Quantum Technologies Conference IX
Manipulating photons, atoms, and molecules

Conference Booklet

September 11 - 16, 2018, Jastarnia in Hel, Poland

Organizing Committee

- **Marek Trippenbach** (Chairman)
  Faculty of Physics, University of Warsaw (Warsaw)
- **Mariusz Gajda** (Co-chairman)
  Institute of Physics of the Polish Academy of Sciences (Warsaw)
- **Maciej Lewenstein** (Co-chairman)
  ICFO - The Institute of Photonic Sciences (Barcelona)
- **Jakub Zakrzewski** (Co-chairman)
  Faculty of Physics, Astronomy and Applied Computer Sciences, Jagiellonian University (Krakow)

- **Tomasz Jedynak** (Secretary of the conference)
  +48 694 878 666, **tomasz.jedynak@globalcongress.pl**

Conference Venue

The conference will be held at the SPA&FAMILY Dom Zdrojowy in Jastarnia.

ADDRESS

Dom Zdrojowy
Kościuszki 2A
84-140 Jastarnia
zdrojowy.com.pl

September 11 - 16, 2018, Jastarnia in Hel, Poland

17:20 – 18:00 **Hans Büchler,** University of Stuttgart

Quantum Electrodynamics with a single Rydberg superatom

buechler@theo3.physik.uni-stuttgart.de

(H.P. Büchler)

The interaction of a single photon with an individual two-level system is the textbook example of quantum electrodynamics. Achieving strong coupling in this system so far required confinement of the light field inside resonators or waveguides. Here, we demonstrate strong coherent coupling between a single Rydberg superatom, consisting of thousands of atoms behaving as a single two-level system due to the Rydberg blockade, and a propagating light pulse containing only a few photons. The strong light-matter coupling in combination with the direct access to the outgoing field allows us to study the effect of the interactions on the driving field at the single photon level. We present a microscopic theoretical understanding of these phenomena and discuss the appearance of correlations between the photons.

18:00 – 18:20 **Dmitry Efimov,** Jagiellonian University

Multiple-electron strong-field ionization of atoms

dmitry.efimov@uj.edu.pl

(D.K. Efimov, J.H. Thiede, J.S. Prauzner-Bechcicki, B. Eckhardt, J. Zakrzewski)

The study of quantum dynamics of atoms and molecules in strong femtosecond and even attosecond laser fields is currently one of the most challenging tasks attracting a considerable portion of scientists' attention. Ionization dynamics and High Harmonics generation (HHG) are both processes of particular interest in the field. While experimental investigations deal mainly with multielectron systems, the majority of theoretical models and corresponding numerical algorithms work in the single-active-electron regime, due to restrictions of presently available computing power. Nevertheless, a number of phenomena like the existence of a second plateau in HHG [2], “knees” in the ionization yield dependences [5] and giant HHG enhancement in Xenon [3] can only be explained as multi-electron effects. Thus, development of numerical and analytical tools for accounting multi-electron dynamics in strong field processes seems necessary.

Here we report our progress in developing numerical tools for simulating two- and three-electron dynamics and applying them for analysis of strong-field processes [1, 4].

References

1. D K Efimov, A Maksymov, J S Prauzner-Bechcicki, J Thiede, B Eckhardt, A Chacon, M Lewenstein, and J Zakrzewski. Restricted space ab initio models for double ionization by strong laser pulses. arXiv preprint arXiv:1803.08364, 2018.

2. P. Koval, F. Wilken, D. Bauer, and C. H. Keitel. Nonsequential double recombination in intense laser fields. Phys. Rev. Lett., 98:043904, Jan 2007.

3. Stefan Pabst and Robin Santra. Strong-field many-body physics and the giant enhancement in the high-harmonic spectrum of xenon. Phys. Rev. Lett., 111:233005, Dec 2013.

4. J H Thiede, B Eckhardt, D K Efimov, J S Prauzner-Bechcicki, and J Zakrzewski. Strong field three electron ionization-ab initio time-dependent study. arXiv preprint arXiv:1804.05773, 2018.

5. B.Walker, B. Sheehy, L. F. DiMauro, P. Agostini, K. J. Schafer, and K. C. Kulander. Precision measurement of strong field double ionization of helium. Phys. Rev. Lett., 73:1227-1230, Aug 1994.

18:40 – 19:00 **Julien Despres,** Ecole Polytechnique

Universal scaling laws for the spreading of correlations in quantum systems

julien.despres@polytechnique.edu

(J. Despres)

The out-of-equilibrium dynamics of strongly correlated quantum systems is one of the most challenging problems of the many-body quantum physics. Indeed, the dramatic progress realized in the field of ultracold atoms allow to simulate particle or spin Hamiltonians of condensed-matter physics with unprecedented control possibilities of the parameters in time. This new experimental opportunity triggers a renewed interest for the topic with many open problems such that the transport of information or the thermalization of a quantum system.

Here, we are interested in the spreading of quantum correlations. Using an unifying quasiparticle framework, we unveil a rich structure of the correlation cone [1], which encodes the footprints of several microscopic properties of the system. When the quasi-particle excitations propagate with a bounded group velocity, we show that the correlation edge and correlation maxima move with different velocities that we derive. For systems with a divergent group velocity, especially relevant for long-range interacting systems, the correlation edge propagates slower than ballistic. In contrast, the correlation maxima propagate faster than ballistic in gapless systems but ballistic in gapped systems [2]. Our unified theory on the correlation spreading [3] sheds new light on existing experimental and numerical observations, and paves the way to the next generation of experiments. For instance, we argue that the dynamics of correlation maxima can be used as a witness of the elementary excitations of the

system.

I will also present several numerical results concerning space-time correlation functions in bosonic or spin lattice models for a dynamics induced by a global or local quench. These results were obtained using algorithms based on the tensor network language, namely time-dependent matrix product state (t-MPS) and time-dependent variational principle (TDVP) using the geometric notion of the MPS manifold. They will provide a numerical proof of the different scaling laws described just above.

References

[1] Lieb, E. H., Robinson, D. W. The finite group velocity of quantum spin systems, Comm. Math. Phys, 28, 251-257, 1972.

[2] Cevolani, L., Carleo, G., Sanchez-Palencia, L. Spreading of correlations in exactly solvable quantum models with long-range interactions in arbitrary dimensions, New J. Phys. 18, 093002, 2016.

[3] Cevolani, L., Despres, J., Carleo, G., Tagliacozzo, L., Sanchez-Palencia, L. Universal scaling laws for correlation spreading in quantum systems with short- and long-range interactions, arXiv:1706.00838v1, 2017.

19:00 – 19:20 **Jacek Dobrzyniecki,** Institute of Physics, Polish Academy of Sciences

Effective two-mode description of the dynamics of bosons in a double well

dobrzyniecki@ifpan.edu.pl

(J. Dobrzyniecki, T. Sowiński)

Typically, when the dynamics of a few bosons in a double-well potential is studied, one uses a two-mode model which assumes that particles can occupy the lowest orbitals localized in the left or the right well. Consequently all excited orbitals are neglected. A typical twomode Hamiltonian, taking into account the tunneling between wells and the interactions between bosons, has the Bose-Hubbard form:

$$H = -J(\hat{a}_L^\dagger \hat{a}_R + \hat{a}_R^\dagger \hat{a}_L) + \frac{U}{2}(\hat{a}_L^\dagger \hat{a}_L^\dagger \hat{a}_L \hat{a}_L + \hat{a}_R^\dagger \hat{a}_R^\dagger \hat{a}_R \hat{a}_R)$$

where the operators a_L, a_R annihilate a boson in a particular (left or right) well.

This traditional model is sufficient to describe the system for sufficiently deep wells and in a weakly interacting regime, i.e., where the interaction energy per particle is much smaller than the single-particle excitation energy. However, the model rapidly becomes inaccurate as the interparticle interaction strength grows, since couplings to higher bands become non-negligible.

In this work we show that, even for quite strong interactions, the dynamical properties of

the system can be recovered accurately in the framework of a two-mode description if appropriate effective modifications are made. We describe two different approaches to this problem. In the first method [1], we describe the system in terms of a specific basis of effective wave functions, uniquely tailored to the problem under study. The basis modes are directly derived from the many-body Hamiltonian. The shapes of the resulting basis wave functions take into account the interaction-induced modifications of the natural orbitals. This effective model gives accurate predictions over a wider range of interactions than the traditional model (Fig. 1b).

The second method [2], which can be used if the number of particles is larger than two, involves extending the many-body Hamiltonian with effective three-body interaction terms. These terms effectively account for various corrections that arise from virtual transitions to excited energy states. Two such terms, an on-site three-body interaction and an interaction-induced single-particle tunneling, are sufficient to recover the exact dynamics with excellent accuracy (Fig. 1c).

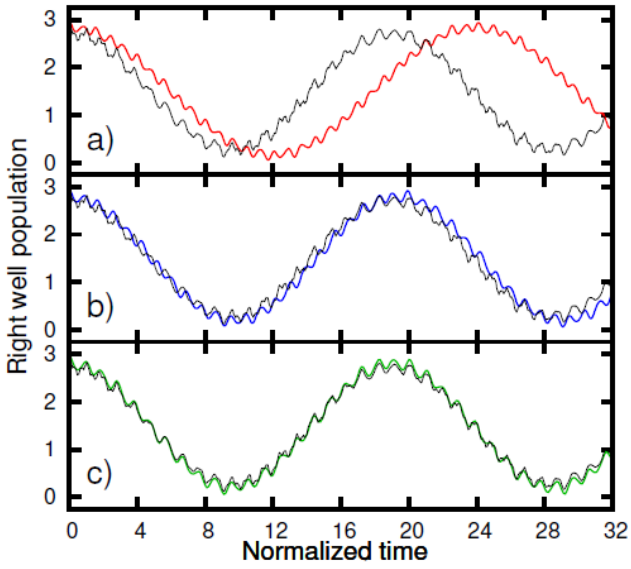


Figure 1: Time evolution of the population in the right well, for a system of three strongly interacting bosons initially occupying the chosen well, predicted by different models: an exact multi-mode model (thin black), the traditional two-mode model (solid red), the improved two-mode model using effective wave functions (solid blue), and the two-mode model extended with effective three-body interactions (solid green). The improved models proposed are clearly more accurate than the traditional two-mode model.

[1] J. Dobrzyniecki and T. Sowinski, Phys. Lett. A 382, 394 (2018).

[2] J. Dobrzyniecki, X. Li, A. E. B. Nielsen, and T. Sowinski, Phys. Rev. A 97, 013609 (2018).

9:00 – 9:40 **Giovanna Morigi,** Saarland University

Collective dynamics of atomic ensembles confined within high-finesse optical cavities

giovanna.morigi@physik.uni-saarland.de

(G. Morigi)

In this talk we will present recent theoretical work on cooling and spontaneous spatiotemporal pattern formation of atomic and molecular ensembles in optical resonators, where the key ingredient of the dynamics are the coherent and dissipative long-range optomechanical forces mediated by multiple scattering of the cavity photons. These dynamics reveal the existence of prethermalized states which are expected to be stable over the experimental time scales. We then present an analysis of this behaviour deep in the quantum limit, and study the role of quantum fluctuations on the stability of these spatio-temporal structures.

9:40 – 10:00 **Nicolas Victorin,** Universite Grenoble Alpes - LPMMC

Bosonic Double Ring Lattice Under Artificial Gauge Fields

nicolas.victorin@lpmmc.cnrs.fr

(N. Victorin, F. Hekking, A. Minguzzi)

We consider a system of weakly interacting bosons confined on a planar double lattice ring subjected to two artificial gauge fields. We determine its ground state by solving coupled discrete nonlinear Schrodinger equations at mean field level. At varying inter-ring tunnel coupling, flux and interactions we identify the vortex, Meissner and biased-ladder phases also predicted for a bosonic linear ladder by a variational Ansatz. We also find peculiar features associated to the ring geometry, in particular parity effects in the number of vortices, and the appearance of a single vortex in the Meissner phase. We show that the persistent currents on the rings carry precise information on the various phases. Finally, we propose a way of observing the Meissner and vortex phases via spiral interferogram techniques.

