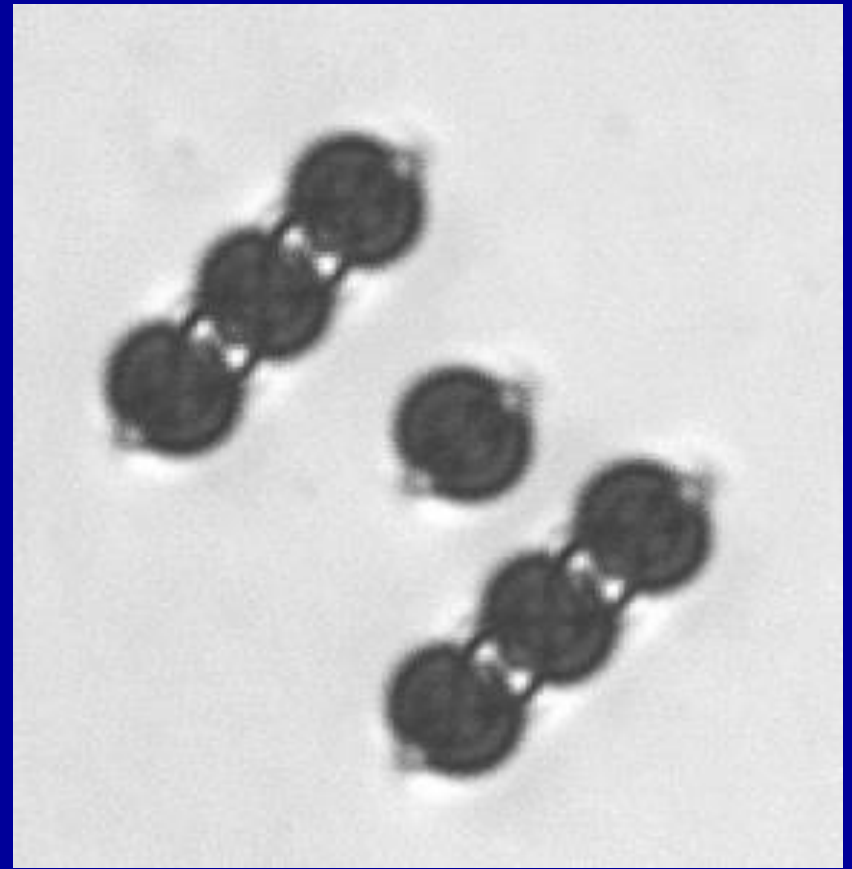


first reported in bulk chiral nematic by Y. Bouligand *J. Physique (France)*(1974).
 Knotted optical fields: Irvine and Bouwmeester, *Nat.Phys.*2008; Dennis et al. *Nat.Phys.* 2010

