Photonic Crystal Fibre Science

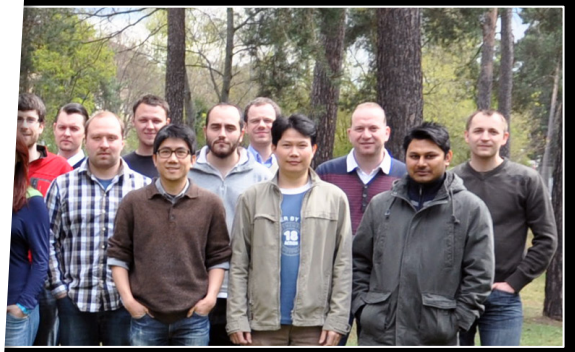
Russell Division
MPI Science of Light

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

MPL
Max Planck Institute
for the science of light

Growth in numbers

Fibre fabrication team



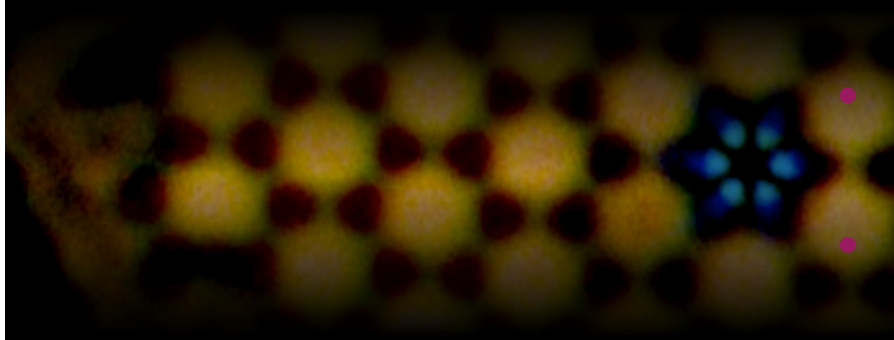
MPL
Max Planck Institute
for the science of light

Activities & Interests

Study of light-matter interactions enabled by microstructured fibres

MPL
Max Planck Institute
for the science of light

Topics



- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

MPL
Max Planck Institute
for the science of light

Twisted fibres


Gordon Wong

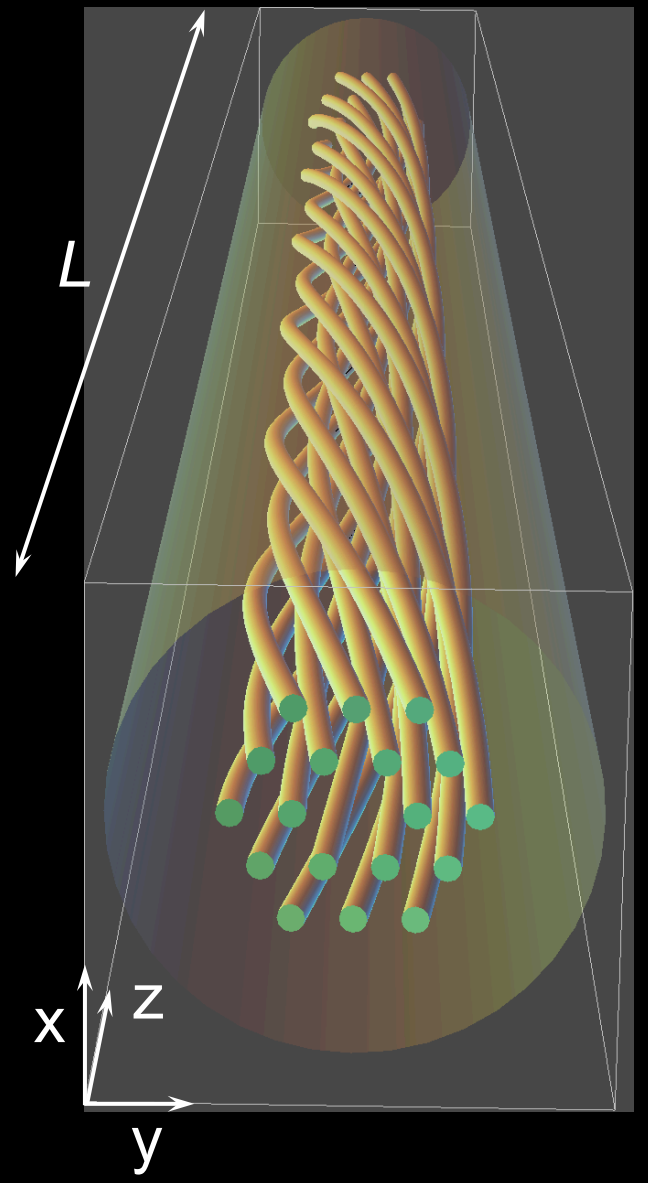

Thomas Weiss


Xiaoming Xi


Fabio Biancalana

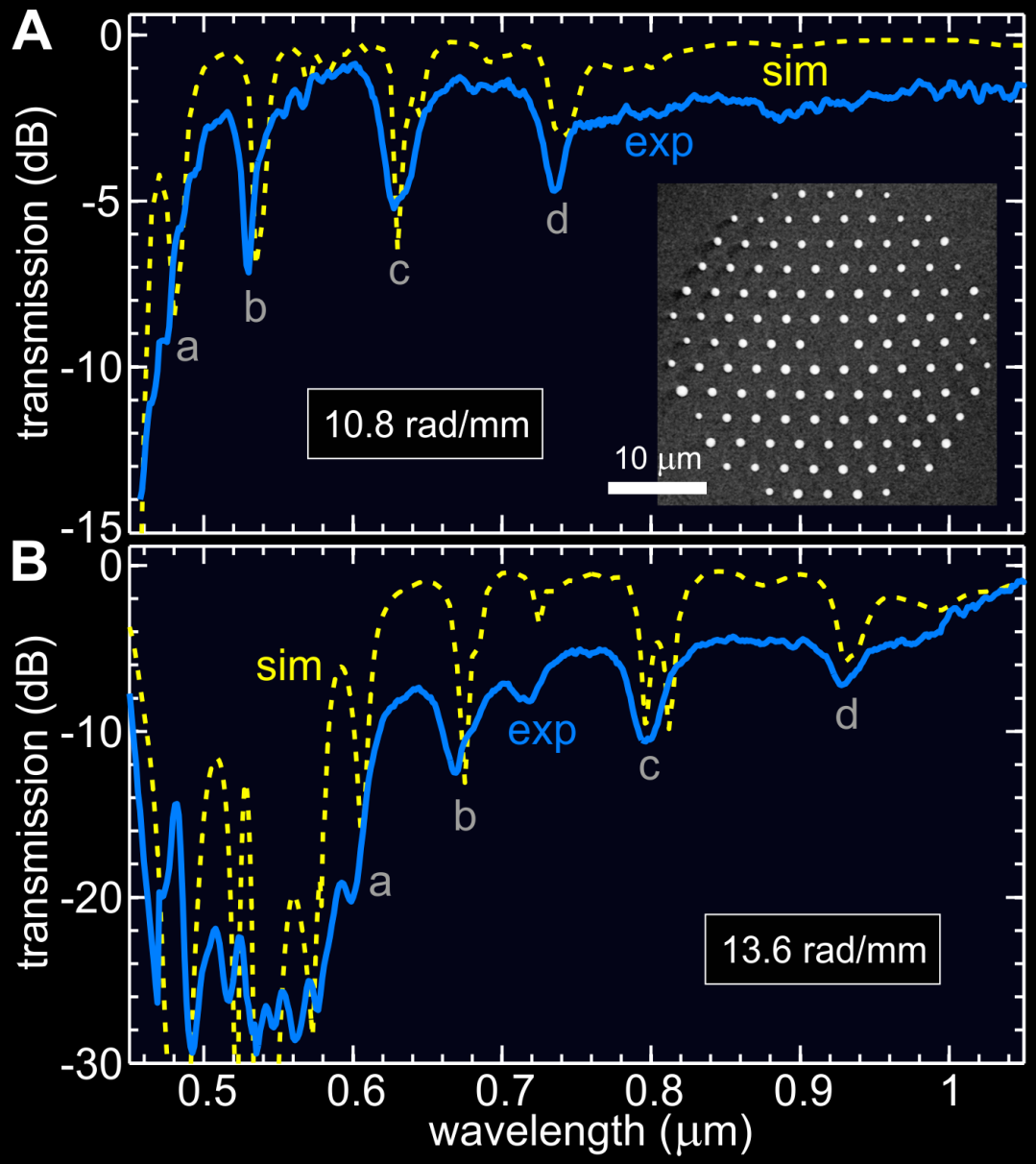
collaboration with Miles Padgett (University of Glasgow),
Stephen Barnett (University of Strathclyde) &
Claudio Conti (La Sapienza)

- twist rate $\alpha = 2\pi / L$
- pitch *L* is much greater than inter-hole spacing
- angle between hollow channels and axis increases with radius



