Group of Levitational Photonics

Department of Microphotonics

ISI CAS Institute of Scientific Instruments The Czech Academy of Sciences

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: 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

THEMATIC RESEARCH FOCUS

Research area
- Light-matter interaction
- Nonlinear stochastic processes with optically trapped objects
- Laser cooling of optically levitated nanoobjects
- Quantum optomechanics

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

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

UP-TO-DATE ACTIVITIES

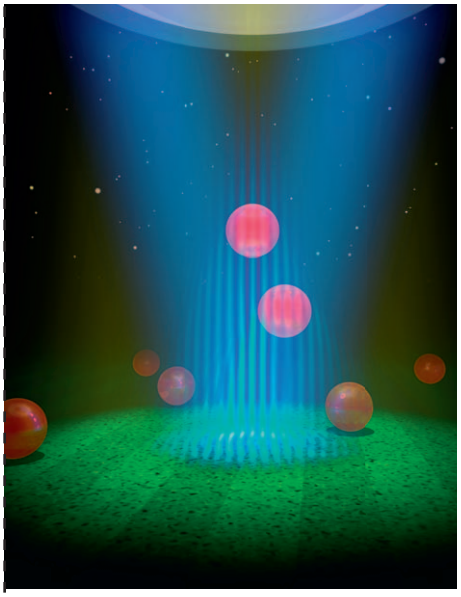
Research orientation
- Investigation of underdamped and overdamped stochastic object motion in nonlinear optical potentials
- Investigation of colloidal photonic crystals assembled by light
- Laser cooling of nanoparticles at low pressures
- Optically-induced rotation and self-arrangement of several objects
- Optical trapping and characterization of plasmonic nanoparticles

Main capabilities
Basic research
- Theoretical and experimental activities related to optical manipulations with micro and nanoobjects

Sub-fields of group activities
- Optical microscopy
- Colloidal chemistry
- Laser spectroscopy
- Optical levitation of nanoobjects in vacuum

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)



Visualization of the optical tractor beam pulling objects against the photon flow.

- 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)

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
- Pavel Zemánek was awarded Praemium Academiae in 2020
- Vojtěch Svak received The "Josef, Marie and Zdeňka Hlávkas Talent Award" in 2021

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 50 papers in impacted journals with very good citation response in the period 2012–2022.

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

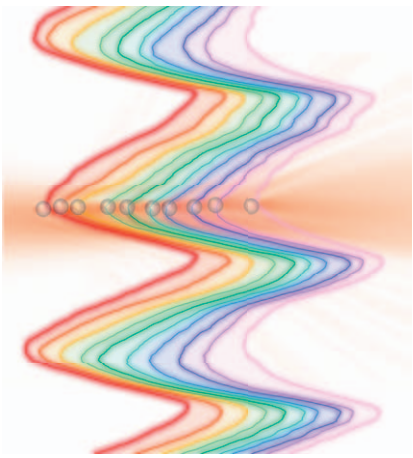
- O. Brzobohatý, V. Karásek, M. Šiler, L. Chvátal, T. Čižmár, P. Zemánek: *"Experimental demonstration of optical transport, sorting and self-arrangement using a 'tractor beam",* Nature Photon. **7**, 123–127, 2013
  This result attracted strong interest of media all over the world: http://www.isibrno.cz/index.php?lang=_an&co=/intranet/novinky.php&nalogovan=&id_druh_menu=3&Nerolovat=1
- J. Damkova, L. Chvatal, J. Ježek, J. Oulehla, O. Brzobohaty and P. Zemanek: *"Enhancement of the 'tractor-beam' pulling force on an optically bound structure"*, Light: Science & Applications **7**, 17135, 2018

Optical sorting of microobjects

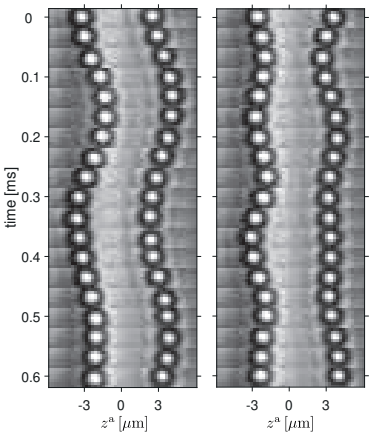
- P. Jákl, A. V. Arzola, M. Šiler, L. Chvátal, K. Volke-Sepúlveda, P. Zemánek: "Optical sorting of nonspherical and living microobjects in moving interference structures", Optics Express **22**, 29746–29760, 2014
- Optical cell-sorter based on fluorescences or Raman spectra of microorganisms (utility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

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 in 1975, 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. H. 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

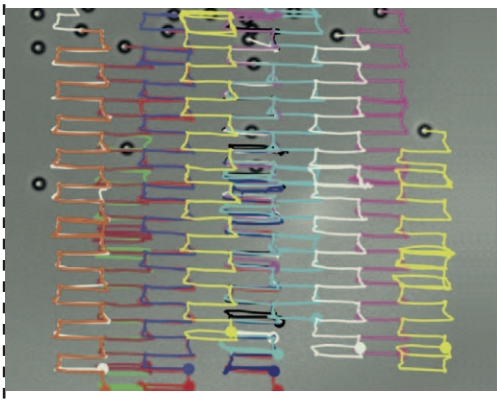


An example of a system of self-arranging optically bound particles in water existing far from the thermodynamic equilibrium in the form of self-sustained oscillations.