Vozlanje in spletanje koloidnih delcev z lasersko pinceto

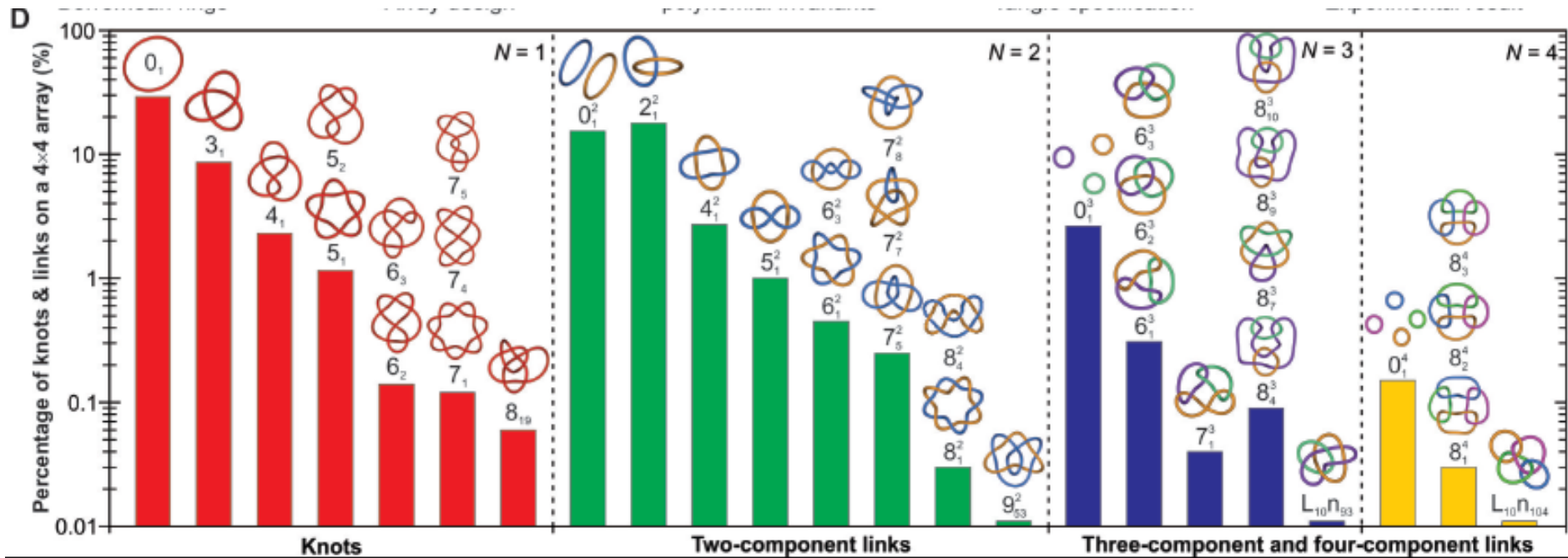


linking a Hopf link



knitting a trefoil knot

