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 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 the one hand, 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 magnetic resonance and magnetic resonance imaging, optical microscopy and imaging, scanning tunnelling, electronic and atomic force microscopy, as well as cold atoms and quantum technologies.

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 Jožef Stefan International Postgraduate School. In 2020, the research was performed within three research programs:

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

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

The research of the programme group *Magnetic Resonance and Dielectric Spectroscopy of New Smart Materials* in 2020 was focused on physical phenomena in condensed matter at the atomic and molecular levels. The purpose of the investigations was to discover the basic laws of physics governing the behaviour of the investigated systems. The attained knowledge provides a key to the understanding of the microscopic and macroscopic properties of various types of solids and is an important condition for the discovery and development of new multifunctional materials and nanomaterials for novel technological applications.

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 group has observed asperomagnetism in high-entropy alloys, determined the quantum critical point in Ce_3Al, investigated the surface quantum properties of topological insulators via the detection of Dirac electrons, developed thick piezoelectric HfO_2-based films, investigated the relation between dielectric and electrocaloric response in relaxor ferroelectrics, observed soliton waves in matter by the method of ultra-cold atoms and contributed importantly to the understanding of quantum and topological magnetism.

The research programme was performed 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 2020 the members of the programme group published 65 original scientific papers in international peer-reviewed scientific journals and one book chapter. Among these, one paper was published in Nature Physics (IF = 19.2), one in Nature Communications (IF = 12.1), one in Angewandte Chemie, Intl. Ed. (IF = 12.9), one in Physical Review Letters (IF = 8.4) and one in Advanced Materials (IF = 27.4).

The investigations were focused on the following research fields:

1. Speromagnetism and asperomagnetism in the Tb-Dy-Ho-Er-Tm high-entropy alloy

In the paper "Speromagnetism and asperomagnetism as the ground states of the Tb-Dy-Ho-Er-Tm IDEAL high-entropy alloy" by M. Krnel, *et al*., Intermetallics **117**, 106680 (2020), we addressed the nature of the collective magnetic state in an ideal high-entropy alloy (HEA) based on rare-earth (RE) elements, representing a magnetically concentrated system with all the lattice sites occupied by localized magnetic moments and containing randomness and frustration due to chemical disorder. Being a "metallic glass on a topologically ordered lattice", HEAs possess simultaneously the properties of an ordered crystal and an amorphous glass. The influence of this crystal-glass duality on the collective magnetic state was studied experimentally on a hexagonal Tb-Dy-Ho-Er-Tm (TDHET) HEA, composed of RE elements with zero pair mixing enthalpies that ensure completely random mixing of the elements and very similar atomic radii that minimize lattice distortions, representing a prototype of an ideal HEA. The TDHET HEA is characterized by probability distributions of the atomic moments $P(\mu)$, the exchange interactions $P(J)$, the magnetocrystalline anisotropy $P(D)$, and the dipolar interactions $P(H_d)$. Based on measurements of the static and dynamic magnetizations, the magnetization $M(H)$ curves (Fig. 1), the thermo-remanent magnetization, the specific heat and the magnetoresistance, we found that the collective magnetic state of the TDHET is temperature dependent, forming a speromagnetic (SPM) state in the temperature range between about 140 and 30 K and an asperomagnetic (ASPM) state below 20 K. In the intermediate temperature range between 30 and 20 K, a spin glass (SG) state is formed, representing a transition state between the speromagnetic and asperomagnetic states. The observed temperature evolution of the magnetic ground state in the TDHET HEA upon cooling in the sequence SPM→SG→ASPM is a result of temperature-dependent, competing magnetic interactions. The distribution of the exchange interactions P(J) shifts continuously on the J axis from the high-temperature SPM-type with the average interaction biased towards a net negative value, $\bar{J}<0$, through the SG-type with $\bar{J}=0$, to the low-temperature ASPM-type with $\bar{J}>0$. This shift is a band-structure effect, closely linked with the crystallinity of the spin system, which the TDHET HEA shares with the topologically ordered crystals. The probability distributions $P(\mu)$, $P(J)$, $P(D)$, and $P(H_d)$ are, on the other hand, a consequence of the chemical disorder, a property that the TDHET HEA shares with amorphous magnets. Both features, the topologically ordered lattice and the amorphous-type chemical disorder, essentially determine the magnetic state of an ideal, RE-based HEA.

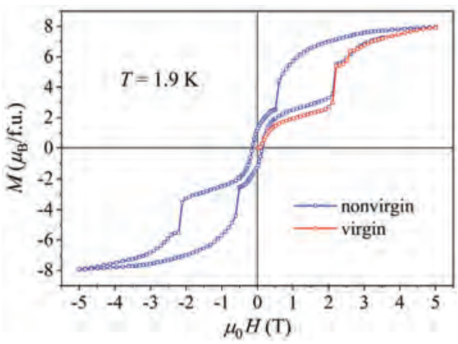

Figure 1: Complicated magnetization versus the magnetic field curve of the TDHET HEA, revealing the interplay of the speromagnetic and asperomagnetic spin ordering.

2. Anisotropic quantum critical point in Ce_3Al

In the paper "Anisotropic quantum critical point in the Ce_3Al system with a large magnetic anisotropy" by S. Vrtnik, *et al*., J. Phys. Commun. **4**, 105016 (2020), we studied experimentally the magnetic field driven quantum critical point (QCP) in the Ce_3Al magnetically anisotropic intermetallic compound, which shows both antiferromagnetic (AFM) ordering and heavy-fermion behaviour. Measurements of the magnetic susceptibility, the magnetoresistance and the specific heat on a Ce_3Al monocrystalline sample performed down to 0.35 K in magnetic fields up to 9 T demonstrate that the QCP is anisotropic regarding the orientation of the magnetic field relative to the magnetically easy direction (Fig. 2). An external magnetic field drives the AFM transition continuously towards zero temperature when applied in the (*a*,*b*) easy plane, reaching the QCP at the critical field $B_c^{a,b} = 4.6 \pm 0.4$ T, where a quantum phase transition from the AFM to the paramagnetic state takes place. The magnetoresistance experiments below 1 K indicate that intermediate magnetic states might have formed near the QCP. For the field applied along the *c* hard direction, the QCP has not been observed within our experimental range of the magnetic field. The anisotropic, magnetic field driven QCP in the Ce_3Al results from competition of the exchange interaction with the Zeeman interaction in the presence of a large magnetocrystalline anisotropy. The anisotropy of the QCP is a consequence of the fact that the magnetic anisotropy locks the magnetization into the easy plane and cannot be pulled out of the plane by the field available in the laboratory. Consequently, only the component of the magnetic field vector that lies in the easy plane participates in the QCP formation. In AFM systems with a large magnetic anisotropy, the magnetic field driven QCP is a continuous variable of the magnetic field's vector orientation relative to the easy direction.

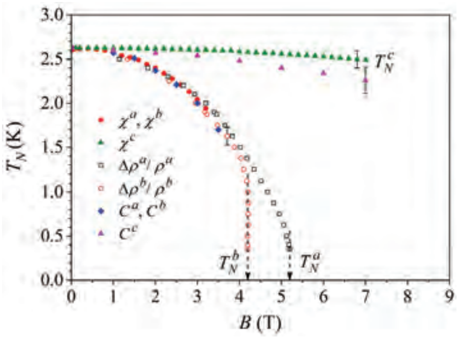

Figure 2: Anisotropic Néel temperatures $T_N^{(a,b,c)}(B)$ as a function of the external magnetic field applied along different crystallographic directions. The Néel temperatures were determined from the magnetic susceptibility, the magnetoresistance and the specific heat (the method is indicated in the legend).

3. Surface quantum properties of topological insulators via the NMR-detection of Dirac electrons

In the paper "Resolving Dirac electrons with broadband high-resolution NMR" by W. Papawassiliou, J. Dolinšek, *et al*., Nat. Commun. **11**, 1285 (2020), we investigated the surface quantum properties (SQPs) of a topological insulator (TI) Bi_2Te_3 in a nanoplatelet morphology. Detecting the metallic Dirac electronic states on the surface of TIs is critical for a study of important SQPs, such as Majorana zero modes, where simultaneous probing of the bulk and edge electron states is required. However, there is a particular shortage of experimental methods, showing at an atomic resolution how Dirac electrons extend and interact with the bulk interior of nanoscale TI systems. By applying advanced broadband solid-state ^{125}Te nuclear magnetic resonance (NMR) methods on Bi_2Te_3 nanoplatelets, we succeeded in uncovering the hitherto invisible NMR signals with magnetic shielding that is influenced by the Dirac electrons, and we subsequently showed how the Dirac electrons spread inside the nanoplatelets (Fig. 3). In this way, the spin and orbital magnetic susceptibilities induced by the bulk and edge electron states were simultaneously measured with an atomic scale resolution, providing a pertinent experimental approach in the study of SQPs.

4. **Stabilization of the perovskite phase in epitaxial thin films via increased interface roughness**

Perovskite $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT) exhibits excellent piezo- and dielectric properties; however, only in the absence of the pyrochlore phase, which results from the PbO loss during synthesis. Pulsed-laser deposition was used to prepare PMN-PT thin films on $LaNiO_3/SrTiO_3$ (LNO/STO) substrates. We found that the bottom electrode has an immense influence on the properties of the overgrown active layer. Specifically, the use of LNO as the electrode material, strongly stabilizes the perovskite phase and significantly expands the process window for the preparation of phase-pure PMN-PT, as compared to a direct deposition on STO substrates. By understanding the mechanism (the stabilization is achieved primarily due to the increased interface roughness, which offers more Pb-binding sites), we were able to prepare a STO/Nb:STO template with a rough surface, which strongly enhanced the stability of the perovskite phase and, consequently, improved the electrical properties of films. The developed approach can be used to design templates for various device configurations. The work was published in U. Gabor, D. Vengust, Z. Samardžija, A. Matavž, V. Bobnar, D. Suvorov, M. Spreitzer, Stabilization of the perovskite phase in PMN-PT epitaxial thin films via increased interface roughness, Applied Surface Science **513**, 145787 (2020).

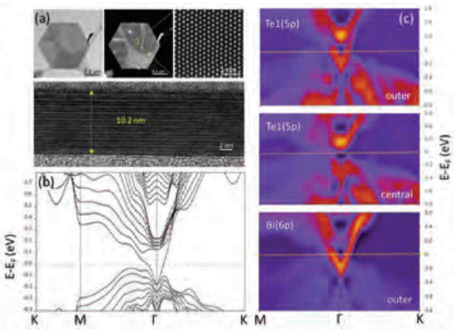

Figure 3: Band-structure analysis and Dirac states of stoichiometric Bi_2Te_3 nanoplatelets. (a) High-resolution TEM and HAADF image of Bi_2Te_3 nanoplatelets (top view and cross-section). (b Band structure of a 9-quintuplets-thick (~10 nm) Bi2Te3 slab. (c) The projected k-resolved DOS of the Te(1) |5p⟩ and Bi |6p⟩ orbital states at the outer (edge) quintuplets, and the Te(1) |5p⟩ orbital states at the central quintuplet. Dirac states are only observed at the edge quintuplets.

5. **Development of thick piezoelectric HfO_2-based films**

In HfO_2-based films, which are mainly prepared by atomic-layer deposition, the desired ferroelectric properties typically vanish for thicknesses above 50 nm. In collaboration with researchers from the Luxembourg Institute of Science and Technology, we have successfully fabricated 1-µm-thick piezoelectric La:HfO_2 films using chemical solution deposition. After identifying the optimal La content, the film thickness was increased from 45 nm to 1 µm. Polarization and strain measurements evidence the persistence of the ferroelectric properties and even a slight improvement due to a better orientation of the polar axis at higher thicknesses. The fine-grained microstructure is believed to help in stabilizing the polar orthorhombic $Pca2_1$ phase in developed films, paving the way towards cost-efficient HfO_2-based sensor and actuator applications. The work was published in T. Schenk, N. Godard, A. Mahjoub, S. Girod, A. Matavž, V. Bobnar, E. Defay, S. Glinšek, Toward thick piezoelectric HfO_2-based films, Physica Status Solidi – Rapid Research Letters **14**, 1900626 (2020).

6. **Relationship between dielectric and electrocaloric responses in relaxor ferroelectrics**

The correlation between dielectric permittivity and electrocaloric (EC) temperature change (ΔT_{EC}) was investigated in $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ relaxor ferroelectric ceramics. Such a relation would help to predict the temperature range wherein the EC effect is the highest. We showed that the peak of the dielectric permittivity is always at a higher temperature (T_m) than the peak of ΔT_{EC}, and that the temperature gap between both maxima progressively increases with increasing applied DC bias. The results, which are explained in terms of the electric field-temperature phase diagram of relaxor systems, thus reveal that T_m can only roughly mark the upper boundary of the temperature-electric-field window, where the EC responsivity is the highest. The work was published in L. Fulanović, A. Bradeško, N. Novak, B. Malič, V. Bobnar, Relation between dielectric permittivity and electrocaloric effect under high electric fields in the $Pb(Mg_{1/3}Nb_{2/3})O_3$-based ceramics, Journal of Applied Physics **127**, 184102 (2020).

