DEPARTMENT OF SOLID STATE PHYSICS F-5

Our research programme focuses on the study of the structure and dynamics of disordered and partially ordered condensed matter at the atomic and molecular levels, with a special emphasis on phase transitions. The purpose of these investigations is to discover the basic laws of physics governing the behaviour of these systems, which represent the link between perfectly ordered crystals, on one side, and amorphous matter, soft condensed matter and living systems, on the other. Such knowledge provides the key to our understanding of the macroscopic properties of these systems and is an important condition for the discovery and development of new multifunctional materials, nanomaterials and biomaterials for new applications. An important part of the research program is devoted to the development of new experimental methods and techniques in the field of cold atoms, quantum magnetism, quantum optics, biophotonics and super-resolution imaging.

Head:
Prof. Igor Muševič

The research programme of the Department of Solid State Physics at the Jožef Stefan Institute is performed in close collaboration with Department of Physics at the Faculty of Mathematics and Physics of the University of Ljubljana, Institute of Mathematics, Physics and Mechanics and the J. Stefan International Postgraduate School. In 2019, the research was performed within three research programmes:

– Magnetic Resonance and Dielectric Spectroscopy of Smart New Materials
– Physics of Soft Matter, Surfaces and Nanostructures
– Experimental Biophysics of Complex Systems

I. Research Programme "Magnetic Resonance and Dielectric Spectroscopy of Smart New Materials"

The research group presented the first experimental proof of existence of "anyone" particles (the particles that are simultaneously fermions and bozons) and discovered new quantum magnetic states in solid-state materials. It has found new multiferroic materials, revealed complex magnetism of high-entropy alloys, developed fully-printed thin-film capacitors and determined the physical-mechanical properties of liquid crystals and liquid-crystalline elastomers.

In 2019, the Research Programme *Magnetic Resonance and Dielectric Spectroscopy of Smart New Materials* focused on the study of physical phenomena in condensed matter at the atomic and molecular levels. The purpose of the research was to discover the basic laws of physics governing the behaviour of the investigated systems. The attained knowledge provides the key to the understanding of the microscopic and macroscopic properties of various types of solids. It is also an important condition for the discovery and development of new multifunctional materials and nanomaterials for novel technological applications.

The research group has observed Kondo screening in a charge-insulating spinon metal, discovered additive manufacturing of ferroelectric-oxide thin-film multilayer devices, reported on the discovery of a giant electrocaloric response in smectic liquid crystals with a direct smectic-isotropic transition, reported on the existence of caesium bright matter-wave solitons and soliton trains in experiments with cold atoms and discovered a high-entropy alloy with excellent magnetic softness.

In our research, we used the following experimental techniques:

- Nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), and nuclear quadrupole resonance (NQR);
- Nuclear double resonance ^{17}O–H and ^{14}N–H;
- Fast field cycling NMR relaxometry;
- Linear and non-linear dielectric spectroscopy in the range 10^{-2} Hz to 10^{9} Hz;
- Frequency-dependent ac calorimetry;
- Measurement of electrical and thermal transport coefficients;
- Magnetic measurements;
- Methods of ultra-cold atoms.

The research programme worked in close collaboration with the Department of Physics at the Faculty of Mathematics and Physics of the University of Ljubljana, Institute of Mathematics, Physics and Mechanics, and the Jožef Stefan International Postgraduate School.

In 2019, members of the research programme published 42 original scientific papers in international peer-reviewed scientific journals. Among these, one paper was published in *Nature Physic* (IF = 21.8), one in *Angewandte*

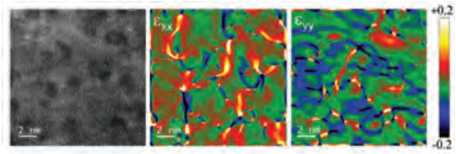

Figure 1: Maps of the ε_{xx} and ε_{yy} strain tensor components over the area of 1515 nm^2, where the highly stressed interfaces between the FeCoNi and the PdCu domains in the FeCoNiPdCu high-entropy alloys are visible.

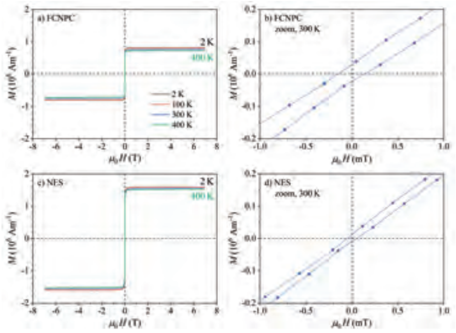

Figure 2: (a) M (H) curves of the FeCoNiPdCu (FCNPC) high-entropy alloy at selected temperatures between 400 and 2 K for a magnetic field sweep from −7 to 7 T. In (b)*, the curve at T = 300 K is zoomed in on the field axis about the origin. Panels (c) and (d) show the corresponding M (H) curves of the non-oriented electrical steel (NES) sample.*

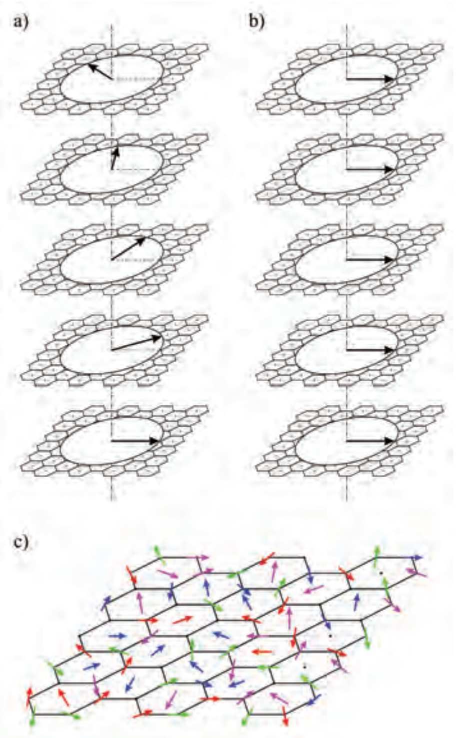

Figure 3: Schematic presentation of magnetic structures present in the Gd-Tb-Dy-Ho-Lu hexagonal high-entropy alloy: (a) basal-plane helical AFM structure; (b) basal-plane FM structure; (c) spin glass structure (magnetic moments of Gd, Tb, Dy and Ho ions are drawn with arrows of different colours and the length of the arrow is proportional to the size of the moment; nonmagnetic Lu ions are presented by black dots).

*Chemie, Intern. E*d. (IF = 12.3), one in *J. Mater. Chem.* (IF = 10.7), one in *ACS Appl. Mater. & Interf.* (IF = 8.5), one in *Appl. Mater. Today* (IF = 8.0), two in *Acta Mater.* (IF = 7.3), one in *J. Mater. Chem. C* (IF = 6.6), one in *Sensors and Actuators B* (IF = 6.3), and 15 papers in the journals with the IFs between 5 and 3.

The investigations focused on the following research fields:

High-entropy alloys

We have been investigating crystalline, multicomponent metallic alloys, known as high-entropy alloys, which are stabilized by the entropic term in the Gibbs free energy of mixing by the immense chemical (substitutional) disorder on the crystal lattice. In the paper "Discovery of a Feconipdcu High-Entropy Alloy with Excellent Magnetic Softness", P. Koželj *et al.*, *Adv. Eng. Mater.* 1801055 (2019), we report on the discovery of a magnetically soft high-entropy alloy with the composition FeCoNiPdCu, which performs comparably to the best commercial soft magnets for static and low-frequency applications. Properly heat-treated FeCoNiPdCu develops a nanostructure that can be viewed as a two-phase bulk nanocomposite of randomly intermixed FeCoNi magnetic domains and PdCu nonmagnetic "spacers", both of 2–5 nm cross dimensions (Figure 1). Due to the nanometric size, the FeCoNi domains are magnetically single-domain particles, and since the particles are exchange-coupled across the boundaries, exchange averaging of the magnetic anisotropy takes place, resulting in an almost vanishing coercive field and excellent magnetic softness (Figure 2). The formation of a two-phase nanostructure favourable for the exchange averaging of magnetic anisotropy is a consequence of specific values of the binary mixing enthalpies for the chosen elements. Experimentally, the magnetic properties of the FeCoNiPdCu high-entropy alloy are compared to the commercial, magnetically soft non-oriented silicon electrical steel (NES).

In the paper "Magnetic Phase Diagram and Magnetoresistance of Gd-Tb-Dy-Ho-Lu Hexagonal High-Entropy Alloy", S. Vrtnik *et al.*, *Intermetallics* **105**, 163–172 (2019), we present a study of the magnetic phase diagram and the magnetoresistance of a Gd-Tb-Dy-Ho-Lu "ideal" hexagonal high-entropy alloy (HEA), composed of the elements from the heavy half of the rare-earth series only. The phase diagram contains an antiferromagnetic (AFM) state, a field-induced ferromagnetic (FM) state above the AFM-to-FM spin-flop transition, and a low-temperature spin-glass state. The complex *(H, T)* phase diagram is a result of competition between the periodic potential arising from the electronic band structure that favours periodic magnetic ordering, the substitutional-disorder-induced random local potential that favors spin-glass-type spin freezing in random directions, the Zeeman interaction with the external magnetic field that favours spin alignment along the field direction, and the thermal agitation that opposes any spin ordering. The magnetoresistance reflects the complexity of the *(H, T)* phase diagram. Its temperature dependence can be explained by a continuous weakening and final disappearance of the periodic potential upon cooling that leads to the destruction of long-range-ordered periodic magnetic structures. The magnetoresistance is large only at temperatures where the AFM and field-induced FM structures are present and exhibits a maximum at the critical field of the AFM-to-FM transition. Within the AFM phase, the magnetoresistance is positive with a quadratic field dependence. Within the field-induced FM phase, it is negative with a logarithmic-like field dependence. At lower temperatures, the long-range periodic spin order "melts" and the magnetoresistance diminishes until it totally vanishes within the low-temperature spin glass phase. The magnetoresistance is asymmetric with respect to the field sweep direction, reflecting the non-ergodicity and frustration of the spin system.

A method for producing polymeric surface-modification layers

The surface properties of a substrate are among the most important parameters in the printing technology of functional materials, determining both the resolution and stability of the printed features. We have developed a method for the preparation of thin polymeric layers with large contact-angle hysteresis, which are used for adjustments of the wetting of arbitrary solid optical-grade substrates. The method is based on coating the surface with a mixture of polymers that undergo a phase separation and form an inhomogeneous, nano-textured surface upon deposition. The wetting is, in the second step, regulated by a surface treatment of the polymeric layer (O_2 plasma, UV/O_3). Our surface-adjustment layer is suitable for various printing applications (inkjet-, gravure-, spray- or screen-printing) or any other application that requires precisely regulated wetting and large contact-angle hysteresis. The results were patented in A. Matavž, B. Malič, V. Bobnar, *A method for producing polymeric surface modification layers*, Patent application MKS/MP7501968, London: Intellectual Property Office, September 23, 2019.

Self-assembled porous ferroelectric thin films with a greatly enhanced piezoelectric response

In thin films, the electromechanical response is obstructed by the mechanical clamping of the substrate, resulting in a deterioration of the piezoelectric coefficients. By utilizing soft-chemistry techniques, we developed a simple and robust method based on the self-assembly of organometallic precursors in a polymer matrix for the deposition of nanostructured oxide thin films. The implemented macro-porosity leads to local elastic relaxations and greatly enhances the macroscopic electromechanical response. Exceptionally large measured piezoelectric coefficients, reaching the level of bulk ceramics, are associated with the increased elastic compliance of the nanostructured films and the highly mobile ferroelastic domain walls.

The results were published in A. Matavž, A. Bradeško, T. Rojac, B. Malič, V. Bobnar, "Self-assembled porous ferroelectric thin films with a greatly enhanced piezoelectric response" *Applied Materials Today* **16**, 83 (2019).

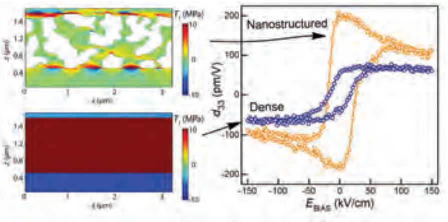

Figure 4: The finite-element-method simulation reveals that a strong tensile stress over the whole dense film thickness is released in a porous film (left), which greatly enhances its macroscopic electromechanical response (right).