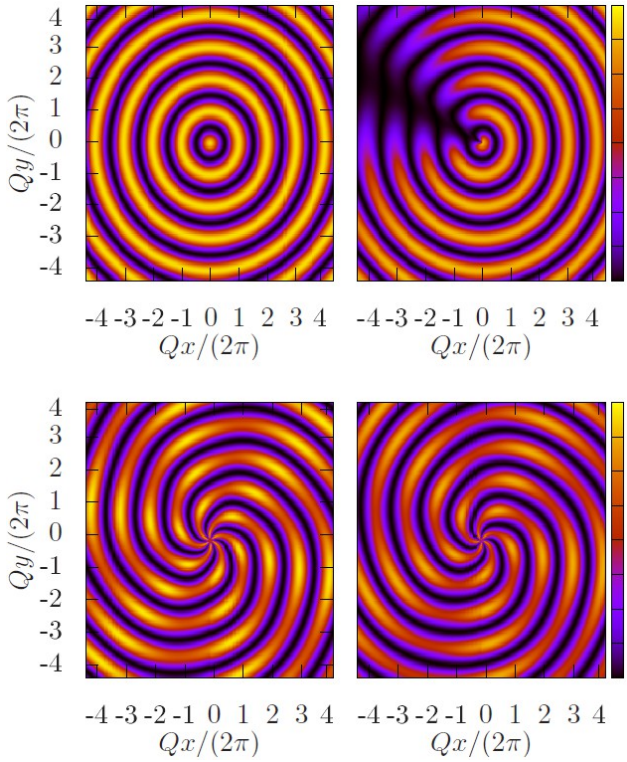


Figure 1: Spiral interferogram in the Meissner phase (upper panels), and in the vortex phase (lower panels) showing the parity effect of the total flux on the number of vortices.

10:00 – 10:20 **Aleksandr Ramaniuk,** University of Warsaw

Spontaneous vortex generation in coupled two-ring resonators with gain and loss

aliaksandr.ramaniuk@fuw.edu.pl

(A. Ramaniuk, N.V. Hung, M. Giersig, K. Kempa, V.V. Konotop, M. Trippenbach)

We present study of the dynamics of two ring waveguide structure with space dependent coupling, linear gain and nonlinear absorption - the system that can be implemented in polariton condensates[1], optical waveguides[2], and nanocavities[3]. Additionally, we propose system realisation in nanoplasmonic structure[4].

We show that by turning on and off local coupling between rings one can selectively generate permanent vortex in one of the rings. We find that due to the modulation instability it is also possible to observe several complex nonlinear phenomena, including spontaneous symmetry breaking, stable inhomogeneous states with interesting structure of currents flowing between rings, generation of stable symmetric and asymmetric circular flows with various vorticities, etc. Depending on coupling parameters, vorticities can be created in pairs or as single vortex in one of the channels, that is later alternating between channels.

[1] Gao, T.; Li, G.; Estrecho, E.; Liew, T. C. H.; Comber-Todd, D.; Nalitov, A.; Steger, M.; K. West, K.; Pfeiffer, L.; Snoke, D. W.; Kavokin, A. V.; Truscott, A. G.; Ostrovskaya, E. A. "Chiral Modes at Exceptional Points in Exciton-Polariton Quantum Fluids". Phys. Rev. Lett. 2018, 120, 065301

[2] Li Y.; Abolmaali, F.; Allen, K. W.; Limberopoulos, N. I.; Urbas, A.; Rakovich, Y.; Maslov, A. V.; Astratov, V. N. "Whispering gallery mode hybridization in photonic molecules". Las. Phot. Rev. 2017, 11, 1600278.

[3] Huet V.; Rasoloniaina A.; Guillemé P.; Rochard P.; Féron P.; Mortier M.; Levenson A.; Bencheikh K.; Yacomotti A.; Dumeige Y. "Millisecond Photon Lifetime in a Slow-Light Microcavity". Phys. Rev. Lett. 2016, 116, 133902.

[4] Ramaniuk, A.; Hung, N.V.; Giersig, M.; Kempa, K.; Konotop, V.V.; Trippenbach, M. "Vortex creation without stirring in coupled ring resonators with gain and loss". Symm. 2018, in print.

[5] Hung, N.V.; Zegadlo, K.B.; Ramaniuk, A.; Konotop, V.V.; Trippenbach, M. "Modulational instability of coupled ring waveguides with linear gain and nonlinear loss". Sci. Rep. 2017 , 7, 4089.

10:40 – 11:00 **Shabnam Safaei,** National University of Singapore

Detection of rotating states in atomtronic rings using a waveguide

cqtshsa@nus.edu.sg

(S. Safaei, L. Amico, L.C. Kwek, R. Dumke)

To measure the rotating states in atomtronic rings, there are already different proposals mainly based on interference patterns and time-of-flight measurements. The problem with these methods is that they are usually destructive. In this work we propose a simple, direct and minimally-destructive method to detect rotation inside atomtronic rings. We consider a physical system consisting of a ring potential for BEC atoms and an (initially) empty waveguide in its vicinity. By numerical simulations we show that, the distribution and net flux of the atoms which tunnel from ring to the waveguide depend on the rotating state of the atoms inside the ring. Therefore, one would be able to measure the rotating state of the atoms inside the ring by looking at the distribution of the atoms inside the waveguide. We observe that, while density of the atoms inside the ring may slightly change and fluctuate as a result of tunneling, the overall rotation remains intact as the tunneling is weak. The effect of atom-atom interaction strength on the process is also addressed.

11:00 – 11:20 **Krzysztof Giergiel,** Jagiellonian University

Long range interactions in time lattices

krzysztof.giergiel@gmail.com

(K. Giergiel, A. Miroszewski, K. Sacha)

Time crystals are many-body systems that, due to interactions between particles, are able to spontaneously self-organize their motion in a periodic way in time by analogy with the formation of crystalline structures in space in condensed matter physics.

In solid state physics properties of space crystals are often investigated with the help of external potentials that are spatially periodic and reect various crystalline structures. Similar approach can be applied for time crystals because periodically driven systems constitute counterparts of spatially periodic systems but in the time domain. Wide class of condensed matter problems can be realized in the time domain if single-particle or many-body systems are resonantly driven. It opens up unexplored territory for investigation of condensed matter physics in time and for invention of novel "time devices" because time is our new ally. We propose[1] a way of creating time lattices similar to optical(space) lattices. In this new type of system almost any long range interactions can be engineered into Bose-Hubbard type Hamilton. This can be achieved by using complexity of configuration space behavior of time localized Wannier states to find periodic Feshbach resonance tuning that leads to a desired interaction profile.

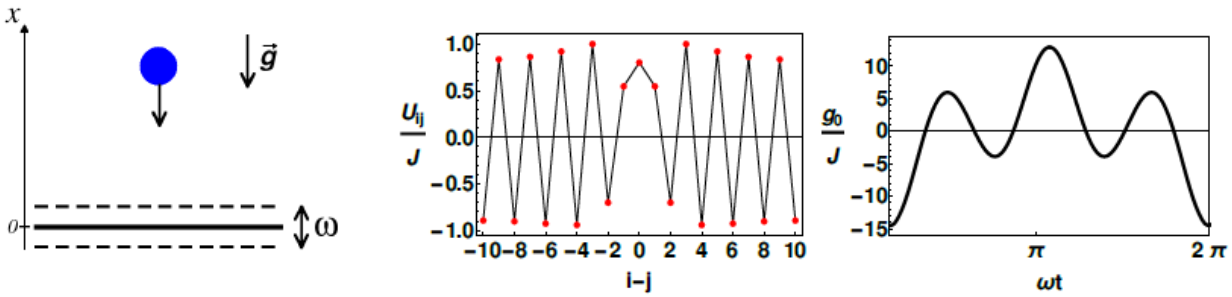


FIG. 1. Example of system with exotic interactions: ultra-cold atoms bouncing on a harmonically oscillating mirror in a 1D model. The 20:1 resonance condition between mirror oscillation frequency and local energy manifold spacing is fulfilled and the many-body system is described by the Hamiltonian

$$\hat{H}_{\text{eff}} = -\frac{J}{2}\sum_{\langle i,j\rangle}\hat{a}_i^\dagger\hat{a}_j + \frac{1}{2}\sum_{i,j}U_{ij}\,\hat{a}_i^\dagger\hat{a}_j^\dagger\hat{a}_j\hat{a}_i$$

Center panel shows the interaction coefficients U_{ij} corresponding to the scattering length $g_0(t)$ that is presented in the right panel.

[1] Giergiel, K., Miroszewski, A. & Sacha, K. 2018, Phys. Rev. Lett., 120, 140401.

11:20 – 11:40 **Krzysztof Zegadło,** Jagiellonian University

Route to chaos in a double microresonator with gain and loss

kbzegadlo@gmail.com

(K. Zegadło, N.V. Hung, V.V. Konotop, J. Zakrzewski, M. Trippenbach)

In the present study we consider chaotic dynamics of a system of two coupled ring waveguide structure with linear gain and nonlinear absorption. It can be implemented in various settings including microresonator nanostructures, polariton condensates, optical waveguides or atomic Bose-Einstein condensates of ultra-cold atoms packed into circular-shaped trap. From the theoretical point of view this system is attractive due to its modulational instability and rich structure, including period doubling bifurcations, eventually leading to chaotic regime. It is described by set of partial differential equations, but we show that the so called Galerkin approximation can explain most of the system dynamics mapping the system behavior to the dynamics of few coupled oscillating modes.

15:00 – 15:40 **Giacomo Roati,** Istituto Nazionale di Ottica

Out of equilibrium dynamics of atomic Fermi gases quenched to strong repulsions

roati@lens.unifi.it

(G. Roati)

We present our experimental study on the out-of-equilibrium dynamics of ultracold Fermi gases of ^{6}Li atoms quenched to strong repulsion [1]. Similarly to pump-probe experiments performed in materials, we employ radio-frequency spectroscopy both to selectively quench the gas onto the repulsive branch near a Feshbach resonance. We probe the emergence of anti- and pairing correlations in a time-resolved fashion and we measure the spectral response of atoms and pairs, retrieving the many-body dynamics in real time.

[1] A. Amico et al., i*n preparation*

15:40 – 16:00 **Iwona Majewska,** University of Warsaw

Theoretical description of photodissociation of ultracold diatomic molecules

iwona.ewa.majewska@gmail.com

(I. Majewska, R. Moszyński)

Chemistry and physics of ultracold (below 1 mK) molecules is a fast growing field with wide possibilities for future applications. One of them is the control of the chemical reactions dynamics. The reaction investigated experimentally by the group of Tanya Zelevinsky at the University of Columbia in New York was a light-induced photodissociation of the diatomic strontium molecule $Sr_2 \rightarrow Sr + Sr$. The experiment was performed with the full control over the initial quantum states of the molecule and final states of the fragments. The theoretical description of the experimental results is based on the formula for the photodissociation cross section

$$\sigma(\theta,\phi) = \sum_{l=0}^{\infty} \sum_{m=0}^{l} \beta_{lm} P_l^m(\cos\theta)\cos(l\phi)$$

where (θ, φ) are the scattering angles and β_{lm} are anisotropy parameters. In the full quantum model, the formulas for the anisotropy parameters were derived using Fermi golden rule with the appropriate transition operator [2].

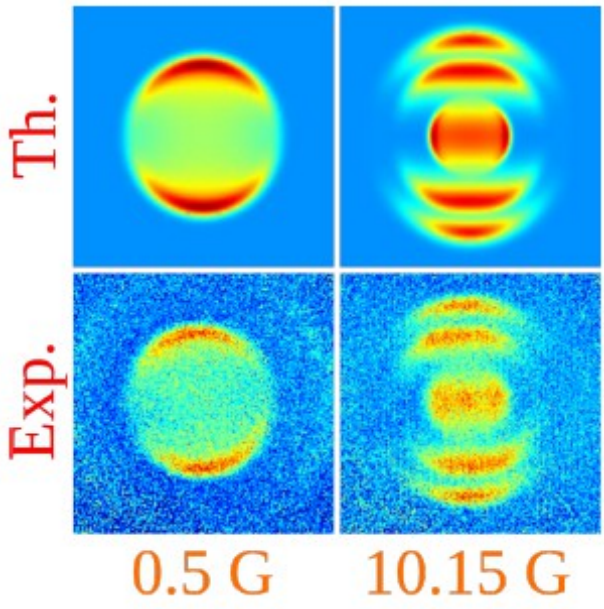


Figure 1: Experimental image compared with quantum prediction for different magnetic fields.