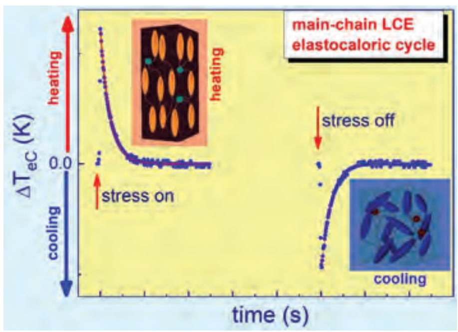

Figure 4: Elastocaloric cooling cycle in main-chain liquid-crystal elastomers.

7. **Study of nanostructured materials' ordering and caloric effects in electronic ceramics and soft materials**

We have shown, by direct measurements and simulations, the existence of the large elastocaloric effect in main-chain liquid-crystal elastomers that can be tuned by the crosslinkers' density. We continued with the studies of the ferroelectric properties, the electromechanical and electrocaloric effect in novel bulk lead-free materials. We demonstrated that these materials could, in all properties, replace materials based on lead. Besides, we have shown that graphene nanoparticles decorated by CoPt could stabilize for optical applications interesting blue phases in liquid crystals. The above results have been published in 17 articles in international scientific journals. Recent papers of our group on multiferroics, multicalorics and soft materials have been cited more than 400 times in 2020. The work was published in five articles.

8. Rapid determination of NQR frequencies using field-cycling magnetic resonance

The main advantage of measuring the nuclear quadrupole resonance (NQR) frequencies is the possibility to study the electron charge distribution in the vicinity of the observed atomic nucleus, for example, the chemical bonds formed by the atom. Due to its high resolution, NQR can also be used as an analytical technique, which clearly distinguishes between molecules and crystal polymorphs. NQR can also be used to study the microscopic state of order in the sample as, for example, in case of an exchange or reorientation. We describe a modified Slusher-Hahn's nuclear quadrupole double resonance (NQDR) technique, which can be used for the rapid location of NQR frequencies. The technique is based on the adiabatic magnetic field cycling between a high magnetic field B_0 and zero magnetic field, where we replace the phase-modulated RF magnetic field by a series of frequency sweeps that pass the NQR frequency (Fig. 5). The new technique enables a rapid scan of the NQR spectrum independent on the NQR frequency. The work was published in T. Apih, A. Gregorovič, V. Žagar, J. Seliger, A rapid determination of nuclear quadrupole resonance frequencies using field-cycling magnetic resonance and frequency modulated RF excitations, J. Magn. Reson. **310** (2020) 106635.

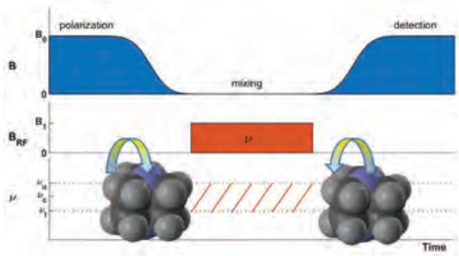

Figure 5: Adiabatic magnetic field cycling between a high magnetic field B_0 and zero magnetic field, where we replace the phase-modulated RF magnetic field by a series of frequency sweeps that pass the NQR frequency.

9. TiO_2 nanostructures doped with Eu^{3+} and Nd^{3+} for temperature sensing

Lanthanide-based optical nanothermometers, operating in the physiological temperature range between 15 °C and 50 °C, with excitation and emission in the first biological transparent window are of special interest for biological applications. In this context, trivalent europium-doped titanium oxide (Eu^{3+}:TiO_2) nanoparticles were prepared via a sol-gel method and their spectroscopic properties were studied. We observed that the intensities of the excitation bands for the $^7F_0 \rightarrow {}^5D_0$ (576 nm) and $^7F_2 \rightarrow {}^5D_0$ (610 nm) transitions, monitoring the $^5D_0 \rightarrow {}^7F_4$ (700 nm) transition have a strong dependence on the temperature (Fig. 6). This dependence, which is explained in terms of the thermal coupling between the Eu^{3+}:^7F_J levels, was used for the construction of an optical nanothermometer. The work was published in L.J. Borrero-González, Selene Acosta, Carla Bittencourt, Maja Garvas, Polona Umek, L.A.O. Nunes. Eu^{3+}-doped titanium oxide nanoparticles for optical thermometry in the first biological window. *Optical Materials* **101** (2020) 109770.

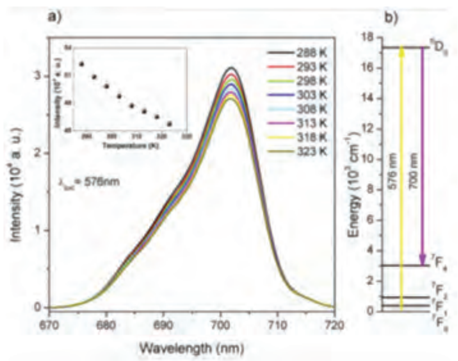

Figure 6: a) Photoluminescence temperature dependence for the emission of the $^5D_0 \rightarrow {}^7F_4$ transition with excitation $^7F_0 \rightarrow {}^5D_0$. The inset shows the integrated intensity of the emission band. (b) Simplified energy-level diagram of Eu^{3+} ion illustrating the excitation and radiative transitions.

10. Transformation of $H_2Ti_3O_7$ nanotubes to anatase nanoparticles

The purpose of the transformation study of $H_2Ti_3O_7$ nanotubes into anatase nanoparticles was to prepare TiO_2 nanoparticles of different morphologies for subsequent toxicity studies. The transformation reactions of the $H_2Ti_3O_7$ nanotubes were conducted under various hydrothermal conditions, as well as with calcination in air. In the case of transformations under hydrothermal conditions, it was found that besides T and pH, the presence of a capping agent in the reaction mixture had an effect on the shape and size of the formed TiO_2 nanoparticles (Fig. 7). TiO_2 nanoparticles of various shapes were later used in toxicity studies. The work was published in Kokot, Hana, Kokot, Boštjan, Sebastijanović, Aleksandar, Podlipec, Rok, Krišelj, Ana, Čotar, Petra, Pušnik, Mojca, Umek, Polona, Pajk, Stane, Urbančič, Iztok, Koklič, Tilen, Štrancar, Janez, et al. Prediction of chronic inflammation for inhaled particles: the impact of material cycling and quarantining in the lung epithelium. *Advanced materials* **32** (2020) 2003913.

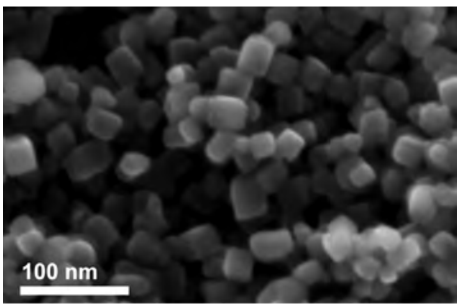

Figure 7: Conversion of $H_2Ti_3O_7$ nanotubes under hydrothermal conditions in an alkaline medium yield anatase nanoparticles of cuboid morphology.

11. Investigation of orientational order parameter in polymer-dispersed liquid-crystal elastomers

Andraž Rešetič and Boštjan Zalar with coworkers and partners from Italy and the Czech Republic investigated the orientational order parameter in polymer-dispersed liquid-crystal elastomers (PDLCE). Their thermomechanical properties are governed by the degree of imprinted particle alignment, achieved during the synthesis in a strong magnetic field. Deuterium NMR was used on the samples with various degrees of imprinted liquid-crystal elastomer (LCE) particle alignment (Fig. 8). The recorded spectra were simulated using the discrete reorientational exchange model. It was determined that the maximum order of the LCE particle alignment is achieved in magnetic fields larger than 5 T, when the dispersion of the orientational distribution settles a 20° and the orientational order parameter at a value of 0.54. The thermomechanical behavior of the same samples follow the above patern. The work was published in Andraž Rešetič, Jerneja Milavec, Valentina Domenici, Blaž Zupančič, Alexej Bubnov, Boštjan Zalar, Deuteron NMR investigation on orientational order parameter in polymer dispersed liquid crystal elastomers, **Phys. Chem. Chem. Phys. 22** (2020) 23064.

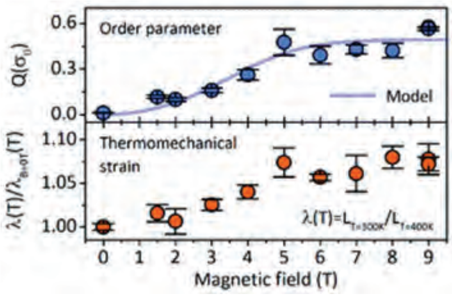

Figure 8: Experimentally determined orientational order parameter $Q(\sigma_0)$ (upper graph) and thermomechanical response (lower graph) of the same PDLCE samples. The maximum order parameter is acieved for $B \geq 5$ T at the value of $Qmax(\sigma_0) = 0.54$. Thermomechanical responses were determined on several pieces of the same sample by measuring the length change when heated from 300 K to 400 K.

12. Quantum and topological magnetism

Martin Klanjšek, in collaboration with partners from France, tested the previously proposed analytical expression for the NMR spin-lattice relaxation rate due to the enhancement of critical spin fluctuations in quasi-one-dimensional spin systems in the vicinity of the magnetic ordering transition. The expression is experimentally confirmed by excellent fits to the published temperature dependence of the spin-lattice relaxation rate data in two representative quasi-one-dimensional spin compounds, $(C_7H_{10}N)_2CuBr_4$ (DIMPY) and $BaCo_2V_2O_8$. A positive test also provides a direct and convenient experimental determination of the Tomonaga-Luttinger-liquid interaction parameter, which is found in very nice agreement with the theoretical predictions. The work was published in the paper M. Horvatić *et al.*, "Direct determination of the Tomonaga-Luttinger parameter *K* in quasi-onedimensional spin systems", *Phys. Rev. B* **101**, 220406(R) (2020).

Matej Pregelj, Andrej Zorko, Denis Arčon and Martin Klanjšek, in collaboration with partners from France, Switzerland and Austria, investigated a frustrated spin-1/2 chain β-$TeVO_4$ by nuclear magnetic resonance (NMR) at high magnetic fields. They were looking for the theoretically predicted spin-nematic phase, i.e., an intriguing state of matter that exhibits higher multipolar order but lacks the usual long-range dipolar order. The research team found that the detected missing fraction of the magnetization, probed by NMR frequency shift, is thermally activated and is thus not a fingerprint of the spin-nematic behaviour, as previously proposed. This fact undermines the presence of the spin-nematic phase in the investigated compound. Moreover, it highlights the importance of careful considerations of a temperature-dependent NMR shift that has been overlooked in previous studies of spin nematicity. The work was published in the paper M. Pregelj *et al.*, "Thermal effects versus spin nematicity in a frustrated spin-1/2 chain", *Phys. Rev. B* **102**, 081104(R) (2020).

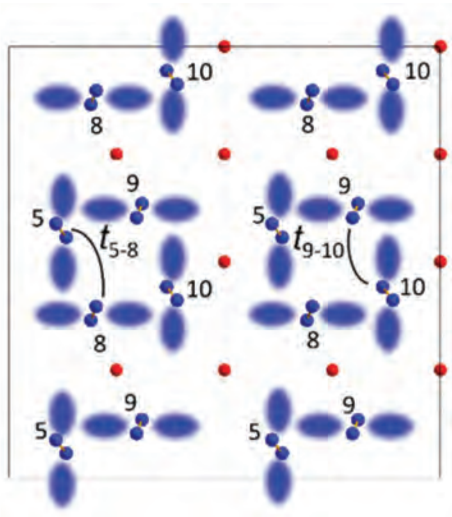

Figure 9: Orbital ordering in Rb_4O_6 drives the quantum magnetic state of weakly coupled spin dimers.

Matej Pregelj, Andrej Zorko and Denis Arčon, in collaboration with partners from Croatia, France and Switzerland, used torque magnetometry to study a frustrated spin-1/2 chain β-$TeVO_4$. They investigated the anisotropy of spin-density-wave (SDW), vector-chiral and spin-stripe phases in magnetic fields of up to 5 T. Their results show that the magnetic-field-induced spin reorientation occurs in the SDW and in the spin-stripe phases in fields greater than 2 Tesla. The presented results should help establish the model of anisotropic magnetic interactions, which are responsible for the formation of complex magnetic phases in β-$TeVO_4$ and similar low-dimensional quantum spin systems. The work was published in the paper M. Herak *et al.*, "Magnetic-field-induced reorientation in the spin-density-wave and the spin-stripe phases of the frustrated spin-1/2 chain compound β-$TeVO_4$", *Phys. Rev. B* **102**, 024422 (2020).

In an extensive study, Tilen Knaflič, Peter Jeglič, Andrej Zorko and Denis Arčon, together with colleagues from Germany, investigated low-temperature quantum magnetism in Rb_4O_6. This study was a continuation of the previous one on the related Cs_4O_6, where we discovered charge ordering similar to the famous Verwey transition. In this study, we discovered a second structural instability at lower temperatures, which is probably related to the orbital ordering (Fig. 9). The low-temperature instability defines the magnetic properties, as experiments with electron paramagnetic resonance at high fields unambiguously show quantum magnetism of weakly coupled spin dimers. The research has been published as "Editor's suggestion" in the article T. Knaflič et al., "Spin-dimer ground state driven by consecutive charge and orbital ordering transitions in the anionic mixed-valence compound Rb_4O_6", *Phys. Rev. B* **101**, 024419 (2020).