Inkjet printing of ferroelectric thin-film multilayer devices

We designed a universal approach to the inkjet printing of metal oxides on arbitrary solid substrates. The full control over the wetting properties was achieved by introducing a few-nanometres-thick polymeric layer with textured topography. In combination with the specially designed ink formulation, it enabled a highly efficient deposition of flat structures with good lateral definition. The developed process is highly efficient and enables conformal stacking of functional oxide layers according to the user-defined geometry, sequence arrangement, and layer thickness – its large potential was demonstrated by the manufacturing of all-printed ferroelectric capacitors composed of as many as 16 individual layers. A detailed structural and electrical characterization revealed the excellent functional properties of the printed devices.

The results were published in A. Matavž, A. Benčan, J. Kovač, C.-C. Chung, J. L. Jones. S. Trolier-McKinstry, B. Malič, V. Bobnar, "Additive manufacturing of ferroelectric-oxide thin-film multilayer devices", *ACS Applied Materials & Interfaces* **11**, 45155 (2019).

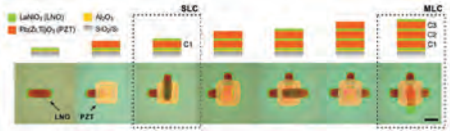

Figure 5: Optical images of sequentially printed LNO and PZT and a schematic of the corresponding cross-section. Alternating stacking was used to fabricate single-layer (SLC) and multilayer (MLC) capacitors with excellent functional properties.

The role of water in the transformation of $H_2Ti_3O_7$ nanoribbons in TiO_2 nanostructures

The investigation of the transformation of $H_2Ti_3O_7$ nanoribbons to anatase was motivated by three goals: (i) to determine the role of water in the transformation, (ii) to understand the behaviour of protonated tri-titanate nanoribbons under hydrothermal conditions over the whole pH range, and (iii) to explain the products' morphology in regard to reaction environments. The transformation reactions of protonated tri-titanate nanoribbons were conducted under various hydrothermal and solvothermal conditions, as well as with calcination in air. A deeper insight into the transformation process as well as the product formation was additionally ensured with the zeta-potential measurements of protonated tri-titanate nanoribbons and a detailed electronic microscopy study coupled with crystallography of the products. Protonated titanate nanoribbons are stable under basic conditions and their transformation to anatase nanoribbons depends on counter ions from the reaction mixture – for example, when ammonium ions acted as an exfoliating reagent. With decreasing pH of the reaction mixture both processes, topotactic transformation and dissolution-recrystallisation, are accelerated, where the nanoribbon is a substrate for the heterogeneous nucleation of anatase nanocrystals afterwards. Sodium titanate nanoribbons are suitable for the transformation to anatase nanoribbons under hydrothermal conditions as well. Water was revealed as being crucial for the transformation progress, since organic solvents served only as a thermal reaction medium and did not encourage catalysis.

The results were published in M. Sluban and P. Umek, "The role of water in the transformation of protonated titanate nanoribbons to anatase nanoribbons", *The journal of physical chemistry. C, Nanomaterials and interfaces* **123**, 23747–75 (2019).

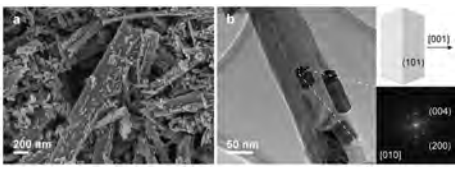

Figure 6: SEM (a) and TEM (b) images of the product formed at the transformation of $H_2Ti_3O_7$ nanoribbons under hydrothermal condition in 0.5-M NH_3(aq). The FFT analysis of the anatase nanocrystal, oriented along the [010] zone axis, confirms its growth in the [001] direction. The dihedral angle between the marked facets reveals that the lateral facets belong to the {101} planes.

Donor-acceptor interaction in halogen-bonded complexes

Halogen-bonded complexes of *N*-iodosuccinimide (NIS) with the nitrogen atoms at the donor and acceptor positions have been investigated by ^{14}N nuclear quadrupole resonance (NQR) spectroscopy. The obtained data were analysed in terms of the correlation between the principal values of the quadrupole coupling tensor and show that the changes of the electron charge distribution at the XB donor and acceptor nitrogen positions are comparable to

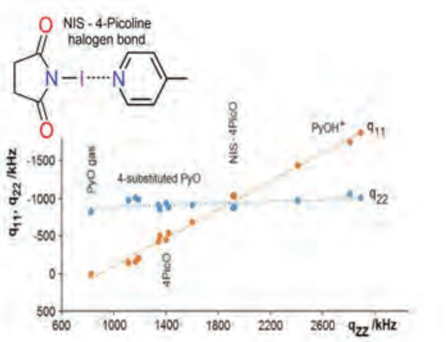

Figure 7: Correlation between the two smaller principal values q_{11} and q_{22} and the largest principal value q_{ZZ} of the quadrupole coupling tensor in PyO and related compounds.

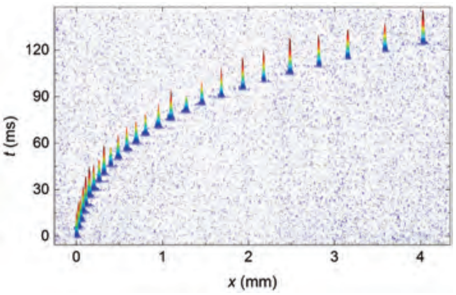

Figure 8: Density absorption images of a caesium soliton accelerating in a quasi-one-dimensional channel.

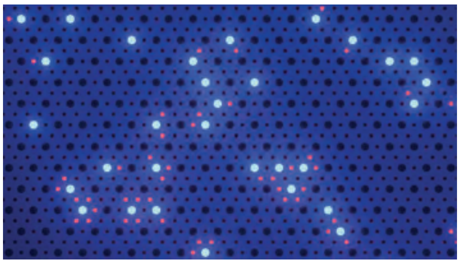

Figure 9: Quantum spin liquid on a kagome lattice.

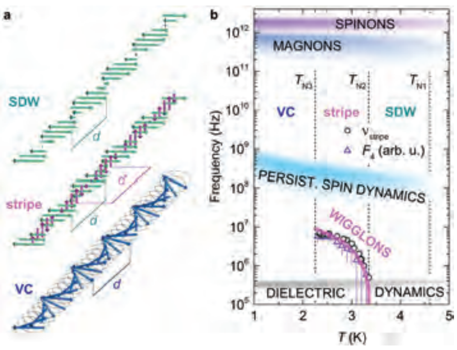

Figure 10: Magnetic structure models corresponding to the spin-density-wave (SDW), spin-stripe and vector-chiral (VC) phases in β-$TeVO_4$.

the changes of the electron charge distribution observed in strong hydrogen-bonded systems. We demonstrated that the deformation of the nitrogen electron orbitals, produced by halogen bond acceptor, is reflected on the principal value Q_{YY} of the ^{14}N quadrupole coupling tensor in NIS, which enables an estimation of the XB acceptor strength and the temperature dependence of the iodine atom displacements. The results were published in T. Apih, G. Gregorovič, V. Žagar, J. Seliger, "A study of donor-acceptor interaction in halogen bonded complexes of N-iodosuccinimide by ^{14}N NQR", *Chem. Phys*. **523**, 12–17 (2019).

Thermomechanical response of main-chain polymer-dispersed liquid-crystal elastomers

We have determined the thermomechanical response of main-chain polymer-dispersed liquid-crystal elastomers (PDLCE), optimized by controlling the concentration of crosslinker molecules. The resulting materials exhibit increased thermomechanical response, up to 25%, and higher elastic modulus, up to 300 kPa, as compared with sidechain PDLCEs. Alternative methods for orienting thermomechanically anisotropic LCE microparticles in isotropic polymer matrices have also been investigated. We have demonstrated that orientational order can be induced by the shear field of a laminar flow. This approach is advantageous with respect to the magnetic field alignment of microparticles, particularly in view of its application potential in additive-manufacturing technologies.

Production of caesium solitons and soliton trains in experiments with cold atoms

Tadej Mežnaršič, Tina Arh, Jaka Pišljar, Žiga Gosar, Erik Zupanič, and Peter Jeglič have demonstrated the production of cerium solitons and soliton trains to study their formation, fragmentation and collisions. When non-interacting Bose-Einstein condensate is confined to a quasi one-dimensional channel, it will spread due to dispersion as dictated by the Schrödinger equation. The spreading rate can be affected by changing the interaction between the atoms via the Feshbach resonance. If the interaction is set to just the right value, the attraction between atoms exactly compensates the dispersion and we get a bright matter-wave soliton. The results were published in T. Mežnaršič *et al.*, "Cesium bright matter-wave solitons and soliton trains", *Physical Review A* **99**, 033625 (2019).

Quantum magnetism

Matjaž Gomilšek, Martin Klanjšek, Matej Pregelj, and Andrej Zorko, in collaboration with partners from Slovenia, Switzerland and China, studied the magnetic state of impurities in a kagome quantum spin liquid Zn-brochantite. They discovered the first case of the Kondo effect in an electric insulator. Typically, conduction electrons screen the local moments of magnetic impurities in ordinary metals. However, in the investigated insulator an analogous phenomenon is possible due to its quantum-spin-liquid ground state, where magnetic spinon excitations forming a Fermi surface effectively replace the itinerant electrons in screening the magnetic moments of localized impurities. This discovery could be important for manipulating topologically protected spin-liquid states in quantum computing. The results were published in M. Gomilšek *et al.*, "Kondo screening in a charge-insulating spinon metal", *Nat. Phys.* **15**, 754 (2019).

Matej Pregelj, Andrej Zorko, Matjaž Gomilšek, Martin Klanjšek and Denis Arčon, in collaboration with partners from Switzerland, the United Kingdom and Croatia, discovered a new type of elementary excitations inherent to the spin-stripe order that emerge in the frustrated zigzag spin-1/2 chain compound β-$TeVO_4$. Employing muon spin relaxation, neutron diffraction and dielectric measurements, they found that these excitations are a bound state of two phason quasiparticles. The latter manifest as a wiggling-like motion of the magnetic moments, dubbed "wigglon", and give rise to unusual low-frequency spin dynamics. This result provides a new insight into the stripe physics of strongly correlated electron systems. The results were published in M. Pregelj *et al.* "Elementary excitation in the spin-stripe phase in quantum chains", *npj Quantum Mater* **4**, 22 (2019).

Matej Pregelj, Andrej Zorko, Martin Klanjšek and Denis Arčon, in collaboration with partners from Switzerland, Germany and Japan, studied magnetic phases in β-$TeVO_4$ in high-magnetic fields up to 25 Tesla. Based on magnetization and neutron-diffraction measurements they found that the transition from the helical ground state to the spin-density-wave state occurs at ~3 T for the magnetic field along the *a* and *c* crystal axes, while at ~9 T for the field along the *b* axis.

Moreover, they discovered that the high-field (HF) state, existing above ~18 T, is an incommensurate magnetically ordered state and not the spin-nematic state, as theoretically predicted. The HF state is likely driven by sizable interchain interactions and symmetric intrachain anisotropies uncovered in previous studies. The results were published in M. Pregelj *et al.* "Magnetic ground state of the frustrated spin-1/2 chain compound β-$TeVO_4$ at high magnetic fields", *Phys. Rev. B* **100**, 094433 (2019).

Andrej Zorko, Matej Pregelj, Martin Klanjšek and Matjaž Gomilšek, in collaboration with partners from Slovenia, United Kingdom, Switzerland and China, studied $YCu_3(OH)_6Cl_3$, which has been recently reported as the first geometrically perfect realization of the kagome lattice with negligible inter-site mixing and a possible quantum-spin-liquid ground state. However, by means of combining magnetization, heat-capacity, and muon-spin-relaxation measurements they found that below T_N = 15 K magnetic ordering is realized. The latter is rather unconventional, as first, a crossover regime where the ordered state coexists with the paramagnetic state extends down to $T_N/3$ and, second, the fluctuation crossover is shifted far below T_N. Moreover, persistent spin dynamics that is observed at temperatures as low as T/T_N = 1/300 could be a sign of emergent excitations of correlated spin loops or, alternatively, a sign of fragmentation of each magnetic moment into an ordered and a fluctuating part. The results were published in A. Zorko *et al*., "Coexistence of magnetic order and persistent spin dynamics in a quantum kagome antiferromagnet with no intersite mixing", *Phys. Rev. B* **99**, 214441 (2019).

