Group of Levitational Photonics

Department of Microphotonics

ISI CAS Institute of Scientific Instruments The Czech Academy of Sciences

THEMATIC RESEARCH FOCUS

Research area

- Optics
- Photonics
- Light-matter interaction
- Stochastics in optical landscape
- Micro(nano) technologies

Excellence

- Force interaction between light and objects (theoretical and experimental aspects)
- Applications of focused laser beams (laser microdissection, optical tweezers, optical cell sorters, long-range optical delivery of micro(nano)objects, polymerization of micro-structures)
- Laser beam shaping by spatial light modulators
- Design and manufacturing of on demand systems using laser beams

Mission

To be at the forefront in developing new optical methods appropriate for contactless, nondestructive investigation of living or inanimate parts of the micro, nano and quantum worlds.

UP-TO-DATE ACTIVITIES

Research orientation

- Investigation of underdamped and overdamped stochastic object motion in nonlinear optical potentials
- Investigation of colloidal photonic crystals assembled by light.
- Laser cooling of nanoparticles at low pressures
- Optically-induced rotation and self-arrangement of several objects
- Optical trapping and characterization of plasmonic nanoparticles
- Mastered technology of photopolymerization, soft-lithography, reactive ion etching, micro-optics-electro-mechanical systems

Main capabilities

Basic research

- Theoretical and experimental activities related to optical micromanipulations with microobjects and nanoobjects

Applied research

- Manufacturing of on-demand opto-mechanical systems using laser beams
- Photopolymerization of microstructures
- Employment of reactive ion etching for surface modifications

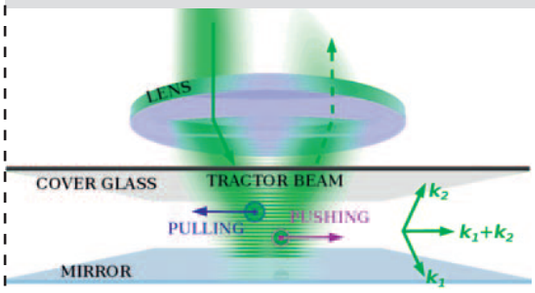
Innovations

- Licence agreement on compact optical tweezers and sorters

Institute of Scientific Instruments
of the CAS, v.v.i.
The Czech Academy of Sciences
Královopolská 147, 612 64 Brno,
The Czech Republic
https://www.isibrno.cz/
en/levitational-photonics

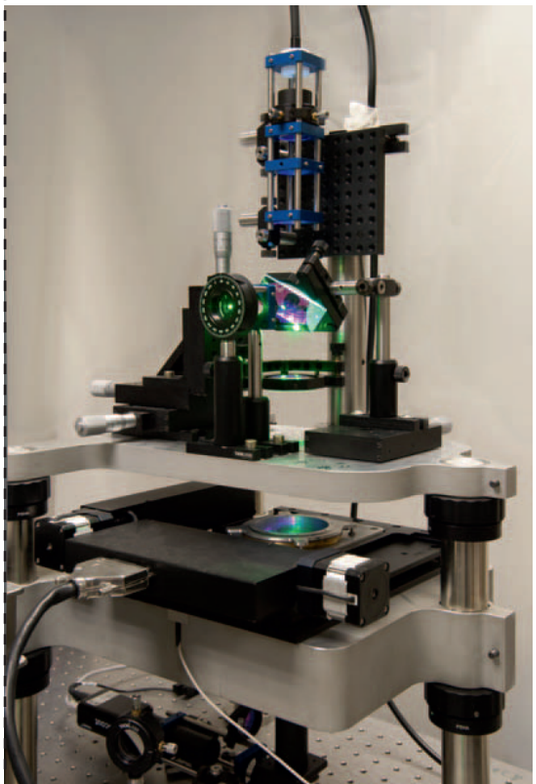
Head of the group: Dr. Oto Brzobohatý
Phone: +420 541 514 283
E-mail: otobrzo@isibrno.cz

Head of the Department:
Prof. Pavel Zemánek
Phone: +420 541 514 202
E-mail: zemanek@isibrno.cz



Geometrical configuration of the tractor beam setup and visualization of the pulling and pushing optical force acting upon particles of different sizes

Experimental setup of the tractor beam



Sub-fields of group activities

- Optical microscopy
- Microtechnology, nanotechnology
- Colloidal chemistry
- Laser spectroscopy

KEY RESEARCH EQUIPMENT

List of devices

- Various CW high power lasers working at 1550 nm, 980 nm, 785 nm, 532nm, 680-1000 nm (Coherent, Spectra Physics, IPG, Sacher).
- Femtosecond laser systems Mira 800 HP, Mai Tai HP Deep See (NKT, Coherent, ...)
- Several different flexible systems for advanced optical micromanipulation experiments (holographic tweezers, dual-beam holographic traps)
- Fast CCD cameras (thousands fps)
- Reactive ion etching system (Plasmalab System 100)