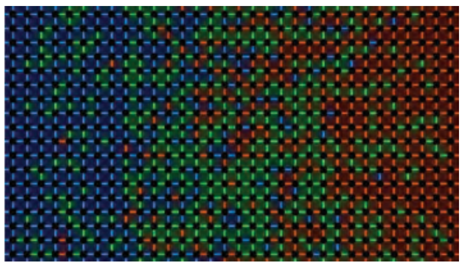

Figure 10: Simulation of random exchange bonds on a 2D square spin lattice.

Matjaž Gomilšek, in collaboration with partners from the United Kingdom, explored the influence of randomized exchange bonds on the magnetism of a $S = 1/2$ quantum Heisenberg antiferromagnet (QHAF) on a quasi-2D square lattice (Fig. 10). The researchers found that magnetic order is strongly suppressed by quenched exchange strength randomness (realized by chemical substitution in $(QuinH)_2Cu(Cl_xBr_{1-x})_4{\cdot}2H_2O$, where QuinH = Quinolinium = $C_9H_8N^+$ and $0 \leq x \leq 1$), with an extended quantum-disordered phase forming over a wide range of intermediate substitution levels, where no ground-state magnetic order is observed. They propose a simple and general energetics-based model of competing local magnetic orders in disordered magnets, and find that it describes the observed critical

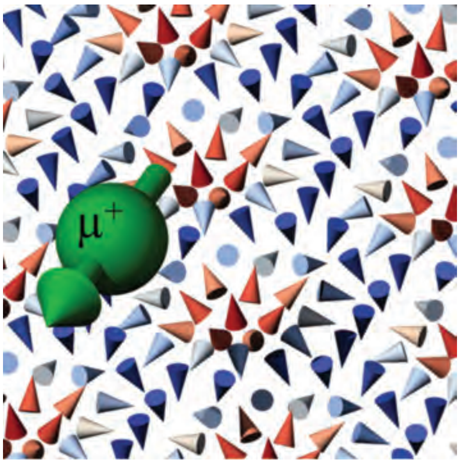

Figure 11: Sketch of a muon over a lattice of topologically non-trivial magnetic Néel skyrmions.

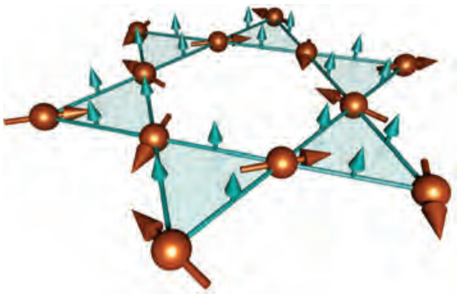

Figure 12: Magnetic ordering on the kagome lattice resulting from Dzyaloshinskii-Moriya interaction.

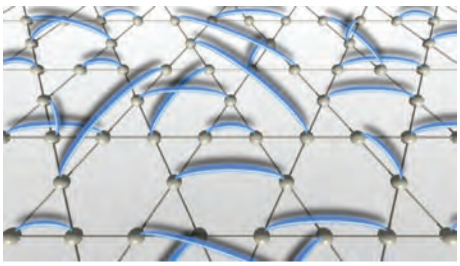

Figure 13: Formation of valence bonds in the spin-liquid ground state of the quantum kagome lattice.

substitution levels in the studied compound. Due to the ubiquity of quenched disorder in many of the most interesting QHAF and other frustrated magnetic materials, this study should have wide implications in the field of quantum magnetism. The work was published in the paper F. Xiao *et al.*, "Magnetic order and disorder in a quasi-two-dimensional quantum Heisenberg antiferromagnet with randomized exchange", *Phys. Rev. B* **102**, 174429 (2020).

Matjaž Gomilšek, in collaboration with partners from the United Kingdom, explored the influence of low levels of chemical substitution on the magnetism of $GaV_4S_{8-y}Se_y$. The researchers showed that the materials in this series exhibit lattices of Néel skyrmions (exotic topological spin textures) over a range of elevated temperatures by studying their dynamics via muon spin relaxation (μSR), as shown in Figure 11. They also found that chemical substitution stabilizes additional skyrmionic precursor states that persist down to even lower temperatures. Finally, at the lowest temperatures, the researchers discover a gradual crossover from cycloidal magnetic order to a ferromagnetic ground state in both the $y = 0$ and the $y = 0.1$ materials, and reveal that chemical substitution leads to an inhomogeneous local spin density in this series of materials. The discovered rich phase diagram and non-trivial substitutional effects make $GaV_4S_{8-y}Se_y$ an especially interesting series of topological magnets. The work was published in the paper T. J. Hicken *et al.*, "Magnetism and Néel skyrmion dynamics in $GaV_4S_{8-y}Se_y$", *Phys. Rev. Research* **2**, 032001(R) (2020).

Tina Arh, Matjaž Gomilšek, Matej Pregelj, Martin Klanjšek and Andrej Zorko studied, with collaborators from the UK, USA and China, the effect of perturbations on the ground state of the quantum kagome spin lattice. They found that magnetic ordering in the investigated compound $YCu_3(OH)_6Cl_3$ is triggered by a sizable Dzyaloshinskii-Moriya interaction that enhances spin correlations within the kagome planes (Fig. 12). They confirmed experimentally the theoretically predicted role of this interaction and the corresponding phase diagram. The findings were published in the article T. Arh *et al*., "Origin of Magnetic Ordering in a Structurally Perfect Quantum Kagome Antiferromagnet", *Phys. Rev. Lett.* **125**, 027203 (2020).

Andrej Zorko and collaborators from France and India determined the exact nature of the spin-liquid ground state in herbertsmithite, an archetypal representative of the quantum kagome spin lattice. The question of the existence of a spin gap in this compound has remained unanswered for many years, despite numerous experimental studies. With an in-depth nuclear magnetic resonance experiment, the researchers proved that the ground state is gapless, and thus showed good agreement with recent theoretical predictions that envisage a Dirac spin-liquid as the ground state of the kagome lattice (Fig. 13). The work was published in the article P. Khuntia *et al*., "Gapless ground state in the archetypal quantum kagome antiferromagnet $ZnCu_3(OH)_6Cl_2$", *Nat. Phys.* **16**, 469 (2020).

13. Superconductivity

Denis Arčon, Peter Jeglič, Martin Klanjšek and Nejc Janša studied superconductivity emerging from the paradigmatic quantum spin liquid in TaS_2, together with colleagues from the F7 and F1 departments. In the study, they focused on the 1T-TaS_2 layered system, which was systematically doped with Se. Using Ta-181 NQR and Se-77 NMR they demonstrated that after the parent spin liquid is destroyed and replaced by the metallic state, antiferromagnetic correlations remain and define the metallic state. Such correlations might be important for the emerging superconducting state in the strong coupling limit. The work has been published in the article I. Benedičič et al., "Superconductivity emerging upon Se doping of the quantum spin liquid 1T-TaS_2", *Phys. Rev. B* **102**, 054401 (2020).

Žiga Gosar, Nejc Janša, Tina Arh, Peter Jeglič, Martin Klanjšek and Denis Arčon, together with colleagues from the University of Texas at Dallas, investigated superconductivity of quasi-one-dimensional metal $Rb_2Mo_3As_3$. Spin-lattice relaxation rate showed a characteristic power-law temperature dependence, which is a signature of Tomonaga-Luttinger liquid (TLL) but in the surprising regime of attractive interactions. The additional presence of three-dimensional electronic band stabilizes superconductivity at the surprisingly high critical temperature. In the article published in Ž. Gosar et al., "Superconductivity in the regime of attractive interactions in the Tomonaga-Luttinger liquid", *Phys. Rev. B* **101**, 220508(R) (2020) we also discussed the relevance of TLL physics for the emerging superconductivity.

14. Functional materials

Denis Arčon participated in a study of the Li_2VO_2F cathode material. Using pulsed and continuous electron paramagnetic resonance (EPR), he showed that the sample, which was charged at the potential 4.1 V, shows EPR spectrum that is a sum of V^{4+} ($3d^1$) and superoxide O_2^- signals. In particular, the discovery of the later component is important as its presence probably influences the reversibility of charging cycles. The research has been published in J. H. Chang et al., "Superoxide formation in Li_2VO_2F cathode material – a combined computational and experimental investigation of anionic redox activity", *J. Mater. Chem. A* 8,16551 (2020).

Tilen Knaflič and Denis Arčon participated in the international collaboration to study potassium-intercalated Tetracene solid. The study is a part of ongoing collaboration in the field of interacalatic aromatic solids. We used EPR method to show that K_2Tetracen is a nonmagnetic insulator. The study has been published in C. I. Hiley et al., "Crystal Structure and Stoichiometric Composition of Potassium-Intercalated Tetracene" *Inorg. Chem*. 59, 12545–12551 (2020).

Peter Jeglič, Tadej Mežnaršič and Denis Arčon, in collaboration with partners from Japan, reported the first study of rubidium-loaded LSX zeolite employing complementary macroscopic and microscopic probes. The ^{87}Rb NMR spin-lattice relaxation of the rubidium cluster component showed temperature-independent behavior. This confirmed the metallic ground state, despite the fact that rubidium clusters are formally confined in the insulating framework. The work was published in the paper P. Jeglič *et al.*, "Metallic State in Rubidium-Loaded Low-Silica X Zeolite", *J. Phys. Soc. Jpn.* 89, 073706 (2020).

Andrej Zorko and other collaborators from the JSI and Norway studied the influence of cobalt doping and the annealing atmosphere on the electrical conductivity and the electrical polarization switching in $BiFeO_3$ ceramics. They proposed a mechanism of hardening, which assumes the existence of two types of pinning centers. The results of the study will help in further optimizing local and macroscopic conductivity, as well as hardening properties of these technologically important ceramics. The results were published in the article M. Makarovič *et al*., "Tailoring the electrical conductivity and hardening in $BiFeO_3$ ceramics", *J. Eur. Ceram. Soc.* 40, 5483 (2020).

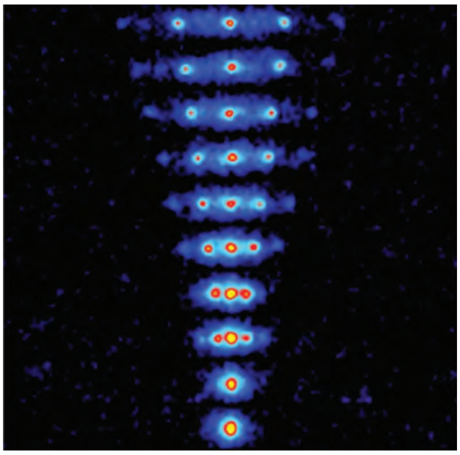

Figure 14: Pairs of matter-wave jets emitted from a modulated cesium Bose-Einstein condensate.

15. Cold atoms

Tadej Mežnaršič, Tina Arh, Erik Zupanič and Peter Jeglič demonstrated the emission of correlated atom jets from a driven matter-wave soliton in a quasi-one-dimensional optical trap (Fig. 14). All the stages of the Bose jet emission were captured in a simple model based on the 1D Gross-Pitaevskii equation, giving an insight into the dynamics of density waves that precede the emission. In the limit of vanishing high-order jets beyond-mean-field number correlations of jet pairs were observed. The results were published in T. Mežnaršič *et al*., "Emission of correlated jets from a driven matter-wave soliton in a quasi-one-dimensional geometry", *Phys. Rev. A* 101, 031601(R) (2020).

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 program is to understand the 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 the macroscopic level, using a simplified physical picture and models. 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.

Using theoretical and numerical approaches, we explain the flow of light through complex structures of topological solitons in frustrated chiral nematics. In a thin layer of unwound cholesteric, we show the chirality amplified periodic self-focusing of a strong laser beam and the formation of similariton. By modelling, we show that with topological defects in an ion-doped nematic liquid crystal we can manipulate charge distributions on chemically homogeneous surfaces. For material flows and morphological dynamics of topological defect lines and loops in 3D active nematics, theoretical and numerical approaches show the importance of the local orientation order surrounding the defects.

Light control by topological solitons in chiral nematics

Topological solitons appearing in different areas of physics are fascinating, localized perturbations of ordering fields enjoying topological protection. We demonstrate refraction, reflection, and lensing of weak laser beams by various topological solitons in frustrated chiral nematic liquid crystals. We show how the interactions of light with such topological solitons are well described using a generalized Snell's law and ray-tracing models. These might lead to new means for controlling the flow of light for use in optics and photonics. The study was made by group members from the Jožef Stefan Institute and the Faculty of Mathematics & Physics at University of Ljubljana in collaboration with the group of Ivan Smalyukh

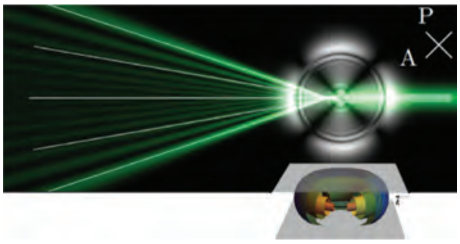

Figure 15: Simulated green light beam lensing from a toron in the unwounded cholesteric layer. Intensity of green colour corresponds to the intensity of light. White lines are obtained by simple ray tracing. The 100-μm toron with the director field illustrated in the inset is visualized with a white-light polarization image.

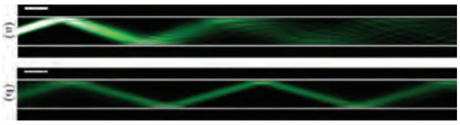

Figure 16: Propagation of a tilted Gaussian light beam inside the unwounded cholesteric layer in the linear (a) and nonlinear – similariton (b) optical regime. The white bars represent 10 μm.