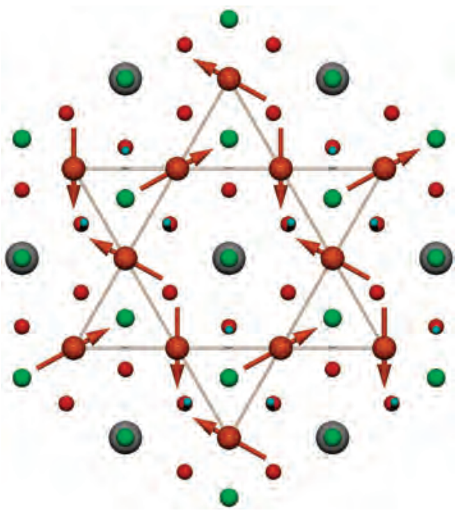

Figure 11: A perfect kagome lattice (lines) of Cu_2+ spin-1/2 ions (orange) in the ab plane of the $YCu_3(OH)_6Cl_3$ compound. The Y_{3+}, O_{2-}, H+, and Cl– ions are shown in grey, red, turquoise, and green, respectively.

Andrej Zorko, Matej Pregelj, Matjaž Gomilšek and Martin Klanjšek, in collaboration with partners from Slovenia, Switzerland and China, studied the magnetic state of a new quantum kagome antiferromagnet $YCu_3(OH)_6Cl_3$. Even though it is one of the cleanest realizations of a 2D kagome spin lattice as it does not possess structural deformations nor detectable amounts of impurities, it still magnetically orders, which defies naive expectations. Researchers used elastic neutron scattering to show that the order arises from an unusually strong spin anisotropy of the Dzyaloshinskii–Moriya type, which is strong enough to push the system past its quantum critical from a disordered quantum-spin-liquid ground state to a ground state of a magnetically-ordered antiferromagnet with negative vector chirality. The results were published in A. Zorko *et al.,* "Negative-vector-chirality 120° spin structure in the defect- and distortion-free quantum kagome antiferromagnet $YCu_3(OH)_6Cl_3$", *Phys. Rev. B* **100**, 144420 (2019).

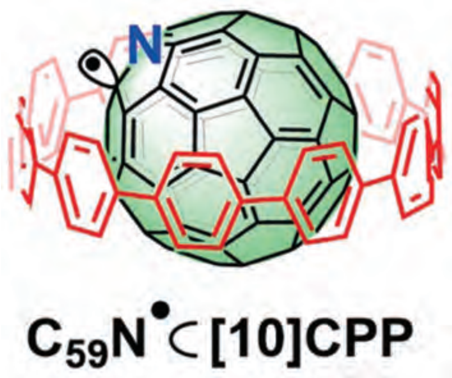

Figure 12: The CPP host and the $C_{59}N$ guest species.

In collaboration with colleagues from France, Germany and Greece, Denis Arčon studied the possibilities of the long-lived stabilization of the fullerene radical centres. A breakthrough in this area was achieved by trapping diamagnetic diamagnetic $(C_{59}N)_2$ in [10] cycloparaphenylene ([10]CPP). The dimer, under the influence of laser light, decomposed into two paramagnetic $C_{59}N$ radicals, while each individual radical was trapped in its own [10]CPP ring (Figure 12). Denis Arčon detected the $C_{59}N$ radicals and investigated them using the pulse electron paramagnetic resonance methods. The stabilization of such radicals can be an important step towards the realization of quantum qubits on a single fullerene molecule, since such complexes can also be properly arranged on the surface or in three dimensions. The results were published in A. Stergiu *et al*., "A Long-Lived Azafullerenyl Radical Stabilized by Supramolecular Shielding with a [10]Cycloparaphenylene", *Angew. Chem. Int. Ed.* **58**, 17745–17750 (2019).

Study of multiferroic nanostructured materials and caloric effects for solid-state cooling applications

We showed, by direct measurements, the existence of large electrocaloric effect in soft materials like liquid crystals and in novel bulk composite lead-free materials. We demonstrated that liquid crystals can be used as active regenerators, thus replacing the current inactive regenerator materials and enhancing the efficiency of the new generation of cooling devices. We showed that perovskite ceramic materials can sustain more than 10^6 cycles without ageing, which is already sufficient for application. In addition, we showed how to avoid ageing and how to regenerate caloric materials. We also demonstrated how to stabilize liquid-crystal blue phases by the addition of specially decorated graphene nanoparticles. The above results have been published in 18 articles in international scientific journals. Recent works on multicalorics and soft materials have been cited more than 400 times in 2019 alone. The results were published in A. Bradeško, *et al*., *Acta Materialia* **169** (2019) 275; E. Klemenčič, M. Trček, Z. Kutnjak, S. Kralj, *Scientific Reports* **9** (2019) 1721; U. Plaznik, M. Vrabelj, Z. Kutnjak, B. Malič, B. Rožič, A. Poredoš, A. Kitanovski, *Int. J. Refrig.* **98** (2019) 139; D. Črešnar, C. Kyrou, I. Lelidis, A. Drozd-Rzoska, S. Starzonek, S.J. Rzoska, Z. Kutnjak, S. Kralj, *Crystals* **9** (2019) 171; A. Kumar, A. Chauhan, S. Patel, N. Novak, R. Kumar, R. Vaish, *Scientific Reports* **9** (2019) 3922.

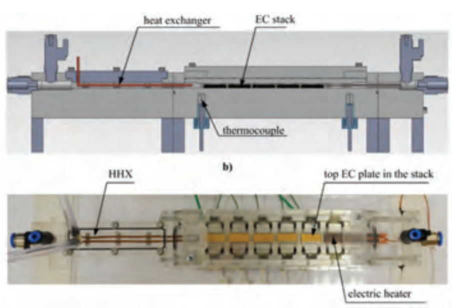

Figure 13: Electrocaloric cooling device with regenerator.

We performed the first numerical study of the topology of three-dimensional active nematic turbulence in a spherical confinement. We applied singularity theory to explain the nature of topological defects in chiral nematic droplets. We develop first high-order multipoles – as high as 64 and 128 poles – based on designed distortions in nematic fluids. We introduced routes for the accurate characterization of the surface morphology of microfilaments that form plants' tracheary systems and are crucial for their mechanical properties. We studied photoluminescence of individual MoS_2 tubes.

II. Research Programme "Physics of Soft Matter, Surfaces, and Nanostructures"

The investigations of the research programme *"Physics of Soft Matter, Surfaces, and Nanostructures"* focuses on novel complex soft-matter systems and surfaces with specific functional properties. The aim of the programme is to understand structural and dynamical properties of these systems, their interactions, their function at the molecular level, and self-assembly mechanisms in soft matter. The underlying idea is that it is possible to understand complex mechanisms, such as self-assembly, on a macroscopic level, using a simplified physical picture and models. In order to provide a comprehensive approach to the problem, the programme combines both experimental and theoretical investigations, supported by modelling and simulations. Special emphasis is given to the possible electro-optic and medical applications.

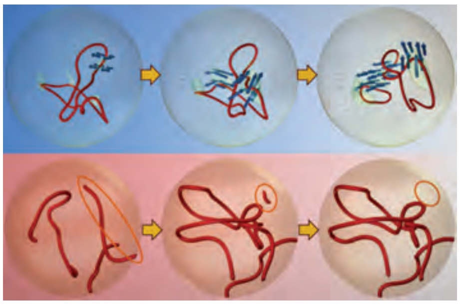

Figure 14: Active nematic topological defect transitions in spherical droplets with homeotropic surface alignment (left) and planar degenerate surface alignment (right).

Topology of Three-Dimensional Active Nematic Turbulence Confined to Droplets

In an active nematic droplet, we realized the first numerical study of the topology of three-dimensional active nematic turbulence. Simulations were performed using a mesoscopic model of active nematic fluids, which are most commonly used to describe biological systems driven by the internal conversion of stored energy (usually chemical) into motion. The chaotic motion in the active turbulence was explained by elementary topological events that affect defect lines appearing in such systems. Additionally, a coupling of surface and bulk dynamics through defects was demonstrated (*Physical Review X*, 2019, DOI: 10.1103/PhysRevX.9.031051).

Singularity theory explains topological defects in LC droplets

In a collaboration with researchers from the University of Warwick we provided a characterization of point defects in droplets of cholesteric liquid crystal, using a combination of experiment, simulation and theoretical analysis. We show that there are certain defects that are incompatible with a uniform sense of chiral twisting for topological reasons. Furthermore, those defects that are compatible with the twist of single handedness are shown to have the structure of the gradient field of an isolated critical point and, hence, are described by singularity theory. We show that the mathematical tools of singularity reproduce, with excellent agreement, the experimental observations of high charge defects and topological molecules. The results have implications beyond liquid-crystal droplets in characterizing chiral materials and their topology in general. (*Phys. Rev. X* 9, 021004, 2019).

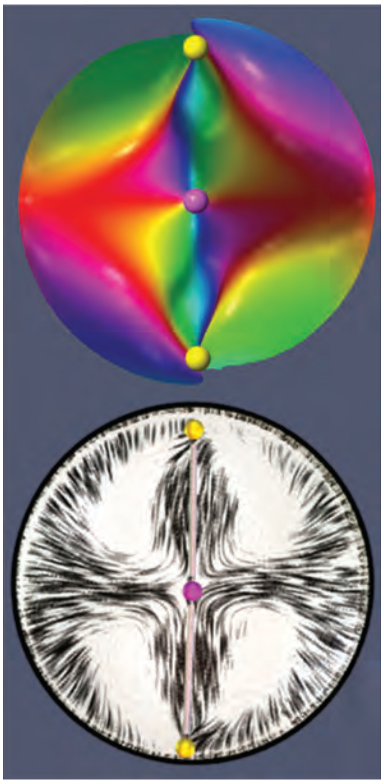

Figure 15: Numerical presentation (top) and experimental observation (bottom) of cholesteric droplet with one chiral and two achiral defects.

High-order elastic multipoles as colloidal atoms

Here we introduce physical design principles allowing us to define high-order elastic multipoles emerging when colloids with controlled shapes and surface alignment are introduced into a nematic host fluid. A combination of experiments and numerical modelling of equilibrium field configurations using a spherical harmonic expansion allow us to probe elastic multipole moments, bringing analogies with electromagnetism and the structure of atomic orbitals. We show that, at least in view of the symmetry of the "director wiggle wave functions," the diversity of elastic colloidal atoms can far exceed that of known chemical elements. The work was a collaboration with the experimental group at the University of Colorado Boulder (*Nature Comm.*, 2019, DOI: 10.1038/s41467-019-09777-8).

Spotting plants' microfilament morphologies and nanostructures

The tracheary systems of plants are crucial for the plants to survive. The curled-up microfilaments form left-handed helices that constitute the contours of tubes responsible for the transport of water and nutrients from the roots to the leaves. The microfilaments have mechanical properties that vary from plant to plant despite having similar polygonal-helical shapes and cellulose skeletons. In this research, that was done within a tight collaboration with the group of M. Godinho in Lisbon, we show that the surface morphology of the microfilaments, sensed by nematic liquid crystal droplets, is at the origin of entanglements, which are responsible for the mechanical behaviour of microfilaments (*PNAS* 2019, DOI: 10.1073/pnas.1901118116). This work introduces routes for the accurate characterization of plants' microfilaments and their potential use for bioinspired textiles.

Designed self-assembly of metamaterial split-ring colloidal particles in nematic fluids

In this work we demonstrate the self-assembly in a nematic fluid of a specific type of colloidal particle, split-ring resonators (SRRs), which are known in photonic metamaterials for their ability to obtain resonances in response to a magnetic field. Using free-energy minimisation calculations, we optimised the geometrical parameters of the SRR particles to reduce and prevent the formation of irregular metastable colloidal states, which in more general view corresponds to concepts of pre-designed self-assembly. Using the pre-designed particles, we then show self-assembly into two- and three-dimensional nematic colloidal crystals of split-ring particles. Our work is a contribution to the development of designed colloidal structures for possible use in photonic applications as tunable metamaterials (*Soft Matter* 2019, DOI: 10.1039/c9sm00842j).