Knots and links on a 4 x 4 colloidal array



REPORTS

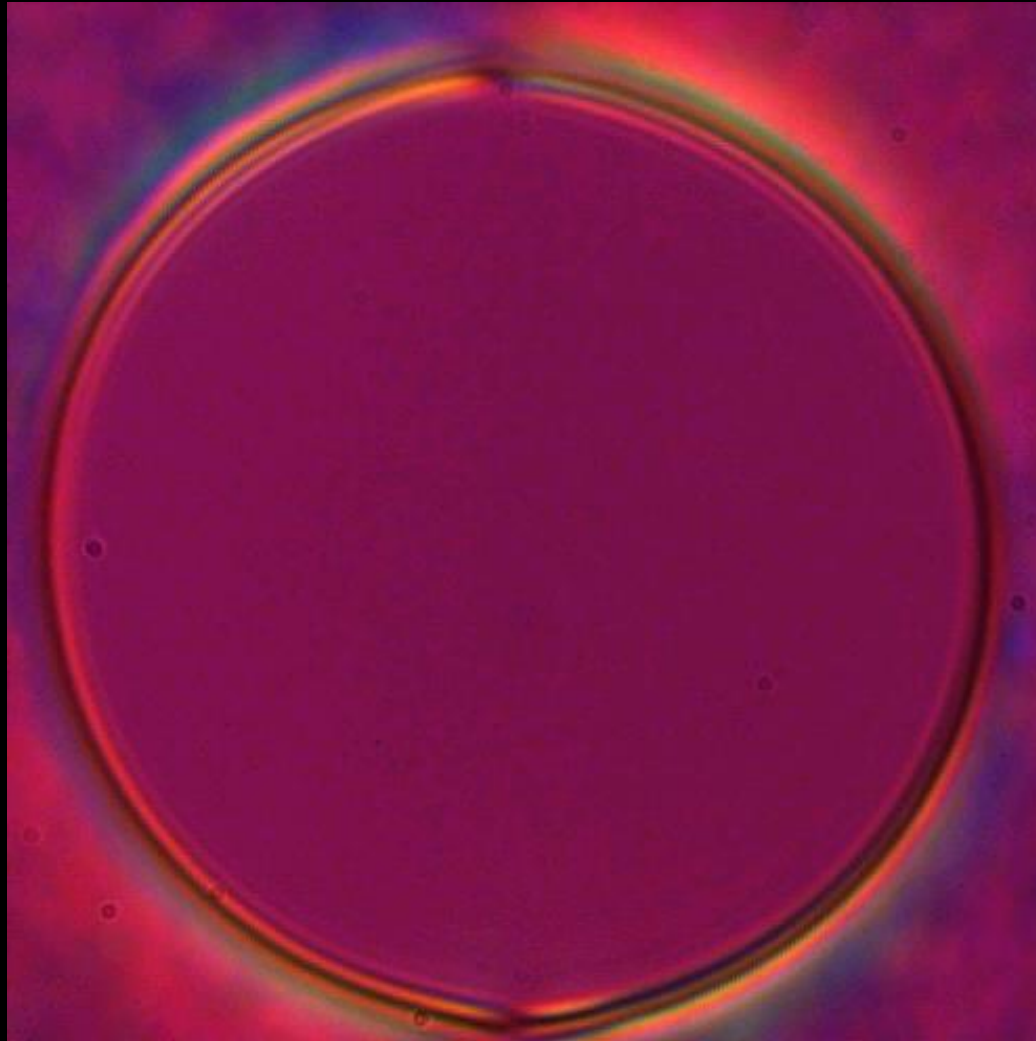
Reconfigurable Knots and Links in Chiral Nematic Colloids