MPL
Max Planck Institute
for the science of light

Transmission spectra



L = 581 µm

inter-hole spacing ~3 µm

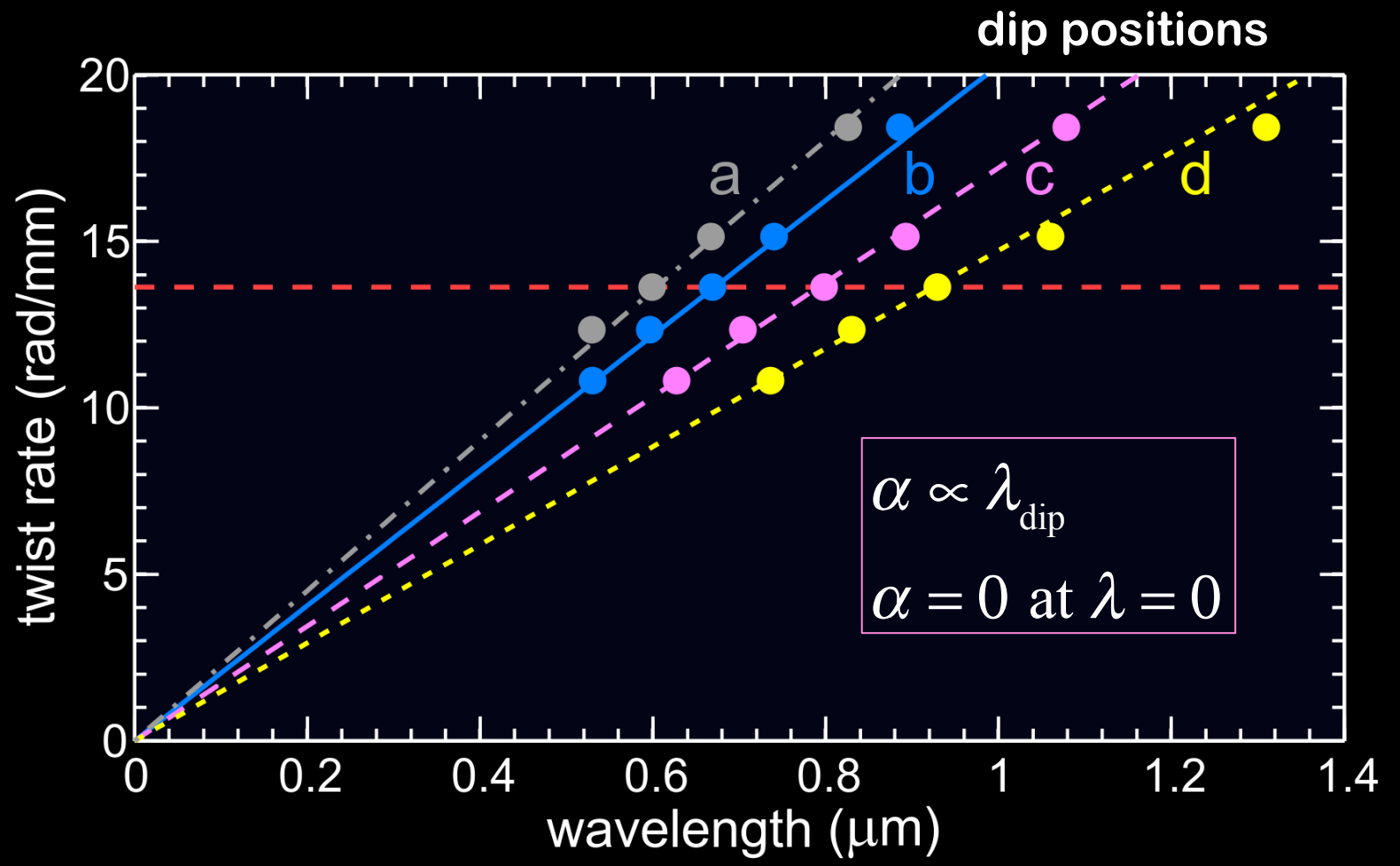
L = 462 µm

Wong et al: Science **337**, 446 (2012)

MPL
Max Planck Institute for the science of light

Twist rate versus resonant wavelength

Wong et al: Science **337**, 446 (2012)

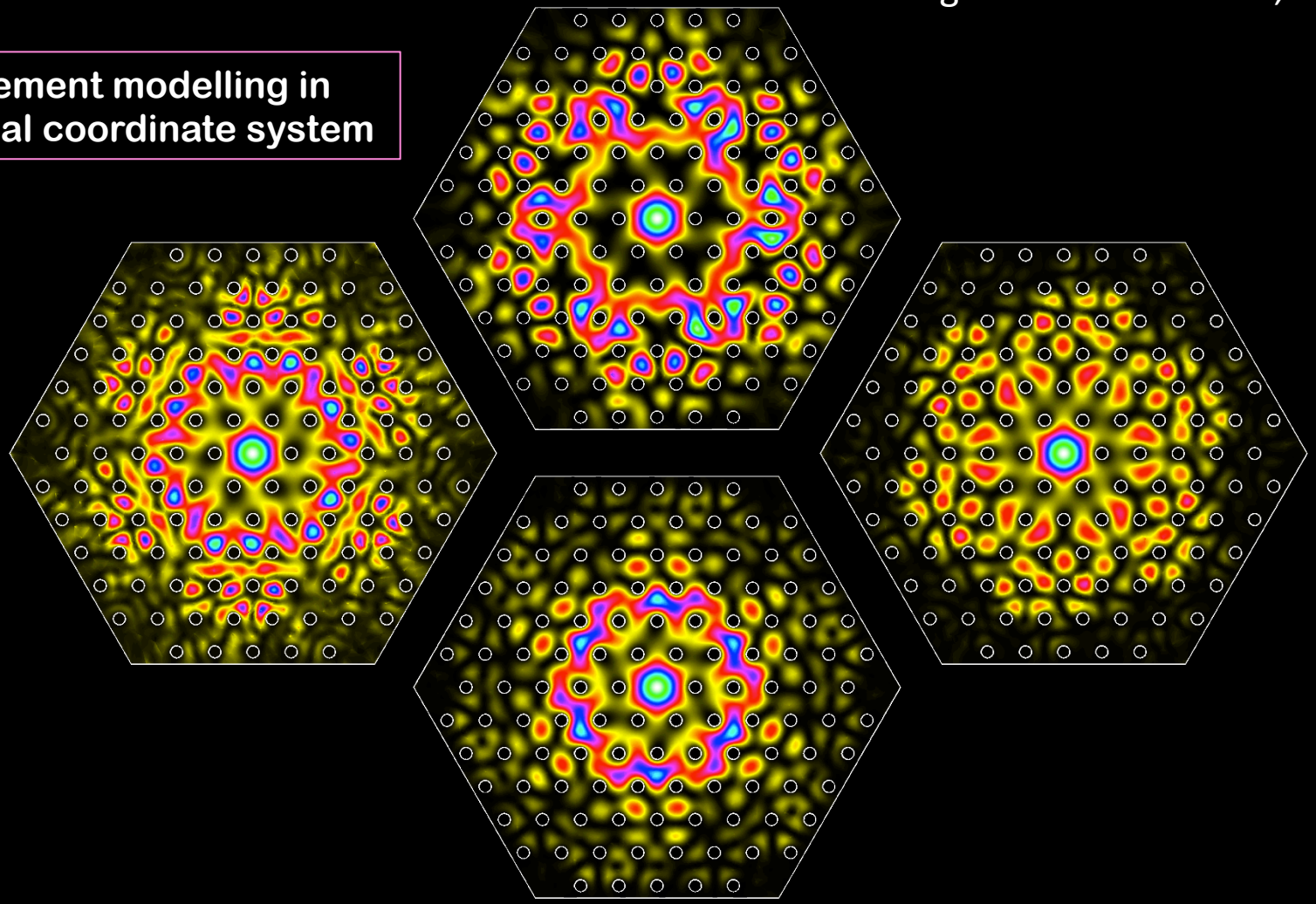


MPL
Max Planck Institute
for the science of light

Axial Poynting vector of orbital resonances

Wong et al: Science **337**, 446 (2012)

finite element modelling in helicoidal coordinate system



MPL
Max Planck Institute for the science of light

Topics

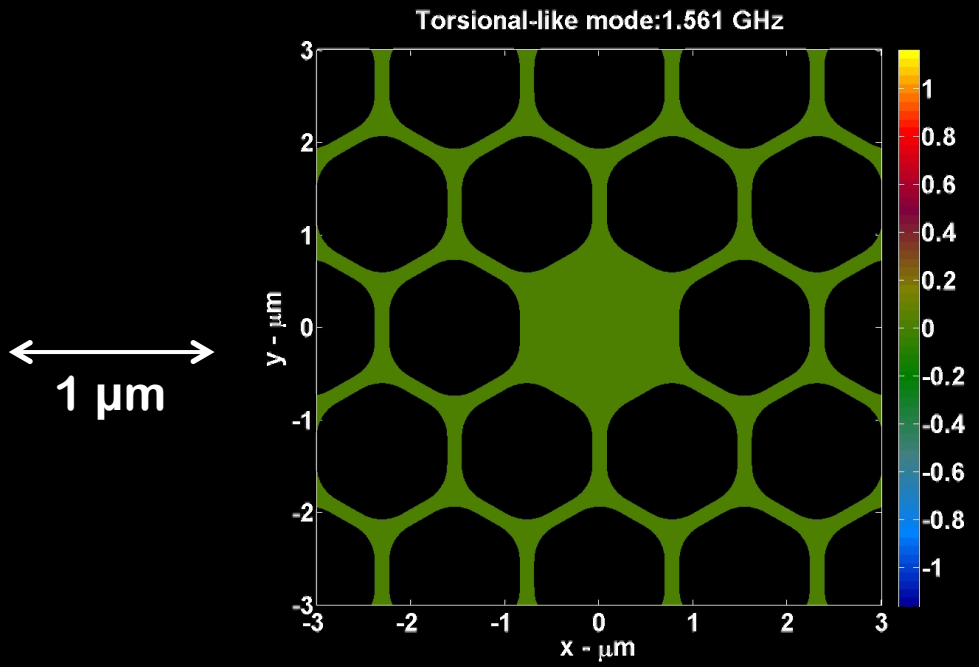
- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

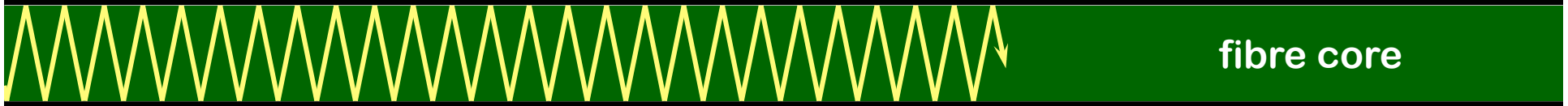
Myeongsoo Kang
(former member)