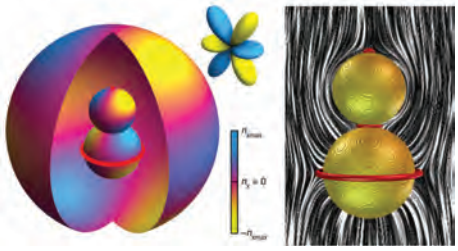

Figure 16: Elastic multipoles realized on specially shaped particles in the nematic liquid crystal.

Ray-based optical visualisation of complex birefringent structures including energy transport

We developed an efficient method to simulate light propagation in lossless and non-scattering uniaxial birefringent media, based on a standard ray-tracing technique supplemented by a newly derived transport equation for the electric field amplitude along a ray and a tailored interpolation algorithm for the reconstruction of the electromagnetic fields. We show that this algorithm is accurate in comparison to a full solution of Maxwell's equations when the permittivity tensor of the birefringent medium typically varies over a length much longer than the wavelength. We demonstrated the usefulness of our code for soft matter by comparing experimental images of liquid crystal droplets with simulated optical micrographs (*Soft Matter* 2019, DOI: 10.1039/c8sm02448k).

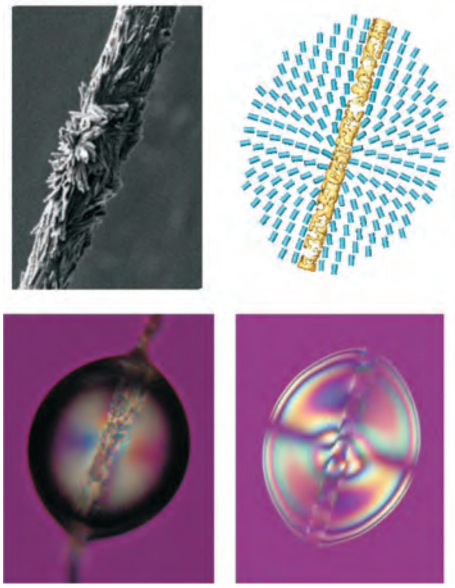

Figure 17: SEM picture of a rough nanofilament and polarization optical micrograph of a nematic droplet decorating the same filament (left) and simulated nematic ordering around such a filament with simulated polarization micrograph (right).

Moving the optical resolution limit in observations of liquid-crystal structures

We demonstrated that Stimulated Emission Depletion (STED) microscopy can be successfully used for high-resolution observations of structures formed in cholesteric liquid crystals (CLCs). Comparing the observations of optical microscopy operated in reflection mode with observations of confocal and STED microscopy, we have shown that the achievable resolution of the STED technique is below ~90 nm, improving on the best-achieved optical resolution of ~150 nm. A crucial step in making use of the fluorescent-probe-based STED technique in CLC possible, was the synthesis of custom fluorescent probes that mix well with LCs and are spectrally tailored to the STED microscope available at the JSI. (*Liquid Crystals,* DOI:10.1080/02678292.2019.1710870)

Tuneable ferroelectric liquid-crystal microlaser

We have studied the Whispering Gallery Mode (WGM) resonances in microdroplets of dye-doped ferroelectric liquid crystals. The emitted laser light of microdroplets exhibiting a ferroelectric Sm C*, excited using a pulsed laser, shows a multimode WGM spectrum. The WGM resonances are red-shifted upon the application of slowly varying electric field along the direction of the excitation light. This spectral shift is a consequence of a soliton-like deformation of the helical ferroelectric Sm C* structure due to the external electric field. It has a value of ~2.3 nm at 1 V/μm field, is fully reversible and quadratic in the applied field. (Liquid Crystals, DOI: 10.1080/02678292.2019.1700567)

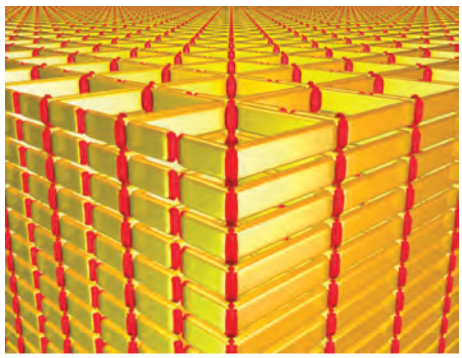

Figure 18: Three-dimensional horseshoe colloidal crystal.

Red Blood Cells' Shape Stabilized by Membrane's In-plane Ordering

Red blood cells (RBCs) are present in almost all vertebrates and their main function is to transport oxygen to the body tissues. The RBCs' shape plays a significant role in its functionality. In almost all mammals in normal conditions, RBCs adopt a disk-like (discocyte) shape, which optimizes their flow properties in vessels and capillaries. Experimentally measured values of the reduced volume (v) of stable discocyte shapes range in a relatively broad window between v~0.58 and 0.8. However, these observations are not supported by existing theoretical membrane-shape models, which predict that the discocytic RBC shape is stable only in a very narrow interval of v values, ranging between v~0.59 and 0.65. In our theoretical and numerical studies we demonstrate that this interval is broadened if a membrane's in-plane ordering and extrinsic curvature are taken into account. (*Scientific Reports,* DOI: 10.1038/s41598-019-561280)

Photoluminescence in MoS_2 microtubes

In collaboration with co-workers from Russia and France, we studied the photoluminescence of individual MoS_2 tubes *(Ann. Phys. (Berlin*) 2019, 1800415*)*. The emission form recombination of direct excitons was found to be strong despite the relatively large thickness of the walls of the tubes containing several dozens of monolayers. The spectra with strong "whispering gallery" mode peaks were recorded at room temperature with the Q-factor as high as several hundred. These results imply the application of these MoS_2 tubes as effective micro-resonators. These spectroscopy studies were included in the best 10 results in the report of the Ioffe Institute for the year 2019.

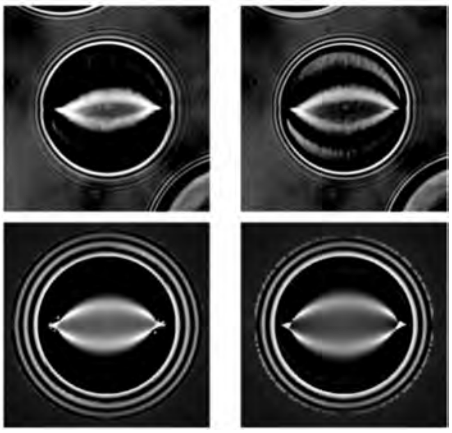

Figure 19: Bright-field micrograph of a nematic droplet before (left) and in (right) focus (top row) and corresponding simulations (bottom row).

Quantum effects in MoS_2 nanotubes

In collaboration with Regensburg University, we reported on the first transport spectroscopy data on a quantum dot defined in a semiconducting multiwall MoS_2 nanotube. Low-temperature measurements performed at 300 mK are dominated by the Coulomb blockade, with regular Coulomb oscillations and features of quantum confinement. In a perpendicular magnetic field, we observed a clear indications of quantum state transitions (*Phys. Status Solidi RRL* 2019, 1900251).

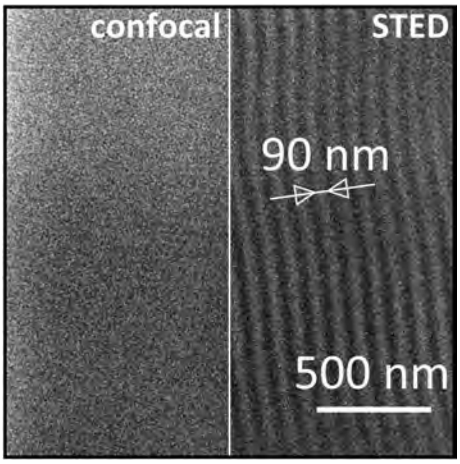

Figure 20: Comparison of structure images obtained using confocal (left) and STED microscopy (right).

MoS_2 nanotubes for the automotive industry

In collaboration with researchers from Austria and Poland, we investigated the feasibility of using MoS_2 nanotubes in the form tapping of zinc-coated automotive parts. The MoS_2 nanotubes are able to form a tribofilm on zinc-coated steel surfaces that results in torque reduction and the lowest sub-surface hardening. Sulfurized olefin polysulfide extreme pressure additive, which is currently widely spread in forming oils has a very good synergy with MoS_2 nanotubes in form tapping making them suitable candidates for being used in prospective formulations of the future nanofluid minimum quantity lubrication formulations (*Journal of Manufacturing Processes* 39, 167–180 (2019)).

Configurational ordering of polarons in superconducting layered crystal 1T-TaSeS

Many two-dimensional metal dichalcogenides including 1T-TaSeS exhibit different irregularly ordered and even amorphous self-assembled electronic structures that can be created and manipulated by short light pulses or by charge injection in addition to periodic charge density waves. In collaboration with the Complex Matter department we explained this behaviour with a sparsely filled charged lattice gas model (*New J. Phys* 21, 083001 (2019)). The computer simulations were supported by images of the surface of 1T-TaSeS taken using a Scanning Tunnelling Microscope. Moreover, we used Scanning Tunnelling Spectroscopy to show that the domain structure that spontaneously forms is not crucial for the existence of superconductivity in these samples.

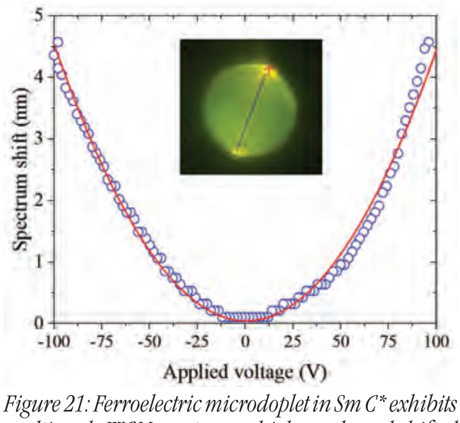

Figure 21: Ferroelectric microdoplet in Sm C exhibits multimode WGM spectrum which can be red-shifted with an applied electric field.*

Tuneable flat band in organic Kagome lattice

A Kagome lattice is expected to be a perfect platform for hosting exotic emergent phenomena such as negative magnetism and unconventional superconductivity. In this work we show how the geometrical frustration of a Kagome lattice leads to a zero probability for electrons to tunnel out of hexagons. When guest molecules are hosted in such a flat band, their states exhibit sharp features due to the localization of electron waves. These characteristics and the chemical tunability of organic Kagome offer a fertile playground to study emergent order in a well-defined system (*Physica Status Solidi* 2019, DOI: 10.1002/pssb.201900346).

Diffusive Memristive Switching on the Nanoscale

We studied the memristive action on the level of individual nanoparticles to find conditions for robust performance and unravel the underlying physical mechanism. Interestingly, we find that the application of alloy nanoparticles as a reservoir for mobile silver species effectively limits the formation of stable metallic filaments and results in reproducible diffusive switching characteristics. Notably, similar behaviour is encountered on macroscopic nanocomposite devices, which incorporate multiple stacks of nanoparticles and offer a high design versatility to tune switching properties and engineer scalable memristive devices with diffusive switching characteristics. No additional forming step is required for the memristive operation, which renders them very attractive for applications (*Sci Rep* 9, 17367 (2019), DOI: 10.1038/s41598-019-53720-2).

III. Research programme "Experimental biophysics of complex systems and imaging in biomedicine"

Based on recent findings on the adverse outcome pathways following the exposure to nanoparticles, we have developed a completely new market idea and set up a spin-out company, Infinite Ltd., to develop cellular sensory systems for predicting lung diseases.