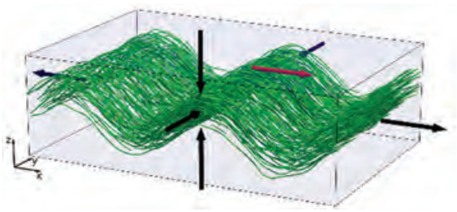

Figure 17: Nematically aligned bundles of microtubules (green) first condense vertically into a ribbon that subsequently forms wrinkles due to active extensile stress.

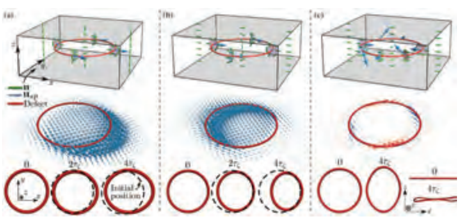

Figure 18: Flows and dynamics of different active nematic defect loops with zero topological charge

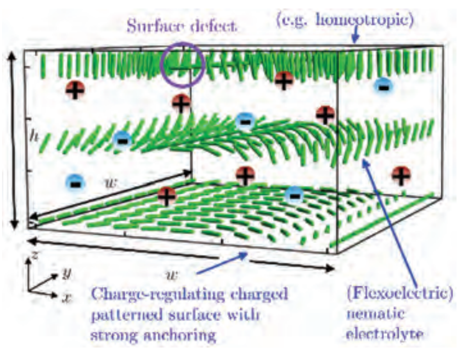

Figure 19: Surface-induced electric-charge variability caused by nematic defects.

from University of Colorado in Boulder. The paper (*Physical Review X, 2020, DOI:* 10.1103/PhysRevX.10.031042*)* was highlighted in *APS Physics Focus* by the editorial article "Liquid-Crystal Vortices Focus Light".

Chirality-enhanced periodic self-focusing of light in frustrated chiral nematics

In achiral liquid crystals, the reorientation of molecules around laser beams with appropriate power is responsible for the generation of spatial optical solitons called "nematicons". We present numerical, experimental, and theoretical evidence of a strong link between chirality and the nonlinear optical response of frustrated chiral liquid-crystal systems. In unwounded chiral nematics, the frustration caused by a confinement incompatible with their lowest-energy states allows a relatively weak light to locally destabilize the initially uniform orientational fields and thus boost their nonlinear optical responses. This yields self-focusing and the formation of similaritons. In short, our study opens, at a fundamental level, a new research paradigm of chirality-enhanced nonlinear optical effects, thus suggesting a range of self-focusing-based applications such as low power light self-actuated flat lenses or all-optical information processing based on spatial optical solitons interacting with chiral topological solitons. The study was made in a collaboration by the Jožef Stefan Institute and the Faculty of Mathematics & Physics at University of Ljubljana with the group of Ivan Smalyukh from University of Colorado in Boulder (*Physical Review Letters, 2020, DOI:* 10.1103/PhysRevLett.125.077801*).*

Wrinkling instability in 3D active nematics

In this experimental and theoretical study we focus on a 3D active nematic consisting of microtubules, kinesin motors, and a depleting agent. It shows rich dynamics evolving from a nematically ordered space-filling distribution of microtubule bundles towards a flattened and contracted 2D ribbon that undergoes a wrinkling instability and subsequently transitions into a 3D active turbulent state. The interplay between the depletion forces and the kinesin motors thus leads to both a contractile stress that compresses the ribbon and an extensile stress that leads to the wrinkling instability. On the macroscopic scale, we used a continuum theory to explain the instability and predict the wavelength of the wrinkles that form. We supplemented the results with a detailed simulation at the molecular scale (using the Cytosim package) that reproduced the dynamics based on the properties of single kinesin motors. We found that the produced forces nearly cancel out, but a small asymmetry in the distribution leads to the build-up of the extensile stress. Whereas the wrinkle wavelength strongly correlates with their formation time, as predicted by the continuum theory, it is independent of the ATP concentration. The 3D to quasi-2D and back to 3D transition in our system represents a novel path of self-organization in active soft matter. The study was mostly performed at Max Planck Institute for Dynamics and Self-Organization in Göttingen *(Nano Letters, 2020, DOI:*10.1021/acs.nanolett.0c01546).

Three-Dimensional Active Defect Loops

We describe the flows and morphological dynamics of topological defect lines and loops in three-dimensional active nematics and show, using theory and numerical modelling, that they are governed by the local profile of the orientational order surrounding the defects. Analysing a continuous span of defect loop profiles, ranging from radial and tangential twist to wedge profiles, we show that the distinct geometries can drive the material flow perpendicular or along the local defect loop segment, whose variation around a closed loop can lead to net loop motion, elongation, or compression of shape, or buckling of the loops. We demonstrate a correlation between the local curvature and the local orientational profile of the defect loop, indicating dynamic coupling between the geometry and the topology. To address the general formation of defect loops in three dimensions, we show their creation via bend instability from different initial elastic distortions. The work was performed in a collaboration between the University of Warwick (Prof. G. Alexander), the Faculty of Mathematics and Physics at the University of Ljubljana and Department of Condensed Matter Physics at the Jožef Stefan Institute *(Physical Review Letters, 2020, DOI:* 10.1103/PhysRevLett.124.088001*).*

Topological-Defect-Induced Surface Charge Heterogeneities in Nematic Electrolytes

We show that the topological defects in an ion-doped nematic liquid crystal can be used to manipulate the surface-charge distribution on chemically homogeneous, charge-regulating external surfaces, using a minimal theoretical model. In particular, the location and type of the defect encodes the precise distribution of surface charges, and the effect is enhanced when the liquid crystal is flexoelectric. We demonstrate the principle for patterned surfaces and charged colloidal spheres. More generally, our results indicate an interesting approach to control the surface charges on external surfaces without changing the surface chemistry *(Physical Review Letters, 2020, DOI:* 10.1103/PhysRevLett.125.037801*)*.

Speckle-free liquid-crystal microscopy with nanosecond illumination

We present a setup for speckle-free, low-light microscopy imaging using 5-ns exposure times. The design is based on the stroboscopic principle and uses fast and incoherent fluorescent emission from a solution of a fluorescent dye, excited by a picosecond laser pulse. The proposed solution of Rhodamine in ethanol put in a glass cuvette gives an excellent image quality with high contrast, excellent stability and tuneable coherence. The setup was used for the photographic measurements with 5-ns exposure time, demonstrated in the imaging of a thermally quenched 5CB liquid crystal, which enables studies of the Kibble-Zurek mechanism of topological defect nucleation and growth at sub-microsecond time resolution and extremely fast cooling rates of ~40,000 K/s. The research was conducted in collaboration with the Faculty of Mathematics and Physics and the Faculty of Pharmacy at University of Ljubljana. (*Liquid Crystals, DOI:* 10.1080/02678292.2020.1790049).

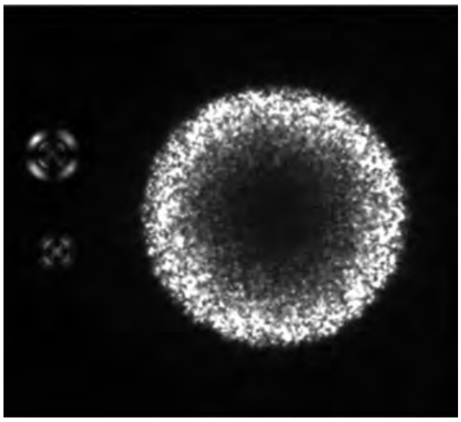

Figure 20: Thermal quenching of liquid crystal with 5-ns exposure time.

Bright flower-like domains in inverse nematic gels

We discovered that mixing the gelator 12-HSA with a nematic liquid crystal results in the creation of localised flower-like domains with a higher concentration of the gelator than the surrounding medium. The gelator in these domains forms fibres, which interact with the molecules of the liquid crystal and stabilise its director into a spiral, toron-like structure. We examined their structure by optical and confocal microscopy. The nematic liquid crystal in the volume around the domains is achiral, but all the domains exhibit the same handedness. The research was conducted in collaboration with the Faculty of Mathematics and Physics at University of Ljubljana and the Raman Institute in Bangalore. *(Soft matter, 2020, DOI:* 10.1039/C9SM02547B*)*.

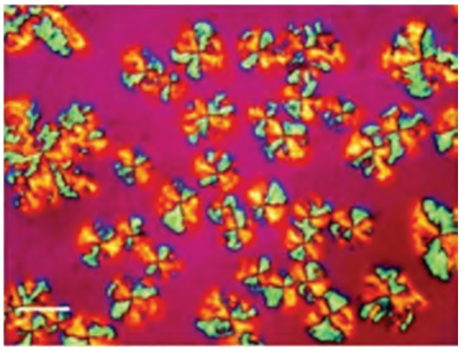

Figure 21: Bright flower-like domains in the inverse nematic gel.

Nematic liquid-crystal necklace structure made by a microfluidic system

We succeeded in fabricating necklace structures made of liquid-crystal droplets that are tens of micrometres in diameter and are connected by birefringent micro-tethers made of a PVA liquid-crystal composite. Micro-tethers can be elastically stretched by applying external force and the elastic constant of the tether was determined using laser tweezers. The Whispering Gallery Modes circulating inside the individual droplets in the necklace structure were also observed. Research was made in collaboration with AIST in Tsukuba (*Langmuir, DOI:* 10.1021/acs.langmuir.0c00101*)*.

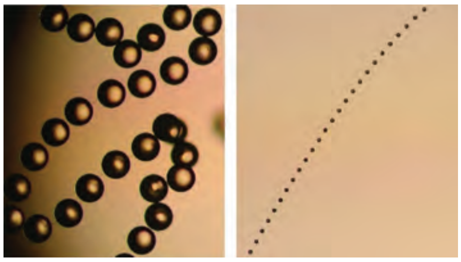

Figure 22: Two necklaces made of LC droplets connected by a micro-tether.

Electric-field-induced reorientation of ferroelectric platelets in a liquid crystal

We demonstrated that ferroelectric micro-platelets can be reoriented in a nematic liquid crystal by linear coupling to an external electric field. The electric dipole moment of the platelets is perpendicular to the plane of platelets and provides torque that rotates the platelets. The experiments were made in dispersions of platelets in a zero dielectric anisotropy nematic liquid crystal, which excludes the reorientation of the dispersion via the dielectric coupling of a liquid crystal. Liquid-crystal molecules are reoriented only via the rotation of platelets. (*Liquid Crystals, DOI:* 10.1080/02678292.2020.1785026)

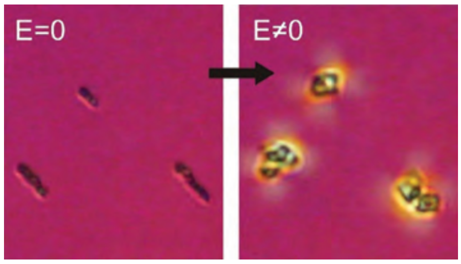

Figure 23: Micro-platelets are rotated in a liquid crystal by the external electric field.

Graphene derivatives, liquid crystal, and CdS/TiO_2 hybrid matrices: optoelectronic and biotechnological aspects

Different assemblies of nanomaterial and related new switchable device technologies are reviewed. Complex systems consisting of graphene and its derivatives, hydrogen-bonded liquid crystals, and semiconducting nanoparticles or nano wires are addressed. Seamless stable assemblies are enabled by relatively strong hydrogen bonds. Of particular interest are the configurations that can undergo sensitive stimulus-induced electro-optical changes between states exhibiting significantly different effective properties. Such assemblies could be exploited in flexible electronics, high contrast ratio smart displays, optoelectronic devices, sensors (monitoring inflammability, explosive nature, or toxicity of chemicals), bio-sensing, and antimicrobial applications. Cost-effective technologies, enabling

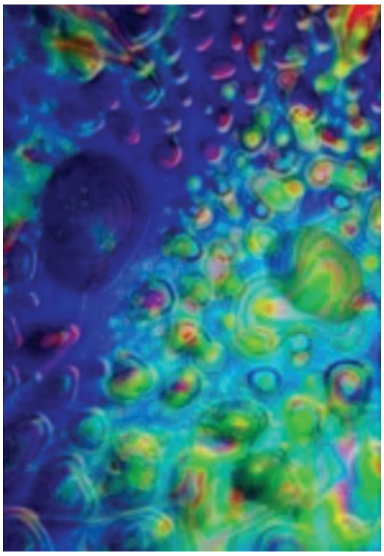

Figure 24: Polarizing-microscopy texture of a hybrid composite.