ACHIEVEMENTS

Awards

- Werner von Siemens Excellence Award for the best result of the basic research in 2013
- Oto Brzobohatý was awarded the Otto Wichterle Award for talented young scientists by the Czech Academy of Sciences in 2014
- Zdeněk Pilát was awarded the best Ph.D. Thesis in 2015 by the Czechoslovak Microscopy Society
- Jana Damková was awarded Young Scientist Award 2016 by the Czech and Slovak Society for Photonics

Publications

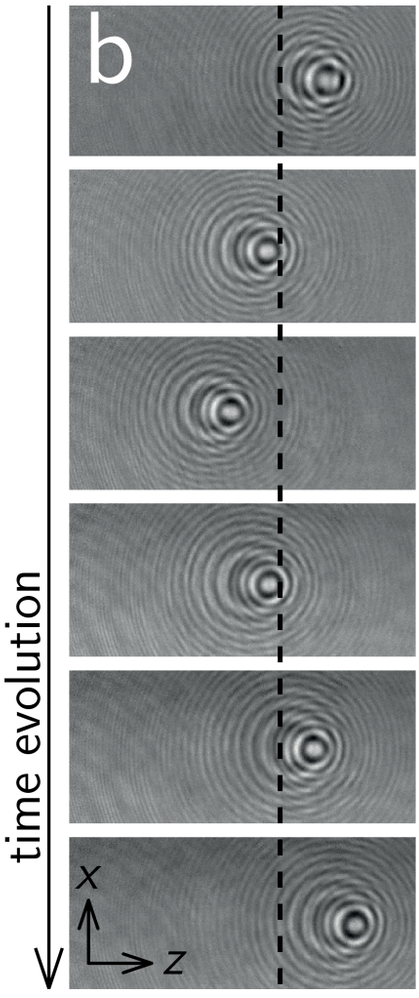
We deepened the understanding of the force interaction between light and micro/nanoobjects and developed original methods how to manipulate with individual particles or even thousands of particles, how to sort and self-arrange them. We published more than 40 papers in impacted journals with very good citation response in the period 2012–2017.

Experimental demonstration of optical "tractor" beam and its utilization in optical sorting and self-arrangement of microobjects.

- O. Brzobohatý, V. Karásek, M. Šiler, L. Chvátal, T. Čižmár & P. Zemánek: **"Experimental demonstration of optical transport, sorting and self-arrangement using a 'tractor beam"**, Nature Photonics **7**, 123–127, 2013
  This result attracted strong interest of media all over the world: http://www.isibrno.cz/index.php?lang=_an&co=/intranet/novinky.php&nalogovan=&id_druh_menu=3&Nerolovat=1

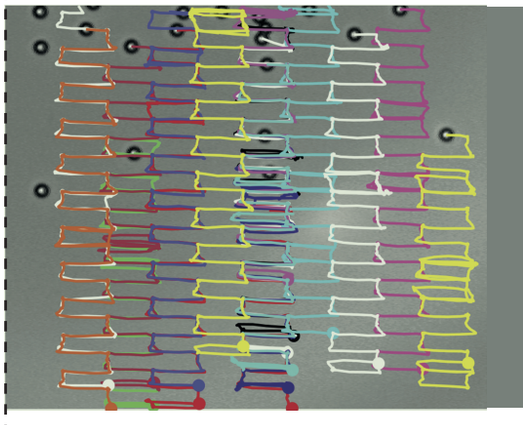
Enhancement of the 'tractor-beam' pulling force on an optically bound structure.

- Jana Damková, Lukáš Chvátal, Jan Ježek, Jindřich Oulehla, Oto Brzobohatý and Pavel Zemánek: **"Enhancement of the 'tractor-beam' pulling force on an optically bound structure"**, Light: Science & Applications **7**, 17135, 2018



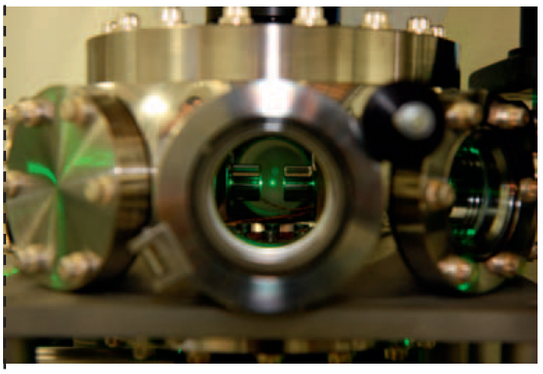
Enhancement of the 'tractor-beam' pulling force on an optically bound structure

Transport of multiple microobejcts using the optical ratchet



Confirmation of an extraordinary optical momentum and force directed perpendicular to the wavevector, and proportional to the optical spin (degree of circular polarization), introduced by Belinfante in field theory 75, and revealing a new type of transverse force, exhibiting polarization-dependent contribution, determined by the imaginary part of the complex Poynting vector.