The research programme *Experimental biophysics of complex systems and imaging in biomedicine* combines research of the processes and structures of biological systems by developing new, advanced experimental techniques of super-resolution microscopies, microspectroscopies and nanoscopies as well as new imaging techniques. Our research is mainly focused on the response of molecular and supramolecular structures to interactions between materials and living cells as well as between light and living cells. We are interested in molecular events and the physical mechanisms with which these events are causally connected, time scales, conditions and applied value of the investigated mechanisms, especially for use in medicine and in the field of health care in general. With the development of new coupled super-resolution and spectroscopic techniques we want to open new possibilities to investigate biological systems and from there onwards to open new possibilities for designing medical materials and devices, for diagnostics, therapy and tissue regeneration, representing key challenges due to the population aging. The investment into the new super-resolution STED system opened up variety of fluorescence microscopy approaches: STED microscopy and two-photon (2PE) microscopy, multichannel spectrally resolved fluorescence lifetime imaging (spFLIM), fluorescence microspectroscopy (FMS). These, coupled with optical tweezers, can be used to examine interactions between materials, nanomaterials and cell lines and the phenomena involved, such as lipid wrapping and nanomaterial passivation, membrane disintegration, and cellular membrane translocation bypassing conventional signalling pathways. We also introduced a method that enables monitoring of the electric field in tumours in the treatment of cancer with electroporation, and further developed a method of multiparametric magnetic resonance imaging for the characterization of food and medicines and various industrial processes. High-resolution magnetic resonance imaging can monitor the effectiveness of surface treatments, the formation and dissolution of gels as well as measure diffusion in confined geometries with the use of modulated gradients.

In 2018 we published an article in Nano Letters demonstrating the use of STED microscopy to directly observe the lipid wrapping of TiO_2 nanotubes in living lung epithelium, for the first time. In collaboration with David Gomez's group at UCD (Dublin, Ireland), which performed proteomic analysis of these lipid wraps, we demonstrated that there are key enzymes in the wraps that could trigger blood clots. That is why in 2019 we identified key cells of an *in vitro* system capable of reproducing and explaining how blood-clot formation occurs *in vivo* in cooperation with the laboratory of Rinku Majumder of LSUHSC School of Medicine (New Orleans, USA). This is the basis for the development of a hypothetical adverse outcome signalling pathway (AOP) and an *in vitro* cell-based system that could predict which nanoparticles could trigger thrombosis.

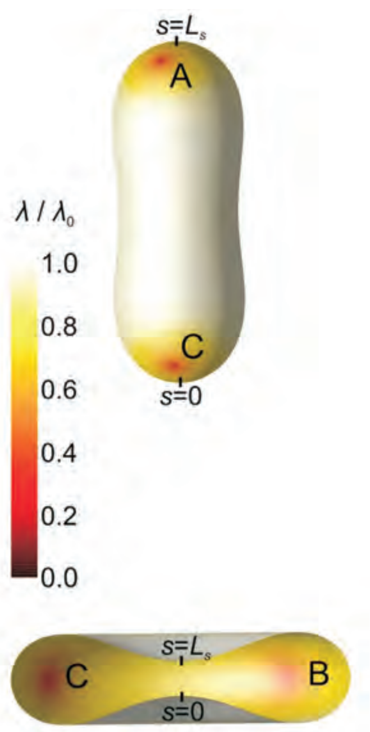

Figure 22: Prolate (top) and oblate (bottom) red-blood-cell shapes hosting topological defects.

A major breakthrough was made in 2019 with the discovery of a mechanism for triggering of chronic inflammation of the lung epithelium following single exposure to nanomaterials. STED and HIM microscopy (partly in collaboration with HZDR Dresden) revealed that epithelial cells passivate some nanomaterials on their surface, reducing the destructive effect of interactions between nanomaterials and various structures in cells (e.g., nucleus, actin networks, inner membranes; all observed by STED microscopy). Passivation can be achieved only by enhanced lipid synthesis (demonstrated by *in vitro* transcriptomics in collaboration with HGMU Munich and *in vivo* in collaboration with NRCWE Copenhagen and Health Canada) and excretion of nanomaterials-lipids agglomerates on the surface (demonstrated by STED microscopy). Unfortunately, immune cells, especially macrophages, recognize these aggregates as foreign matter and die while trying to degrade them. As a result, the material is again excreted into the space between the cells, which means that the circle closes - as the material is ready to be uptaken again by the epithelial cells. The circle repeats in a living system if dead macrophages are replaced by new ones, actually induced by the signalling of the epithelial cells. With modelling, we have shown that, in certain combinations of passivation, signalling and toxicity rates, a long-term (chronic) response to a single exposure is actually obtained. The paper is being prepared. At the same time, during the study of the mechanism, we identified certain techniques for detecting these events, based on which sensory systems can be made with the ability to predict disease states. We registered this knowledge with the IJS as hidden knowledge and founded a spin-out company Infinite Ltd.

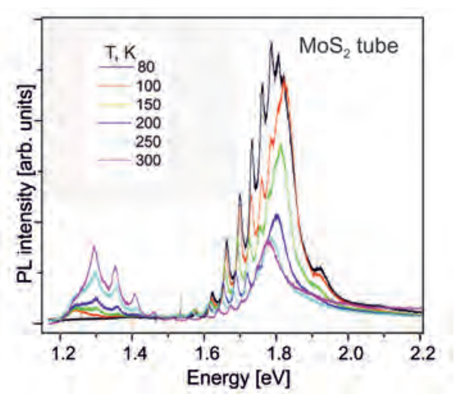

Figure 23: Temperature variation of micro photoluminescence spectra in MoS_2 tube of 2 μm in diameter.

In collaboration with the University of Oxford (UK), we have been developing advanced fluorescence microspectroscopic methods for the characterisation of local molecular environments. In particular, we greatly expanded the reliability and flexibility of super-resolution fluorescence

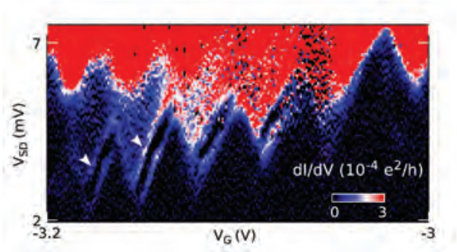

Figure 24: Discrete conductance resonances within the single-electron tunnelling regions. corresponding to an excitation energy of 500 μeV.

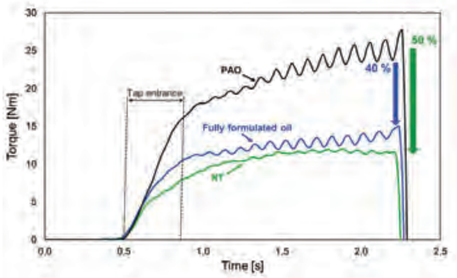

Figure 25: Torque as a function of time during tap entry for the threads formed using pure PAO oil, PAO with 5 wt.% MoS_2 nanotubes (NT) and reference fully formulated oil.

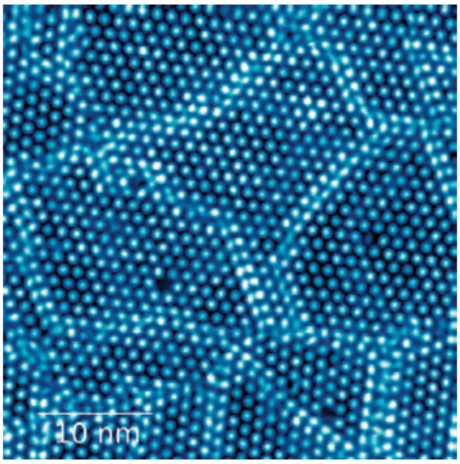

Figure 26: STM image of the surface of 1T-TaSeS exhibiting charge density wave domains separated by domain walls.

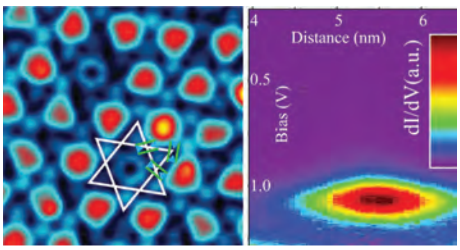

Figure 27: Molecular resolution STM image showing Kagome lattice of $(BETS)_2GaCl_4$. States of guest molecules are protected due to destructive interference on the frustrated lattice.

correlation spectroscopy (STED-FCS) by introducing adaptive optics to circumvent optical aberrations [1]. We shared our extensive expertise in STED-FCS in a comprehensive description of the method, published in *Nature Protocols* [2]. Using environment-sensitive dyes and other microspectroscopies, we also revealed that the molecular properties of biomembranes reflect their microscopic mechanical properties, which we reported in *Communications Biology* (by *Nature Publishing Group*) [3].

For efficient labelling we have investigated, synthesized and tested a series of new STED-able fluorophores where we specifically aim at very low bleaching rates to enable 3D time-lapse STED microscopy and tracking interactions in 3D. Few par-fluorophores for nano-temperature mapping have also been synthesized to allow temperature profiling in micro-boiling, an activity run in collaboration with prof. Golobič from the University of Ljubljana, Faculty of Mechanical Engineering.

Based on the experimental results achieved in the framework of the ARRS project (L7-7561) completed in 2019, we have developed a new methodology for the diagnosis of vascular leakage in ocular tissues and the detection of the pathological conditions on the retinal epithelium. For the purpose of the research, besides the concept, we developed and produced an advanced and cost-effective hyperspectral system based on the detection of tissue autofluorescence. In addition, part of the research aimed at hyperspectral detection of coagulation was summarized in a scientific paper (Podlipec *et al.*, *Journal of Biophotonics,* In submission).

As part of the another ongoing ARRS project (L2-9254), we conducted the first theranostics experiments with a time-based modular laser system developed at the Laboratory for Photonics and Laser Systems (FOLAS) on a real biological system. With the development of the laser system and its upgrade to our super-resolved STED microscope, we have successfully performed advanced diagnostics based on the detection of fluorescence lifetime on the ocular tissue, as well as therapeutics to the local target area. The essential results of the study were summarized in a scientific paper (Podlipec *et al.*, *Applied Physics A,* In submission).

Part of the research was also devoted to a new international project Crossing Borders and Scales (CROSSING) between the Jožef Stefan Institute (IJS) and the Helmholz-Zentrum Dresden Rossendorf (HZDR), where our group participates in the first of the four work packages covering the field of the correlative microscopy. We were able to acquire the first correlative images on the nanoscale combining optical super-resolution STED and helium-ion microscope (HIM) on the relevant biological sample of the nanoparticles interacting with the *in-vitro* pulmonary epithelium system. More results and publication of the results of the ongoing study is expected in 2020.

Use of magnetic resonance in the study of controlled-release polymer tablets

Controlled drug-delivery systems are widely used in the pharmaceutical industry because of their numerous advantages. For hydrophilic polymers, it is generally accepted that, once in contact with body fluids, they hydrate and swell, forming a gel layer that regulates the penetration of body fluids into the tablet and the dissolution of the incorporated drug. Therefore, the knowledge of the gel layer characteristics is of crucial importance for the use of controlled drug-delivery systems. Previous studies of xanthan tablets have shown the dependence of xanthan swelling and drug-release kinetics on the pH and ionic strength of the medium in which the tablet swells. The medium molecules and polymer-chain dynamics are very important for the drug release kinetics from hydrophilic matrix tablets, as these lead to constantly changing polymer-chain mesh sizes and distributions, which can change the diffusion pathways for the drug carried in the gel layers. The dynamic properties of the medium and the polymer molecules in xanthan gels at different xanthan concentrations were investigated by fast-field cycling NMR relaxometry. The study demonstrated faster medium dynamics in the more diluted xanthan gels than in those more concentrated. In addition, different media pHs also influenced the gel dynamics, with slower water and polymer-chain dynamics in the acid medium. The results were published in the article Urška Mikac, Ana Sepe, Anton Gradišek, Julijana Kristl, Tomaž Apih, "Dynamics of water and xanthan chains in hydrogels studied by NMR relaxometry and their influence on drug release", International journal of pharmaceutics, ISSN 0378-5173, 2019, 563, 373-383.

Measurement of cement-hydration dynamics by diffusion spectra

In the magnetic resonance imaging laboratory, we are examining different approaches to diffusion measurements in porous materials over a longer period of time. Our original contribution to science in this field is the development of a method for the measurement of diffusion spectra by means of modulated magnetic field gradients. In this way, unlike other groups, we use a constant gradient. This, when used in a combination with a multi-spin echo sequence, becomes effectively oscillating and thus enables the measurement of the diffusion constant at the frequency determined by the oscillation of the effective gradient. The method also has technical constraints associated with the frequency bandwidth of radio-frequency pulses. A few years ago, we showed how to circumvent these restrictions and confirmed the method on test samples; however, we did not yet show the practical aspect of this method. In a recent study published in: SERŠA, Igor. Sequential diffusion spectra as a tool for studying time-dependent translational molecular dynamics: a cement hydration study. *Molecules*. 2020, vol. 25, no. 1, pp. 68-1-68-15 the use of this method was presented to monitor the hydration of white cement.