Anna Butsch

MPL
Max Planck Institute
for the science of light

Guided acoustic modes in PCF core

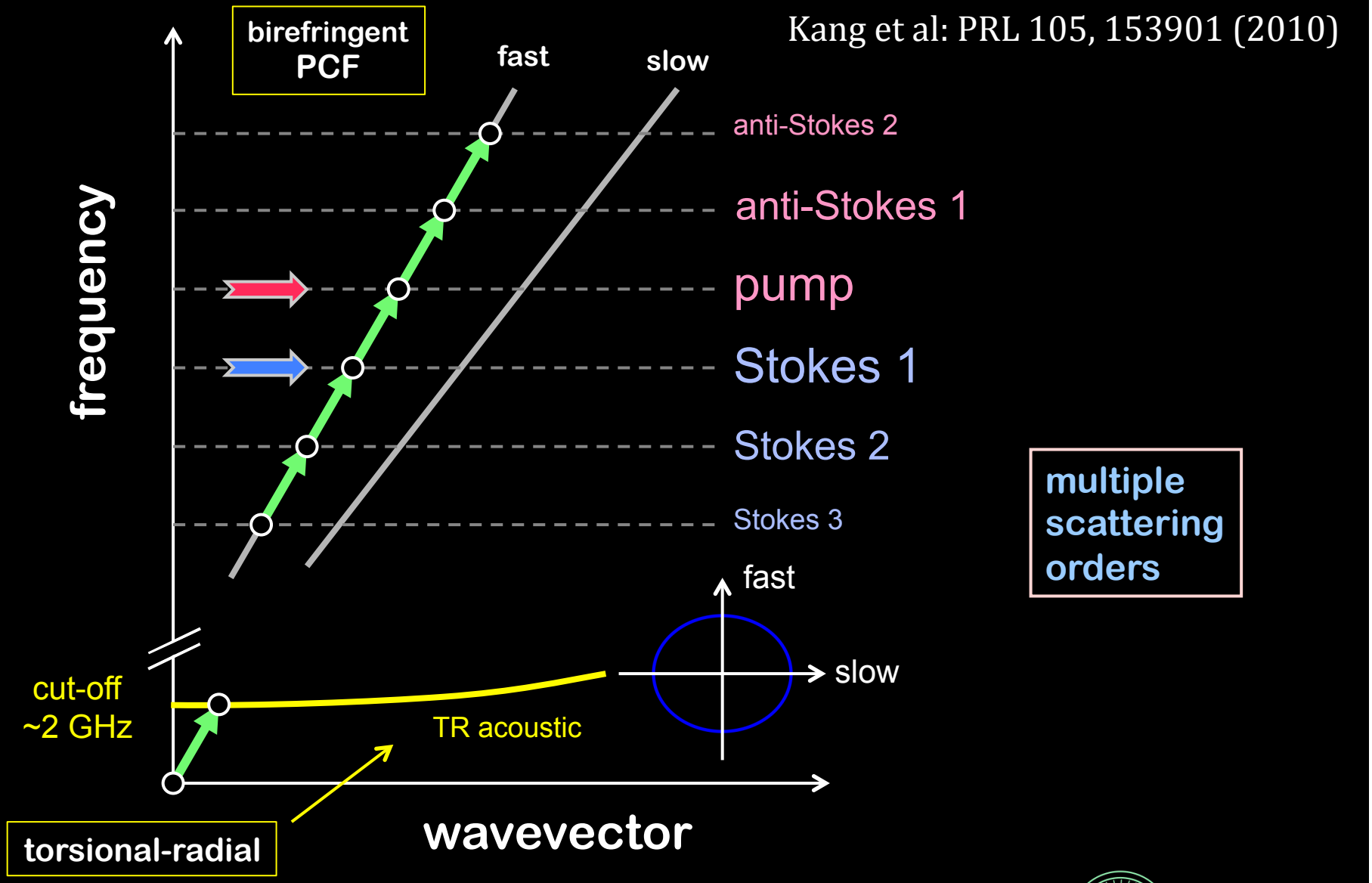




- very high phase velocity but very low group velocity
- sound and light tightly confined in small space
- cut-off when rays are perpendicular to axis

MPL
Max Planck Institute
for the science of light

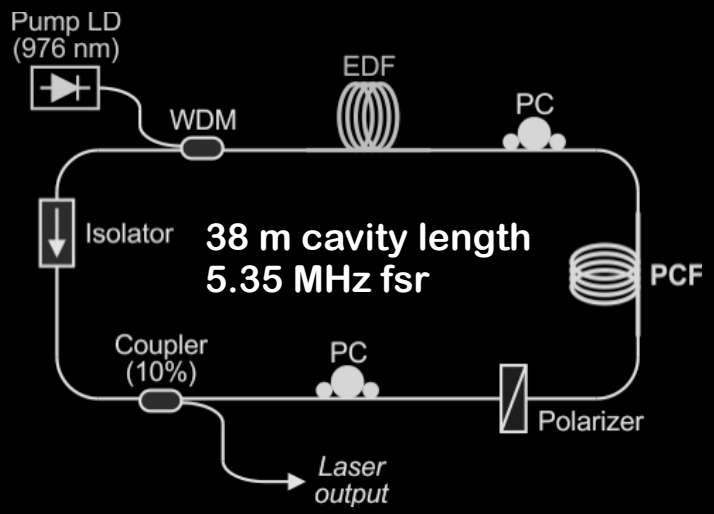
Stimulated Raman-like scattering: SRLS



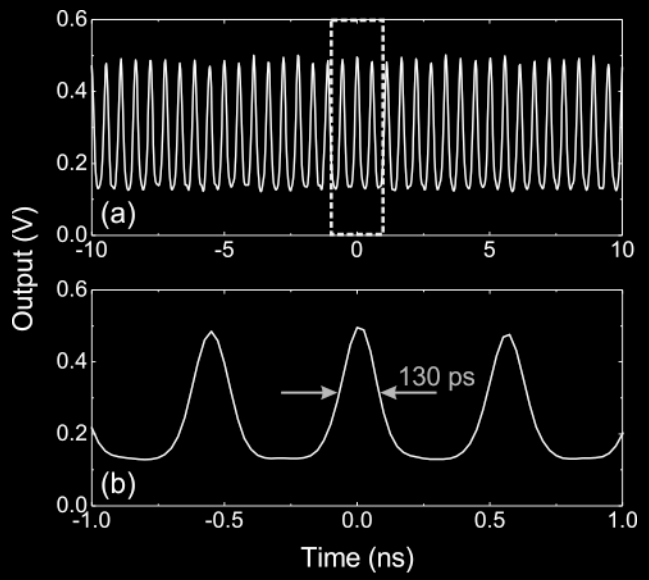
MPL
Max Planck Institute for the science of light

Ring laser passively mode-locked at 337th harmonic

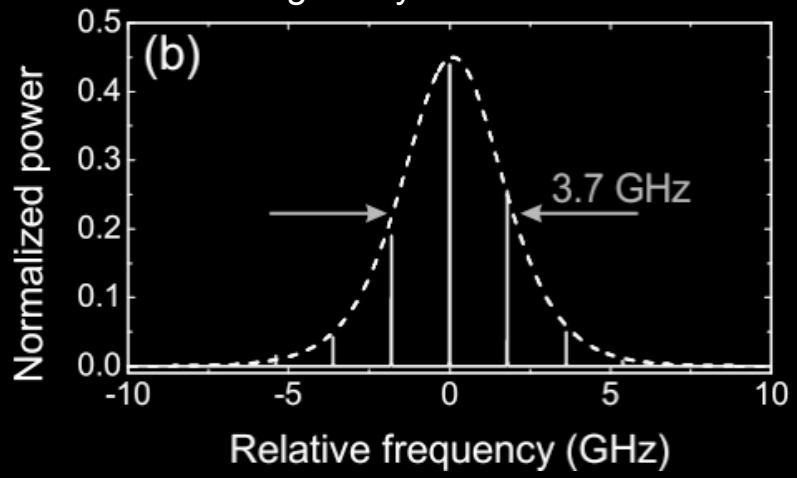
Kang et al: Optics Letters **38**, 561–563 (2013)

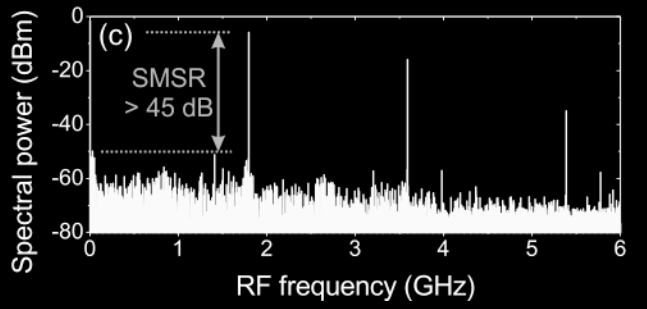


acoustic core resonance at 1.8 GHz



scanning Fabry-Pérot

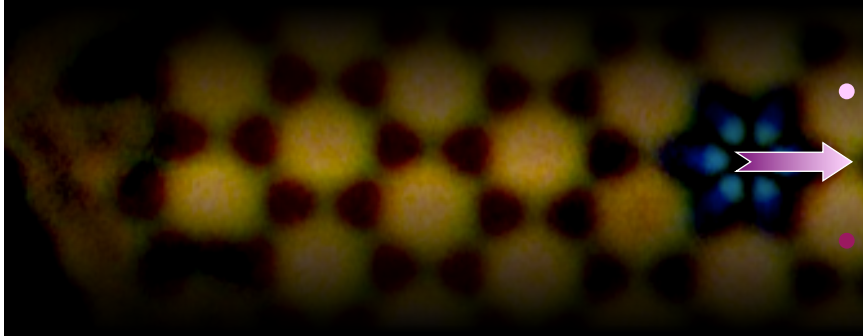




other harmonics suppressed by 45 dB

MPL
Max Planck Institute for the science of light

Topics



- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

MPL
Max Planck Institute
for the science of light

Optomechanics

Anna Butsch

Johannes Kohler

Silke Rammler
(former member)