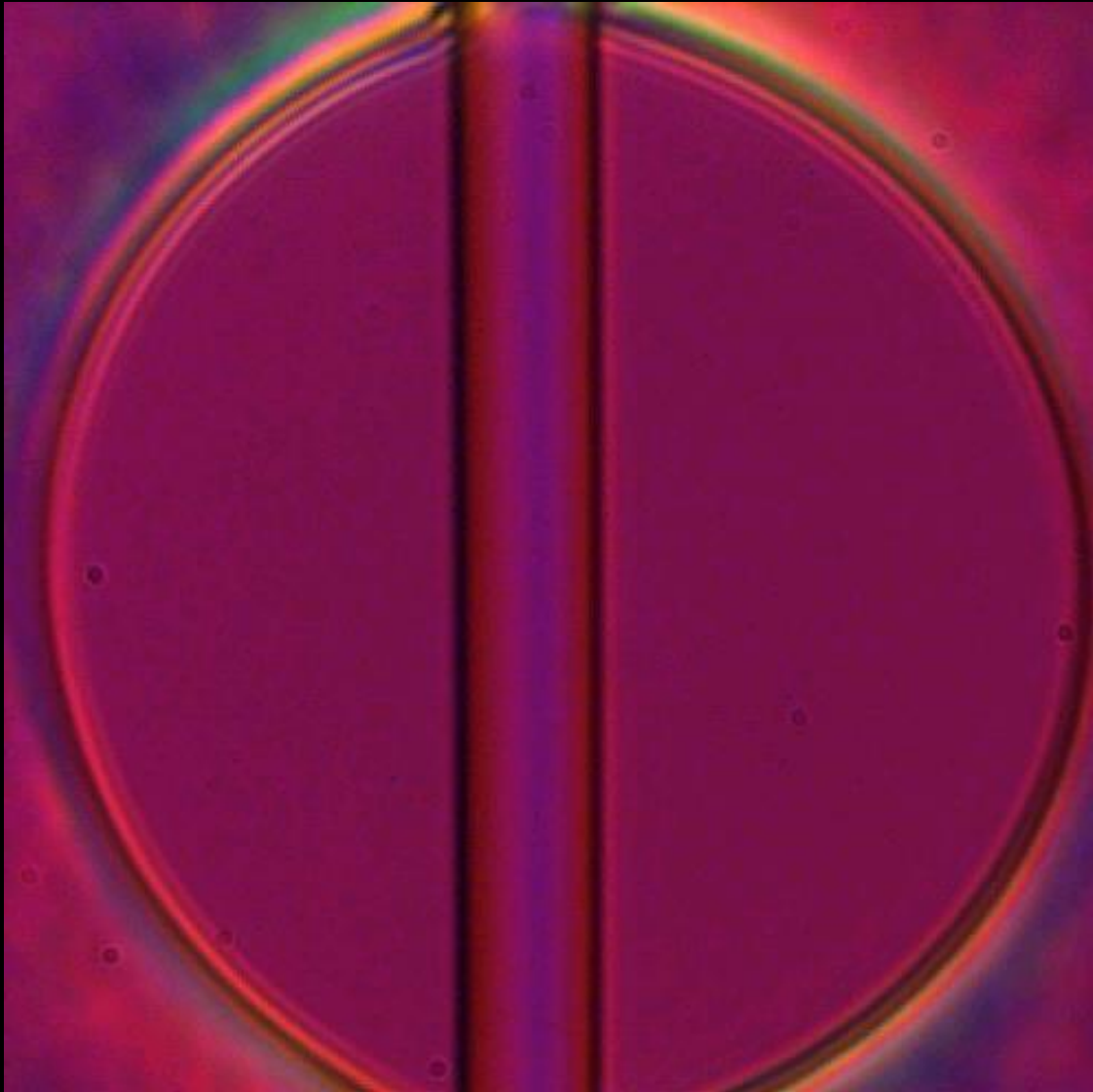
Uroš Tkalec,^{1,†} Miha Ravnik,^{2,3} Simon Čopar,³ Slobodan Žumer,^{1,3} Igor Muševič^{1,3,*}