Examples of center of mass motion mode and breathing mode of two optically bound particles levitating in vacuum.

Transport of multiple microobjects using the optical ratchet



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
- M. Šiler, L. Ornigotti, O. Brzobohatý, P. Jákl, A. Ryabov, V. Holubec, P. Zemánek, R. Filip: *"Diffusing up the Hill: Dynamics and Equipartition in Highly Unstable Systems"*. Phys. Rev. Lett. **121**, 23601, 2018

Omnidirectional transport in fully reconfigurable 2D optical ratchets

- A. V. Arzola, M. Villasante-Barahona, and K. Volke-Sepúlveda, P. Jákl and P. Zemánek : *"Omnidirectional Transport in Fully Reconfigurable Two Dimensional Optical Ratchets"*, Phys. Rev. Lett. **118**, 138002, 2017

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

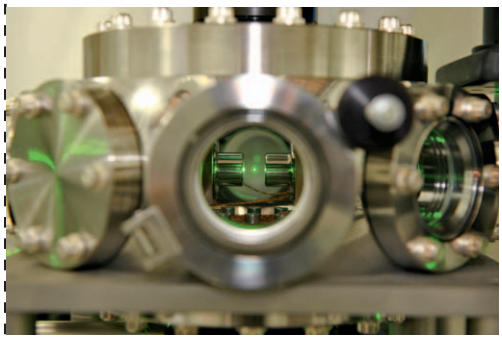
- M. G. Donato, O. Brzobohatý, S. H. Simpson, A. Irrera, A. A. Leonardi, M. J. L. Faro, V. Svak, O. M. Maragò, P. Zemánek: *"Optical trapping, optical binding, and rotational dynamics of silicon nanowires in counter-propagating beams"*, Nano Lett. **19**, 342–352, 2019
- S. H. Simpson, P. Zemánek, O. M. Maragò, P. H. Jones, and S. Hanna: *"Optical Binding of Nanowires"*, Nano Lett., **17 (6)**, 3485–3492, 2017
- 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
- S. H. Simpson, L. Chvátal, P. Zemánek: *"Synchronization of colloidal rotors through angular optical binding"*, Physical Review A **93**, 023842, 2016
- 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
- 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. 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

Experimental demonstration of non-equilibrium particle dynamics caused by optical spin force and showing a transition between stochastic Brownian motion and deterministic orbital motion

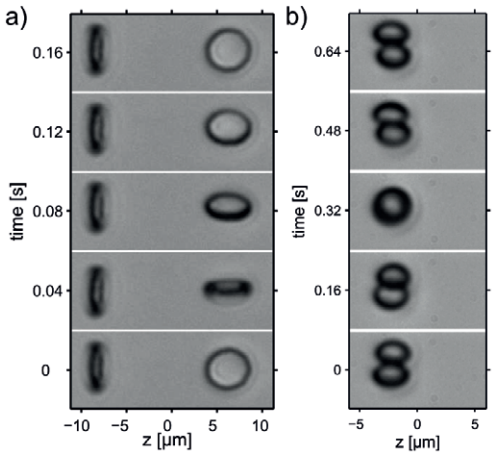
- V. Svak, O. Brzobohatý, M. Šiler, P. Jákl, J. Kaňka, P. Zemánek, S. H. Simpson: *"Transverse spin forces and non-equilibrium particle dynamics in a circularly polarized vacuum optical trap."* Nature Commun., **9**, 5453, 2018

Optical manipulation and electrical tuning of microlasers formed from liquid crystal droplets

- A. Jonáš, Y. Pilát, J. Ježek, S. Bernatová, P. Jedlička, M. Aas, A. Kiraz, P. Zemánek: *"Optically transportable optofluidic microlasers with liquid crystal cavities tuned by the electric field"*. ACS Applied Materials & Interfaces **13**, 50657−50667, 2021