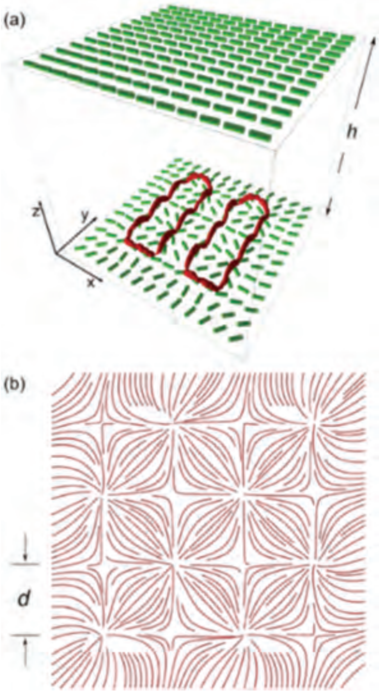

Figure 25: a) Typical defect configuration, b) bottom plate enforced nematic pattern.

large scalability and seamless heterogeneous integration are presented *(Critical Reviews in Solid State and Materials Sciences, 2020, DOI:* 10.1080/10408436.2020.1805295*).*

Reconfigurable multi-stable topological defect patterns

We report on robust theoretical and experimental investigations in which an external electric field is used to switch between pre-determined stable chargeless disclination patterns in a nematic cell. The different defect configurations are stabilized by a master substrate that enforces a lattice of surface defects exhibiting zero total topological charge value. Theoretically, we model disclination configurations using a Landau-de Gennes phenomenological model. Experimentally, we enable diverse defect patterns by implementing an in-house-developed Atomic Force Measurement scribing method, where NLC configurations are monitored via polarised optical microscopy. We show numerically and experimentally that an “alphabet” of up to 18 unique line defect configurations can be stabilized in a 4×4 lattice of alternating s=±1 surface defects, which can be “rewired” multistably using appropriate field manipulation. Our proof-of-concept mechanism may lead to a variety of applications, such as multi-stable optical displays and rewireable nanowires. Research was performed in collaboration with Case Western Reserve University Cleveland *(Physical Review Research, 2020, DOI:* 10.1103/PhysRevResearch.2.013176*).*

Emergent collective colloidal currents generated via exchange dynamics in a broken dimer state

We investigated the dynamics of paramagnetic colloidal particles confined between two planes. When subjected to a precessing magnetic field, they show a rich phase diagram depending on the rotation frequency, cell thickness, precession angle and particle density. We used linear-stability analysis to theoretically predict the boundaries between the phases. They include single particles on a hexagonal lattice, synchronously and asynchronously rotating particle pairs. Between them, a particularly interesting phase emerges where dimers form and break transiently. Therefore, an edge current emerges where particles at one boundary move in one direction and those at the opposite boundary in the opposite direction. These results demonstrate how similar physical phenomena can exist across a range of length scales. The research was conducted in the collaboration of researchers from University of Barcelona Max Planck Institute for Dynamics and Self-Organization in Göttingen *(Science Advances, 2020, DOI:*10.1126/sciadv.aaz2257*).*

Generation of microdroplets and microbeads with nanometre precision

We demonstrated that it is possible to produce small droplets and solid spheres of an unprecedented monodispersity of 1 nm and 20 nm, respectively. For the droplets, the corresponding coefficient of variation is only 0.0042 %, which improves the size precision by three orders of magnitude compared to standard production methods such as reported in microfluidics. Encoding of short words and numbers has been demonstrated by producing three beads with predefined sizes. The stored information has been read from the emitted spectrum. The potential to store information on such a small scale, which can be read purely through the spectrum, has the potential for barcoding various products, for security applications and even for tagging and tracking of individual live cells. The article that was featured on the back cover of the journal *Lab on a Chip* was made in collaboration with the Harvard Medical School *(Lab on a Chip, 2020, DOI:* 10.1039/C9LC01034C*).*

Blood flow limits endothelial cell extrusion in the zebrafish dorsal aorta

We studied the formation of the dorsal aorta, the main artery in the developing zebrafish embryo. We combined confocal imaging on live embryos with a theoretical prediction of the stress distribution in the tissue surrounding the blood vessel. The latter is amplified in the proximity of another blood vessel, but reduced in the proximity of the stiff notochord. We show that cells migrate towards a direction that coincides with the maximum pulsatile stress during the heartbeat. On the other hand, reduced blood flow facilitates cell extrusion, pointing to a mechanism that regulates the blood-vessel diameter. Our study demonstrates how the formation and growth of blood vessels depend on an intricate interplay of chemical signals, tissue mechanics and fluid dynamics. The research was conducted in the collaboration of researchers from Université de Strasbourg and Max Planck Institute for Dynamics and Self-Organization in Göttingen *(Cell Reports, 2020, DOI:*10.1016/j.celrep.2020.03.069).

Control of viscosity in biopharmaceutical protein formulations

Controlling the viscosity of concentrated protein solutions (usually reducing) is an open challenge, with major recent relevance in protein formulations for biopharmaceutical, medical, food, and other applications. It is of major importance to be able to establish control over the combination of viscosity-affecting additives and adequate protein stability, usually at high protein concentrations. Here, we demonstrate the control and manipulation of the viscosity profile of a selected protein solution (monoclonal antibody of immunoglobulin gamma type – IgG) of direct biopharmaceutical relevance, by identifying elementary viscosity contributions via selected additives that target different protein-protein interactions. Specifically, a combined study of viscosity control and protein aggregation is performed with the viscosity characterized by microfluidic measurements and protein aggregation by size-exclusion chromatography, where aggregation data is further supplemented with conformational stability measurements via thermal and chemical protein denaturation. More generally, we show control over the interplay of viscosity, potency and stability in a distinct protein system, as a general contribution to understanding the viscosity in different colloidal, biological, and soft materials. The work was performed as collaboration between the Lek Pharmaceuticals d.d, part of Novartis, the Faculty of Mathematics and Physics and the Biotechnical Faculty at the University of Ljubljana and Department of Condensed Matter Physics at the Jožef Stefan Institute. *(J. Coll. Int. Sci., 2020, DOI:* 10.1016/j.jcis.2020.06.105*)*

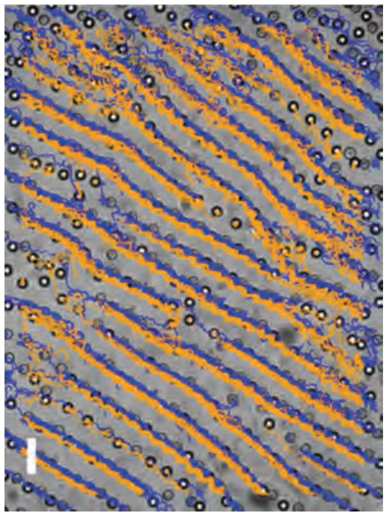

Figure 26: Trajectories of magnetic particles in a precessing field. Particles in the proximity of both planes move in opposite directions (blue and yellow traces).

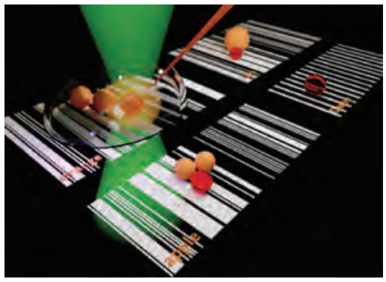

Figure 27: Graphic of four groups of microbeads, each with embedded information, which can be read by a laser.

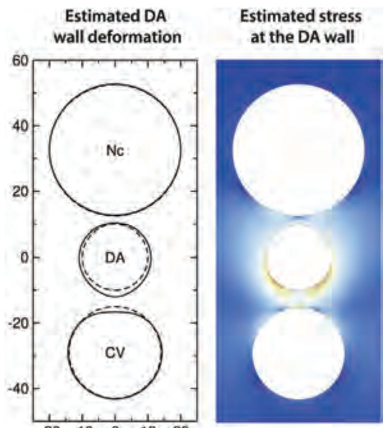

Figure 28: Theoretical prediction of mechanical stress in the tissue surrounding the dorsal aorta (DA).

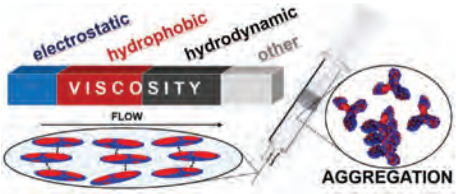

Figure 29: Control of viscosity in biopharmaceutical protein formulations via design of different protein interactions.

Antimicrobial coatings based on MoO_3 nanowires

A novel antimicrobial nanocomposite was designed from inert biocompatible PVDF-HFP and water-soluble PVP polymers with incorporated MoO_3 nanowires. Dissolving in water in a concentration of 5mg/ml, it lowers the pH value to 4.6 in 5 min. Anti-microbial activity studied in collaboration with the Biotechnical Faculty University in Ljubljana was explained by a two-step action: in the first stage, MoO_3 dissolves, causing a drop in pH, which then triggers the hydrolysis of the PVP polymer and the release of the ammonium salt. Complete deactivation of *Staphylococcus aureus*, *Listeria monocytogenes*, *Escherichia coli* and *Pseudomonas aueroginosa* was achieved within 6 h, and deactivation of *Penicilium verrucosum* and *Pichia anomala* within 24 h (*Journal of Nanomaterials 2020, DOI:* 10.1155/2020/9754024*)*.

New quasi-two-dimensional W_nO_{3n-1} crystals

We synthesized new quasi-two-dimensional tungsten oxide crystals, which nucleate by epitaxial growth on the $W_{19}O_{55}$ nanowires. In a single platelet, several stoichiometric phases were identified for the first time: $W_{18}O_{53}$, $W_{17}O_{50}$, $W_{16}O_{47}$, $W_{15}O_{44}$, $W_{14}O_{41}$, and W_9O_{26}. The structure was directly resolved from high-resolution electron microscopy images and modelled using electron and X-ray diffraction data. These layered crystals show a new kind of polycrystallinity, where crystallographic shear planes accommodate an oxygen deficiency and at the same time contribute to the stability of a particular phase. (*Nanoscale, 2020, DOI:* 10.1039/D0NR02014A).

Spatial ordering of the charge-density waves in $NbSe_3$

The ordering of the two incommensurate charge-density waves (CDWs) in the quasi-one-dimensional $NbSe_3$ structure was studied using low-temperature scanning–tunnelling microscopy (PRB 102, 075442 (2020)). Larger (100) van der Waals surfaces were analysed using one-dimensional Fourier transforms along the trigonal prismatic columns. The procedure enabled unambiguous differentiation between both CDWs, modulating individual columns and allowed quantitative comparison of modulation amplitudes along different columns of the same type. The results suggest the formation of CDW nanodomains. The possibility of interchanging both CDWs along columns forming symmetry-related pairs results in a charge difference, which is supposed to be the possible origin of CDW sliding. The paper was published in collaboration with a researcher from Canada (Physical Review B, 2020, *DOI:* 10.1103/PhysRevB.102.075442*)*.

The ultra-high-TP charge-density wave in the monoclinic phase of NbS_3

We reported on high-temperature studies of electrical conductivity of the monoclinic phase of NbS_3 type-II (J. Alloys & Compounds, 854, 157098 (2020)). The compound was shown to be stable up to a temperature $T \approx 550$ K. At $T_{P0} \approx 450–475$ K a step-like growth of conductivity was observed, clear evidence that T_{P0} is the temperature of a third, high-temperature CDW formation. The synchronization at moderate frequencies, 10–50 MHz, demonstrates coherent sliding of CDW-0. The charges condensed in this CDW show a relatively high density and, at the same time, extremely low mobility. Their mobility appears low in the single-particle states as well, giving a plausible clue to the surprising dielectric-like temperature variation of σ above T_{P0}. The paper was published in collaboration with groups from Taiwan and Russia *(Journal of Alloys and Compounds, 2020, DOI:* 10.1016/j.jallcom.2020.157098*)*.

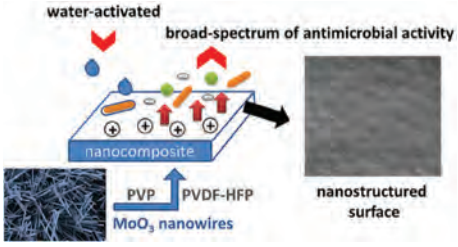

Figure 30: Schematic illustration of antimicrobial activation of PVDF-HFP/PVP/MoO_3 nanowires composite.

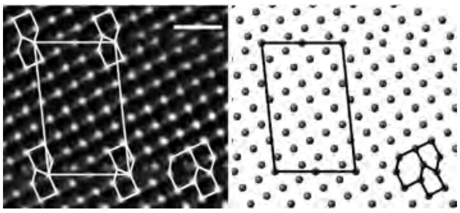

Figure 31: HRTEM image and its simulation of the $W_{16}O_{47}$ phase with pentagonal and hexagonal tunnels at crystallographic shear planes. The scale bar is 1 nm.

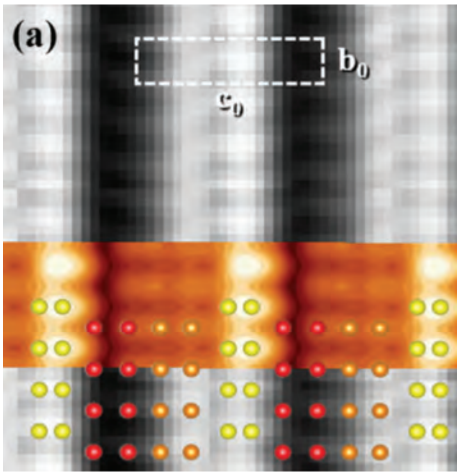

Figure 32: STM image of the surface of NbSe3 shown with the uppermost Se atoms and a DFT simulated STM image.

We developed the world's first animal-free in-vitro model for the prediction of chronic inflammation after nanoparticle inhalation, which we published in the prestigious journal Advanced Materials.

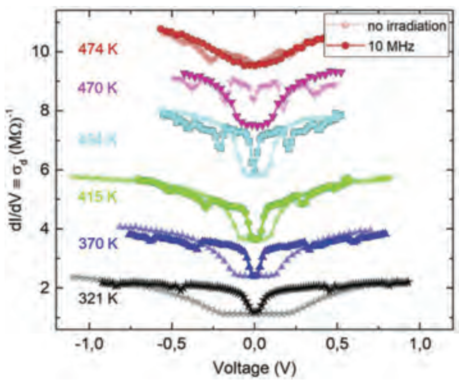

Figure 33: Temperature dependence of I-V curves with and without the RF irradiation applied.