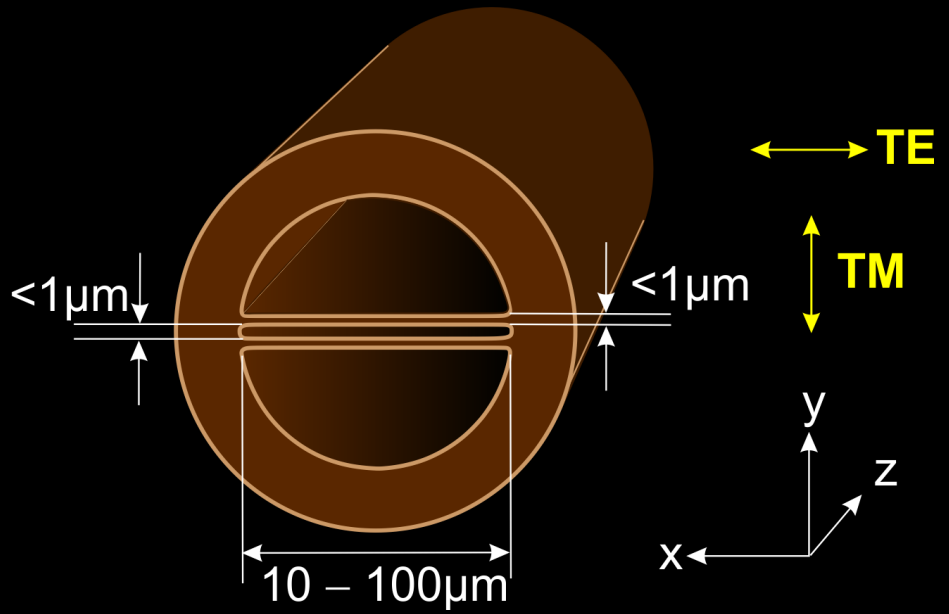
Tijmen Euser

Fabio Biancalana

Myeongsoo Kang
(former member)

Claudio Conti
(Humboldt Fellow)

Butsch et al: Phys. Rev. Lett. **108**, 183904 (2012)
Conti et al., Phys. Rev. A **86**, 013830 (2012)
Butsch et al: Phys. Rev. Lett. **108**, 093903 (2012)

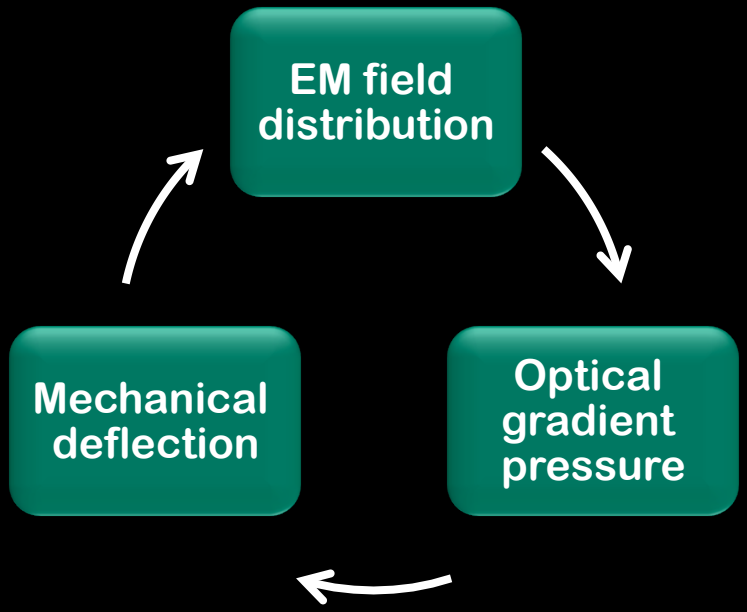


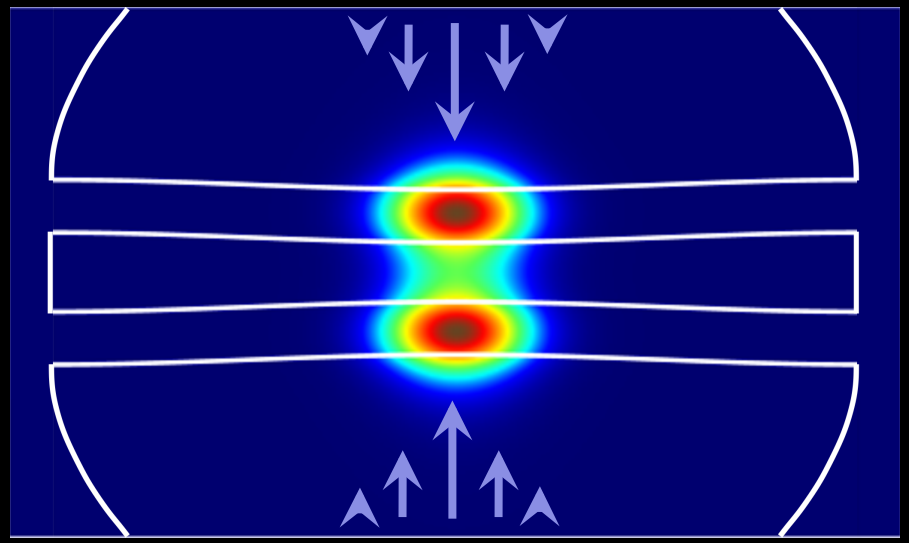
- two suspended air-clad silica nanowebs
- long optomechanical interaction length

MPL
Max Planck Institute
for the science of light

Optomechanical self-channelling

Butsch et al: Phys. Rev. Lett. **108**, 093903 (2012)
Conti et al., Phys. Rev. A **86**, 013830 (2012)



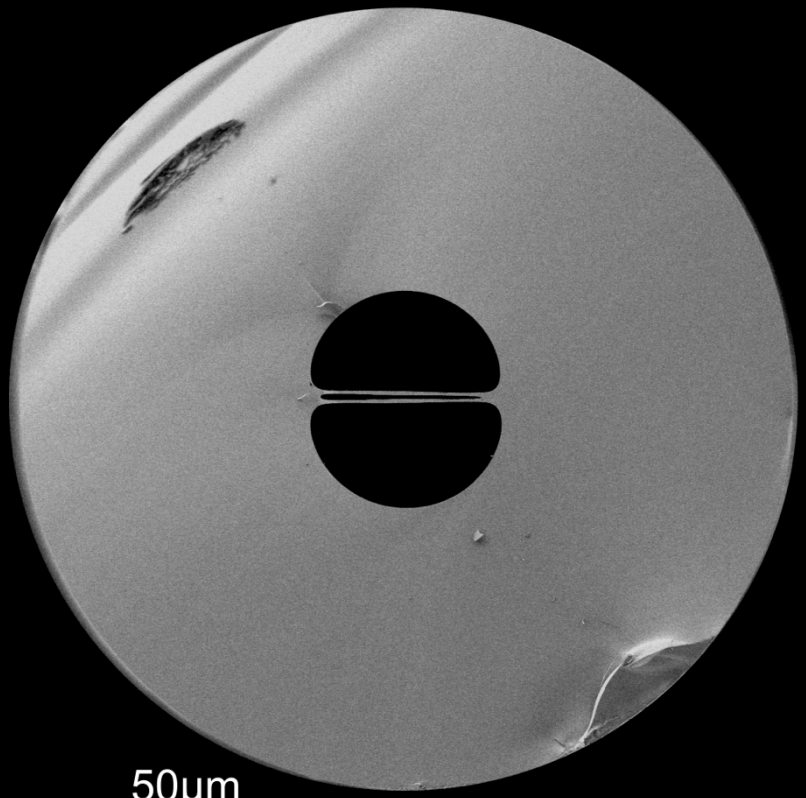


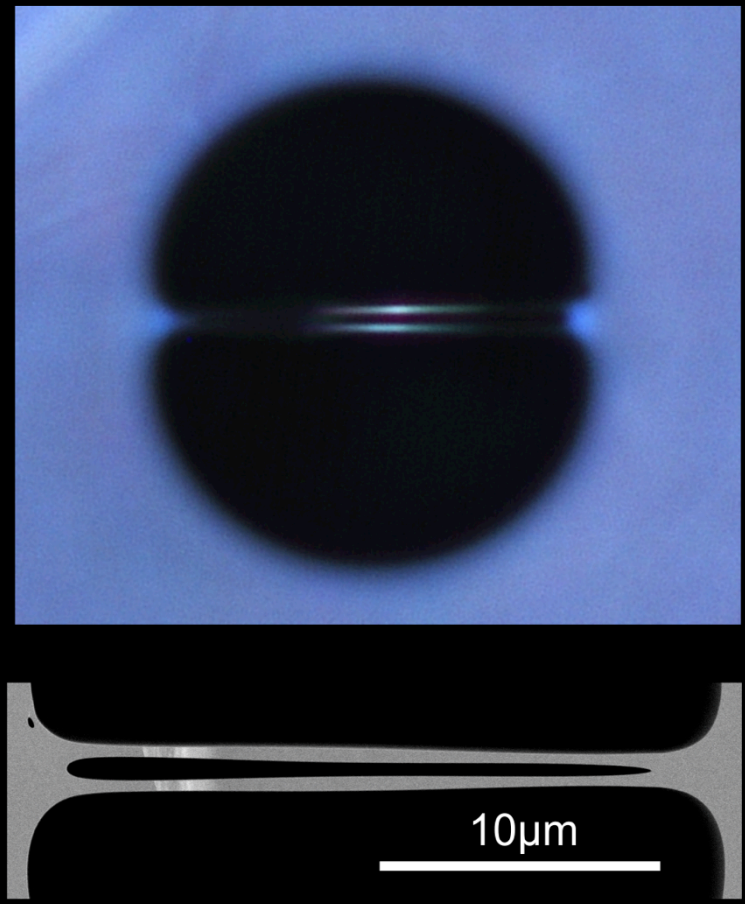
- optomechanical nonlinear refractive index
- formation of self-channeled guided beams
- highly non-local nonlinearity

MPL
Max Planck Institute for the science of light

Guiding dual-nanoweb fiber

- fabricated by stack-and-draw technique
- web thickness 440 nm, spacing 550 nm, width 22 µm
- slightly convex thickness profile