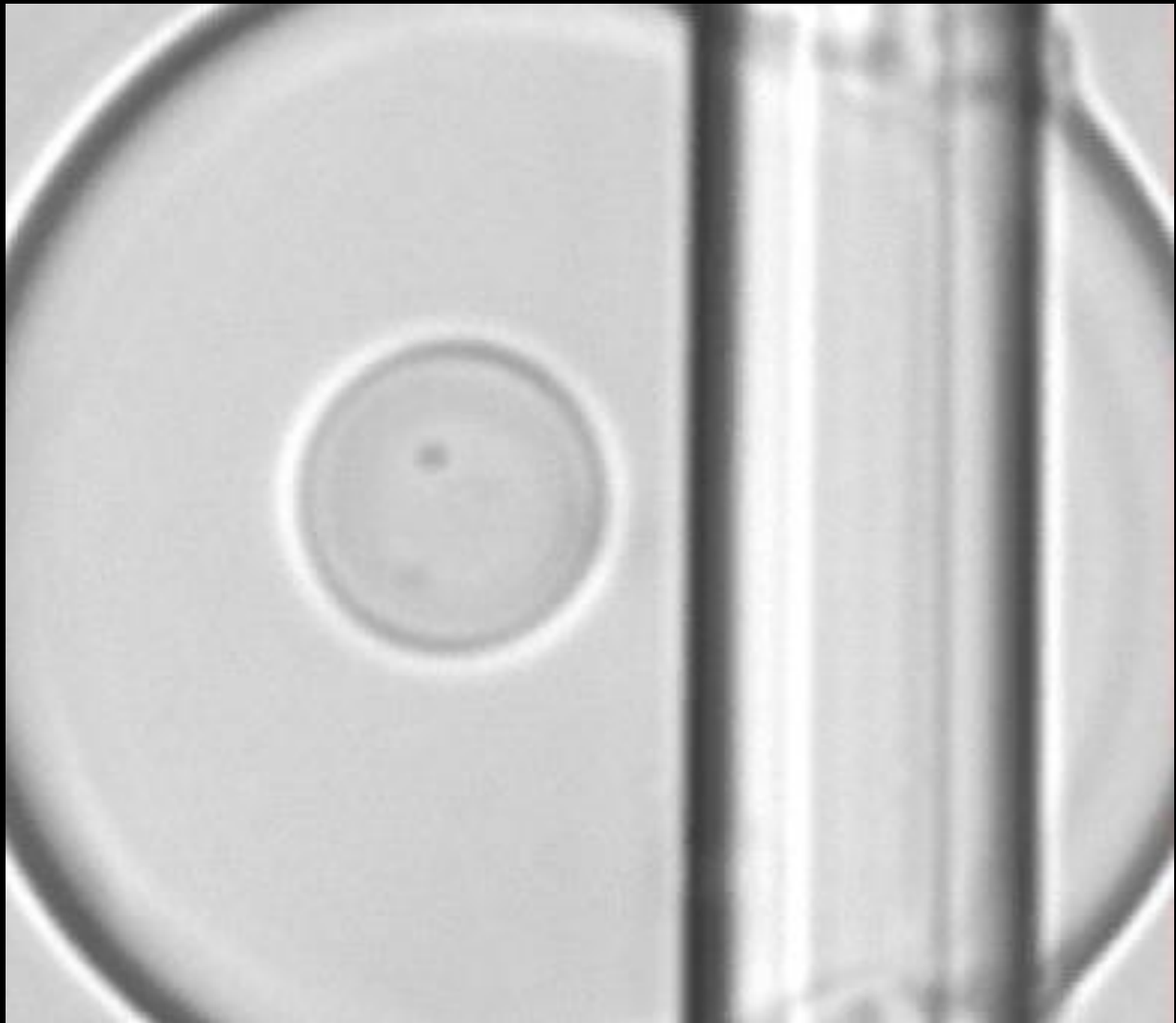
Tying knots and linking microscopic loops of polymers, macromolecules, or defect lines in complex materials is a challenging task for material scientists. We demonstrate the knotting of microscopic topological defect lines in chiral nematic liquid-crystal colloids into knots and links of arbitrary