The theoretical results full explained unexpected experimental findings. It was proven that the well-known quasiclassical model of the photodissociation [3] is not sufficient to describe the experiment with full quantum state control.

The photodissociation model was extended to the case where the total angular momentum is not conserved. The violation of the $\Delta J = 0, \pm 1$ selection rule for E1 transition in the magnetic field due to the Zeeman interaction was observed experimentally and supported by the quantum mechanical calculations [1]. The theoretical model fully explained surprisingly complicated experimental patterns by including higher angular momenta and predicting strong mixing of partial waves in the photofragment continuum.

[1] M. McDonald, I. Majewska, C.-H. Lee, S. S. Kondov, B. H. McGuyer, R. Moszynski, T. Zelevinsky, Phys. Rev. Lett, 120, 033201 (2018).

[2] M. McDonald, B. H. McGuyer, F. Apfelbeck, C.-H. Lee, I. Majewska, R. Moszynski, and T. Zelevinsky, Nature, 535, 122 (2016).

[3] R. Zare, Mol. Photochem., 4, 1 (1972).

16:00 – 16:20 **Daniel Pęcak,** Institute of Physics, Polish Academy of Sciences

Beyond the adiabaticity in few-fermion systems

pecak@ifpan.edu.pl

(X. Li, D. Pęcak, T. Sowiński, J. Sherson, A.E.B. Nielsen)

Adiabatic processes are widely used to transfer one quantum state to another in a very controlled manner by a slow change of an external parameter. It would be desirable for many reasons to speed up such a transfer. Here, we consider a system of a two-component mixture of few fermions confined in a one-dimensional harmonic trap. The Hamiltonian of the system reads:

$$\hat{\mathcal{H}} = \sum_{i=1}^{N_\downarrow}\left[-\frac{1}{2}\frac{\partial^2}{\partial x_i^2}+\frac{1}{2}x_i^2\right]+\sum_{j=1}^{N_\uparrow}\left[-\frac{1}{2\mu}\frac{\partial^2}{\partial y_j^2}+\frac{\mu}{2}y_j^2\right]+g(t)\sum_{i,j=1}^{N_\downarrow,N_\uparrow}\delta(x_i-y_j)$$

where $N\uparrow$, $N\downarrow$ denotes the number of fermions of each type, while μ is the mass ratio between ↑ and ↓ component. Fermions of two different types interact with each other via a δ-like potential with the strength g(t) that can be changed in time in a wide range.

We study a transfer of the non-interacting ground state $|\Psi_{g=0}\rangle$ of the Hamiltonian to a strongly interacting ground state $|\Psi_{g=10}\rangle$. To achieve that in a short time, we make the system evolve in a non-trivial way according to a time-dependent interaction g(t). With the help of the evolutionary algorithms, we find an optimal way to control the interaction strength g(t) that speeds up fourfold the transfer from $|\Psi_{g=0}\rangle$ to $|\Psi_{g=10}\rangle$ state when compared to the adiabatic process. The whole procedure is robust to small deviations of the optimal g(t) which is desirable from the experimental point of view.

[1] X. Li, D. Pecak, T. Sowinski, J. Sherson, A. E. B. Nielsen, Physical Review A 97, 033602 (2018).

16:40 – 17:00 **Laurence Pruvost,** Universite Paris-Saclay

Interplay between atoms and optical vortices through a Raman transition

laurence.pruvost@u-psud.fr

(A. Chopinaud, M. Jacquey, B. Viaris de Lesegno, L. Pruvost)

The orbital angular momentum of light (OAM) is a quantized variable, which is explored for quantum technology, its key strength being a wide set of values offering a large basis for encoding, entanglement, etc. In this context we study the interplay between vortices and atoms to realize quantum memories, vortex-pairs, OAM-conversion or OAM mathematical operations.

Using a Raman two-photon transition experienced in a rubidium vapor, namely the 5S1/2-5D5/2 one (see Fig.1), we have studied the vortex conversion from a red input vortex (at 776 nm) to a blue output one (at 420 nm) for large OAMs (ℓ from -30 to 30) and we have examined the efficiency and the selection rules associated to the orbital angular momentum exchange [1].

The atomic vapor is excited by two co-propagating input lasers (780 and 776 nm) which produce a photon pair (5.23 µm and 420 nm) via the decay of the 5D level. In this four-wave mixing process we analyze the blue output wave (its shape, OAM and power) when the input laser at 776 nm is an optical vortex with ℓ varying from -30 to 30. We show that the output blue vortex respects the azimuthal phase matching, has a size determined by the product of the input beam intensities, a power decreasing with in agreement with their overlap. Finally the propagation indicates that the generated blue wave is a nearly pure mode. In addition, we explain why the input OAM is mainly transferred to the blue wave, with at large OAM input the possibility of sharing the OAM between the IR and blue wave: it relies on a combined phase-matching of the azimuthal and the Gouy phases. This work opens to new interplays between atoms and optical vortices as configurations with many vortices or the possibility of OAM storage or operation.

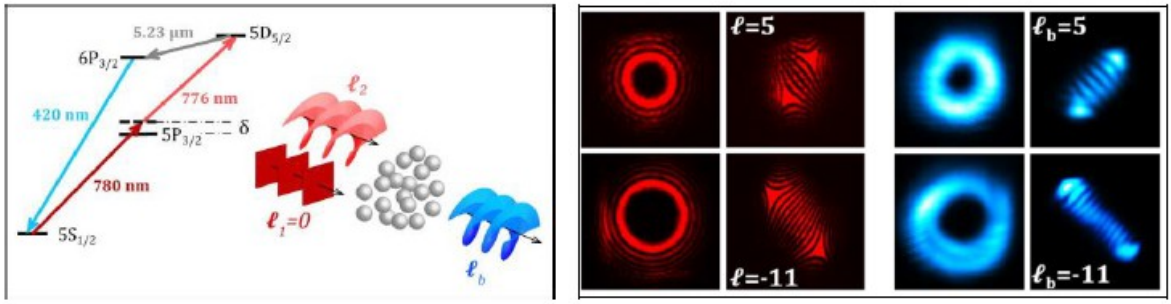


Fig. 1: on the left : principle of vortex conversion based on the two-photon Raman transition in rubidium. On the right : input red vortices and corresponding output blue vortices for ℓ=5 and ℓ=-11. The rings are the intensity profiles, the fringes pattern are the OAM characterization.

[1] A. Chopinaud, M. Jacquey, B. Viaris de Lesegno and L. Pruvost, *High Helicity Vortex Conversion in a Rubidium Vapor*, Phys Rev A 2018, to appear

17:00 – 17:20 **Martin Robert De Saint Vincent,** Centre National de la Recherche Scientifique

Dissipative cooling of spin chains by a bath of dipolar particles

martin.rdsv@univ-paris13.fr

(M. Robert-de-Saint-Vincent, P. Pedri, B. Laburthe-Tolra)

The coupling of quantum systems to environments can lead to various consequences: typically it produces decoherence towards classical behaviors, but specific situations on the contrary produce quantum correlations [1, 2]. This is an exciting new paradigm, that opens the fascinating perspective of environment engineering to protect or produce entangled states. In the context of quantum simulation of magnetism with cold atoms, this kind of dissipative approaches may contribute in preparing low energy many-body spin states of atoms in optical lattices. Recently such proposals involve the use of light as a bath, and spontaneous emission as the dissipative process [3, 4].

In the present work [5], we explore theoretically binary atomic mixtures, one species acting as spin chain, the other as bath. Namely, the spin chain is composed of spinful fermionic atoms in the Mott insulating regime, and it is coupled to a Bose Einstein condensate of a different species. The low-energy many-body states of the spin chain are driven by nearest-neighbor super-exchange interactions. Magnetic dipole interaction between fermions and bath lead to spin flips in the chain, associated with spontaneous phonon emission in the BEC. Thus, spin-thermalization can arise, due to the spin-orbit coupling conveyed by dipole-dipole interactions, an effect which is connected to the Einstein-de Haas effect. As we show here, spin-orbit coupling offers a possibility to directly cool the collective spin degrees of freedom in a spin-chain.

Starting from an uncorrelated thermal sample, we demonstrate in realistic settings, with spin chains of alkali atoms interacting with a BEC of a strongly dipolar species, that the dissipative cooling produces highly entangled low energy spin states of the chain in a timescale of a few seconds. In practice, the lowest energy singlet state driven by super-exchange interactions is efficiently produced. This dissipative approach is a promising alternative to cool spinful atoms in spin-independent lattices. It provides direct thermalization of the spin degrees of freedom, while traditional approaches are plagued by the inherently long timescale associated to the necessary spatial redistribution of spins under the effect of super-exchange interactions [6]. Furthermore, while the many-body ground state of the Heisenberg antiferromagnetic Hamiltonian has a singlet character at half-filling, in most experiments the collective spin is a conserved quantity which is typically not under control; thus, the possibility to couple to the total spin of the chain is essential to generically provide cooling down to the lowest energy states of spin chains.

[1] S. Diehl, A. Micheli, A. Kantian, B. Kraus, H.P. Buchler and P. Zoller, Nature Phys. 4,878 (2008).

[2] F. Verstraete, M. M. Wolf and J. I. Cirac, Nature Phys. 5,633 (2009).

[3] W. Yi, S. Diehl, A.J. Daley and P. Zoller, NJP 14, 055002 (2012).

[4] J. Kaczmarczyk, H. Weimer and M. Lemeshlo, New J. Phys. 18, 093042 (2016).

[5] M. Robert-de-Saint-Vincent, P. Pedri and B. Laburthe-Tolra, arXiv:1803.10663 (2018).

[6] D. C. McKay and B. DeMarco, Rep. Prog. Phys. 74, 054401 (2011).

17:20 – 17:40 **Andrzej Syrwid,** Jagiellonian University

Dark soliton signatures in one-dimensional unpolarized Fermi-Fermi mixture

asyrwid@gmail.com

(A. Syrwid, D. Delande, K. Sacha)

Two-component Fermi gas with contact interspecies attractive interactions can be described by the Yang-Gaudin model. Applying the Bethe ansatz approach one finds analytical formulae for the system eigenstates that are uniquely parametrized by the solutions of the corresponding Bethe equations. The lowest energy eigenstates at given non-zero total momentum subspaces called *yrast* states were analyzed in the presence of periodic boundary conditions, recently. The numerical studies show that the *yrast* spectrum of the Yang-Gaudin model resembles *yrast* dispersion relation of the Lieb-Liniger model which in turn matches the dark soliton dispersion obtained within nonlinear Schrödinger equation. It was shown that such conjecture in the case of Lieb-Liniger model was not accidental and dark soliton features emerged in the course of particle positions measurement if the system was prepared initially in an *yrast* eigenstate. Following the idea of particle detection we employ the Bethe ansatz approach as well as numerical diagonalization and show that starting with *yrast* eigenstates the key soliton signatures, like density notch and phase flip, are visible in the wave function when all fermions have been detected but two belonging to different species. With the help of Bethe ansatz we study soliton signatures in a wide range of interaction strength. The discussion is supplemented by the analysis of the formation of two-particle bound state built up by fermions belonging to different spin components.