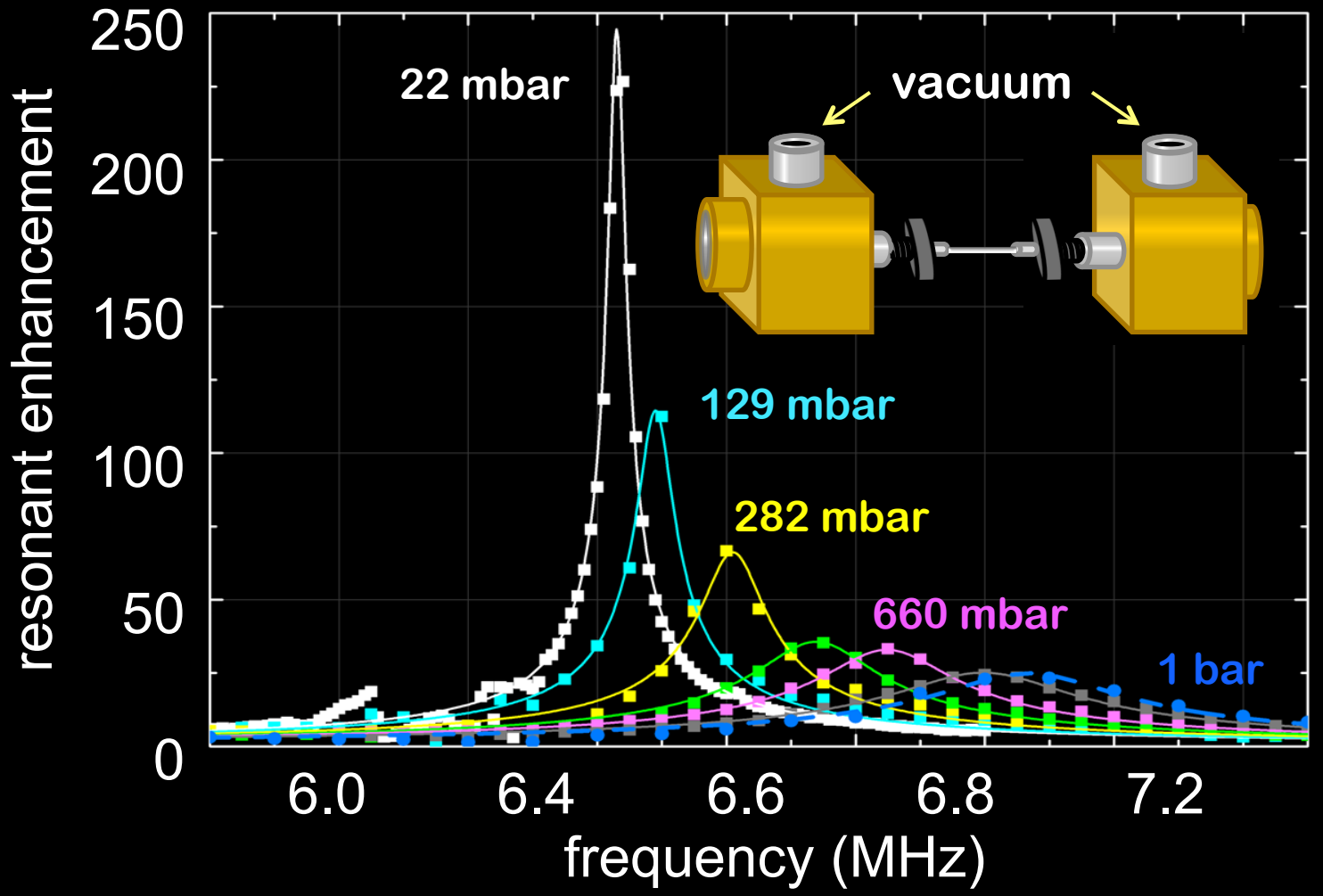




MPL
Max Planck Institute
for the science of light

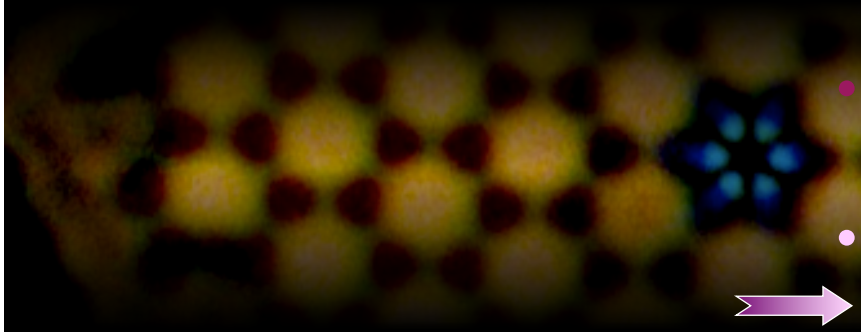
Pressure dependence

Butsch et al: Frontiers in Optics, paper FM3H.2 (2012)



MPL
Max Planck Institute
for the science of light

Topics



- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

MPL
Max Planck Institute
for the science of light

Propelling matter with light

Tijmen Euser

Sarah Unterkofler

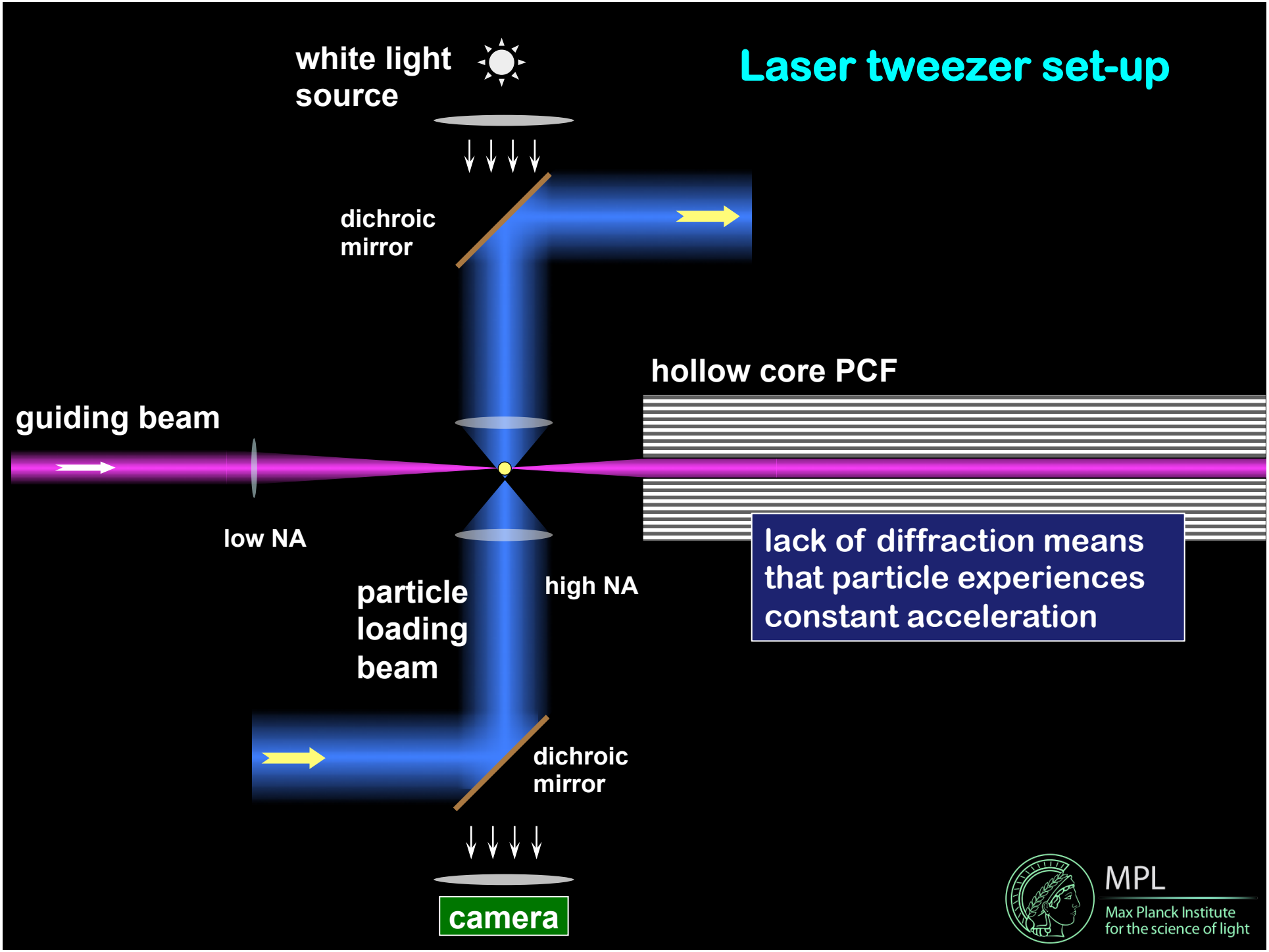
Oliver Schmidt

Graeme Whyte (EAM)

Fatma Tümer

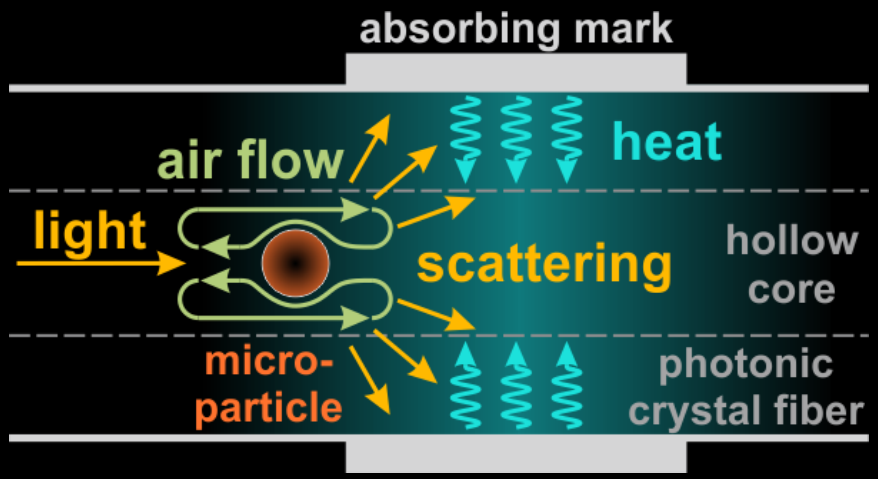
Martin Garbos (former member)