Spontaneous Antiferromagnetic Ordering in a Single Layer of $(BETS)_2GaCl_4$ Organic Superconductor

The fabrication of well-defined and atomically clean interfaces between materials of different orders are of fundamental interest to engineer novel functionalities and to study emergent phenomena in condensed-matter physics. Our study was focused on the interplay between electronic orders of a hybrid mix of nested antiferromagnetic molecular chains and superconducting molecular stripes at the single-layer limit. The results of low-temperature scanning–tunnelling microscopy and spectroscopy have shown that low-level vibronic and magnetic excitations that dominate the higher temperature phase are absent below T_c, which point to their cooperative existence and possible renormalization to mediate superconductivity in such d-wave superconductors. The paper was published in collaboration with the group at Nihon University, Tokyo (*Advanced Electronic Materials, 2020, DOI:* 10.1002/aelm.202000461).

Air pollution by nanoparticles released during a football match

We measured air pollution with nanoparticles during a derby between the football clubs NK Olimpija Ljubljana and NK Maribor on March 2019 in Stožice. The fan groups of both teams, Green Dragons and Viola Maribor, lit torches and pyrotechnics in support of their clubs, despite the ban. The number of nanoparticles ranging in size from 30 nm to 300 nm in the air when the torches were lit increased by 1200 %, and the players inhaled 300 % more particles than in a low-pollution environment. Chemical analysis showed that in addition to carbon, there were also elements that were potentially toxic and used for colour effects and as fuel: strontium (red), barium (green), potassium, magnesium and chlorine (*Atmospheric Environment 2020, DOI:* 10.1016/j.atmosenv.2020.117567*)*.

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

The programme group "**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, micro-spectroscopies 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 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 aging population. The investment into the new super-resolution STED system opened a variety of fluorescence microscopy approaches: STED microscopy and two-photon (2PE) microscopy, multichannel spectrally resolved fluorescence lifetime imaging (spFLIM), fluorescence micro-spectroscopy (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 the diffusion in confined geometries with the use of modulated gradients.

Epidemiological evidence suggests that the inhalation of pollutants, including the nanoparticles in polluted air, contributes to around 4 million deaths worldwide. However, it is still not known which nanoparticles are responsible. In collaboration with the National Research Centre for the Working Environment (NRCWE) (Denmark) we have shown that among several different types of anatase TiO_2 nanoparticles only the nanotubes triggered chronic inflammation in mice.

After our discovery in 2019 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) we have developed the world's first animal-free in-vitro model for the prediction of chronic inflammation after nanoparticle inhalation. It is based on the complex mechanism discovered within intensive collaborative research as a part of a work package that we led within the €8m European Horizon 2020 SmartNanoTox project. The mechanism of nanomaterial toxicity is based on three key events: 1) formation of agglomerates of nanoparticles and biomolecules on the surface of lung epithelial cells, 2) toxicity of the material to macrophages, and 3) cell signalling, all linked in a perpetual cycle of events. The resulting publication in the prestigious journal Advanced Materials was selected as the frontispiece by the editor and is currently in the top 5% of all research outputs scored by Altmetric. This enormous collaborative work has been directed by our researchers T. Koklič and J. Štrancar and co-authored by many of the world's top toxicologists from Germany, France, Denmark, Canada, Finland, Sweden, Ireland, and UK.

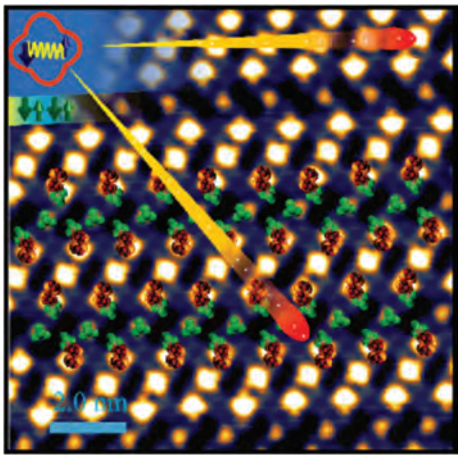

Figure 34: Hybrid order of two ground states where molecular magnetic chains are nested within a single-layer organic superconductor

In collaboration with the University of Oxford (UK), we have been developing advanced fluorescence microscopy and microspectroscopy methods for the characterisation of local molecular environments. We greatly expanded the flexibility of super-resolution fluorescence correlation spectroscopy (STED-FCS) by integrating faster detection electronics. We introduced an aberration-resilient depletion pattern for more reliable STED-FCS measurements in 3D and applied adaptive optics to characterise the diffusion in challenging cellular environments. We also investigated new probes for gentler super-resolution imaging technique RESOLFT. For our future development of advanced nanospectroscopies, we obtained and started a new ARRS research project (J7-2596) in collaboration with the Visual Cognitive Systems Laboratory from the Faculty of Computer and Information Science, University of Ljubljana.

The research work conducted within the ARRS project Microspectroscopy-based optimization of the effects of laser pulses on the retina (L7-7561) were published in two peer-reviewed papers. Here we report the capabilities of the in-house-developed 2-photon laser system (Laboratory for Photonics and Laser Systems (FOLAS), Faculty of Mechanical Engineering as LBF partner) for the retinal tissue theragnostics and the capabilities of fluorescence hyperspectral imaging with a bespoke data-analysis algorithm for tracking blood coagulation and oxygenation dynamics conducted in *ex-vivo* retinal vessels. Besides publications, the extensive work on the projects has resulted in a granted European patent "Image-processing apparatus and image-processing method for detection of irregularities in tissue" (PCT/SI2018/050007, EP2018713384).

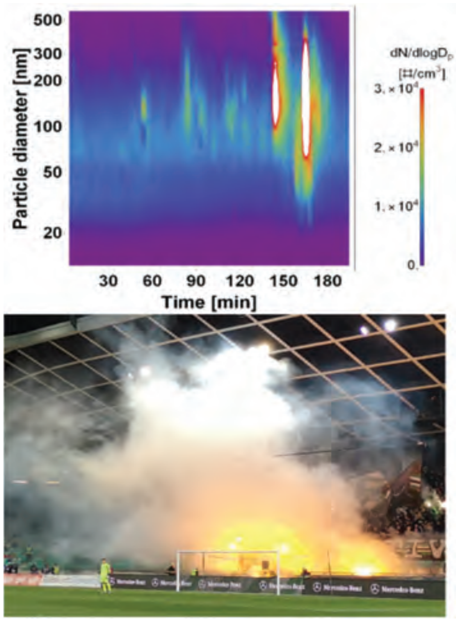

Figure 35: Use of flares and pyrotechnics during a match caused an up to 12-fold increase in the number concentration of nanoparticles in the air.

In the framework of the next ARRS project (L2-9254) focused on the spatial and temporal design of the laser systems for minimally invasive ophthalmological applications, our STED laser system was upgraded with a new beam line for testing a newly developed adaptive laser system (Laboratory for Photonics and Laser Systems (FOLAS), Faculty of Mechanical Engineering as LBF partner). Diagnostics and therapy capabilities together with the new algorithm and concepts for theragnostic approaches were characterized on human retinal tissue. The findings of the research will be published in 2021.

Further studies have been performed for the project focused on nano-temperature mapping done in collaboration with the Laboratory for Heating Technology LTT, Faculty of Mechanical Engineering. Temperature profiling for micro-boiling studies has been tested with a newly developed temperature-sensitive organic and inorganic molecules and particles. Based on the preliminary findings, new collaboration with Advanced Materials Department (K9) was established for the continued experimental work in 2021.

A lot of work has been dedicated to the running project Crossing Borders and Scales (CROSSING) focused on the advanced applications of correlative microscopy (CM) using state-of-the-art high-resolution imaging and analysis techniques provided at the JSI and partnering HZDR. The continued research focused on nanoscale CM characterization of nanomaterial interacting with the biological matter (model lung epithelium, neuron network) contributed to the high-impact-journal publication and to a better understanding of the molecular events potentially responsible for toxicological behaviour. New analytical CM approaches have been tested and planned for 2021 to provide further details of the relevant biological system.

Another activity in 2020, led by the Laboratory of Biophysics, was the submission of the application for the involvement in the JSI Infrastructure program for the period from 2022–2027. Based on vast expertise and the available infrastructure of advanced and multimodal optical microscopies, we have applied, together with the few JSI departments, for the new centre called the Center for advanced optical microscopies, which would be a part of CEMM centre.

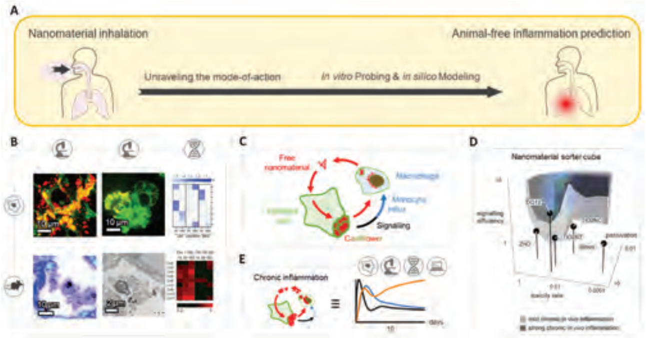

Figure 36: A) Development of the world's first animal-free prediction of chronic inflammation after nanoparticle inhalation: B) first, the mechanism of nanomaterial-induced inflammation was discovered using advanced microscopies and omics on in vitro and in vivo systems. C) The discovered events were causally connected into a network of events, shown here by a simplified scheme. D) Computer modelling of the network of events enabled classification of nanomaterials according to the predicted outcome of exposure based on three nanomaterial-specific parameters. E) By combining in vitro probing of these parameters and the in silico model, chronic inflammation can be predicted for any metal oxide nanomaterial in a time- and cost-efficient manner without animal testing.

Metamorphosis of the Carniolan bee (Apis mellifera carnica) monitored by MR microscopy

In cooperation with the Biotechnical Faculty (BF UL), we started studying the metamorphosis of the Carniolan bee with sequential MR microscopy in the summer of 2018. The study was demanding, as we had to provide the best conditions for the development of the bee inside the MR magnet during imaging, which lasted 14 days for an individual bee sample. We first isolated an individual cell with a larva and then imaged it until the emergence of an adult bee. During this time, approximately 80 three-dimensional images with a resolution of 80 micrometres were taken with a time interval of 4 hours. The recorded images were then segmented so that we could extract information on the temporal change in the volume of various organs (digestive tract, respiratory system, honey stomach, etc.). With the help of structural analysis of images using the grey-level cooccurrence matrix (GLCM) method, we were also able to determine the transformation of the flight muscle. To ensure the statistical significance of the results, imaging was performed on two bee samples. The results of MR images of bees were also verified by X-ray computed tomography that was taken at the department B1 at JSI, as well as with histological analysis performed by the BF UL. The results of this study were published in the article: Aleš Mohorič, Janko Božič, Polona Mrak, Kaja Tušar, Lin Chenyun, Ana Sepe, Urška Mikac, Georgy Mikhaylov, Igor Serša, "In vivo continuous three-dimensional magnetic resonance microscopy : a study of metamorphosis in Carniolan worker honey bees (Apis mellifera carnica)", *Journal of Experimental Biology*, Nov. 2020, vol. 223, iss. 21, DOI: 10.1242/jeb.225250.

A new method to improve the signal-to-noise ratio of MR images

We have developed a new method that can be used to improve the signal-to-noise ratio (SNR) in MR images. The method is based on the signal aliasing effect. This occurs in MR imaging when the imaging field of view (FOV) is smaller than the sample size. The phenomenon leads to artefacts of MR images in usual samples, as parts of the sample outside the FOV are fold over into the image, which can lead to their overlap with the image of the sample within the FOV. We found that for a special type of sample, i.e., for periodic samples, this undesirable phenomenon can be used for the constructive superposition of the aliased signals and thus for signal amplification without any noise increase, if these samples are imaged at FOV equal to the unit cell size of the periodic sample. The method was first theoretically analysed, then verified on a model sample in two dimensions, and finally the practical use of this method was demonstrated by the imaging of a periodic array of drug tablets with extremely low NMR signals due to the low moisture content in the tablets. There was not enough signal from a single tablet to be able to get its MR image. However, with the presented method, it was straightforward to obtain the image of the tablet. The results of this study were published in the article: Igor Serša, "Magnetic resonance microscopy of samples with translational symmetry with FOVs smaller than sample size", *Scientific reports*, 2021, vol. 11, 541-1-541-12, IDOI: 10.1038/s41598-020-80652-z.

Study of medial and ulnar nerve morphology

This study was initiated by our partners from the Institute of Anatomy (MF UL). In the study three radiological methods are compared according to their diagnostic potential for separating fine structures within individual nerve fibres. Nerve-fibre samples were isolated human medial and ulnar nerves, then they were imaged, and finally we wanted to pinpoint the number and size of individual fascicles from their images. The radiological methods used were clinical MR imaging at 3T (3T-MRI), high-resolution ultrasound imaging (HRUS), magnetic resonance microscopy (MRM) at 9.4 T. Images of these three methods were also compared with the reference histological analysis method. The results of the study showed that of all the three radiological methods, MRM imaging has the highest diagnostic potential, less efficient but still relatively good was HRUS, while 3T-MRI proved to be the worst. The results of this study were published in a leading journal in the field of radiology in the article: Žiga Snoj, Igor Serša, Urša Matičič, Erika Cvetko, Gregor Omejec, "Nerve fascicle depiction at MR microscopy and high-frequency US with anatomic verification", *Radiology*, 2020, vol. 297, no. 3, pp. 1-3, DOI: 10.1148/radiol.2020201910.