17:40 – 18:00 **Jacek Szczepkowski,** Institute of Physics, Polish Academy of Sciences

Towards ultracold alkali-alkaline-earth diatomic molecules

jszczep@ifpan.edu.pl

(J. Szczepkowski, A. Ciamei, V. Barbé, A. Bayerle, C.-C. Chen, A. Grochola, P. Kowalczyk, B. Pasquiou, L. Reichsollner, S.M. Tzanova, F. Schreck, W. Jastrzębski)

In recent years big strides were made towards ultracold molecules composed of one alkali and one alkaline-earth atom, boosted by the achievement of quantum degeneracy with alkaline-earth(-like) atoms. Such heteronuclear open-shell molecules have a non-zero electronic spin angular momentum as well as a strong permanent electric dipole moment in their rovibrational ground state. These properties enable new ways to tune the interactions between molecules and open promising perspectives to create a quantum gas of ground-state molecules or to study lattice-spin systems (magnetic excitons, topological phases). Since the ground state of these molecules is of $^2\Sigma$ symmetry, they may be also used as sensitive magnetic field probes, measuring the electron electric dipole moment, test time variation of the electron-to-proton mass ratio and test beds to study parity-violating effects [1-2]. If one can produce a quantum degenerate gas of such molecules, where all degrees of freedom are under control, one may study chemical reactions on a quantum level, and their dynamics at the most fundamental level, with full control over the reactants and a clear signal from the reaction products. However in order to generate such molecules at ultracold temperatures one needs to have accurate potential energy curves of chosen molecular electronic states, particularly including the potential of the ground state.

We present results of two independent experiments concerning such alkali–alkaline-earth RbSr molecules. The first is based on two-colour photoassociation spectroscopy, while in the second experiment thermoluminescence spectroscopy, and LIF (Laser Induced Fluorescence) methods are used. Both types of experiments are carried out for the first time for this system. By combining results from both experiments in a joint analysis, and exploiting state-of-the-art *ab-initio* calculations, we can provide a potential energy curve for the RbSr electronic ground-state. The calculations performed with the final, experimental potentials demonstrated their power, since we were able to predict positions of Feshbach resonances, confirmed in later experiments and currently exploited for attempting magnetoassociation in RbSr [3]. In the next steps results of this work will be used to guide RbSr two-colour spectroscopy and stimulated Raman adiabatic passage (STIRAP) of weakly-bound RbSr to the rovibronic groundstate.

[1] E. Altuntas,J. Ammon, S. B. Cahn, D. DeMille, *Demonstration of a Sensitive Method to Measure Nuclear-Spin-Dependent Parity Violation*, Phys. Rev. Lett. 120, 142501 (2018)

[2] M. Kajita, G. Gopakumar, M. Abe, M. Hada, Characterizing of variation in the proton-to-electron mass ratio via precise measurements of molecular vibrational transition frequencies,J. Mol. Spectrosc. 300, 99 (2014)

[3] V. Barbé, A. Ciamei, B. Pasquiou, L. Reichsöllner, F. Schreck, P. S. Żuchowski, J. M. Hutson, *Observation of Feshbach resonances between alkali and closed-shell atoms*, arXiv:1710.03093, accepted by Nat. Phys.

18:00 – 18:20 **Mariusz Semczuk,** University of Warsaw

Towards physics in mixed dimensions with potassium and cesium mixture

Mariusz.Semczuk@fuw.edu.pl

(M. Semczuk)

In this talk I will report on the development of a new potassium-cesium mixture experiment. This mixture is a relative newcomer to the field of ultracold atoms and I will emphasize some of its features that we wish to exploit in future experiments. In particular, I will focus on the possibility of trapping potassium in potentials of different dimensionality than that experienced by cesium. Physics in reduced dimensionality has attracted great attention because non-3D systems turned out to exhibit quantum behavior not present in three dimensional samples ranging from novel type of phase transitions to the presence of quasiparticles with fractional statistics. In heteronuclear mixtures, confinement in one and two dimensional traps can reduce inelastic collision rates stabilizing such mixtures, which is of use for experiments with e.g. reactive ground state molecules. With the mixture implemented in our laboratory we will focus our efforts on Efimov trimers formed between (bosonic) potassium atoms confined in one- or two dimensional trap and surrounded by a three dimensional cesium cloud. This new setup will exploit the tune-out wavelength for cesium (~880.2 nm) and will let us explore regimes of the Efimov physics beyond the current experimental state of the art.

9:00 – 9:40 **Tim Langen,** University of Stuttgart

Dipolar gases - from magnetic atoms to molecules

t.langen@physik.uni-stuttgart.de

(T. Langen)

In the first part of my talk, I will report on a series of recent experiments with ultracold dysprosium atoms, which feature a permanent magnetic dipole moment of almost 10 μ_B. Such strongly dipolar quantum gases enable the observation of many-body phenomena arising from anisotropic, long-range interactions. One example is the formation of self-bound droplets that are stabilized by beyond mean-field corrections, which arise from quantum fluctuations [1]. These droplets are 100 million times less dense than liquid helium droplets, but exhibit similar liquid-like properties. We study the excitations of these exotic quantum objects [2] and outline prospects to reach a phase-coherent, self-organized multi-droplet state in confined geometries [3].

In the second part, I will present an ongoing effort to directly cool diatomic molecules to the quantum regime. With typical electric dipole moments of several Debye, such molecules promise orders of magnitude higher interaction energies than magnetically dipolar atoms. Moreover, they offer unique experimental possibilities for precision measurements and cold chemistry. I will discuss both the current status of collisions and evaporative cooling in hydroxyl radicals (OH) [4,5], as well as a new experiment aiming to directly laser cool barium monofluoride (BaF).

[1] M. Schmitt, M. Wenzel, F. Böttcher, I. Ferrier-Barbut, and T. Pfau Nature **539**, 259 (2016).

[2] I. Ferrier-Barbut, M. Wenzel, F. Böttcher, T. Langen, M. Isoard, S. Stringari, and T. Pfau Phys. Rev. Lett. **120**, 160402 (2018).

[3] M. Wenzel, F. Böttcher, T. Langen, I. Ferrier-Barbut, and T. Pfau Phys. Rev. A **96**, 053630 (2017).

[4] D.L. Reens, H. Wu, T. Langen, and J. Ye Phys. Rev. A **96**, 063420 (2017).

[5] H. Wu, D.L. Reens, T. Langen, Y. Shagam, D. Fontecha, and J. Ye Phys. Chem. Chem. Phys. (in print), arxiv:1802.10179

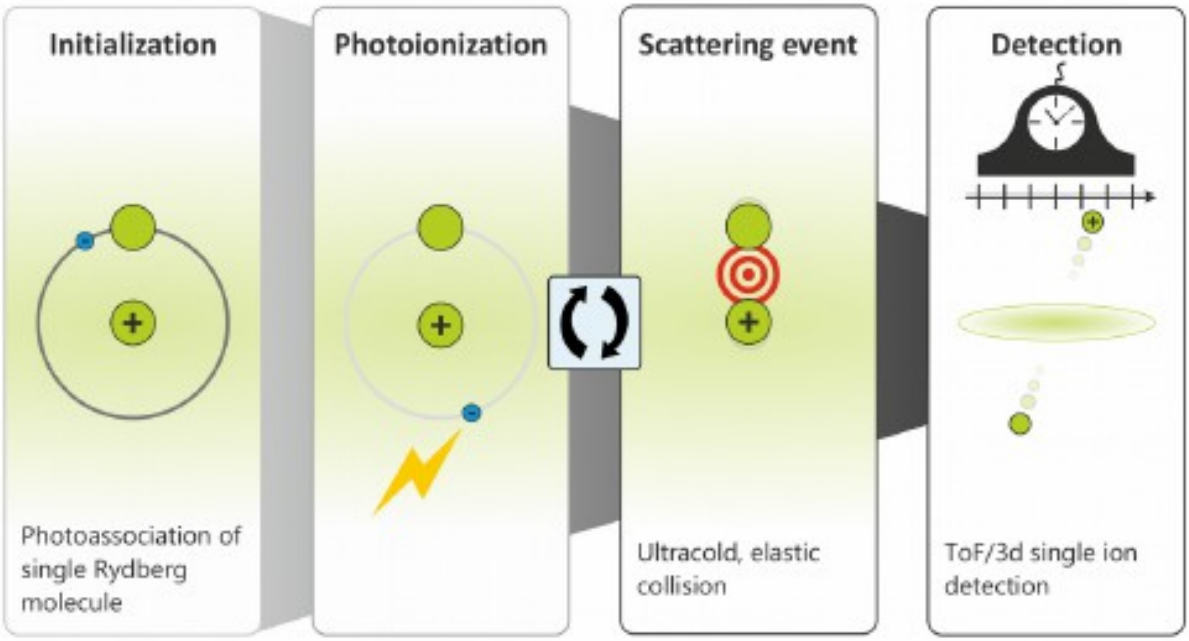
9:40 – 10:00 **Michał Tomza,** University of Warsaw

Rydberg molecules for ion-atom scattering in the ultracold regime

michal.tomza@fuw.edu.pl

(T. Schmid, C. Veit, N. Zuber, R. Low, T. Pfau, M. Tarana, M. Tomza)

We propose a novel experimental method to extend the investigation of ion-atom collisions from the so far studied cold, essentially classical regime to the ultracold, quantum regime [1]. The key aspect of this method is the use of Rydberg molecules to initialize the ultracold ion-atom scattering event. We exemplify the proposed method with the lithium ion-atom system, for which we present simulations of how the initial Rydberg molecule wave function, freed by photoionization, evolves in the presence of the ion-atom scattering potential. We predict bounds for the ion-atom scattering length from *ab initio* calculations of the interaction potential. We demonstrate that, in the predicted bounds, the scattering length can be experimentally determined from the velocity of the scattered wave packet in the case of ^{6}Li-^{6}Li and from the molecular ion fraction in the case of ^{7}Li-^{7}Li. The proposed method to utilize Rydberg molecules for ultracold ion-atom scattering, here particularized for the lithium ion-atom system, is readily applicable to other ion-atom systems as well.



[1] T. Schmid, C. Veit, N. Zuber, R. Löw, T. Pfau, M. Tarana, M. Tomza, Phys. Rev. Lett. 120, 153401 (2018)

10:00 – 10:20 **Michal Śmiałkowski,** University of Warsaw

Interactions and chemical reactions in ionic three-body systems: $A^+ + AB, AB^+ + A, A_2B^+$

m.smialkowski@chem.uw.edu.pl

(M. Śmiałkowski, M. Tomza)

The presentation covers interactions, energetics, and chemical reaction paths in ionic three-body systems A^++AB, AB^++A, and $A_2B^+$of alkali-metal and alkaline-earth-metal atoms in the context of modern experiments with cold hybrid ion-atom systems [1].

Ab initio electronic struture calculations of the lowest state with different multiplicities of diatomic AB^+ (see Fig. 1) and triatomic A_2B^+ molecular ions consisting of Li, Na, K, Rb, Cs, Mg, Ca, Sr, Ba and Yb atoms are performed. Equilibrium distances, dissociation energies, ionization potentials, and permanent electric dipole moments are obtained for dimers and trimers. A variety of equilibrium geometries for the trimers from linear through isosceles triangular to equilateral triangular are discovered. Three-body non-addtive interactions in these systems are also evaluated and characterized at equilibrium geometries.

Possible channels of chemical reactions are identified and characterized. Example calculations of minimum energy paths for for isomerisation reactions of linear alkaline-metal trimers in triplet electronic states from AAB^+ arrangements to more symmetric ABA^+ ones are investigated. The present results open the way for investigating more complex molecular ions important in chemistry as well as chemical reactions controlled by external laser or magnetic fields and other applications of molecular ions formed in cold hybrid ion-atom systems.

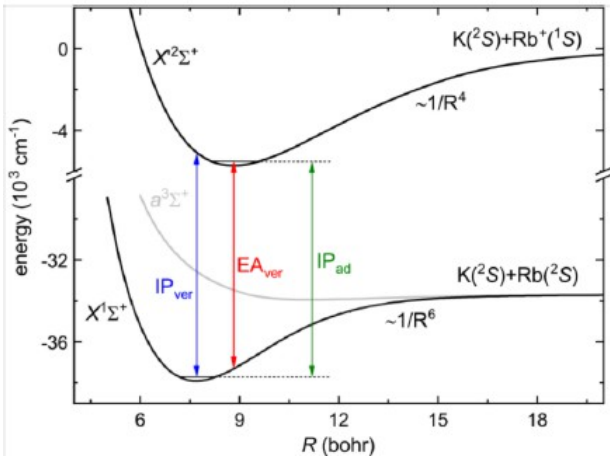


Fig. 1 Ground-state potential energy curves for the KRb molecule and KRb + molecular ions together with definitions of adiabatic and vertical ionization potentials (IP_{ad} and IP_{ver}) and vertical electron attachment energy (EA_{ver}).