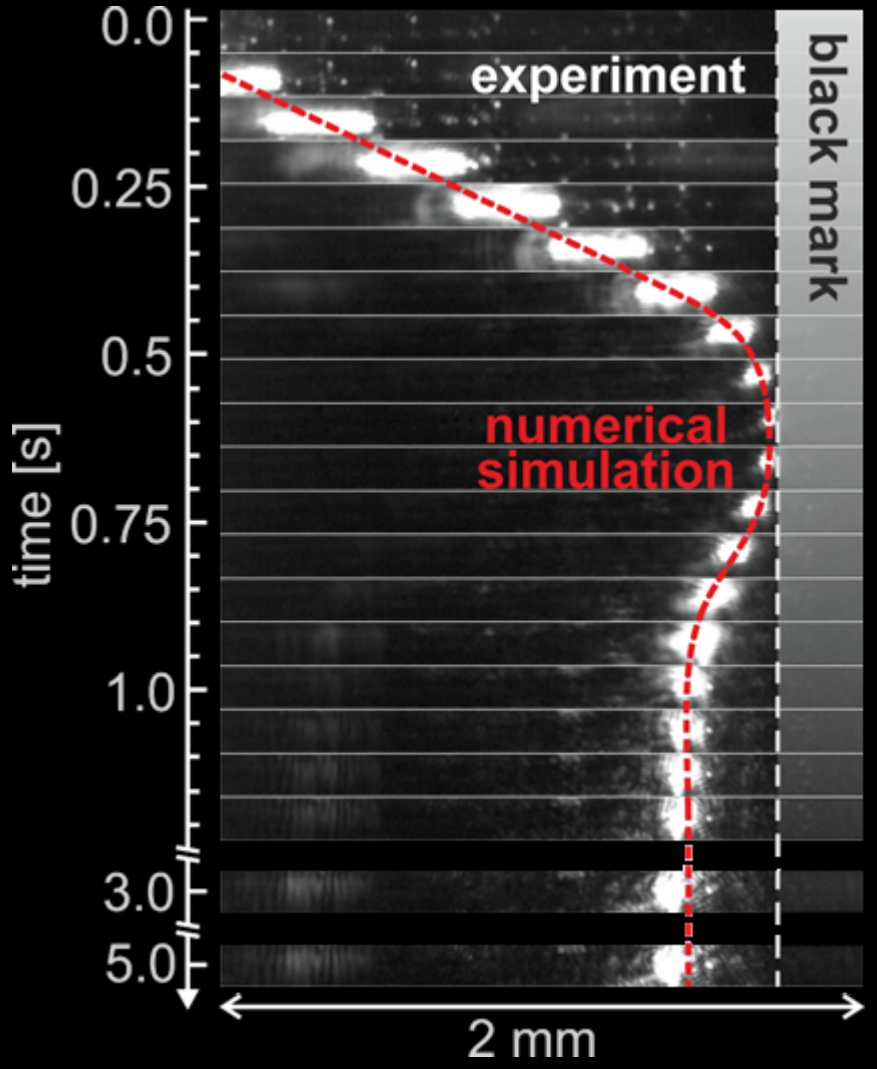
MPL
Max Planck Institute for the science of light


white light source
Laser tweezer set-up
dichroic mirror
hollow core PCF
guiding beam
low NA
high NA
particle loading beam
lack of diffraction means that particle experiences constant acceleration
dichroic mirror
camera
MPL
Max Planck Institute for the science of light

Optothermal trapping

Schmidt et al, PRL **109**, 024502 (2012)

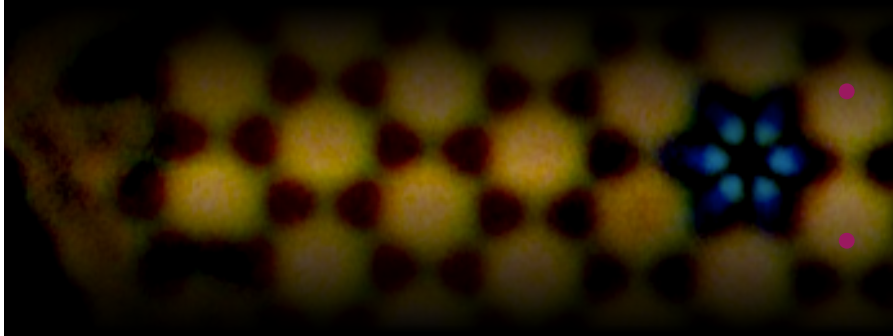




- stable trapping position
- independent of power (30 – 200 mW)
- thermal force ∝ optical power

MPL
Max Planck Institute for the science of light

Topics

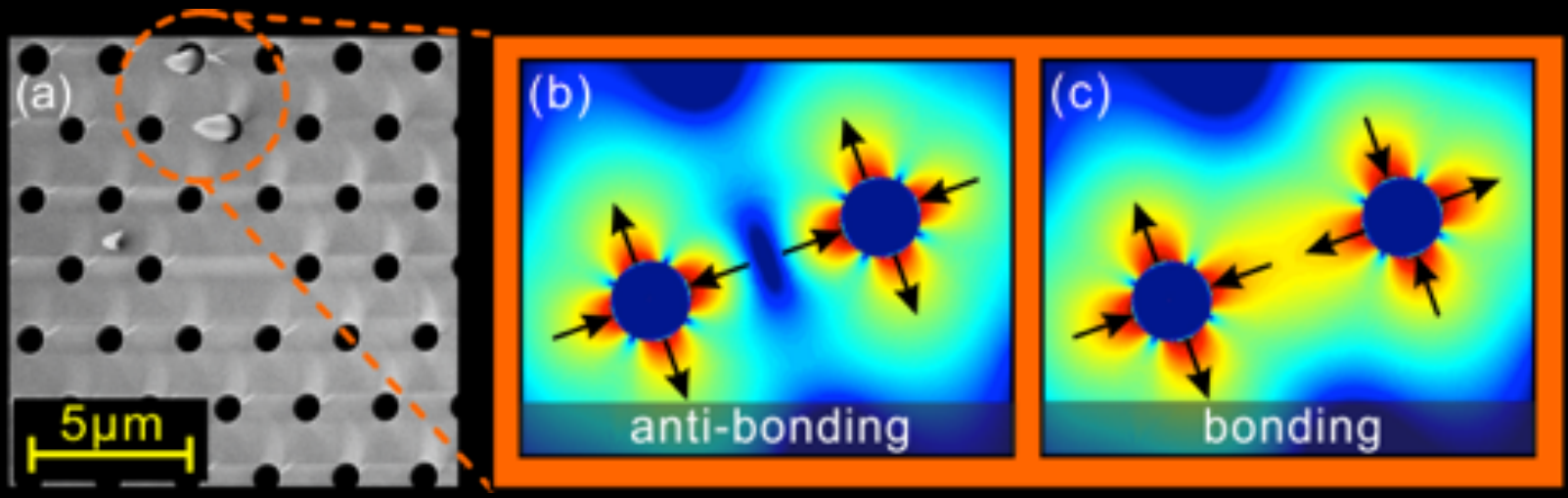


- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

MPL
Max Planck Institute
for the science of light

Nanowires

Gold nanowire "molecule", Lee et al: Opt. Lett. 37, 2946–2948 (2012)



Patrick Uebel

Nicolai Granzow

Sebastian Bauerschmidt

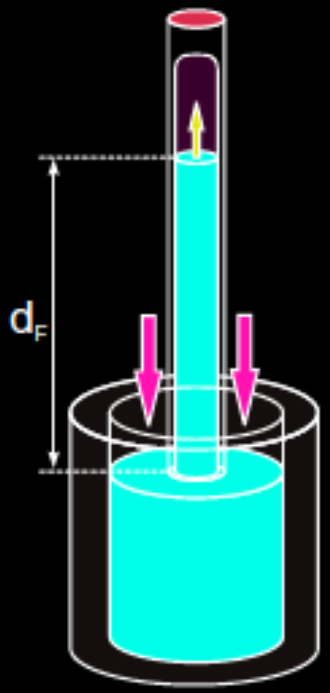
Howard Lee (former member)

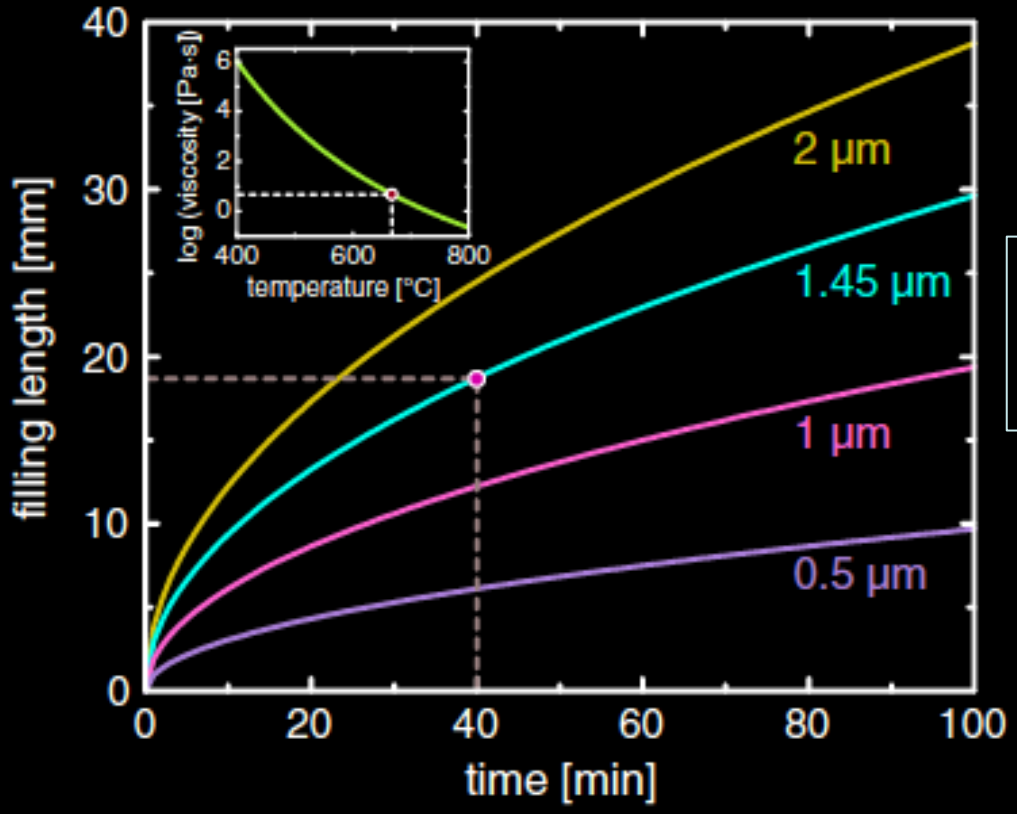
Markus Schmidt (former member)