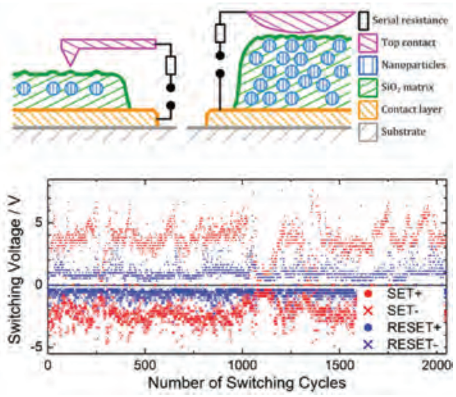

Figure 28: Measurements layout and the results of switching voltages as extracted from individual hysteresis loops for 2000 switching cycles in a SiO_2/AgPt/SiO_2 stack, measured by C-AFM on an individual AgPt nanoparticle.

Development of MRI methods for the diagnosis of malignant pleural mesothelioma

Diseases related to exposure to harmful asbestos are common in Slovenia. One of the worst forms of these is the pleural cancer known as malignant pleural mesothelioma. The treatment of patients with this disease is very demanding and good imaging diagnostic tools are needed to monitor its treatment. In this study, we have shown that magnetic resonance imaging using contrast agents can provide a good diagnostic tool. We analysed the dynamics of the accumulation of contrast agents using various existing pharmacokinetic models, determined their parameters, and then analysed their predicted value so that we compared the parameter values of the cancerous tissue with those of the healthy tissue. This study was also a doctoral thesis theme of the MPŠ PhD student Martina Vivoda Tomšič, who was successfully defended her PhD thesis in 2019 under the co-supervision of Prof. Dr. Igor Serša. Results of the study were published in a scientific article Martina Vivoda Tomšič, Sotirios Bisdas, Viljem Kovač, Igor Serša, Katarina Šurlan Popović, "Dynamic contrast-enhanced MRI of malignant pleural mesothelioma: a comparative study of pharmacokinetic models and correlation with mRECIST criteria", *Cancer imaging*. 2019, **19**, no. 1, 1-11.

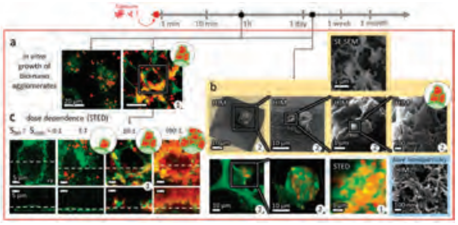

Figure 29: Passivation of TiO_2 nanotubes on the surface of lung epithelial cells. A) development of bionano agglomerates (left image 1h after nanoparticle exposure, right image 2 days after nanoparticle exposure, green and red colour code membranes and nanomaterial, respectively); B) different magnifications of bionano agglomerates on the surface of epithelial cells by STED (color coding same as for A), HIM and SEM microscopy; numbers 1 and 2 indicate two samples. C) dose dependence of bionano agglomerates formation - horizontal (upper row) and vertical (lower row) cross-sections obtained by STED microscopy, colour coding as in A.

Assessment of the caries of teeth *in vivo* by the use of T2 relaxation time mapping of dental pulps

Dental caries of patients is usually diagnosed by X-ray imaging. In a study on extracted teeth done a few years ago we demonstrated that magnetic resonance imaging (MRI) has a high potential for the evaluation of caries. This presence of caries can be detected by MRI in the demineralized region of the dentine and in dental pulp with changes in diffusion constants and T2 relaxational times. This study has now been repeated *in vivo* by measuring maps of T2 relaxation times in dental pulps of patients with caries and of healthy volunteers. We have shown that despite the low resolution of the obtained maps *in vivo* the method of T2 relaxation time mapping still enabled a good assessment of the degree of caries. These assessments gave comparable results with those obtained using the standard approach based on the international scale of caries (ICDAS). The results of this study were published in the article Ksenija Cankar, Jernej Vidmar, Lidija Nemeth, Igor Serša, "T2 mapping as a tool for assessment of dental pulp response to caries progression: in vivo MRI study", *Caries Research*, 2019, ISSN 0008-6568. DOI: 10.1159/000501901.

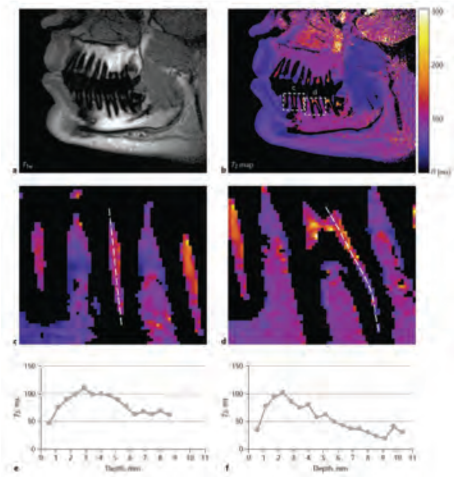

Figure 30: T1-weighted image (a) and the corresponding T2 map (b) of a representative patient's teeth in a sagittal slice. In the T2 map, two regions of interest (ROIs) are indicated by a dashed line, one is containing a single-rooted tooth and the other a molar. The magnified ROIs are shown in panels (c) and (d), respectively. (e), (f) Graphs of dental pulp T2 value depth profiles that were measured along a dashed line central to the dental pulp as indicated in the corresponding T2 maps of the ROIs.

MR Microscopy of cerebral blood clots as a tool for the assessment of thrombectomy outcome

The treatment of ischemic stroke, similar to the treatment of myocardial infarction, is shifting from the use of thrombolysis to the mechanical removal approach by using catheter devices, i.e., thrombectomy. The performance of thrombectomy strongly depends on the blood clot, its length, composition, the degree of retraction, etc. Many of these parameters cannot be determined from CT scans that are recorded before the treatment of patients. In this study, that was done with retrieved cerebral blood clots, we have shown that much more information on blood clots can be obtained by MRI, especially if it includes different imaging methods such as T1, T2 and ADC mapping. We also showed that there is a weak correlation between the duration of the clot removal and some of the parameters obtained from MR images of the clots. The results of this study were published in the article Jernej Vidmar, Franci Bajd, Zoran Miloševič, Igor Kocijančič, Miran Jeromel, Igor Serša, “Retrieved cerebral thrombi studied by T2 and ADC mapping preliminary results”, *Radiology and oncology,* 2019, **53**, no. 4, 427-233.

The research of our department has been supported by a number of international projects financed by the European Union. It was also supported within many bilateral projects and other scientific cooperations. In 2019, the Department had cooperations with 113 partners from Slovenia and abroad. Among them were the following institutions:

1. BASF, Heidelberg, Germany
2. Ben Gurion University, Beersheba, Israel
3. Chalmers University of Technology, Physics Department, Göteborg, Sweden
4. Clarendon Laboratory, Oxford, UK
5. Centre national de la recherché scientifique, Laboratory de Marseille, Marseille, France
6. Centre national de la recherché scientifique, Laboratoire de Spectrochimie Infrarouge et Raman, Thiais, France
7. Department of Chemistry, College of Humanities and Sciences, Nihon University, Tokyo, Japan
8. Deutsches Krebsforschungszentrum, Heidelberg, Germany
9. Deutsches Elektronen-Synchrotron, Hamburg, Germany
10. École Polytechnique Fédérale de Lausanne, Lozana, Switzerland
11. Eidgenössische Technische Hochschule - ETH, Zürich, Switzerland
12. Elettra (Synchroton Light Laboratory), Basovizza (Bazovica), Italy
13. European Synchrotron Radiation Facility, Grenoble, France
14. Facultad de Ciencia y Technologia, Universidad del Pais Vasco UPV/EHU, Leioa, Spain
15. Faculty of Physics, Adam Mickiewicz University, Poznanj, Poland
16. Florida State University, Florida, USA
17. Forschungszentrum Dresden Rossendorf, Dresden, Germany
18. Gunma National College of Technology, Maebashi, Japan
19. High-Magnetic-Field Laboratory, Grenoble, France
20. High Magnetic Field Laboratory, Nijmegen, Netherlands
21. High Magnetic Field Laboratory, Tallahassee, Florida, USA
22. Humboldt Universität Berlin, Institut für Biologie/Biophysik, Berlin, Germany
23. Illie Murguescu Institute of Physical Chemistry of the Romanian Academy, Bucharest, Romania
24. International Human Frontier Science Program Organisation, Strasbourg, France
25. Institut Ruđer Bošković, Zagreb, Croatia
26. Institut za Teoretično fiziko univerze v Göttingenu, Göttingen, Germany
27. Institute of Molecular Physics, Polish Academy of Sciences, Poznanj, Poland
28. Institute of Electronic Materials Technology, Warsaw, Poland
29. Institut für Experimentalphysik der Universität Wien, Vienna, Austria
30. Institut für Biophysik und nanosystemforschung OAW, Graz, Austria
31. Institut za kristalografijo Ruske akademije znanosti, Moscow, Russia
32. Instituto Superior Tecnico, Departamento de Fisica, Lisbon, Portugal
33. International Center for Theoretical Physics, Trieste, Italy
34. ISIS, Rutherford Appleton Laboratory, Didcot, UK
35. A.F. Ioffe Physico-Technical Institute, Saint Petersburg, Russia
36. Kavli Institute for Theoretical Physics, Santa Barbara, USA
37. King’s College, London, UK
38. University Medical Centre Ljubljana, Ljubljana, Slovenia
39. Korea Basic Science Institute, Daejeon, South Korea
40. Kyung Hee University of Suwon, Impedance Imaging Research Center, Seoul, South Korea
41. KTH Royal Institute of Technology, Stockholm, Sweden
42. KMZ - CNC obdelava kovin in drugih materialov Zalar Miran s.p., Ljubljana, Slovenia
43. Liquid Crystal Institute, Kent, Ohio, USA
44. Max Planck Institute, Dresden, Germany
45. Mayo Clinic, Rochester, Minnesota, USA
46. Merck KGaA, Darmstadt, Germany
47. MH Hannover, Hannover, Germany
48. National Academy of Sciences of Ukraine, Institute of Physics, Kiev, Ukraine
49. National Center for Scientific Research “Demokritos”, Aghia Paraskevi Attikis, Greece
50. National Institute for Research in Inorganic materials, Tsukuba, Japan

51. Vinča Institute of Nuclear Sciences, Beograd, Serbia
52. Oxford University, Department of Physics, Department of Materials, Oxford, UK
53. Paul Scherrer Institut, Villigen, Switzerland
54. Politecnico di Torino, Dipartimento di Fisica, Torino, Italy
55. Radbound University Nijmegen, Research Institute for Materials, Nijmegen, Netherlands
56. Rwth Aachen University, Aachen, Germany
57. School of Physics, Hyderabad, Andhra Prades, India
58. SISSA, Trieste, Italy
59. State College, Pennsylvania, USA
60. Faculty of Medicine of the University of Rijeka, Rijeka, Croatia
61. University of Zagreb, Institute of Physics , Zagreb, Croatia
62. Technical University of Catalonia, Barcelona, Spain
63. Technical University Vienna, Vienna, Austria
64. The Geisel School of Medicine at Dartmouth, Hanover, USA
65. The Max Delbrück Center for Molecular Medicine in Berlin, Berlin, Germany
66. Tohoku University, Sendai, Japan
67. Tokyo University, Bunkyo, Tokyo, Japan
68. University of Aveiro, Aveiro, Portugal
69. Universita di Pisa, Dipartimento di Chimica e Chimica Industriale, Pisa, Italy
70. Université de Picardie Jules Verne, Amiens, France
71. Université de la Méditerranée, Marseille, France
72. University of Bristol, Bristol, UK
73. University of California at Irvine, Beckman Laster Institute and Medical Clinic, Irvine, California, USA
74. University of Durham, Durham, UK
75. University of Duisburg, Duisburg, Germany
76. University of Innsbruck, Innsbruck, Austria
77. Universität Freiburg, Institut für Makromolekulare Chemie, Freiburg, Germany
78. University of Linz, Institute of Chemistry, Department of Physical Chemistry & Linz Institute of Organic Solar Cells, Linz, Austria
79. University of Leeds, Leeds, UK
80. University of Loughborough, Loughborough, UK
81. Universität Mainz, Geowissenschaften, Mainz, Germany
82. Université de Nice, Nica, France
83. Université Paris Sud, Paris, France
84. University of Provence, Marseille, France
85. University of Tsukuba, Tsukuba, Ibaraki, Japan
86. University of Utah, Department of Physics, Salt Lake City, Utah, USA
87. University of Waterloo, Department of Physics, Waterloo, Ontario, Canada
88. Universität Regensburg, Regensburg, Germany
89. University of Zürich, Zürich, Switzerland
90. Univerza v Münchenu in MPQ, München, Germany
91. University of Mons, Mons, Belgium
92. Univerza v Pavii, Pavia, Italy
93. University of Maribor, Maribor, Slovenia
94. University of North Carolina, Chapel Hill, USA
95. University of Wisconsin, Madison, USA
96. Wagenigen University, Laboratory of Biopyhsics, Wageningen, Netherlands
97. Weizman Institute, Rehovot, Israel
98. Yonsei University, Seoul, South Korea

that made the reported studies possible.