- M. Antognozzi, C. R. Bermingham, R. L. Harniman, S. Simpson, J. Senior, R. Hayward, H. Hoerber, M. R. Dennis, A. Y. Bekshaev, K. Y. Bliokh, F. Nori: **"Direct measurements of the extraordinary optical momentum and transverse spin-dependent force using a nano-cantilever"**, Nature Physics, **12**, 731-735, 2016



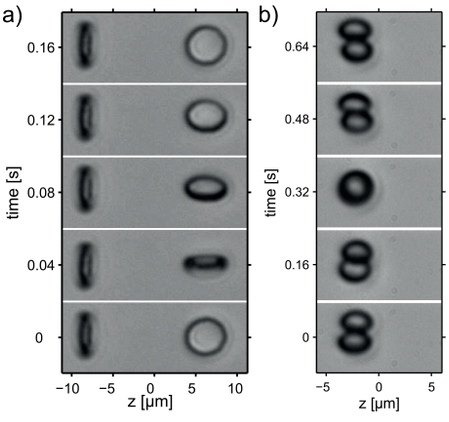
An optically trapped nanoparticle inside the vacuum chamber.

Omnidirectional transport in fully reconfigurable 2D optical ratchets

- Alejandro V. Arzola, Mario Villasante-Barahona, and Karen Volke-Sepúlveda, Petr Jákl and Pavel Zemánek **"Omnidirectional Transport in Fully Reconfigurable Two Dimensional Optical Ratchets"**, Phys. Rev. Lett. **118**, 138002

Description of stochastic behaviour of a Brownian particle in nonlinear potential

- R. Filip, P. Zemánek: **"Noise-to-signal transition of a Brownian particle in the cubic potential: I. general theory"**, Journal of Optics **18**, 065401, 2016
- P. Zemánek, M. Šiler, O. Brzobohatý, P. Jákl, R. Filip: **"Noise-to-signal transition of a Brownian particle in the cubic potential: II. optical trapping geometry"**, Journal of Optics **18**, 065402, 2016
- A. Ryabov, P. Zemánek, R. Filip: **"Thermally induced passage and current of particles in a highly unstable optical potential"**. Phys. Rev. **E 94**, 042108, 2016
- M. Šiler, P. Jákl, O. Brzobohatý, A. Ryabov, R. Filip, P. Zemánek. **"Thermally induced micro-motion by inflection in optical potential"**, Scientific Reports, **7**, 1697, 2017

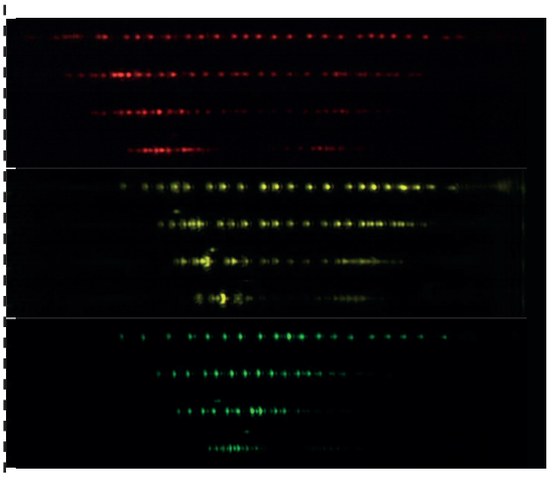


An example of simultaneous trapping and rotation of disc-like objects in counter-propagating laser beams with circular polarizations.

Pioneering results related to optically induced alignment or rotation of microobjects and nanoobjects

- Stephen H. Simpson, Pavel Zemánek, Onofrio M. Maragò, Philip H. Jones, and Simon Hanna: **"Optical Binding of Nanowires"**, Nano Lett., **17 (6)**, 3485–3492, 2017
- A. V. Arzola, P. Jákl, L. Chvátal, P.Zemánek: **"Rotation, oscillation and hydrodynamic synchronization of optically trapped oblate spheroidal microparticles"**, Optics Express **22**, 16207-1622, 2014
- O. Brzobohatý, A. V. Arzola, M. Šiler, L. Chvátal, P. Jákl, S. Simpson, P. Zemánek **"Complex rotational dynamics of multiple spheroidal particles in a circularly polarized, dual beam trap"**, Optics Express **22**, 7273-7287, 2015
- S. H. Simpson, L. Chvátal, P. Zemánek: **"Synchronization of colloidal rotors through angular optical binding"**, Physical Review A **93**, 023842, 2016
- O. Brzobohatý, M. Šiler, J. Trojek, L. Chvátal, V. Karásek, A. Paták, Z. Pokorná, F. Mika, P. Zemánek: **"Three-Dimensional Optical Trapping of a Plasmonic Nanoparticle using Low Numerical Aperture Optical Tweezers"**, Scientific Reports **5**, 8106, 2015
- A. Irrera, A. Magazzu, P. Artoni, S. H. Simpson, S. Hanna, P. H. Jones, F. Priolo, P. G. Gucciardi, and O. M. Marago: **"Photonic Torque Microscopy of the Nonconservative Force Field for Optically Trapped Silicon Nanowires"**, Nano Lett.**16** 4181-4188, 2016
- J. Trojek, L. Chvatal and P. Zemanek: **"Optical alignment and confinement of an ellipsoidal nanorod in optical tweezers: a theoretical study"** J. Opt. Soc. Am. A **29**, 1224-1236, 2012