MPL
Max Planck Institute for the science of light

Pressure-assisted melt-filling technique

- low-melting-point materials in a fused silica host matrix
- strand diameters as narrow as 90 nm





viscosity 5 Pa.s
temperature 665°C
pressure 50 bar

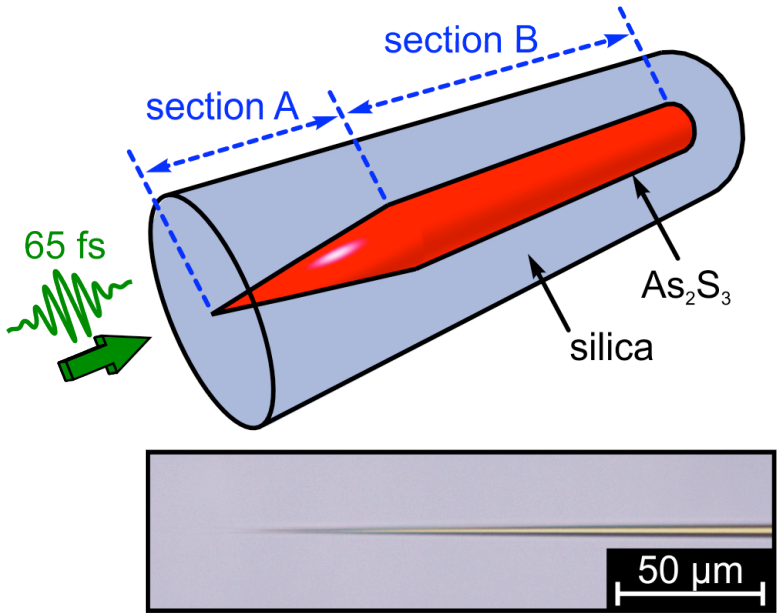
MPL
Max Planck Institute
for the science of light

Infrared supercontinuum

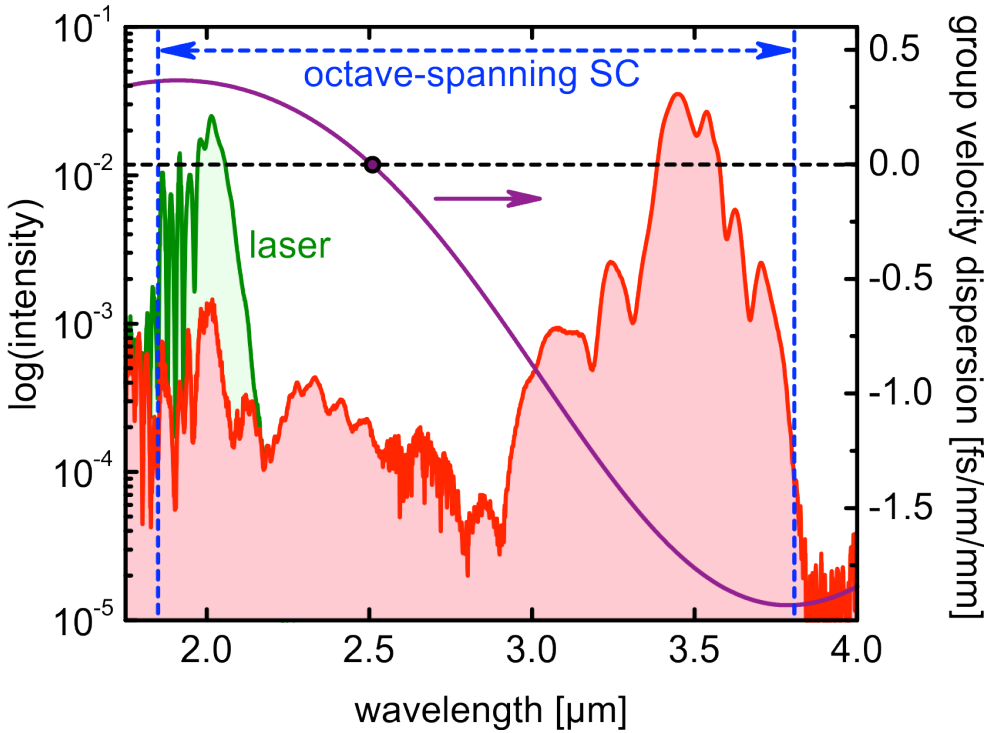
Granzow et al: Optics Express, April 2013

section B: diam. 1 μm, length 1.7 mm

Tm fibre laser: 65 fs, 100 MHz, 1.95 μm



As_2S_3 glass in silica: diameter at tip < 200 nm

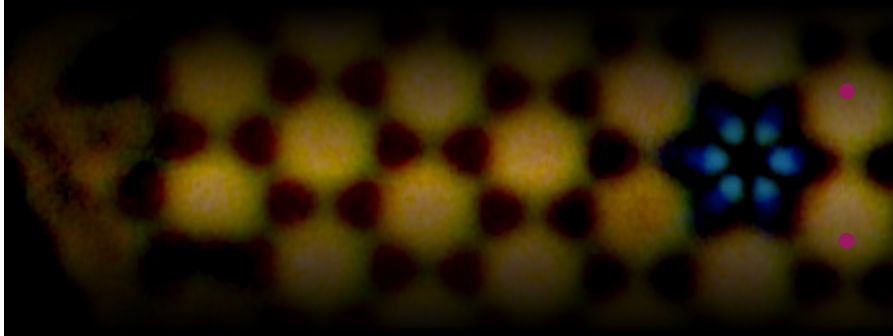


UNIVERSITÉ DE RENNES 1

IMRA
The Femtosecond Fiber Laser Company

MPL
Max Planck Institute for the science of light

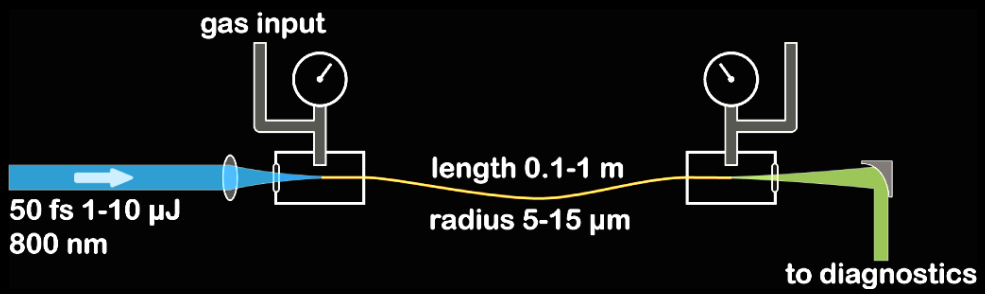
Topics



- Twisted fibres
  - putting light into orbit
- Son et lumière
  - optoacoustic interactions
- Mutual attraction of nanowebs
  - optomechanical nonlinearities
- Fear of the dark
  - propelling matter with light
- Wired light
  - glass and gold nanowires
- Pumping up the pressure
  - ultrafast light-gas interactions