[1] Tomza et al, arXiv:1708.07832 (2017)

10:40 – 11:00 **Marta Sroczyńska,** University of Warsaw

Trap-induced shape resonances in an ultracold few-body system of atom and static impurities

msroczynska@fuw.edu.pl

(M. Sroczyńska, T. Wasak, K. Jachymski, T. Calarco, Z. Idziaszek)

Hybrid systems of ultracold atoms and trapped ions or Rydberg atoms can be useful for quantum simulation purposes. By tuning the geometric arrangement of the impurities it is possible to mimic solid state and molecular systems. Here we study a single trapped atom interacting with a set of arbitrarily arranged static impurities and show that the problem admits an analytical solution. We analyze in detail the case of two impurities, finding multiple trap-induced resonances which can be used for entanglement generation. Our results serve as a building block for the studies of quantum dynamics of complex systems.

11:00 – 11:20 **Klaudia Zaremba-Kopczyk,** University of Warsaw

Quantum dynamics of two interacting polar molecules trapped in optical lattice

klaudia.kopczyk@gmail.com

(K. Zaremba-Kopczyk, K. Jachymski, M. Tomza)

We investigate two interacting polar molecules trapped in an optical lattice or in optical tweezers as a fundamental building block for quantum computing. We discuss the properties and dynamics of two polar molecules confined in two neighboring sites of a deep optical lattice in the presence of an external electric field that induces long-range dipole-dipole interactions between the lowest rotational states. In our model the molecules are described as quantum rigid rotors trapped in two separate three-dimensional harmonic traps. The energy spectra and eigenstates are obtained by means of the exact diagonalization including all energetically relevant molecular rotational states and lowest modes of the trap. We analyze the prospect for implementing single- and two-qubit quantum gates and quantum speed limit for such a system using optimal control theory to find the time-dependence of control electric field.

11:20 – 11:40 **Maciej Pylak,** Institute of Physics, Polish Academy of Sciences

Finite temperature influence on generation of entangled atom pairs from BEC

pylak@ifpan.edu.pl

(M. Pylak, P. Ziń)

The generation of non-classical states in atomic ensembles is a rapidly developing direction in trapped ion and cold neutral atomic physics [1]. One of the possible states that are particle entangled, and can be used to increase the sensitivity of precision measurements is so-called twin-Fock state $|n,n\rangle$ [2, 3]. Such state can be created in experiments generating atom pairs with well defined momenta in quasi-one dimensional systems. This can be done e.g. by modulation of the effective one-dimensional atomic interaction parameter [4]. However, in experiment reported in [4] this effect was not seen. Moreover, pair production was much smaller than predicted by the Bogoliubov theory. This suggests that the interaction between quasiparticles significantly influences the pair production. To check that prediction, the pair creation process emerging from modulation of the interaction parameter has been theoretically analysed.

It was shown that parametric process is described by a single parameter δ describing the strength of the amplification, while the interaction between quasiparticles is described by a quasiparticle decay constant γ. The process of pairs production practically stops if γ is much larger than δ. Additionally it was found that depending on the parameters of the system the Cauchy-Schwarz inequality may be not violated. This results would provide possible explanation of experimental results obtained in [4].

References

[1] Pezze L, Smerzi A, Oberthaler M K., Schmied R, Treutlein P 2016 arXiv:1609.01609

[2] Bouyer P and Kasevich M A 1997 *Phys. Rev. A* 56 R1083

[3] Dunningham J A, Burnett K and Barnett S M 2002 *Phys. Rev. Lett.* 89 150401

[4] Jaskula J C, Partridge G B, Bonneau M, Lopes R, Ruaudel J, Boiron D and Westbrook C I 2012 *Phys. Rev. Lett.* 109(22) 220401

11:40 – 12:00 **Mateusz Borkowski,** Nicolas Copernicus University

Optical Clock Transitions in Weakly Bound Molecules

mateusz@fizyka.umk.pl

(M. Borkowski, M. Bylicki, P. Tecmer)

Weakly bound molecules promise unparalleled sensitivity to temporal variations of the proton-to-electron mass ratio and in searches for new interactions beyond the Standard Model. Both applications, however, rely on measurements of vibrational state positions of yet unrealized accuracy. To mitigate this, we propose to observe clock 1S0-3P0 transitions in weakly bound bosonic $^{174}Yb_2$ molecules [1]. As in bosonic atomic clocks, a small transition dipole moment could be induced by means of a weak external magnetic field [2]. The positions of molecular clock lines can be determined to high accuracy: ground bound state positions have been measured with two-color photoassociation spectroscopy [3], while excited 1S0+3P0 0u- vibrational states can be predicted accurately using an interaction potential with *ab initio* long range parameters [4] and fitted to the recently measured 174Yb 1S0-3P0 scattering length [5]. The necessary ground state Yb2 molecules could be efficiently produced by STIRAP. Thanks to favorable Franck-Condon factors the magnetically induced molecular Rabi frequencies can be comparable to the atomic Rabi frequencies under same laser intensities and magnetic fields. Using new *ab initio* potentials [6] we evaluate the sensitivity of the excited clock states to changes in the proton-to-electron mass ratio and explore the prospects of using an ytterbium molecular clock for searches of temporal variation of this fundamental constant.

References

[1] Borkowski M 2018 *Phys. Rev. Lett.* 120 083202

[2] Taichenachev AV, Yudin VI, Oates CW, Hoyt CW, Barber ZW, and Hollberg L 2006 *Phys. Rev. Lett.* 96 083001

[3] Borkowski M, Buchachenko AA, Ciuryło R, Julienne PS, Yamada H, Kikuchi Y, Takahashi K, Takasu Y, and Takahashi Y 2017 *Phys. Rev. A* 96 063405

[4] Porsev SG, Safronova MS, Derevianko A, and Clark CW 2014 *Phys. Rev. A* 89 012711

[5] Franchi L, Livi LF, Cappellini G, Binella G, Inguscio M, Catani J, and Fallani L 2017 *New J. Phys.* 19 103037

[6] Tecmer P, et al. (in preparation)

13.09.2018 Thursday (Afternoon – special session)

16:00 – 16:40 Vladimir Konotop

Spin-orbit coupled Bose-Einstein condensates in lattices

16:40 – 17:20 Kazimierz Rzążewski

Quantum carpets of fermions

17:40 – 18:00 Michał Matuszewski

Selected themes of nonlinear optics

18:00 – 18:20 Paweł Ziń

From spontaneous initiation to bosonic stimulation

18:20 – 18:40 Cao Long Van

My memories with prof. Marek Trippenbach

18:40 – 19:40 Lewenstein, Gajda, Zakrzewski, Idziaszek

Complete surprise

9:00 – 9:40 **Maciej Lewenstein,** Institute de Ciencies Fotoniques

Quantum Simulators and Machine Learning

maciej.lewenstein@icfo.eu

(M. Lewenstein)

Machine Learning (ML) and Quantum Computing (QC) are two disruptive technological advances that are predicted to shape the informatics and, through it, industry in coming decades. Together they are the largest part of scientific oriented research budget in firms like Google, Microsoft and IBM. It is expected that especially fruitful will be synergy of those two fields. Quantum Simulators (QS) - which may be seen as quantum version of analog computers, are designed for particular tasks and are already working, show supreme capabilities over classical computations in particular areas (fermionic systems, dynamical systems), are robust and reliable. **In this lecture I will explore a possible synergy between Machine Learning and Quantum Simulators.**

I will start reminding the ideas of various neural network models(NN) and machine learning (ML). I will then argue that the and many body physics for area may be "married" in various ways: i) ML and NN for QS; ii) QS and many body physics for NN and ML.

9:40 – 10:00 **Piotr Sierant,** Jagiellonian University

Many-body localization of bosons in optical lattices

sierant.piotr@gmail.com

(P. Sierant, J. Zakrzewski)

This contribution is based mainly on [1]. Many-body localization for a system of bosons trapped in a one dimensional lattice is discussed. Two models that may be realized for cold atoms in optical lattices are considered. The first one is Bose–Hubbard model with a random on–site potential

$$H = -J\sum_{\langle i,j\rangle}\hat{a}_i^{\dagger}\hat{a}_j + \frac{U}{2}\sum_i \hat{n}_i(\hat{n}_i - 1) + \sum_i \mu_i \hat{n}_i$$

where $a^{\dagger}_i$ and a_i are operators creating and annihilating boson at site i of the lattice, J and U are respectively tunneling amplitude and interaction strength and μ_i is a random on–site potential distributed uniformly in interval [-W,W]. The model (1) is compared with random interactions model [2-3]

$$H = -J \sum_{\langle i,j \rangle} \hat{a}_i^\dagger \hat{a}_j + \frac{1}{2} \sum_i U_i \hat{n}_i (\hat{n}_i - 1)$$

where $U_i \in [0;U]$ is random interaction strength. While the origin and character of the disorder in both systems is different they show interesting similar properties. In particular, many-body localization appears for a sufficiently large disorder strengths W and U as verified by a time evolution of initial density wave states as well as using statistical properties of energy levels for small system sizes. Starting with different initial states, we observe that the localization properties are energy-dependent which reveals an inverted many-body localization edge in both systems – that finding is also verified by statistical analysis of energy spectrum – see Fig. 1. Moreover, we consider computationally challenging regime of transition between many body localized and extended phases where we observe a characteristic algebraic decay of density correlations which may be attributed to subdiffusion (and Griffiths-like regions) in the studied systems. Ergodicity breaking in the disordered Bose-Hubbard models is compared with the slowing-down of the time evolution of the clean system at large interactions.

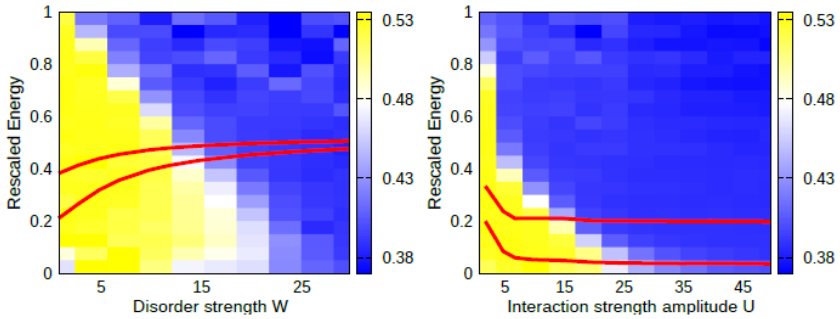


Fig. 1: The mean gap ratio r in the plane of disorder strength (W or U depending on the model) and the relative position in the spectrum of the system e with N = 12 bosons on L = 8 sites. Left panel – random chemical potential for U = 1; right panel – the random interactions case. Yellow color corresponds to $r \approx 0.53$ and to the ergodic regime, whereas the blue color denotes r characteristic for localized states. Red curves indicate energies of the density wave states $|2121\ldots\rangle$ and $|3030\ldots\rangle$ which are studied in the context of their localization properties. Observe that both systems are characterized by an inverted mobility edge – a feature characteristic for bosonic systems.