are created. Each particle is encircled by its own micro-loop, also called a Saturn's ring, in which the degree of molecular order is reduced in the ~10-nm-thick core, and the director exhibits fast spatial variations, making the rings visible under an optical microscope (16). The Saturn's ring behaves as an elastic strip that can be stretched and deformed with laser tweezers (17–20). More importantly, several Saturn's rings can be fused together by using the laser tweezers to entangle a pair or multiple colloidal particles (21, 22). Here,

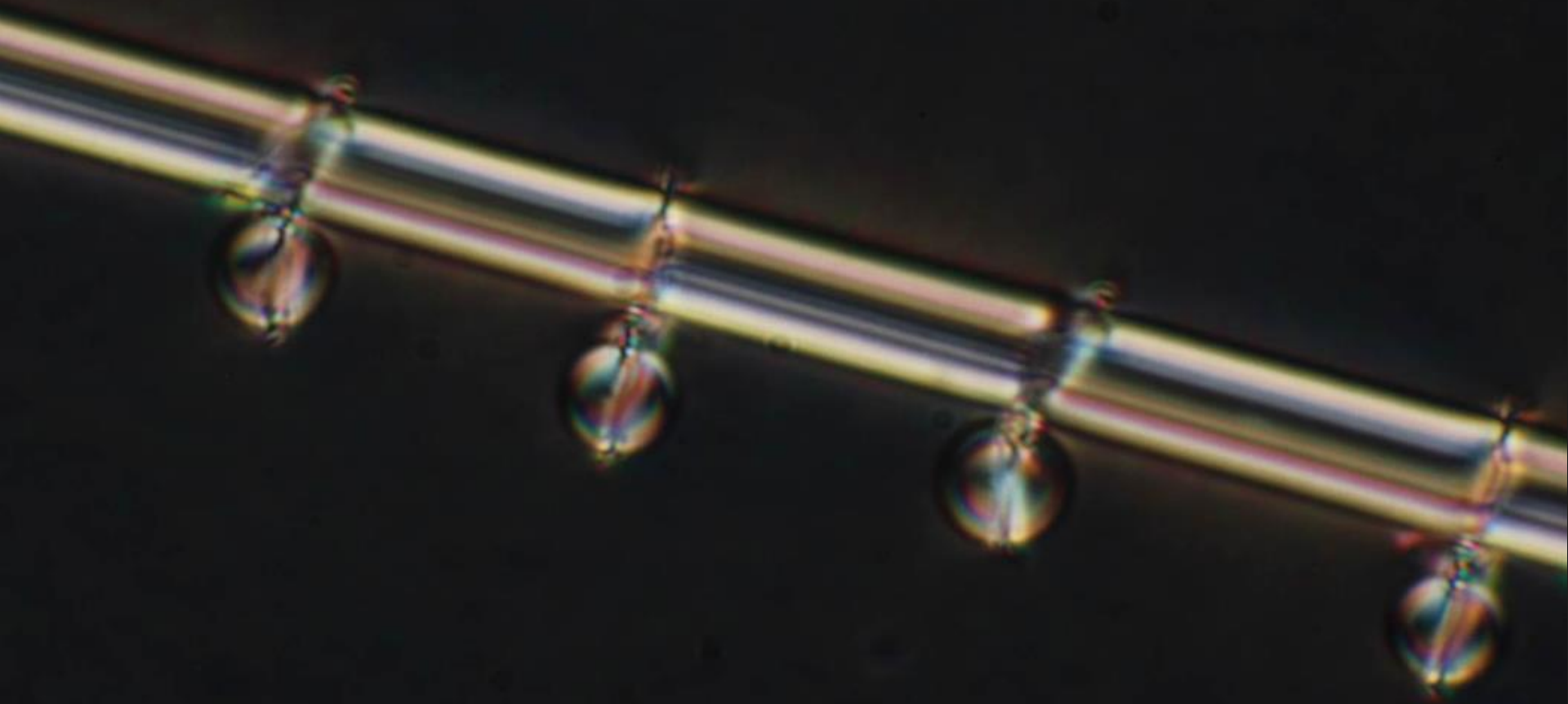
Topologijo uporabljamo za vezavo elementov:







Izdelamo lahko zanimive strukture, ki so osnova
za bodoča vezja



Zaključek

- Iz tekočih kristalov lahko izdelavo vse osnovne elemente za svetlobna vezja.
- Svetlobni elementi so tekoči, oblikuje jih zgolj površinska napetost.
- V teh snoveh opazimo množico zanimivih topoloških defektov (tudi vozli in spleti).
- Pokazali smo, da lahko na svetlobo v teh elementih učinkujemo z drugo svetlobo.
- Vsi elementi so lahko bio-kompatibilni.

Zahvala sodelavcem

- Miha Škarabot, JSI, Ljubljana
- Uroš Tkalec, JSI, Ljubljana
- Matjaž Humar, JSI, Ljubljana
- Venkata S. Rao Jampani, JSI, Ljubljana
- Maryam Nikkhou, JSI, Ljubljana

- Miha Ravnik, UNI LJ, Ljubljana
- Simon Čopar, UNI LJ, Ljubljana
- Slobodan Žumer, UNI LJ, Ljubljana

- Ulyana Ognysta, IOP, Kiev
- Andriy Nych, IOP, Kiev

- Christian Bahr, MPIDS, Goettingen,
- Stephan Herminghaus, MPIDS, Goettingen
- Karthik Peddireddy, MPIDS, Goettingen
- Shashi Thutupalli, MPIDS, Goettingen