MPL
Max Planck Institute
for the science of light

Ultrafast dynamics in gas-filled hollow core PCF

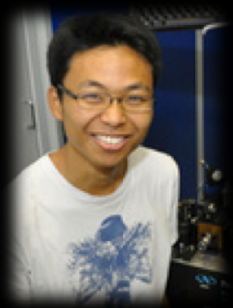



John Travers


Nicolas Joly

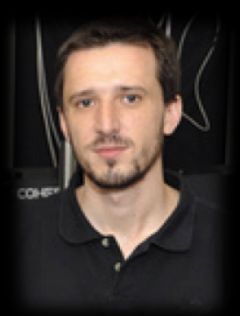

Philipp Hoelzer


Francesco Tani


KaFai Mak


Mohuideen Azhar


Amir Abdolvand


Federico Belli


David Novoa


Wonkeun Chang


Gordon Wong

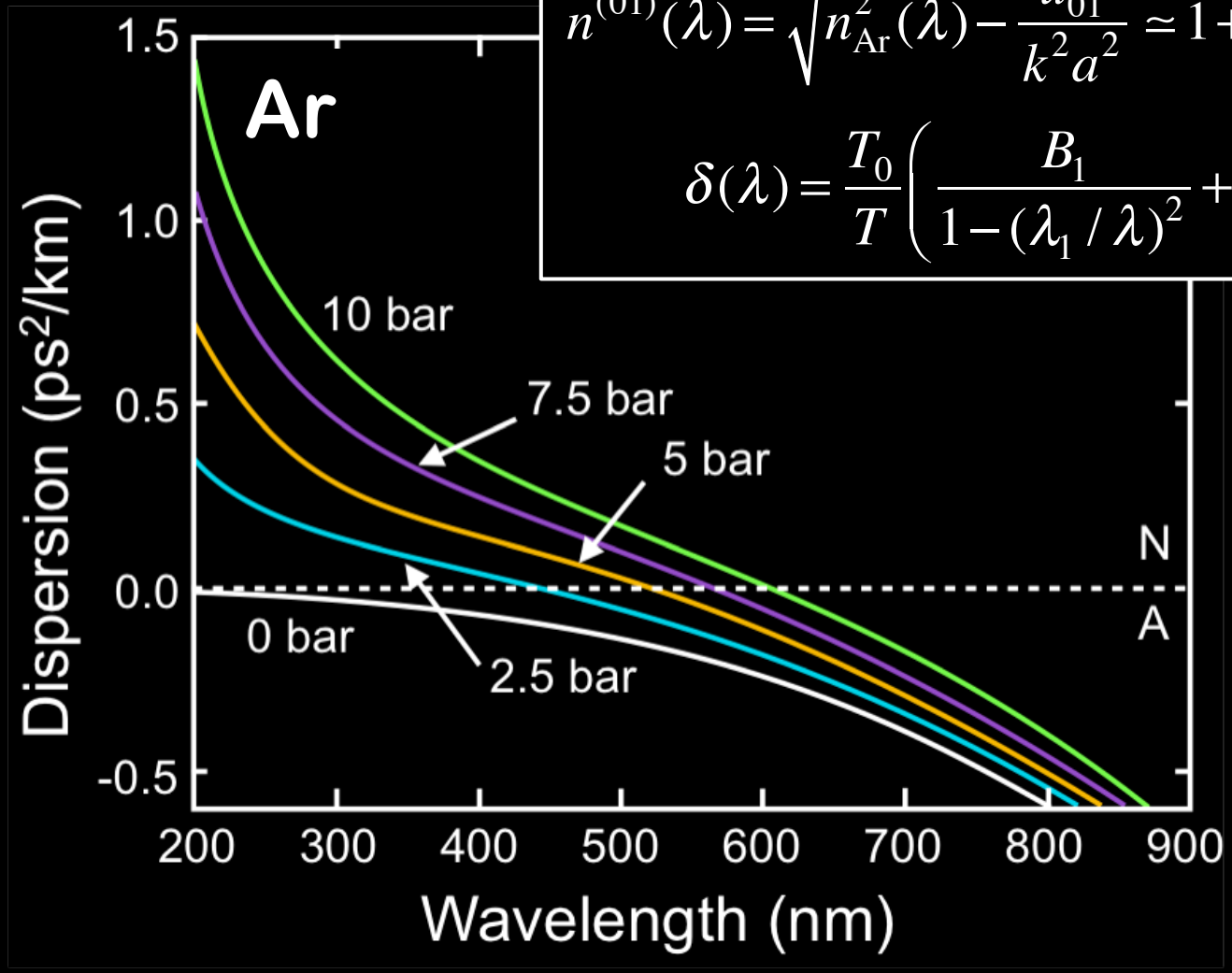
MPL
Max Planck Institute
for the science of light

Pressure-dependent dispersion: kagome PCF

Joly et al, PRL 106, 203901 (2011)

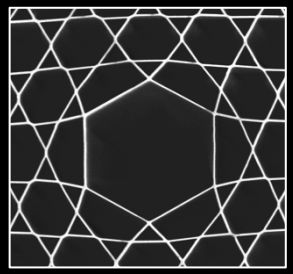
$$n^{(01)}(\lambda) = \sqrt{n_{\mathrm{Ar}}^2(\lambda) - \frac{u_{01}^2}{k^2 a^2}} \simeq 1 + \delta(\lambda)\frac{p}{2p_0} - \frac{u_{01}^2}{2k^2 a^2}$$

$$\delta(\lambda) = \frac{T_0}{T}\left(\frac{B_1}{1-(\lambda_1/\lambda)^2} + \frac{B_2}{1-(\lambda_2/\lambda)^2}\right)$$



kagome PCF

29.6 µm

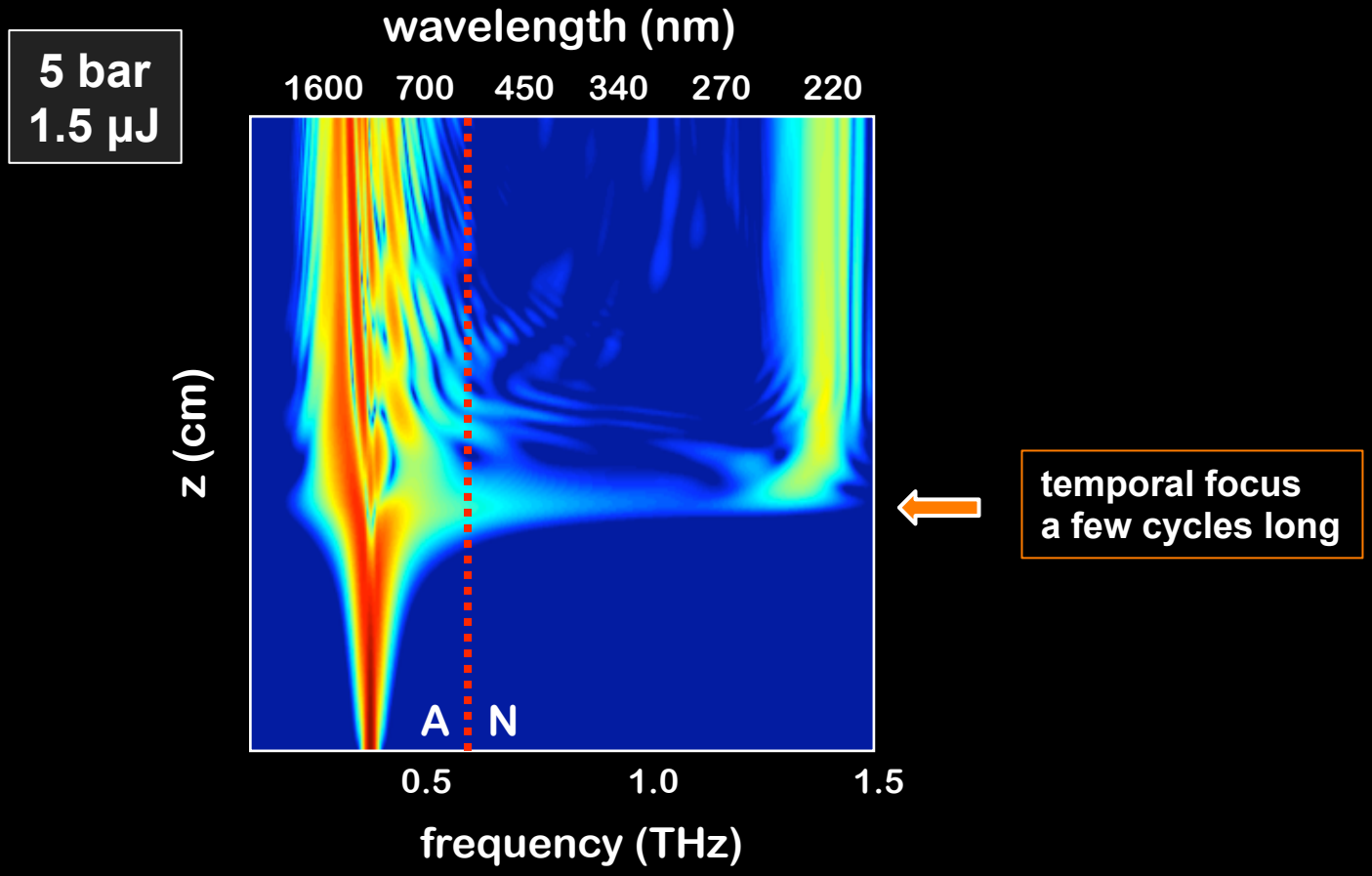


MPL

Max Planck Institute for the science of light

Numerical modelling (GNLSE)

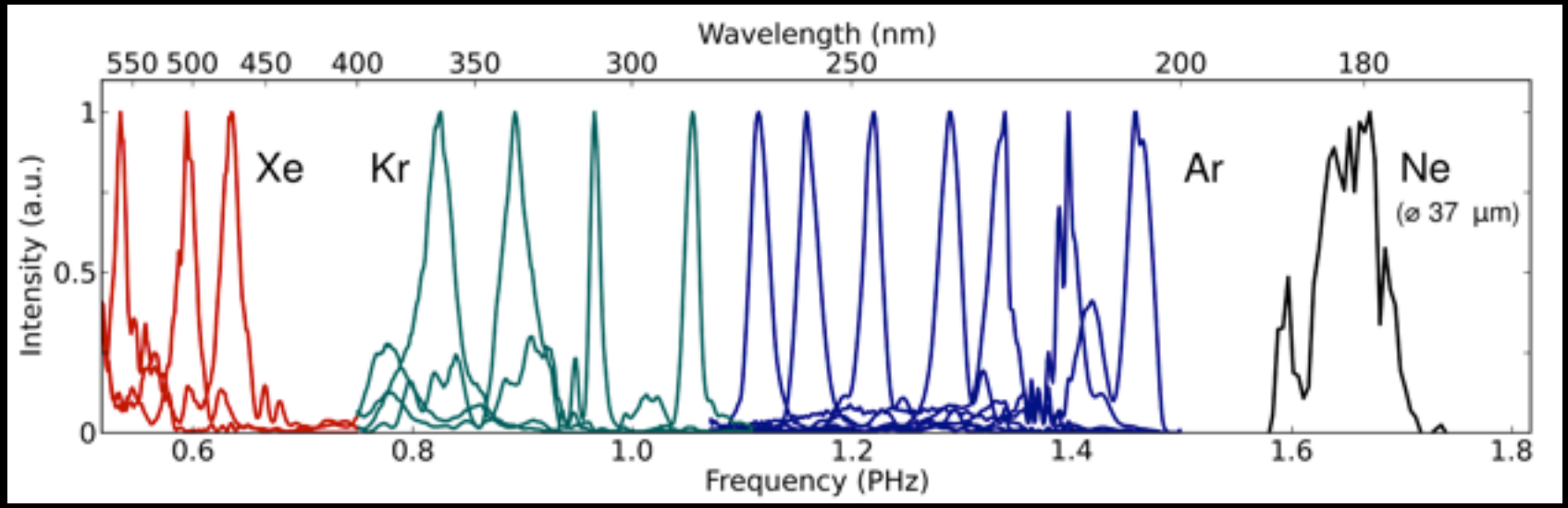
Joly et al, PRL 106, 203901 (2011)



MPL
Max Planck Institute
for the science of light

Widely tunable UV

Mak et al: Optics Express, to appear (2013)



MPL
Max Planck Institute
for the science of light

Scottish collaborations

- **Miles Padgett (Glasgow) & Steve Barnett (Strathclyde)**
  - Orbital angular momentum in fibres
- **Fabio Biancalana (Heriot Watt & MPL)**
  - Many topics, linear and nonlinear

- **Anita Jones (Edinburgh, Chemistry)**
  - Hollow core fibre as a photochemical microreactor

- **Kishan Dholakia (St. Andrews)**
  - Potential: biophotonics

MPL
Max Planck Institute
for the science of light