[1] P. Sierant and J. Zakrzewski, Many-body localization of bosons in optical lattices, New J. Phys. 20 043032 (2018)

[2] Piotr Sierant, Dominique Delande, and Jakub Zakrzewski, Many-body localization due to random interactions, Phys. Rev. A 95, 021601 (2017)

[3] Piotr Sierant, Dominique Delande, Jakub Zakrzewski, Many-body localization for randomly interacting bosons, Acta Physica Polonica A 132, 1707 (2017)

10:00 – 10:20 **Artur Maksymov,** Jagiellonian University

Parametric motion of energy levels in delocalized 1D spin-1/2 XXZ system

maxyartur@gmail.com

(A. Maksymov, P. Sierant, J. Zakrzewski)

By means of full exact diagonalization we studied the dynamics of energy level in 1D spin model across the transition from quantum chaos to integrability. As 1D spin system we considered XXZ Heisenberg spin chain, which shows chaotic behavior in delocalized ergodic regime, realized for small amplitudes of external random field, and tends to many-body localizations and integrability with increase of field strength. During transition from ergodic to many-body localized regime the statistics of eigenenergies is changed from Wigner-Dyson to Poison one as it was shown before in [1]. In the focus of interest of current work becomes the distribution of first and second derivatives of level dynamics over the control parameter, i.e. their velocities and curvatures [2, 3]. The amplitude of external random filed was chosen as a control parameter of level dynamics. The following Hamiltonian is considered

$$\hat{H} = J\sum_{i=1}^{L}\left(S_i^x S_{i+1}^x + S_i^y S_{i+1}^y\right) + \Delta\sum_{i=1}^{L} S_i^z S_{i+1}^z + \sum_{i=1}^{L} h_i S_i^z$$

where J and Δ are the coupling for XY and Z components respectively, and h_i is the Zeeman splitting that describes the uniformly distributed random field with strength W. We chose the system with lattice size L = 12, with 6 spin up and 6 spin down, that after diagonalization gives the spectrum of 924 eigenenergies. However, for statistics only 400 energy levels from the middle of spectrum were considered.

For delocalized regime the curvatures of energy levels were numerically obtained and the ratio of two consequent curvatures was analyzed. Such a measure of curvatures does not depend on local density of states and, therefore, the unfolding of energy spectrum is not required. From the analyzes of distribution of curvatures ratio the additional peaks in the distribution were detected, which become more pronounced during the transition to localized regime. We hope that observed features may be used along with level spacing statistics as additional characteristic of many body system's localization.

[1] M. Serbyn, J. E. Moore, Phys. Rev. E 93 (2016) 041424(R).

[2] J.Zakrzewski, D. Delande, Phys. Rev. E 47 (1993) 1650.

[3] F. von Oppen, Phys. Rev. E. 51 (1995) 2647.

10:40 – 11:00 **Konrad Szymański,** Jagiellonian University

Coherence protection through spin self-rephasing

konrad.jan.szymanski@gmail.com

(K. Szymański, K. Pawłowski)

In this work a system consisting of a number of atoms evolving under the influence of external magnetic field is analyzed. Due to the inhomogenities of the external field, the atomic spins undergo dephasing: classically, since each atom feels different field along its trajectory, the spin rotation differs as well and the average spin decays. In a quantum mechanical context this corresponds to entanglement of spin and spatial degrees of freedom; additionally, two other modes of dephasing are possible: formation of internally (spin-spin) entangled state and population transfer to nonsymmetric spin state. The spin dephasing can be prevented by tuning the interaction between the atoms: such an effect, called spin self-rephasing has been observed experimentally [1] and can increase the coherence time by a large factor. While such systems have been studied from a semiclassical point of view, a quantum mechanical description does not exist yet. In this work we fill in the gap by providing a numerical simulation of the behavior of the quantum mechanical system of several interacting, indistinguishable particles in the presence of inhomogenous magnetic field and analysis of the spin rephasing and coherence.

A work in progress involving evolution analysis of so-called anticoherent state (Schrodinger's cat, equal superposition of maximal and minimal spin projection states along fixed axis) and squeezed state, which both can not be approximated semiclassically, may lead to interesting results regarding feasibility of quantum metrology schemes. Such states are sensitive to external perturbations, which makes them useful simultaneously lowering their stability.

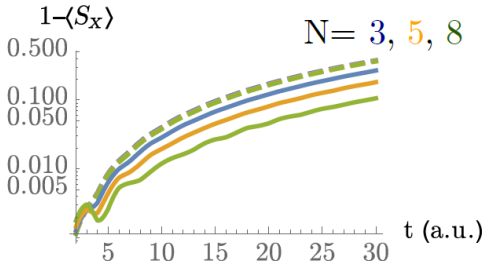


Figure 1. Envelope of visibility S_x for different number of particles. The parameters expressed in oscillator units are: temperature T = 0.1, interaction strengths $g_{\downarrow\downarrow}$ = 0:0099; $g_{\uparrow\uparrow}$ = 0:011; g_t = 0:01, and magnetic field B(x) = 0.03 x^2. Solid line denotes presence of particle-particle interactions, dashed - interaction-free case. Progressively better (with growing number of particles) coherence protection is visible: already for N = 8 the coherence time is increased by factor of 5 (note the logarithmic scale).

[1] C. Deutsch et al., Physical Review Letters 105.2, 020401 (2010)

[2] G. K. Buuning et al., Physical Review Letters 106.24, 240801 (2011)

11:00 – 11:20 **Piotr Deuar,** Institute of Physics, Polish Academy of Sciences

A semiclassical field theory free of UV divergence and cutoff dependence

deuar@ifpan.edu.pl

(P. Deuar, J. Piotraszewicz)

A modified classical field description has been constructed that no longer suffers from the UV divergence catastrophe or cutoff dependence, but whose computational efficiency scales the same way as standard classical field methods. To achieve this, an SGPE-like reservoir coupling is mustered to act as a constraint on the high-energy part of the system. The key to avoiding the UV divergence is then to preserve the quantum properties of this constraining reservoir coupling. Examples in 1d and 3d will be given, including the famous case of collective modes that have previously eluded accurate description with classical fields. Overall this approach gives good prospects for c-field calculations that are quantitatively accurate without tweaking arbitrary technical parameters.

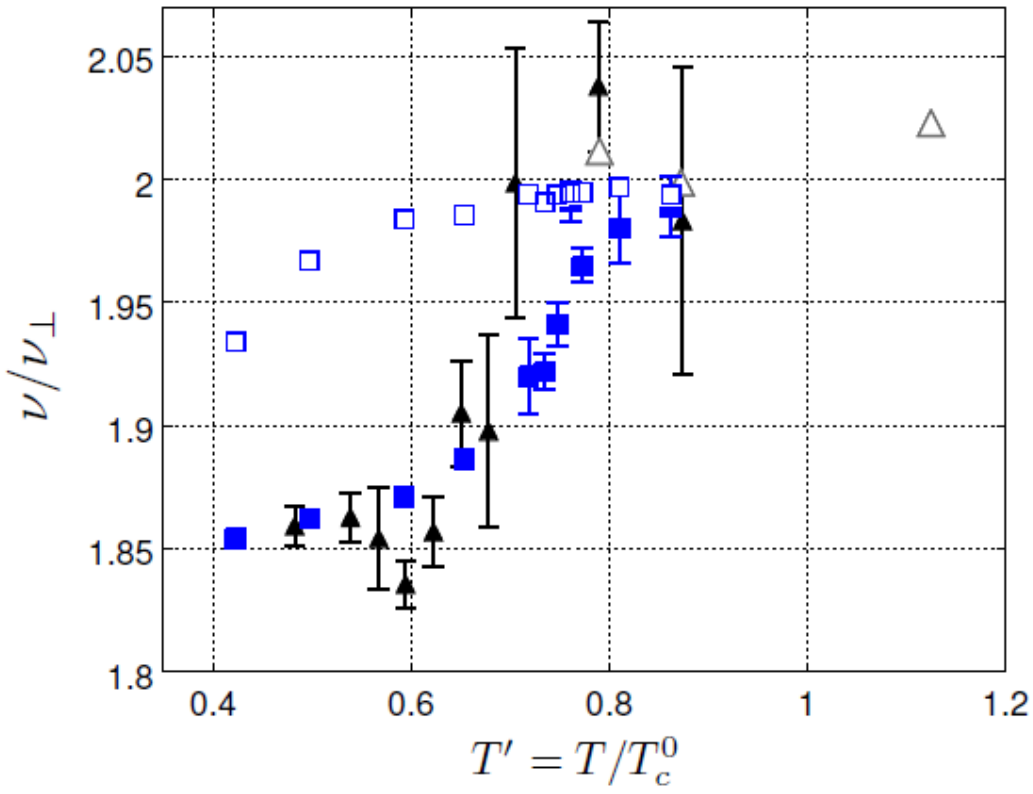


Figure 1. Frequencies of the m = 0 collective mode at high temperatures, in the widely studied Jila experiment [PRL 78, 764]. Black: experiment, blue: modified classical field simulation. Solid symbols: condensate, open symbols: thermal cloud.

11:20 – 11:40 **Krzysztof Gawryluk,** University of Bialystok

Signatures of a universal jump in the superfluid density of two-dimensional finite particles Bose gas

k.gawryluk@uwb.edu.pl

(K. Gawryluk)

We study, within a grand canonical formalism, a two-dimensional weakly interacting Bose gas of a finite number of particles. By using the classical fields approximation we show that Bose gases with finite number of atoms exhibit, in addition to the Berezinskii-Kosterlitz-Thouless (BKT) and thermal phases, the intermediate region. This region is characterized by an algebraic decay of the first-order correlations with decay exponent increasing with temperature beyond the critical value. It turns out that the density of the superfluid fraction at the temperature which separates the BKT phase from the intermediate region matches the one found by Nelson and Kosterlitz for two-dimensional superfluids in the thermodynamic limit.

15:00 – 15:40 **Marzena Szymańska,** University College London

Polariton quantum fluids in and out of equilibrium

m.szymanska@ucl.ac.uk

(M.H. Szymańska)

State-of-the-art semiconductor microcavities allowed recently to achieve a fully thermalised photonic system analogous to cold atoms or liquid Helium. We predict and observe the Berezinskii-Kosterlitz-Thouless transition for a 2D gas of exciton-polaritons with its clear signature in the first-order coherence both in space and time (Fig. 1). We show that the mechanism of pairing of the topological defects (vortices) is responsible for the transition to the algebraic order and achieve a thermodynamic equilibrium phase transition in an otherwise open driven/dissipative system [1]. At the same time, it has been shown that driven-dissipative polariton fluid could potentially exhibit a truly novel non-equilibrium order, where superfluidity is accompanied by stretched exponential decay of correlations. This celebrated Kardar-Parisi-Zhang (KPZ) phase has not been achieved in any physical system in 2D and even 1D realisations are not conclusive. We show [2] that driven microcavity polaritons in the OPO configuration (Fig. 2) can act as a natural and unifying laboratory for the exploration of a variety of intrinsic non-equilibrium phenomena, including the so far experimentally elusive KPZ phase in two dimensions. Key features are the high tuneability of microscopic parameters in general, and of the spatial anisotropy of the microscopic physics in particular.

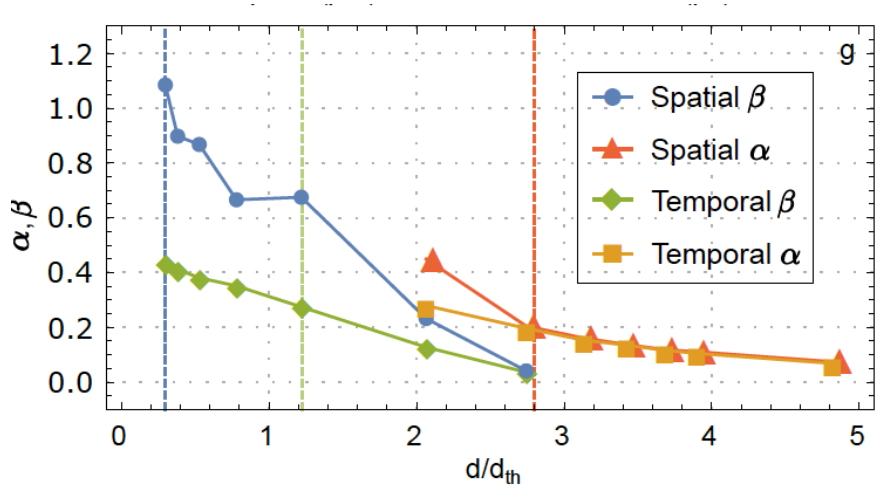


Figure 1: Algebraic exponents of spatial and temporal coherence.