Development of MR contrast agents based on magneto-liposomes

We participated in the characterization of the MR properties of a new type of contrast agents developed by the department K7 at JSI. These contrast agents are based on superparamagnetic iron nanoparticles, which are incorporated into the bilayer membrane of liposomes for better biocompatibility and therapeutic possibilities, thus obtaining magneto-liposomes (MLs). In the study, we first measured the NMR relaxation properties of differently concentrated aqueous ML solutions. This was followed by experiments on a culture of healthy and cancerous (T24) urothelial cells, to which MLs were added at various concentrations. The cell-culture samples were MR imaged using the T2 mapping method. In the experiments, we showed that MLs accumulate more markedly in cancer cells, so the MR signal of these cells is much shorter (T2-NMR relaxation time is greatly shortened) and thus allows efficient separation between healthy and cancer cells. The results of this study are published in the article: Nina Kostevšek, Calvin Cheung, Igor Serša, Mateja Erdani-Kreft, Ilaria Monaco, Mauro Comes Franchini, Janja Vidmar, Wafa Al-Jamal, "Magneto-liposomes as MRI contrast agents: a systematic Study of different liposomal formulations", *Nanomaterials*, 2020, vol. 10, no. 5, pp. 889-1-889-18,DOI: 10.3390/nano10050889.

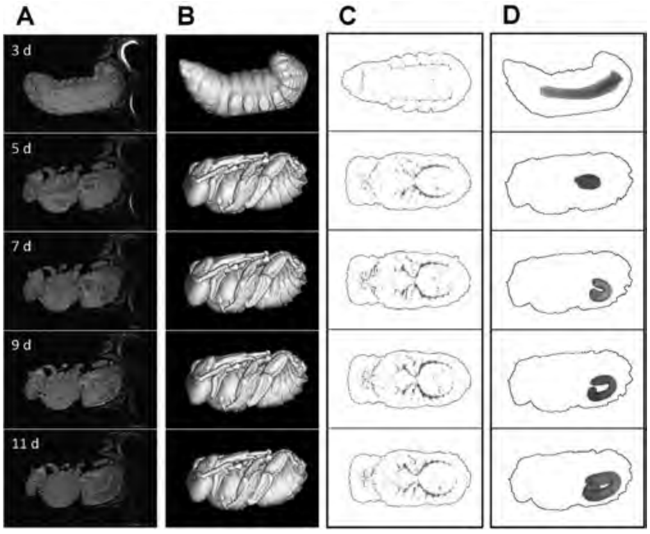

Figure 37: MR images of the metamorphosis of the Carniolan bee (Apis mellifera carnica) taken at two-day intervals: (A) T1-weighted MRI images from the 3D image set, (B) the corresponding volume rendered images, (C) the corresponding segmented respiratory system images, and (D) the corresponding segmented digestive tract images.

MR imaging study of controlled-release tablets

We studied the effect of different pH and mechanical stresses on the formation of a gel layer and on the release of pentoxifylline from xanthan tablets. The mechanical stress on the tablets was caused by a flow of liquid surrounding the tablets. A biomodal method was used for tablet testing. In it, MR imaging was used to monitor the formation of a gel layer and sampling of the liquid medium in which the tablet dissolved allowed us to monitor the release of the drug from the tablets. The obtained results showed that in the pH neutral medium (water) the structure of the gel layer is weaker and less resistant to erosion than the structure of the gel layer obtained in the acid medium. Different pH values of the medium also influenced the different mechanisms of drug release from the tablets. This was predominantly erosive in the case of a neutral medium and was diffusive in the case of an acidic medium. The effect of fluid flow around the tablets was important in the erosive release mode at neutral pH, while the effect of flow was negligible in the case of the diffusion release mode at acidic pH due to the increased compactness of the gel layer. The results of the study were published in the article: MIKAC, Urška, KRISTL, Julijana. Magnetic resonance methods as a prognostic tool for the biorelevant behavior of xanthan tablets. *Molecules*. 2020, vol. 25, no. 24, pp. 1-12, DOI: 10.3390/molecules25245871.

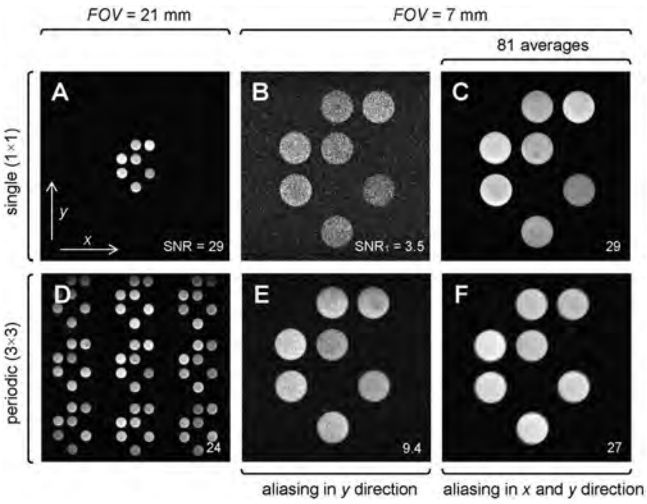

Figure 38: MR images of the test 2D periodic sample: (A-C) the sample consists only of the central object with the unit-cell dimension of 7 mm and (D-F) the sample consists of nine identical objects arranged in a 3 × 3 matrix. (A, D) When the central object was imaged at a field of view (FOV) equal to three times the unit-cell dimension, the SNR was nine times higher than in case (B) when this object was imaged at the FOV equal to the unit cell. When imaging a 2D periodic sample with the FOV equal to the unit cell, the SNR is increased relative to example (B) by a factor of: (E) three times when the constructive signal aliasing is present only in the phase direction and (F) nine times when the constructive signal aliasing is present along both axes of symmetry. (C) An image of the same SNR as in example (F) can also be obtained with 81 averages of the image signals of example (B).

The research in our department has been supported by a number of international projects financed by the European Union. It was also supported by many bilateral projects and other scientific cooperations. In 2020, the Department had cooperation 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, Great Britain
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, Lausanne, Switzerland
11. Eidgenössische Technische Hochschule - ETH, Zürich, Switzerland
12. Elettra (Synchroton Light Laboratory), Basovizza, 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, Poznan, 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, the 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. Institute for Theoretical Physics in Göttingen, Göttingen, Germany
27. Institute of Molecular Physics, Polish Academy of Sciences, Poznan, 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. Institute for Crystallography, Russian Academy of Sciences, 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, Great Britain
35. A.F. Ioffe Physico-Technical Institute, Saint Petersburg, Russia
36. Kavli Institute for Theoretical Physics, Santa Barbara, USA
37. King's College, London, Great Britain
38. Klinični center 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, Kyiv, Ukraine
49. National Center for Scientific Research "Demokritos", Aghia Paraskevi Attikis, Greece
50. National Institute for Research in Inorganic materials, Tsukuba, Japan
51. Nuklearni Institut Vinča, Beograd, Serbia
52. Oxford University, Department of Physics, Department of Materials, Oxford, Great Britain
53. Paul Scherrer Institut, Villigen, Switzerland
54. Politecnico di Torino, Dipartimento di Fisica, Torino, Italy
55. Radbound University Nijmegen, Research Institute for Materials, Nijmegen, the 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. Sveučilište u Rijeci, Medicinski fakultet, Rijeka, Croatia
61. Sveučilište u Zagrebu, Institut za fiziku, 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, Bunkjo, 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, Great Britain
73. University of California at Irvine, Beckman Laster Institute and Medical Clinic, Irvine, California, USA
74. University of Durham, Durham, Great Britain
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, Great Britain
80. University of Loughborough, Loughborough, Great Britain
81. Universit*ä*t Mainz, Geowissenschaften, Mainz, Germany
82. Université de Nice, Nice, 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. Universit*ä*t Regensburg, Regensburg, Germany
89. University of Zürich, Zürich, Switzerland
90. University of Munich and MPQ, Munich, Germany
91. University of Mons, Mons, Belgium
92. University of Pavia, Pavia, Italy
93. Universy of Maribor, Maribor, Slovenia
94. University of North Carolina at Chapel Hill, Chapel Hill, USA
95. University of Wisconsin–Madison, Madison, USA
96. Wagenigen University, Laboratory of Biopyhsics, Wageningen, the Netherlands
97. Weizman Institute, Rehovot, Israel
98. Yonsei University, Seoul, South Korea

that made the reported studies possible.

Some outstanding publications in 2020

1. T. Arh, M. Gomilšek, P. Prelovšek, M. Pregelj, M. Klanjšek, A. Ozarowski, S. J. Clark, T. Lancaster, W. Sun, J.-X. Mi, A. Zorko. *Origin of magnetic ordering in a structurally perfect quantum kagome antiferromagnet*. Phys. Rev. Lett. **125** (2020) 027203.
2. P. Khuntia, M. Velazquez, Q. Barthélemy, F. Bert, E. Kermarrec, A. Legros, B. Bernu, L. Messio, A. Zorko, P. Mendels "Gapless ground state in the archetypal quantum kagome antiferromagnet ZnCu3(OH)6Cl2", Nat. Phys. 16, 469 (2020).
3. A. J. Hess, G. Poy, Jung-Shen B. Tai, S. Žumer, I. I. Smalyukh. *Control of light by topological solitons in soft chiral birefringent media.* Phys. Rev. X **10** (2020) 031042.
4. G. Poy, A. J. Hess, I. I. Smalyukh, S. Žumer. *Chirality-Enhanced Periodic Self-Focusing of Light in Soft Birefringent Media.* Phys. Rev. Lett. **125** (2020) 077801.
5. T. Strübing, A. Khosravanizadeh, A. Vilfan, E. Bodenschatz, R. Golestanian, I. Guido. *Wrinkling Instability in 3D Active Nematics*. Nano Lett. **20** (2020) 6281–6288.
6. J. Binysh, Ž. Kos, S. Čopar, M. Ravnik, G. P. Alexander. *Three-Dimensional Active Defect Loops.* Phys. Rev. Lett. **124** (2020) 088001.
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8. D. Richter, M. Marinčič, M. Humar. *Optical-resonance-assisted generation of super monodisperse microdroplets and microbeads with nanometer precision*. Lab Chip **20** (2020) 734–74.
9. P. Campinho, P. Lamperti, F. Boselli, A. Vilfan, J. Vermot. *Blood Flow Limits Endothelial Cell Extrusion in the Zebrafish Dorsal Aorta*. Cell Reports **31** (2020) 107505.
10. L. Pirker, B. Višić, S. D. Škapin, G. Dražić, J. Kovača, M. Remškar. *Multi-stoichiometric quasi-two-dimensional W_nO_{3n-1} tungsten oxides.* Nanoscale **12** (2020) 15102–15114.

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12. H. Kokot, B. Kokot, A. Sebastijanović, R. Podlipec, A. Kriševlj, P. Čotar, M. Pušnik, P. Umek, S. Pajk, I. Urbančič, T. Koklič, J. Štrancar, et al. *Prediction of chronic inflammation for inhaled particles:the impact of material cycling and quarantining in the lung epithelium*. Adv. Mater. **32** (2020) 2003913.
13. A. Barbotin, I. Urbančič, S. Galiani, C. Eggeling, M. J. Booth. *Background reduction in sted-fcs using a bi-vortex phase mask*. ACS Photonics **7** (2020) 1742–1753.
14. A. Frawley, V. Wycisk, Y. Xiong, S. Galiani, E. Sezgin, I. Urbančič, A. Vargas Jentzsch, K. G. Leslie, C. Eggeling, H. L. Anderson. *Super-resolution resolft microscopy of lipid bilayers using a fluorophore-switch dyad.* Chem. Sci. 11 (2020) 8955–8960.

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 117 (2019) 13188-13193.
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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.

Awards and Appointments

1. Dr Matjaž Gomilšek: Jožef Stefan Golden Emblem Prize for his doctoral thesis "Quantum spin liquids on geometrically frustrated kagome lattices", Ljubljana, Jožef Stefan Institute
2. Prof. Samo Kralj, PhD: the Zois Certificate of Recognition for important research achievements in the field of soft-matter physics, Ljubljana

Patents granted

1. Luka Drinovec, Griša Močnik, Photo-thermal interferometer, EP3492905 (B1), European Patent Office, 29. 04. 2020, US10768088 (B2), US Patent Office, 08. 09. 2020.