An example of optically self-arranged colloidal waveguide. The distance between the particles is tuneable by the width of two counter-propagating beams which is followed with different spectral properties of the whole structure shown at red, yellow and green wavelengths.



Optical sorting of microobjects

- P. Jákl, A. V. Arzola, M. Šiler, L. Chvátal, K. Volke-Sepúlveda, P. Zemánek: **"Optical sorting of nonspherical and living microobjects in moving interference structures"**, Optics Express **22**, 29746-29760, 2014
- Optical cell-sorter based on fluorescences or Raman spectra of microorganisms (utility model in cooperation with Photon Systems Instruments)

Compact optical tweezers modules compatible with majority of optical microscopes (utility model awarded, in cooperation with Meopta-Optika)

MAIN COLLABORATING PARTNERS

Collaboration with academic partners

- Brno University of Technology (Brno, CZ)
- Consiglio Nazionale delle Ricerche (Messina, IT)
- Institute of Experimental Physics, Slovak Academy of Sciences (Košice, SK)
- Istanbul Technical University (Istanbul, TR)
- Koc University (Istanbul, TR)
- Lehigh University (Bethlehem, USA)
- Masaryk University (Brno, CZ)
- Palacky University (Olomouc, CZ)
- Universidad Nacional Autonoma de Mexico (Mexico City, MX)
- University of Bristol (Bristol, UK)
- University of Dundee (Dundee, GB)
- University of Naples Frederico II (Naple, IT)
- University of St. Andrews (St. Andrews, GB)

Collaboration with companies

- IQ Structures (Praha, CZ)
- Measurement Technic Moravia Ltd. (Zastávka u Brna, CZ)
- Meopta (Přerov, CZ)
- Photon Systems Instruments (Drásov, CZ)
- Tescan Orsay Holding (Brno, CZ)

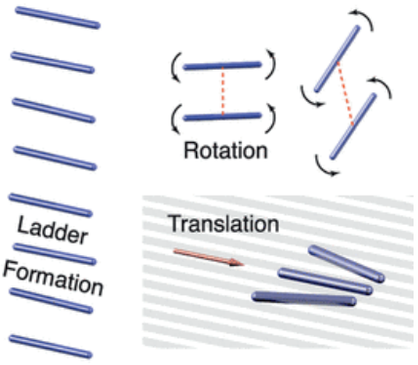
EXPECTATIONS

Offers

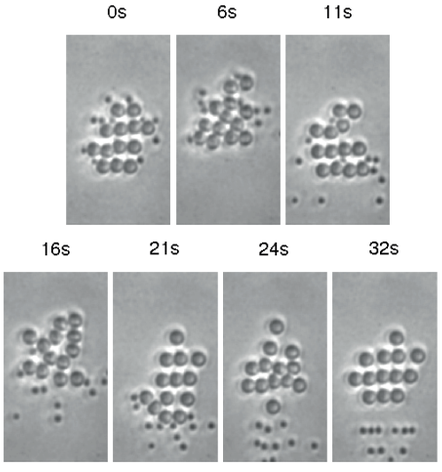
- We offer collaboration in the areas of our expertise.
- Partnership in international projects.
- Custom manufacturing of opto-memechanical systems using laser beams.

Requirements

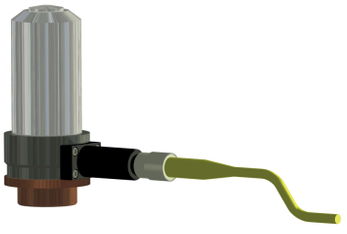
We look for cooperation with academic partners as well as companies in the fields of optics, biophotonics, microtechnologies, nanotechnologies, applications of optical methods.



Optical Binding of Nanowires



Example of optical sorting of suspension of polystyrene particles of sizes 800 nm and 1600 nm in travelling interference fringes.



A visualization of compact optical tweezers

Custom-made selective plane illumination microscope (OpenSPIM)