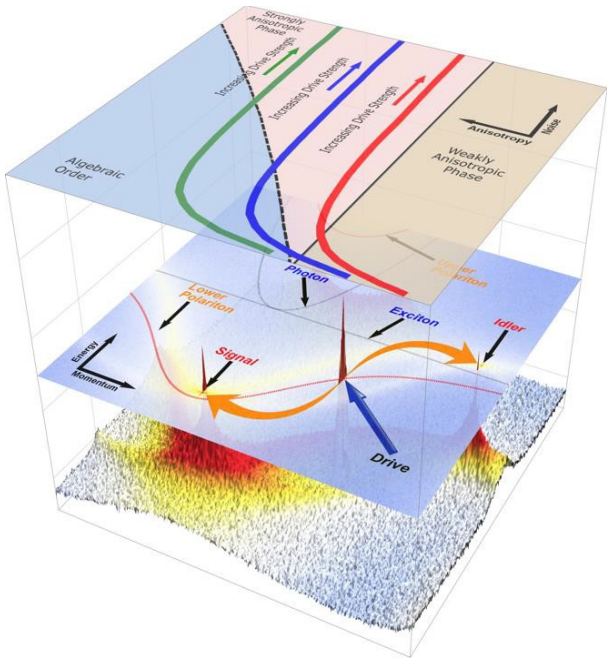


Figure 2: Polarriton OPO spectrum (bottom) and phase diagram (top).

[1] D. Caputo, D. Ballarini, G. Dagvadorj, C. Sánchez Muñoz, M. De Giorgi, L. Dominici, K. West, L. N. Pfeiffer, G. Gigli, F. P. Laussy, M. H. Szymanska, D. Sanvitto, *"Topological order and thermal equilibrium in polariton condensates"*, *Nature Materials* 17, 145 (2018)

[2] A. Zamora, L. M. Sieberer, K. Dunnett, S. Diehl, and M. H. Szymanska, *"Tuning across Universalities with a Driven Open Condensate"*, *Phys. Rev. X* 7, 041006 (2017)

15:40 – 16:00 **Bogdan Damski,** Jagiellonian University

Spatial Kibble-Zurek mechanism through susceptibilities

bogdan.damski@uj.edu.pl

(B. Damski, M. Łącki)

We study the quantum Ising model in the transverse inhomogeneous magnetic field. Such a system can be approached numerically through exact diagonalization and analytically through the renormalization group techniques. Basic insight into its physics, however, can be obtained by adopting the Kibble-Zurek theory of non-equilibrium phase transitions to description of spatially inhomogeneous systems at equilibrium. We study derivatives of longitudinal and transverse magnetizations, which have extrema near the critical point. We discuss how these extrema can be used for locating the critical point and for verification of the Kibble-Zurek scaling predictions in the spatial quench.

16:00 – 16:20 **Michal Białończyk,** Jagiellonian University

One half of the Kibble-Zurek quench followed by free evolution

mbialoncz@gmail.com

(M. Białończyk, B. Damski)

We drive the one-dimensional quantum Ising chain in the transverse field from the paramagnetic phase to the critical point and study its free evolution there. We analyze excitation of such a system at the critical point and dynamics of its transverse magnetization and Loschmidt echo during free evolution. We discuss how the system size and quench-induced scaling relations from the Kibble-Zurek theory of non-equilibrium phase transitions are encoded in quasi-periodic time evolution of the transverse magnetization and Loschmidt echo.

16:40 – 17:00 **Oskar Prośniak,** Jagiellonian University

Quantum critical point of the Ising chain from boundary effects

oskar.krak@gmail.com

(O.A. Prośniak)

Quantum phase transitions have been extensively studied in solid state systems. Ultracold atoms and ions have been recently found to be promising setups for such studies. Such systems are in general not thermodynamically large. One of the parameters describing critical phenomena is the position of the critical point. Its identification in small systems may be difficult, since even for the finite-size scaling procedure the system must be sufficiently large.

We have proposed the observable for finite-size quantum Ising chains with open boundary conditions, which is sensitive to quantum criticality even in small systems. It measures the distance at which the boundaries affect longitudinal and transverse magnetizations. Such an observable is similar to the healing length of a Bose-Einstein condensate. By numerical simulations, we have shown that one can obtain the location of the critical point and the value of the correlation length critical exponent by applying the finite-size scaling procedure to the proposed observable. We expect that our results can be generalized to other systems and should be useful for studies of critical phenomena in cold atom and ion setups.

17:00 – 17:20 **Aleksandra Sierant,** Jagiellonian University

Optical dipole mirror for cold atoms based on Surface Plasmon Polaritions

aleksandra.plawecka@doctoral.uj.edu.pl

(A. Sierant, R. Panas, J. Fiutowski, T. Kawalec)

Surface plasmon polaritons (SPPs) are electromagnetic excitations resulting from collective oscillations of the electron gas in a metallic diffraction grating coupled with an electromagnetic wave. The SPPs resonance together with the calculated distribution of the electromagnetic field effective intensity above two gold grooves is shown in the inset of Fig. 1a. To measure the effective intensity of the SPPs in the diffraction grating system we have implemented it in an optical dipole mirror for cold rubidium atoms (^{87}Rb isotope) [1]. Such a mirror uses a repulsive dipole force associated with a high intensity gradient of the SPPs to reflect atoms falling under the gravity force, as can be seen in Fig. 1b [1],[2]. Atomic mirror is then a desirable tool for atom control and manipulation and can be used for a construction of a surface trap in the future. We have also directly monitored the thermal effects inherently linked to the light absorption accompanying SPPs excitation.

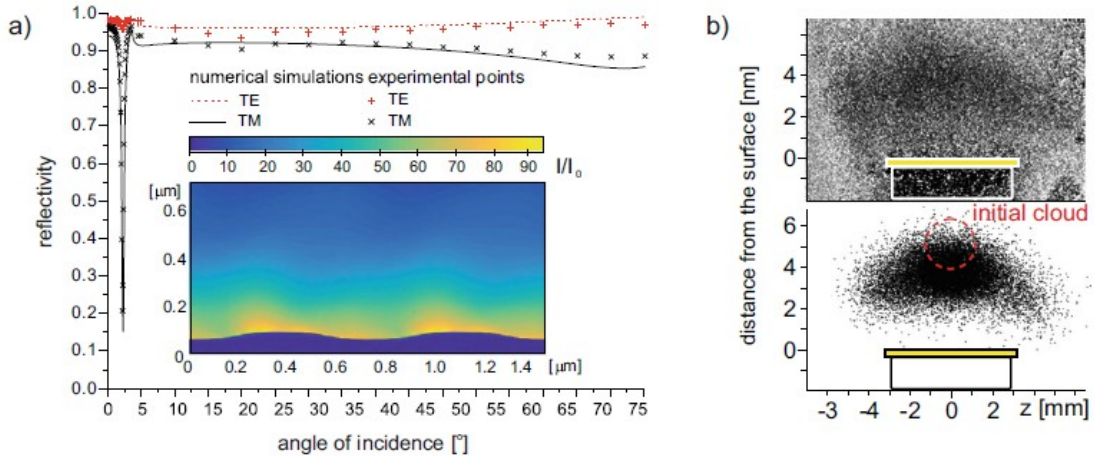


Fig. 1: a) Reflectivity versus angle of incidence for two linear polarizations (TM and TE) of a 785 nm excitation laser beam – calculations and measurements. The inset shows calculated relative field intensity distributions for the preferred angle of incidence. b) Measured (top) and calculated (bottom) distribution of 105 atoms, 17 ms after the reflection off the disc. The outline of the disc and its mounting platform as well as the size of the initial cloud are also shown.

[1] T. Kawalec et al., Surface Plasmon Polaritons Probed with Cold Atoms, Plasmonics, 13, 639, (2018)

[2] T. Kawalec et al., Optical dipole mirror for cold atoms based on a metallic diffraction grating, Opt. Lett. 39, 2932 (2014)

17:20 – 17:40 **Jordi Tura,** Max Planck Institute of Quantum Optics

Bounding the set of classical correlations of a many-body system

jordi.tura@mpq.mpg.de

(M. Fadel, J. Tura)

We present a method to certify the presence of Bell correlations in experimentally observed statistics, and to obtain new Bell inequalities [Phys. Rev. Lett. 119, 230402 (2017)]. Our approach is based on relaxing the conditions defining the set of correlations obeying a local hidden variable model, yielding a convergent hierarchy of semidefinite programs (SdP's). Because the size of these SdP's is independent of the number of parties involved, this technique allows to characterize correlations in many-body systems. As an example, we illustrate our method with the experimental data presented in [Science 352, 441 (2016)]. Local measurements on quantum systems can display correlations that can not be explained by any local hidden variable model (LHVM) [1] or, in other words, that can not be reproduced by local deterministic strategies (LDS), even if assisted by shared randomness [2]. Bell inequalities bound the space of LHVM or "classical" correlations, and correlations that violate a Bell inequality are termed nonlocal. Beside their fundamental interest, nonlocal correlations are a resource that enables novel quantum information processing tasks [3]. From a geometrical point of view, LHVM correlations form a polytope, i.e. a bounded convex set that can be described as the convex hull of a finite number of vertices, or equivalently as the intersection of a finite number of half-spaces. The vertices of the LHVM polytope correspond to LDS, while the half-spaces in which it is contained are defined by Bell inequalities. For this reason, finding all Bell inequalities gives a necessary and sufficient condition for deciding membership in the LHVM set. However, results in computer science indicate that this search is an extremely demanding problem [4], which is NP-complete even in the bipartite case [5]. Therefore, a complete list of Bell inequalities exists only for the simplest scenarios; e.g. only up to 3 parties [6-10].

To characterize correlations in scenarios with a large number of parties, one necessarily has to relax the condition of membership in the LHVM set. This can be done by projecting the LHVM polytope onto the space of observables of a particular form, e.g. permutationally invariant [11], with low-order correlators [12, 13], or translationally invariant [14, 15]. Finding Bell inequalities in these particular spaces has allowed the detection of Bell correlations in a Bose-Einstein condensate (BEC) of 480 ^{87}Rb atoms [16]. However, even in these low dimensional spaces, the complexity of the commonly adopted method (going from the vertices description of the polytope, to the dual half-spaces description) [17] still prohibits one to obtain all Bell inequalities for many-body scenarios, leaving undiscovered potentially useful inequalities. In this work [18], we present a technique to approximate the set of symmetric LHVM correlations from the outside. This technique is based on a hierarchy of semidefinite programs (SdP's), aproximating convex hulls of semialgebraic sets [19-22], and it can be seen as checking all Bell inequalities of a specific form with a single test. Contrary to other existing SdP's hierarchies [23], in our work the size of the SdP's are independent of the number of parties, and the hierarchy

shows convergence already after few levels (see Fig. 1). In summary, our method provides an efficient sufficient condition for a set of correlations to be nonlocal, and it naturally provides a Bell inequality that they violate.

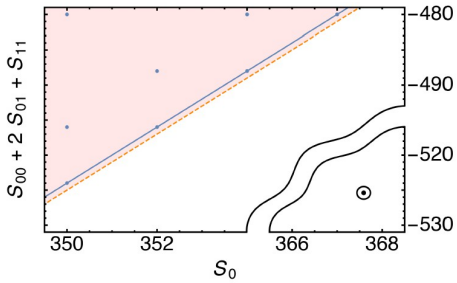


Figure 1. Cut of the projected LHVM polytope of symmetric, two-body correlations P^S_2 along two directions. Black circled dot, point (367.6;-525.4) measured experimentally in [16] for a squeezed BEC with a number of particles N = 476. Blue points, projected vertices of P^S_2. Blue line, bound given by the Bell inequality $-2S_0+(S_{00} + 2S_{01} + S_{11})/2+2\ N\geq 0$, from [12, 16]. Pink region is the approximation to P^S_2 given by our method. Orange dashed line, Bell inequality obtained numerically by our method. The distance between the blue and the orange lines is 1.000002, meaning that the error of our method compared to the tight classical bound scales as 1=N.