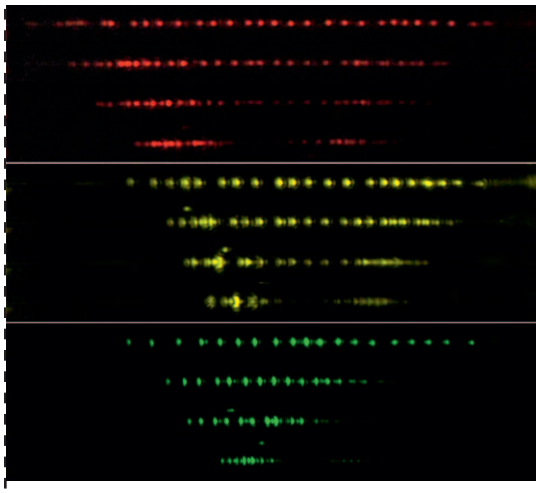


An optically trapped nanoparticle inside the vacuum chamber



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

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



Conversion of spin to orbital angular light momentum and its detection

- A. C. Valero D. Kislov, E. A. Gurvitz, H. K. Shamkhi, A. A. Pavlov, D. Redka, S. Yankin, P. Zemánek, A. S. Shalin: *"Nanovortex-driven all-dielectric optical diffusion boosting and sorting concept for lab-on-a-chip platforms"*. Advanced Science **7**, 2020
- A. V. Arzola, L. Chvátal, P. Jákl, P. Zemánek: *"Spin to orbital light momentum conversion visualized by particle trajectory"*. Scientific Reports **9**, 4127:1–7, 2019

Optical formation of colloidal waveguides and demonstration of tunability of their spectral properties

- O. Brzobohatý, L. Chvátal, A. Jonáš, M. Šiler, J. Kaňka, J. Ježek, P. Zemánek: *"Tunable Soft-Matter Optofluidic Waveguides Assembled by Light"*. ACS Phot. **6**, 403-410, 2019

Properties of optically levitating systems

- J. Flajšmanová, M. Šiler, P. Jedlička, F. Hrubý, O. Brzobohatý, R. Filip, P. Zemánek: *"Using the transient trajectories of an optically levitated nanoparticle to characterize a stochastic Duffing oscillator"*. Scientific Reports **10**, 14436, 2020
- Y. Arita, S. H. Simpson, P. Zemánek, K. Dholakia: *"Coherent oscillations of a levitated birefringent microsphere in vacuum driven by nonconservative rotation-translation coupling"*. Science Advances **6**, 2020
- V. Svak, J. Flajšmanová, L. Chvátal, M. Šiler, A. Jonáš, J. Ježek, S. H. Simpson, P. Zemánek, O. Brzobohatý: *"Stochastic dynamics of optically bound matter levitated in vacuum"*. Optica **8**, 220–229, 2021
- S. H. Simpson, Y. Arita, K. Dholakia, P. Zemánek: *"Stochastic Hopf bifurcations in vacuum optical tweezers"*. Phys. Rev. A **104**, 043518, 2021

Extensive review on an optically induced transport of objects

- P. Zemánek, G. Volpe, A. Jonáš, O. Brzobohatý: *"Perspective on light-induced transport of particles: from optical forces to phoretic motion"*. Advances in Optics and Photonics **11**, 577–678, 2019

MAIN COLLABORATING PARTNERS

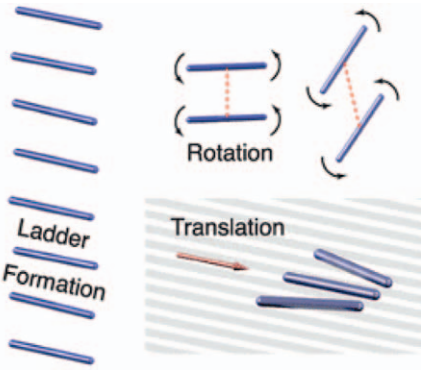
Collaboration with academic partners

- 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)
- Palacký University Olomouc (Olomouc, CZ)
- Universidad Nacional Autonoma de Mexico (Mexico City, MX)
- University of Bristol (Bristol, UK)
- University of Dundee (Dundee, UK)
- University of Naples Frederico II (Naples, IT)
- University of St. Andrews (St. Andrews, UK)

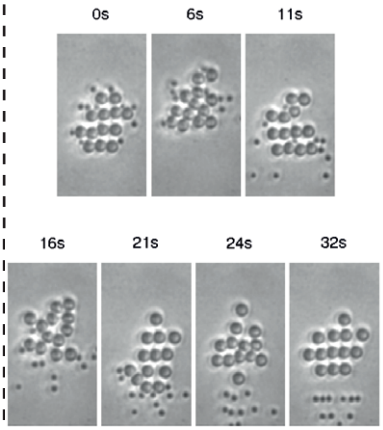
EXPECTATIONS

Offers

- Collaboration in the areas of our expertise
- Partnership in international projects



Optical Binding of Nanowires



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