INTERNATIONAL PROJECTS

1. Small Services
   Dr. Polona Umek
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. COST CA15209; European Network on NMR Relaxometry
   Prof. Tomaž Apih
   Cost Office
5. COST CA16109; Chemical On-Line Composition and Source Apportionment of Fine Aerosol
   Prof. Griša Močnik
   Cost Office
6. COST CA16218; Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies
   Dr. Abdelrahim Ibrahim Hassanien
   Cost Association Aisbl
7. COST CA16221; Quantum Technologies with Ultra-Cold Atoms
   Dr. Peter Jeglič
   Cost Association Aisbl
8. COST CA17121; Correlated Multimodal Imaging in Life Sciences
   Prof. Janez Štrancar
   Cost Association Aisbl
9. COST CA17139; European Topology Interdisciplinary Action
   Prof. Slobodan Žumer
   Cost Association Aisbl
10. COST CA16202; International Network to Encourage the Use of Monitoring and Forecasting Dust Products
    Prof. Griša Močnik
    Cost Association Aisbl
11. COST CA9108 - HiSCALE; High-Temperature SuperConductivity for AcceLerating the Energy Transition
    Dr. Abdelrahim Ibrahim Hassanien
    Cost Association Aisbl
12. BIO-OPT-COMM; A Living Optically-Communicating Neural Network
    Asst. Prof. Matjaž Humar
    Hfspo- International Human Frontier
13. H2020 - SmartNanoTox; Smart Tools for Gauging Nano Hazards
    Prof. Janez Štrancar
    European Commission
14. H2020 - ENGIMA; Engineering of Nanostructures with Giant Magneto-Piezoelectric and Multicaloric Functionalities
    Prof. Zdravko Kutnjak
    European Commission
15. H2020 - Cell-Lasers; Intracellular Lasers: Coupling of Optical Resonances with Biological Processes
    Asst. Prof. Matjaž Humar
    European Commission
16. Conservation of Cultural Heritage Indoors - The Case of Leonardo da Vinci's „Last Supper"
    Prof. Griša Močnik
    Slovenian Research Agency
17. Lipid Wrapped Nanoparticles and Activity of Factor Xa
    Dr. Tilen Koklič
    Slovenian Research Agency
18. Studies of Nanoporous Materials for Hydrogen Storage
    Prof. Janez Dolinšek
    Slovenian Research Agency
19. Magnetoresonance Study of Spin-Liquid Candidates
    Prof. Andrej Zorko
    Slovenian Research Agency
20. Advanced Organic and Inorganic Thin-Film Composites with Enhanced Dielectric and Electromechanical Response
    Prof. Zdravko Kutnjak
    Slovenian Research Agency
21. New Electronic States Emergent via Cross-Coupling between Magnetism and Electrical Conduction in Itinerant Antiferromagnetic Systems
    Prof. Denis Arčon
    Slovenian Research Agency
22. Hemoglobin-Based Nano-Spectral Non-Linear Imaging for Future Label-Free Medical Diagnostics
    Dr. Rok Podlipec
    Slovenian Research Agency
23. Impact of Fireworks on Air Pollution in Urban Environments
    Asst. Prof. Anton Gradišek
    Slovenian Research Agency
24. Investigation of Air Pollution with Nanoparticles Caused by Fireworks
    Prof. Maja Remškar
    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. Phase transitions towards coordination in multilayer networks
Dr. Uroš Jagodič
5. Development of building blocks for new European quantum communication network
Dr. Peter Jeglič
6. High-resolution optical magnetometry with cold cesium atoms
Dr. Peter Jeglič
7. Integrated multi-channel artificial nose for vapor trace detection
Prof. Igor Muševič
8. Photonic devices made entirely out of edible materials
Asst. Prof. Matjaž Humar
9. Probing spin states near the surface of quantum spin materials
Prof. Denis Arčon
10. Advanced soft nematocaloric materials
Asst. Prof. Brigita Rožič
11. Multicaloric cooling
Prof. Zdravko Kutnjak
12. Optimization of MRI techniques for assessment of thrombolytic treatment outcome
Prof. Igor Serša
13. Intracellular lasers: Coupling of optical resonances with biological processes
Asst. Prof. Matjaž Humar
14. Study of intracellular forces by deformable photonic droplets
Asst. Prof. Matjaž Humar
15. Electrocaloric elements for active cooling of electronic circuits
Prof. Vid Bobnar
16. Advanced inorganic and organic thin films with enhanced electrically-induced response
Prof. Vid Bobnar
17. Adverse outcome pathway leading to atherosclerosis
Dr. Tilen Koklič
18. Liquid-crystal microdroplet lasers for sensing inside live cells
Zuhail Kottoli Poyil
19. Stabilization and destabilisation of spin liquids by perturbations
Prof. Andrej Zorko
20. Physics of Majorana fermions in Kitaev magnets
Dr. Martin Klanjšek
21. Novel experimental approach for determination of quantum spin liquids
Prof. Andrej Zorko
22. Topological turbulence in confined chiral nematic fields
Prof. Miha Ravnik
23. Controllable broadband electromagnetic-radiation shielding
Dr. Matej Pregelj
24. Intelligent Content-Aware Nanospectroscopy (iCAN) of molecular events in nanoparticles-induced neurodegeneration
Dr. Iztok Urbančič
25. Biopharmaceuticals: sensor for aggregation of protein particles based on liquid crystals
Prof. Miha Ravnik
26. Spatial and temporal shaping of laser light for minimally invasive ophthalmic procedures
Prof. Janez Štrancar
27. Domain engineered ferroelectric ceramic layer elements for efficient energy harvesting and energy conversion applications
Prof. Zdravko Kutnjak
28. Magnetic, electric and stress – field programming of shape response in polymer-dispersed liquid crystal elastomers – based actuators
Dr. Andraž Rešetič
29. Building blocks, tools and systems for the Factories of the Future – GOSTOP
Prof. Janez Štrancar
Ministry of Education, Science and Sport
30. Reimbursement of costs of scientific publications in golden open access for 2019, 2020
Prof. Igor Muševič
Slovenian Research Agency

NEW CONTRACTS

1. Magnetic, electric and stress - field programming of shape response in polymer-dispersed liquid crystal elastomers - based actuators
Dr. Andraž Rešetič
Kmz - Zalar Miran S.p.
2. Characterization of ferric carboxymaltose by atomic force microscopy
Prof. Miha Škarabot
Lek d. d.
3. Characterisation of iron-carboksimaltose with the electron paramagnetic resonance (EPR) technique
Prof. Denis Arčon
Lek d. d.
4. AerOrbi - Aerosol soft photo ionisation Orbitrap mass spectrometry
Prof. Griša Močnik
Aerosol d. o. o.

VISITORS FROM ABROAD

1. Hanani Zouhair, Cadi Ayyad University, Marrakesh, Morocco, 15 November 2019–15 January 2020
2. Dr Wencka Magdalena, Institute of Molecular Physics, Polish Academy of Sciences, Poznań, Poland, 15 January–31 December 2020
3. Petrinović Toma, University of Zagreb, Institute of Physics, Zagreb, Croatia, 5–14 January 2020
4. Prof. Lancaster Tom, PhD, Durham University, Durham, United Kingdom, 12–17 January 2020
5. Dr Fukuda Jun-ichi, Kyushu University, Fukuoka, Japan, 12–18 January 2021
6. Dr Komitov Lachezar, University of Gothenburg, Gothenburg, Sweden, 2–7 March 2020
7. Dr Jampani Venkata Suba Rao, University of Luxembourg, Luxembourg, Luxembourg, 3 September–10 October 2020
8. Dr Višić Bojana, Institute of physics Belgrade, Belgrade Serbia, 1–10 October 2020
9. Nikolai Cyepurnyi, Ostbayerische Technische Hochschule Regensburg, Regensburg, Germany, 8–31 October 2020

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102. Ana Sepe, B. Sc.
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BIBLIOGRAPHY

Original Article

1. Geonhyeong Park, Simon Čopar, Ahram Suh, Minyong Yang, Uroš Tkalec, Dong Ki Yoon, "Periodic arrays of chiral domains generated from the self-assembly of micropatterned achiral lyotropic chromonic liquid crystal", *ACS central science*, 2020, **6**, 11, 1964-1970.
2. Aurelien Barbotin, Iztok Urbančič, Silvia Galiani, Christian Eggeling, Martin J. Booth, "Background reduction in STED-FCS using a bi-vortex phase mask", *ACS photonics*, 2020, **7**, 7, 1742-1753.
3. Abdou Hassanien, Biao Zhou, Akiko Kobayashi, "Spontaneous antiferromagnetic ordering in a single layer of $(BETS)_2GaCl_4$ organic superconductor", *Advanced electronic materials*, 2020, **6**, 10, 2000461.
4. Rijeesh Kizhakidathazhath, Yong Geng, Venkata Subba R. Jampani, Cyrine Charni, Anshul Sharma, Jan P. F. Lagerwall, "Facile anisotropic deswelling method for realizing large-area cholesteric liquid crystal elastomers with uniform structural color and broad-range mechanochromic response", *Advanced functional materials*, 2020, **30**, 7, 1909537.
5. Hana Kokot *et al.* (34 authors), "Prediction of chronic inflammation for inhaled particles: the impact of material cycling and quarantining in the lung epithelium", *Advanced materials*, 2020, **32**, 47, 2003913.
6. Honey Dawn C. Alas, Thomas Müller, Kay Weinhold, Sascha Pfeifer, Kristina Glojek, Asta Gregorič, Griša Močnik, Luka Drinovec, Francesca Costabile, Martina Ristorini, A. Wiedensohler, "Performance of microAethalometers: real-world field intercomparisons from multiple mobile measurement campaigns in different atmospheric environments", *Aerosol and air quality research*, 2020, **20**, 12, 2640-2653.
7. Manos Anyfantakis, Venkata Subba R. Jampani, Rijeesh Kizhakidathazhath, Bernard P. Binks, Jan P. F. Lagerwall, "Responsive photonic liquid marbles", *Angewandte Chemie*, 2020, **59**, 43, 19260-19267.
8. I. Antonyshyn *et al.* (11 authors), "Micro-scale device—an alternative route for studying the intrinsic properties of solid-state materials: the case of semiconducting TaGeIr", *Angewandte Chemie*, 2020, **59**, 27, 11136.
9. Anja Sadžak, Janez Mravljak, Nadica Maltar-Strmečki, Zoran Arsov, Goran Baranović, Ina Erceg, Manfred Kriechbaum, Vida Strasser, Jan Přibyl, Suzana Šegota, "The structural integrity of the model lipid membrane during induced lipid peroxidation: the role of flavonols in the inhibition of lipid peroxidation", *Antioxidants*, 2020, **9**, 5, 430.
10. Ema Valentina Brovč, Stane Pajk, Roman Šink, Janez Mravljak, "Protein formulations containing polysorbates: are metal chelators needed at all?", *Antioxidants*, 2020, **9**, 5, 441.
11. Itir Bakis Dogru-Yuksel, Mertcan Han, Gregor Pirnat, Emir Salih Magden, Erkan Senses, Matjaž Humar, Sedat Nizamoglu, "High-Q, directional and self-assembled random laser emission using spatially localized feedback via cracks", *APL photonics*, 2020, **5**, 10, 106105.
12. Rok Podlipec, Jaka Mur, Jaka Petelin, Janez Štrancar, Rok Petkovšek, "Two-photon retinal theranostics by adaptive compact laser source", *Applied physics. A, Materials science & processing*, 2020, **126**, 6, 405.
13. Urška Gabor, Damjan Vengust, Zoran Samardžija, Aleksander Matavž, Vid Bobnar, Danilo Suvorov, Matjaž Spreitzer, "Stabilization of the perovskite phase in PMN-PT epitaxial thin films via increased interface roughness", *Applied Surface Science*, 2020, **513**, 145787.
14. Asta Gregorič, Luka Drinovec, Irena Ježek, Janja Vaupotič, Matevž Lenarčič, Domen Grauf, Longlong Wang, Maruška Mole, Samo Stanič, Griša Močnik, "The determination of highly time-resolved and source-separated black carbon emission rates using radon as a tracer of atmospheric dynamics", *Atmospheric chemistry and physics*, 2020, **20**, 22, 14139-14162.

15. S. Vratolis *et al.* (18 authors), "Comparison and complementary use of *in situ* and remote sensing aerosol measurements in the Athens Metropolitan Area", *Atmospheric environment*, 2020, **228**, 117439.
16. Luka Pirker, Anton Gradišek, Bojana Višić, Maja Remškar, "Nanoparticle exposure due to pyrotechnics during a football match", *Atmospheric environment*, 2020, **233**, 117567.
17. Luka Drinovec, Jean Sciare, Iasonas Stavroulas, Spiros Bezantakos, Michael Pikridas, Florin Unga, Chrysanthos Savvides, Bojana Višić, Maja Remškar, Griša Močnik, "A new optical-based technique for real-time measurements of mineral dust concentration in PM_{10} using a virtual impactor", *Atmospheric measurement techniques*, 2020, **13**, 7, 3799-3813.
18. Martin Rigler, Luka Drinovec, Gašper Lavrič, Athanasia Vlachou, Andre S. H. Prévôt, Jean-Luc Jaffrezo, Iasonas Stavroulas, Jean Sciare, Judita Burger, Irena Kranjc, Janja Turšič, Anthony D. A. Hansen, Griša Močnik, "The new instrument using a TC-BC (total carbon-black carbon) method for the online measurement of carbonaceous aerosols", *Atmospheric measurement techniques*, 2020, **13**, 8, 4333-4351.
19. Bradley Visser, Jannis Röhrbein, Peter Steigmeier, Luka Drinovec, Griša Močnik, Ernest Weingartner, "A single-beam photothermal interferometer for *in situ* measurements of aerosol light absorption", *Atmospheric measurement techniques*, 2020, **13**, 12, 7097-7111.
20. Aurélien Barbotin, Iztok Urbančič, Silvia Galiani, Christian Eggeling, Martin J. Booth, Erdinc Sezgin, "z-STED imaging and spectroscopy to investigate nanoscale membrane structure and dynamics", *Biophysical journal*, 2020, **118**, 10, 2448-2457.
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