Some outstanding publications in 2019

1. M. Gomilšek, R. Žitko, M. Klanjšek, M. Pregelj, C. Baines, L. Yuesheng, Q. Zhang, A. Zorko, *Kondo screening in a charge-insulating spinon metal.* Nature Physics **15** (2019) 754.
2. A. Matavž, A. Benčan, J. Kovač, C.C. Chung, J.L. Jones, S. Trolier-McKinstry, B. Malič, V. Bobnar, *Additive manufacturing of ferroelectric-oxide thin-film multilayer devices*. ACS Applied Materials & Interfaces **11** (2019) 45155.

3. B. Senyuk, J. Aplinc, M. Ravnik, I. I. Smalyukh, High-order elastic multipoles as colloidal atoms. Nature Communications **10** (2019) art. no. 1825, doi: 10.1038/s41467-019-09777-8.
4. S. Čopar, J. Aplinc, Ž. Kos, S. Žumer, M. Ravnik, Topology of three-dimensional active nematic turbulence confined to droplets. Physical Review X **9** (2019) 031051-1-031051-13,
5. J. Pollard, G. Posnjak, S. Čopar, I. Muševič, G. P. Alexander. Point defects, topological chirality and singularity theory in cholesteric liquid-crystal droplets. Physical Review X **9** (2019) 021004-1-021004-19,
6. A. P. Almeida, J. Canejo, U. Mur, S. Čopar, P. Almeida, S. Žumer. M. H. Godinho, Spotting plants´ microfilament morphologies and nanostructures. Proceedings of the National Academy of Sciences of the United States of America **116** (2019) 13188-13193.
7. T. Emeršič, R. Zhang, Ž. Kos, S. Čopar, N. Osterman, J. J. de Pablo, U. Tkalec, Sculpting stable structures in pure liquids. Science Advances **5** (2019) art. no. eaav4283.
8. E. Sezgin, F. Schneider, S. Galiani, I. Urbančič, D. Waithe, B. Lagerholm, B. Christoffer, Ch. Eggeling, Measuring nanoscale diffusion dynamics in cellular membranes with super-resolution STED-FCS, Nature protocols 14 (2019) 1054–1083.
9. J. Steinkühler, E. Sezgin, I. Urbančič, Ch. Eggeling, R. Dimova, Mechanical properties of plasma membrane vesicles correlate with lipid order, viscosity and cell density, Communications Biology 2 (2019) 337–1–337–8.

Some outstanding publications in 2018

1. N. Janša, A. Zorko, M. Gomilšek, M. Pregelj, K.W. Krämer, D. Biner, A. Biffin, C. Rüegg, M. Klanjšek. Observation of two types of fractional excitation in the Kitaev honeycomb magnet. *Nature Physics* **14**, (2018), 786-790.
2. P. Adler, P. Jeglič, T. Knaflič, M. Komelj, D. Arčon, et al. Verwey-type charge ordering transition in an open-shell p-electron compound. *Science Advances* 4, (2018), eaap7581.
3. S. Gao, S. Vrtnik, J. Luzar, et al. Dipolar spin ice states with a fast monopole hopping rate in $CdEr_2X_4$ (X=Se, S). *Physical Review Letters* **120** (2018), 137201.
4. Yu.O. Zagorodniy, B. Zalar et al. Chemical disorder and ^{207}Pb hyperfine fields in the magnetoelectric multiferroic $Pb(Fe_{1/2}Sb_{1/2})O_3$ and its solid solution with $Pb(Fe_{1/2}Nb_{1/2})O_3$. *Physical Review Materials* **2** (2018), 014401.
5. J. Dolinšek. Electronic transport properties of complex intermetallics. *Crystal growth of intermetallics*, Eds. P. Gille, Yu. Grin (Berlin: De Gruyter, 2018), 260-278.
6. Pramanick, A., Dmowski, W., Egami, T.I, Setiadi Budisuharto, A., Weyland, F., Novak, N., Christianson, A., Borreguero, J. M., Abernathy, D., Jørgensen, M. R. V.. Stabilization of Polar Nanoregions in Pb-free Ferroelectrics. *Physical Review Letters* **120** (2018), 207603.
7. Guillamat, Pau, Kos, Žiga, Hardoüin, Jérôme, Ignés-Mullol, Jordi, Ravnik, Miha, Sagués, Francesc. Active nematic emulsions. *Science Advances* 4 (2018), 2375-2548.
8. Urbančič, Iztok, Garvas, Maja, Kokot, Boštjan, Majaron, Hana, Umek, Polona, Škarabot, Miha, Arsov, Zoran, Koklič, Tilen, Čeh, Miran, Muševič, Igor, Štrancar, Janez, et al. Nanoparticles can wrap epithelial cell membranes and relocate them across the epithelial cell laye. *Nano Letters* **18** (2018), 5294-5305.
9. Aničić, Nemanja, Vukomanović, Marija, Koklič, Tilen, Suvorov, Danilo. Fewer defects in the surface slows the hydrolysis rate, decreases the ROS generation potential, and improves the Non-ROS antimicrobial activity of MgO. *Small* **14** (2018), 1800205.
10. Santos, Ana Mafalda, Urbančič, Iztok, et al. Capturing resting T cells: the perils of PLL. *Nature Immunology* **19** (2018), 203-205.

Some outstanding publications in 2017

1. M. Klanjšek, A. Zorko, R. Žitko, J. Mravlje, Z. Jagličić, P.K. Biswas, P. Prelovšek, D. Mihailović, D. Arčon. A high-temperature quantum spin liquid with polaron spins. *Nature Physics* 13 (2017), 1130–1134.
2. Y. Takabayashi, M. Menelaou, H. Tamura, N. Takemori, T. Koretsune, A. Štefančič, G. Klupp, A.J.C. Buurma, Y. Nomura, R. Arita, D. Arčon, M.J. Rosseinsky, K. Prassides. π-electron $S = 1/2$ **quantum spin-liquid state in an ionic polyaromatic hydrocarbon.** *Nature Chemistry* 9 (2017), 635–643.
3. B. Rožič, J. Fresnais, C. Molinaro, J. Calixte, S. Umadevi, S. Lau-Truong, N. Felidj, T. Kraus, F. Charra, V. Dupuis, T. Hegmann, C. Fiorini-Debuisschert, B. Gallas, E. Lacaze. Oriented gold nanorods and gold nanorod chains within smectic liquid crystal topological defects. *ACS Nano* 11 (2017), 6728–6738.
4. A. Zorko, M. Herak, M. Gomilšek, J. van Tol, M. Velázquez, P. Khuntia, F. Bert, P. Mendels. Symmetry reduction in the quantum Kagome antiferromagnet Herbertsmithite. *Physical Review Letter* 118 (2017), 017202.

5. M. Gomilšek, M. Klanjšek, R. Žitko, M. Pregelj, F. Bert, P. Mendels, Y. Li, Q. M. Zhang, A. Zorko. Field-induced instability of a gapless spin liquid with a spinon Fermi surface. *Physical Review Letter* 119 (2017), 137205.
6. L. Giomi, Ž. Kos, M. Ravnik, and A. Sengupta. Cross-talk between topological defects in different fields revealed by nematic microfluidics. *Proceedings of the National Academy of Sciences of the United States of America* 114 (2017), E5771-E5777.
7. S. M. Hasheimi, U. Jagodič, M. R. Mozaffari, M. R. Ejtehadi, I. Muševič, and M. Ravnik, Fractal nematic colloids. *Nature Communications* 8 (2017), 12106.
8. G. Posnjak, S. Čopar and I. Muševič. Hidden topological constellations and polyvalent charges in chiral nematic droplets. *Nature Communications* 8 (2017), 14594.
9. A. Nych, Jun-ichi Fukuda, U. Ognysta, S. Žumer, I. Muševič. Spontaneous formation and dynamics of half-skyrmions in a chiral liquid-crystal film. *Nature Physics* 13 (2017), 1215.
10. E. Sezgin, F. Schneider, V. Zilles, I. Urbančič, E. Garcia, D. Waithe, A.S. Klymchenko, C. Eggeling. Polarity-Sensitive Probes for Superresolution Stimulated Emission Depletion Microscopy. *Biophysical Journal* 113 (2017), 1321-1330.
11. M. Kranjc, S. Kranjc,F. Bajd, G. Serša, I. Serša, D. Miklavčič. Predicting irreversible electroporation-induced tissue damage by means of magnetic resonance electrical impedance tomography. *Scientific Reports* 7 (2017*)*, 1-10.

Awards and Appointments

1. Dr Nych Andriy, Fukuda Jun-ichi, Ognysta Uliana, Prof. Žumer Slobodan, PhD, and Prof. Muševič Igor, PhD: award for the best paper published in 2018 in the field of liquid crystals, “Spontaneous formation and dynamics of half-skyrmions in a chiral liquid-crystal film”, Tsukuba, Ibaraki , Japan, The Japanese Liquid Crystal Society
2. Prof. Arčon Denis, PhD: The Žiga Zois Prize for outstanding scientific achievements in the field of quantum magnetism and unusual superconductivity, Ljubljana, awarded by the Republic of Slovenia
3. Gačnik Darja, MPhys: the award for the best oral presentation in the young scientists’ category, “Superconductivity in Ti–Zr–Hf–(Sn,Ni,Nb) high-entropy alloys”, Dresden, Germany, European C-MetAC Days 2019
4. Dr Jelen Andreja: the award for the best poster, “Microstructure and magnetic properties of a single-crystalline FeCoCrMnAl high-entropy alloy”, Kranjska Gora, The 14th International Conference on Quasicrystals (ICQ14)
5. Dr Klanjšek Martin: The Blinc Award for Extraordinary One-time Achievements for proving the existence of unusual quasiparticles called anyons, Ljubljana, Faculty of Mathematics and Physics, University of Ljubljana and Jožef Stefan Institute
6. Dr Koželj Primož: Golden Emblem Prize for his doctoral thesis with the highest impact in Slovenia and abroad, “Physical properties of high-entropy alloys and their Missing words
7. Assoc. Prof. Ravnik Miha: Žiga Zois Award for outstanding achievements in the field of soft-matter physics, Ljubljana, awarded by the Republic of Slovenia
8. Dr Rožič Brigita: Fulbright grant for her excellent scientific and research work and congratulations of the President of the United States of America, Ljubljana, the US Embassy in Ljubljana as part of the Fulbright programme financed by the US government
9. Prof. Žumer Slobodan, PhD: Frederiks medal for outstanding achievements in the theory of liquid crystals and related materials, Wrocslaw, Poland, Russian Liquid Crystal Society

Organization of conferences, congresses and meetings

1. Expert Meeting of Laboratory of Biophysics, Zelenica, 27–28 May 2019
2. The 14th International Conference on Quasicrystals (ICQ14), Kranjska Gora, 26–31 May 2019

Patent granted

1. Andraž Rešetič, Jerneja Milavec, Blaž Zupančič, Boštjan Zalar
   Polymer dispersed liquid crystal elastomers (PDLCE)
   EP3119855 (B1), European Patent Office, 19. 06. 2019.

INTERNATIONAL PROJECTS

1. MERCK - AFM Investigations
   Prof. Miha Škarabot
   Merck Kgaa
2. Double-Beam Laser Interferometer Measurement
   Prof. Vid Bobnar
   Tdk Electronics Gmbh & Co Og
3. CROSSING - Crossing Borders and Scales - An Interdisciplinary Approach
   Prof. Janez Štrancar
   Helmholtz-zentrum Dresden-rossendorf E.v.
4. Small Services
   Dr. Polona Umek
5. EPR Measurements
   Prof. Denis Arčon
6. Irradiation and Analysis of Nano SiC Samples in the Year 2019
   Prof. Vid Bobnar
   Institute of Radiation Problems of the Academy of Sciences of Azerbaijan
7. 7 FP; ERA CHAIR ISO-FOOD - Era Chairs for Isotope Techniques in Food Quality, Safety and Traceability
   Prof. Maja Remškar
   European Commission
8. COST CA15107; Multi-Functional Nano-Carbon Composite Materials Network
   Dr. Polona Umek
   Cost Office
9. COST CA15209; European Network on NMR Relaxometry
   Prof. Tomaž Apih
   Cost Office
10. COST CA16109; Chemical On-Line Composition and Source Apportionment of Fine Aerosol
    Asst. Prof. Griša Močnik
    Cost Office
11. COST CA16218; Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies
    Dr. Abdelrahim Ibrahim Hassanien
    Cost Association Aisbl
12. COST CA16221; Quantum Technologies with Ultra-Cold Atoms
    Dr. Peter Jeglič
    Cost Association Aisbl
13. COST CA17121; Correlated Multimodal Imaging in Life Sciences
    Prof. Janez Štrancar
    Cost Association Aisbl
14. COST CA17139; European Topology Interdisciplinary Action
    Prof. Slobodan Žumer
    Cost Association Aisbl
15. COST CA16202; International Network to Encourage the Use of Monitoring and Forecasting Dust Products
    Asst. Prof. Griša Močnik
    Cost Association Aisbl
16. H2020 - SmartNanoTox; Smart Tools for Gauging Nano Hazards
    Prof. Janez Štrancar
    European Commission
17. H2020 - ENGIMA; Engineering of Nanostructures with Giant Magneto-Piezoelectric and Multicaloric Functionalities
    Prof. Zdravko Kutnjak
    European Commission
18. Superconductivity and Magnetism: Two Faces of Electron Correlations in Carbon- and Fe-Based Superconductors
    Prof. Denis Arčon
    Slovenian Research Agency
19. Transport and Field Emission Properties of Low-Dimensional Molybdenum and Tungsten Based Nanomaterials
    Prof. Maja Remškar
    Slovenian Research Agency
20. Testing Biocompatibility of Molybdenum and Tungsten based Nanoparticles: Measuring Cytotoxicity and Inflammatory Response in Human Cell Lines
    Prof. Maja Remškar
    Slovenian Research Agency
21. The Lipid-Peroxidation Inhibition Governed by Interactions between Nanocarried Flavonoids and Model Lipid Membranes
    Prof. Janez Štrancar
    Slovenian Research Agency
22. Dynamic Hysteresis in the Study of Magnetic Nanoparticle Efficacy for Hyperthermia Therapy
    Prof. Janez Dolinšek
    Slovenian Research Agency
23. Conservation of Cultural Heritage Indoors - The Case of Leonardo da Vinci's „Last Supper"
    Asst. Prof. Griša Močnik
    Slovenian Research Agency
24. Lipid Wrapped Nanoparticles and Activity of Factor Xa
    Dr. Tilen Koklič
    Slovenian Research Agency
25. Studies of Nanoporous Materials for Hydrogen Storage
    Prof. Janez Dolinšek
    Slovenian Research Agency
26. Magnetoresonance Study of Spin-Liquid Candidates
    Asst. Prof. Andrej Zorko
    Slovenian Research Agency
27. Advanced Organic and Inorganic Thin-Film Composites with Enhanced Dielectric and Electromechanical Response
    Prof. Zdravko Kutnjak
    Slovenian Research Agency

RESEARCH PROGRAMMES

1. Magnetic resonance and dielectric spectroscopy of „smart" new materials
   Prof. Janez Dolinšek
2. Physics of Soft Matter, Surfaces and Nanostructures
   Prof. Slobodan Žumer
3. Experimental Biophysics of Complex Systems
   Prof. Janez Štrancar

R & D GRANTS AND CONTRACTS

1. Sensor technologies in diagnostics and monitoring of cultural heritage buildings
   Prof. Janez Dolinšek
2. Electroporation-based treatments with new high-frequency electroporation pulses
   Prof. Igor Serša
3. Reconstruction of electrical conductivity of tissues by means of magnetic resonance techniques
   Prof. Igor Serša
4. Correlated electrons in cnofined molecular systems
   Prof. Denis Arčon
5. High-resolution optical magnetometry with cold cesium atoms
   Dr. Peter Jeglič
6. Integrated multi-channel artificial nose for vapor trace detection
   Prof. Igor Muševič
7. Probing spin states near the surface of quantum spin materials
   Prof. Denis Arčon
8. Advanced soft nematocaloric materials
   Dr. Brigita Rožič
9. Multicaloric cooling
   Prof. Zdravko Kutnjak
10. Optimization of MRI techniques for assessment of thrombolytic treatment outcome
    Prof. Igor Serša
11. Intracellular lasers: Coupling of optical resonances with biological processes
    Asst. Prof. Matjaž Humar
12. Study of intracellular forces by deformable photonic droplets
    Asst. Prof. Matjaž Humar
13. Electrocaloric elements for active cooling of electronic circuits
    Prof. Vid Bobnar
14. Advanced inorganic and organic thin films with enhanced electrically-induced response
    Prof. Vid Bobnar
15. Adverse outcome pathway leading to atherosclerosis
    Dr. Tilen Koklič
16. Performance of wood and lignocelolosic composites in outdoor applications
    Prof. Igor Serša
17. Advanced electrocaloric energij conversion
    Prof. Zdravko Kutnjak
18. Biopharmaceuticals: sensor for aggregation of protein particles based on liquid crystals
    Prof. Miha Ravnik
19. Spatial and temporal shaping of laser light for minimally invasive ophthalmic procedures
    Prof. Janez Štrancar
20. Microspectroscopy-based optimization of the effects of laser pulses on the retina
    Prof. Janez Štrancar
21. Domain engineered ferroelectric ceramic layer elements for efficient energy harvesting and energy conversion applications
    Prof. Zdravko Kutnjak
22. Building blocks, tools and systems for the Factories of the Future – GOSTOP
    Prof. Janez Štrancar
    Ministry of Education, Science and Sport
23. Conference ICQ14, International Conference on Quasicrystals, Kranjska Gora, Slovenia, 26. - 31. 05. 2019
    Prof. Janez Dolinšek

NEW CONTRACT

1. AerOrbi - Aerosol soft photo ionisation Orbitrap mass spectrometry
   Asst. Prof. Griša Močnik
   Aerosol d. o. o.

VISITORS FROM ABROAD

1. Prof. Tanigaki Katsumi, Tohoku University, Materials Physics & Nano Solid-State Physics, Sendai, Japan, 12–14 February 2019
2. Takuma T., Tohoku University, Materials Physics & Nano Solid-State Physics, Sendai, Japan, 12 February–23 March 2019
3. Prof. Stępień Ewa, Jagiellonian University, Medical Physics, Krakow, Poland, 18–23 February 2019
4. Dr Belhadi Jamal, Université de Picardie Jules Verne, Amiens, France, 21 February–1 March 2019
5. Prof. Sebastião Pedro, PhD, Instituto Superior de Ciências Sociais e Políticas, Lisbon, Portugal, 22. February–2 March 2019
6. Dr Salopek Branka, Institut Ruđer Bošković, Zagreb, Croatia, 4 March 2019
7. Dr Majhen Dragomira, Nestić Davor, Božinović Ksenija and De Bisschop Lenn, Institut Ruđer Bošković, Zagreb, Croatia, 18 March 2019
8. Prof. Rasing Theo, PhD, Radboud University, Nijmegen, The Netherlands, 19–30 March 2019
9. Miller Zachary, University of Missouri, Columbia, USA, 24–30 March 2019
10. Dr Hae Jin Kim, Korea Basic Science Institute, Daejeon, South Korea, 31 May–4 June 2019
11. Benyoussef Manal, Université de Picardie Jules Verne, Amiens, France, 7–28 June 2019
12. El Marssi Mimoun, Université de Picardie Jules Verne, Amiens, France, 29 June–12 July 2019
13. Nestić Davor, Institut Ruđer Bošković, Zagreb, Croatia, 1–5 July 2019
14. Dr Šegota Suzana and Sadžak Anja, Institut Ruđer Bošković, Zagreb, Croatia, 1–5 July 2019
15. Dr Majhen Dragomira, Institut Ruđer Bošković, Zagreb, Croatia, 9 July 2019
16. Zouhair Hanani, Cadi Ayyad University, Marrakesh, Morocco, 20 July–5 August 2019
17. Prof. Amjoud M'barek, PhD, Cadi Ayyad University, Marrakesh, Morocco, 15 July–13 August 2019
18. Prof. Mezzane Daoud, Cadi Ayyad University, Marrakesh, Morocco, 14 July–31 August 2019
19. Prof. Abdelhadi Alimousa, PhD, Cadi Ayyad University, Marrakesh, Morocco,14–28 July 2019
20. Ivanchenkov Serhii, Nanotechcenter Llc, Kiev, Ukraine, 1–31 August 2019 and 14 November–21 December 2019
21. Assist. Prof. Huettel Andreas K., University of Regensburg, Regensburg, Germany, 20 August 2019 and 14–18 November 2019
22. Merselmiz Soukaina, Cadi Ayyad University, Marrakesh, Morocco, 1–31 August 2019
23. Drożdż Anna, Smoluchowski Institute of Physics, Kracow, Poland, 1–30 September 2019
24. Xiaoxuan Wang, School of Biological Sciences & Medical Engineering, Southeast University, Nanjing, China, 1 September –30 November 2019
25. Acosta Selena, University of Mons, Mons, Belgium, 9–25 October 2019
26. Igarashi Mutsuo, Gunma National College of Technology, Maebashi, Japan, 2–7 November 2019
27. Lushnikov Sergey, Ioffe Physical Technical Institute, Saint Petersburg, Russia, 4 November–22 December 2019
28. Bakış Doğru, Koc University, Istanbul, Turkey, 3–16 November 2019
29. Ferrero Luca, Università degli Studi di Milano-Bicocca, Milan, Italy, 3–6 November 2019
30. El Marssi Mimoun, Université de Picardie Jules Verne, Amiens, France, 13–16 December 2019
31. Dr Spasojević Vojislav and Bošković Marko, Institut Ruđer Bošković, Zagreb, Croatia, 18–21 December 2019

STAFF

Researchers

1. Prof. Tomaž Apih
2. Prof. Denis Arčon*
3. Asst. Prof. Zoran Arsov*
4. *Asst. Prof. Zoran Arsov, left 01.04.19*
5. Prof. Vid Bobnar
6. Prof. Janez Dolinšek*
7. Asst. Prof. Anton Gradišek
8. Dr. Alan Gregorovič
9. Abdelrahim Ibrahim Hassanien, B. Sc.
10. Asst. Prof. Matjaž Humar
11. Dr. Peter Jeglič
12. Dr. Martin Klanjšek
13. Dr. Tilen Koklič
14. Prof. Samo Kralj*
15. Prof. Zdravko Kutnjak
16. Dr. Mojca Urška Mikac
17. Asst. Prof. Griša Močnik*
18. Asst. Prof. Aleš Mohorič*
19. **Prof. Igor Muševič*, Head**
20. Dr. Andriy Nych
21. Asst. Prof. Stane Pajk*
22. Asst. Prof. Dušan Ponikvar*
23. Dr. Matej Pregelj
24. Prof. Miha Ravnik*
25. Prof. Maja Remškar
26. Dr. Brigita Rožič
27. Prof. Igor Serša
28. Prof. Miha Škarabot
29. Prof. Janez Štrancar
30. Asst. Prof. Uroš Tkalec*
31. Dr. Polona Umek
32. Dr. Herman Josef Petrus Van Midden
33. Asst. Prof. Andrej Vilfan
34. Dr. Stanislav Vrtnik
35. Prof. Boštjan Zalar
36. Prof. Aleksander Zidanšek
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