[1] John S Bell, \On the einstein-podolsky-rosen paradox," Physics 1, 195{200 (1964).

[2] Arthur Fine, \Hidden variables, joint probability, and the bell inequalities," Phys. Rev. Lett. 48, 291{295 (1982).

[3] Nicolas Brunner, Daniel Cavalcanti, Stefano Pironio, Valerio Scarani, and Stephanie Wehner, \Bell nonlocality," Rev. Mod. Phys. 86, 419{478 (2014).

[4] Laszlo Babai, Lance Fortnow, and Carsten Lund, \Nondeterministic exponential time has two-prover interactive protocols," computational complexity 1, 3{40 (1991).

[5] David Avis, Hiroshi Imai, Tsuyoshi Ito, and Yuuya Sasaki, \Deriving tight bell inequalities for 2 parties with many 2-valued observables from facets of cut polytopes," (2004), arXiv:quant-ph/0404014.

[6] Denis Rosset, Jean-Daniel Bancal, and Nicolas Gisin, \Classifying 50 years of bell inequalities," Journal of Physics A: Mathematical and Theoretical 47, 424022 (2014).

[7] John F. Clauser, Michael A. Horne, Abner Shimony, and Richard A. Holt, \Proposed experiment to test local hidden-variable theories," Phys. Rev. Lett. 23, 880-884 (1969).

[8] Stefano Pironio, \All clauser{horne{shimony{holt polytopes," Journal of Physics A: Mathematical and Theoretical 47, 424020 (2014).

[9] Itamar Pitowsky and Karl Svozil, \Optimal tests of quantum nonlocality," Phys. Rev. A 64, 014102 (2001).

[10] Cezary Sliwa, \Symmetries of the bell correlation inequalities," Physics Letters A 317, 165 { 168 (2003).

[11] Jean-Daniel Bancal, Nicolas Gisin, and Stefano Pironio, \Looking for symmetric Bell inequalities," Journal of Physics A: Mathematical and Theoretical 43, 385303 (2010).

[12] J. Tura, R. Augusiak, A. B. Sainz, T. Vertesi, M. Lewenstein, and A. Acn, \Detecting nonlocality in many-body quantum states," Science 344, 1256{1258 (2014).

[13] J. Tura, R. Augusiak, A.B. Sainz, B. L ucke, C. Klempt, M. Lewenstein, and A. Acn, \Nonlocality in many-body quantum systems detected with two-body correlators," Annals of Physics 362, 370 { 423 (2015).

[14] J Tura, A B Sainz, T Vertesi, A Acn, M Lewenstein, and R Augusiak, \Translationally invariant multipartite bell inequalities involving only two-body correlators," Journal of Physics A: Mathematical and Theoretical 47, 424024 (2014).

[15] Jordi Tura, Gemma De las Cuevas, Remigiusz Augusiak, Maciej Lewenstein, Antonio Acn, and J. Ignacio Cirac, \Energy as a detector of nonlocality of many-body spin systems," (2016), arXiv:1607.06090.

[16] Roman Schmied, Jean-Daniel Bancal, Baptiste Allard, Matteo Fadel, Valerio Scarani, Philipp Treutlein, and Nicolas Sangouard, \Bell correlations in a bose-einstein condensate," Science 352, 441{444 (2016).

[17] Bernard Chazelle, \An optimal convex hull algorithm in any fixed dimension," Discrete & Computational Geometry 10, 377{409 (1993).

[18] Matteo Fadel and Jordi Tura, \Bounding the set of classical correlations of a many-body system," Phys. Rev. Lett. 119, 230402 (2017).

[19] Jo~ao Gouveia, Pablo A. Parrilo, and Rekha R. Thomas, \Theta bodies for polynomial ideals," SIAM Journal on Optimization 20, 2097{2118 (2010).

[20] Jo~ao Gouveia and Rekha R. Thomas, \Chapter 7: Spectrahedral approximations of convex hulls of algebraic sets," in Semidefinite Optimization and Convex Algebraic Geometry (2012).

[21] J.B. Lasserre, Moments, Positive Polynomials and Their Applications, Series on Optimization and Its Applications Series (Imperial College Press, 2009).

[22] M. F. Anjos and J.B. Lasserre, Handbook on Semidefinite, Conic and Polynomial Optimization, International Series in Operations Research & Management Science (Springer US, 2012).

[23] Flavio Baccari, Daniel Cavalcanti, Peter Wittek, and Antonio Acn, \Efficient device-independent entanglement detection for multipartite systems," (2016), arXiv:1612.08551.

9:00 – 9:40 **Mikhail Lemeshko,** Institute of Science and Technology Austria

The angulon quasiparticle: from molecules in superfluids to ultrafast magnetism

mikhail.lemeshko@ist.ac.at

(M. Lemeshko)

Recently we have predicted a new quasiparticle - the angulon – which is formed when a quantum impurity (such as an electron, atom, or molecule) exchanges its orbital angular momentum with a manyparticle environment (such as lattice phonons or a Fermi sea) [1,2].

Soon thereafter we obtained strong evidence that angulons are formed in experiments on molecules trapped inside superfluid helium nanodroplets [3]. The angulon theory thereby provided a simple explanation for experimental data accumulated during the last two decades. Moreover, casting the many-particle problem in terms of angulons amounts to a drastic simplification and allows to tackle previously intractable problems related to quantum dynamics [4].

In this presentation we will introduce the angulon concept and discuss novel physical phenomena [1,5,6] arising from the angular momentum exchange in quantum many-particle systems. We will describe the applications of angulons to modern experiments on quantum impurities and on non-equilibrium magnetism [7].

[1] R. Schmidt, M. Lemeshko, Phys. Rev. Lett. 114, 203001 (2015)

[2] R. Schmidt, M. Lemeshko, Phys. Rev. X 6, 011012 (2016)

[3] M. Lemeshko, Phys. Rev. Lett., 118, 095301 (2017); Viewpoint: Physics 10, 20 (2017)

[4] B. Shepperson, A. A. Sondergaard, L. Christiansen, J. Kaczmarczyk, R. E. Zillich, M. Lemeshko, H. Stapelfeldt, Phys. Rev. Lett. 118, 203203 (2017)

[5] E. Yakaboylu, M. Lemeshko, Phys. Rev. Lett. 118, 085302 (2017)

[6] E. Yakaboylu, A. Deuchert, M. Lemeshko, Phys. Rev. Lett. 119, 235301 (2017)

[7] J.H. Mentink, M.I. Katsnelson, M. Lemeshko, arXiv:1802.01638 (2018)

9:40 – 10:00 **Jakub Janarek,** Laboratoire Kastler Borssel / Jagiellonian University

Quantum boomerang effect in interacting systems

jakub.janarek@lkb.upmc.fr

(J. Janarek, D. Delande, J. Zakrzewski)

Anderson localization, the inhibition of transport in disordered potentials [1], has been thoroughly studied theoretically and realized in many experiments. However, only recently the topic of a kicked wave packet moving through a disordered potential was investigated [2, 3]. The dynamics of such a motion is far from obvious. In a naive guess one expects that packet's velocity components randomize leading to stopping of the motion, followed by the localization. Simple semi-classical analysis shows that packet's center of mass should reach the distance of mean scattering length *L*.

In the [2, 3] authors have shown that due to Anderson localization the result of the evolution is very different. Indeed, the center of mass reaches the mean scattering length *L*, but then it returns to the initial position, where the localization takes place. This phenomenon dubbed quantum boomerang effect has been carefully analyzed and understood in 1 dimensional systems for 1-particle systems. Also, the authors have studied systems with weak nonlinearities, which describe particles in the mean field approximation.

In the systems with interacting particles Anderson localization had remained unexplored for a long time, until influential paper by Basko et al. [4] was published. The new phenomenon was called many-body localization. In our work, we analyze the boomerang effect in a presence of interactions using full many-body physics. In this situation, particle interactions leading to the many-body localization can affect the boomerang effect. Additionally, our aim is to understand the role of interactions in the studied phenomenon based on a comparison between interacting and noninteracting systems.

[1] P. W. Anderson, Phys. Rev. 109, 1492 (1958).

[2] T. Prat, Ph.D. thesis, Universite P. et. M. Curie, Paris (2017)

[3] T. Prat, D. Delande, and N. Cherroret, Arxiv e-prints, arXiv:1704.05241 (2017)

[4] D. Basko, I. Aleiner, and B. Altschuler, Ann. Phys. (NY) 321, 1126 (2006).

10:00 – 10:20 **Tomasz Świsłocki,** Warsaw University of Life Sciences

Dynamic hysteresis from bistability in an antiferromagnetic spinor condensate

tomasz_swislocki@sggw.pl

(T. Świsłocki, A. Zembrzuski, M. Matuszewski, E. Witkowska)

We study the emergence of hysteresis during the process of quantum phase transition from an antiferromagnetic to a phase-separated state in a spin-1 Bose Einstein condensate of ultracold atoms. We explicitly demonstrate the appearance of a hysteresis loop with various quench times showing that it is rate-independent for large magnetizations only. In other cases scaling of the hysteresis loop area is observed, which we explain by using the Kibble-Zurek theory in the limit of small magnetization. The effect of an external harmonic trapping potential is also discussed.

10:40 – 11:00 **Marcin Płodzień,** Institute of Physics, Polish Academy of Sciences

Few-fermion thermometry

mplodzien@gmail.com

(M. Płodzień)

Potential realization of the quantum thermometer operating in nanokelvin regime, formed by a few-fermionic mixture confined in a one-dimensional harmonic trap is proposed. Thermal states of the system are studied theoretically from the point of view of fundamental sensitivity to temperature changes. It is pointed out that the ability to control the interaction strength in such systems, allows obtaining high-temperature sensitivity in the regime where the temperature is much lower than the characteristic temperature scale determined by a harmonic confinement. This sensitivity is very close to the fundamental bound that involves optimal engineering of level separations. Performance of practical measurement schemes and possible experimental coupling of the thermometer to the probe are discussed.

11:00 – 11:20 **Emilia Witkowska,** Institute of Physics, Polish Academy of Sciences

Spin-squeezed atomic crystal

ewitk@ifpan.edu.pl

(D. Kajtoch, E. Witkowska, A. Sinatra)

We propose a method to obtain a regular arrangement of two-level atoms in a three-dimensional optical lattice with unit filling, where all the atoms share internal state coherence and metrologically useful quantum correlations. Such a spin-squeezed atomic crystal is obtained by adiabatically raising an optical lattice in an interacting two-component Bose-Einstein condensate. We study numerically and analytically the spin-squeezing dynamics, the adiabaticity condition and the limits imposed by particle losses.

11:20 – 11:40 **Vladimir Yurovsky,** Tel Aviv University

Quantum many-body effects in matter-wave breathers

volodia@post.tau.ac.il

(V.A. Yurovsky)

Breather is a non-linear superposition of two solitons with the 3:1 mass ratio and zero relative velocity. This exact solution of a one-dimensional (1D) Gross-Pitaevskii equation (GPE) oscillates without decay and can be formed by the fourfold quench of the attractive interaction strength from a fundamental soliton. The quantum counterpart of the 1D GPE, a system of 1D atoms in a flat potential with zero-range interactions (the Lieb-Liniger-McGuire model) has exact Bethe-ansatz solutions. Solutions of such kind are applied here to analyses of the quench in the quantum system. Exact analytic expressions for transition probabilities, obtained with computer algebra for up to N=20 atoms, demonstrate a formation of two-soliton states with arbitrary relative velocities. The velocity distribution width is scaled as $\sqrt{N}$, leading to a dissociation of breathers in $\sqrt{N}$ periods [1]. This is a robust quantum many-body effect, while the dissociation of mean-field breathers is forbidden by integrability of the 1D GPE. The scaling law agrees with the results of truncated Wigner simulation [2] even for N=10^4. The Bethe-ansatz solutions are also used here for the fidelity calculation. The dephasing due to the spread of the relative kinetic energy of the constituent solitons leads to decay of the fidelity oscillation amplitude by half in the course of ~2.5 breather periods. In real experiments, a quasi-1D gas can be realized with atoms trapped in a 3D elongated trap. The effect of axial trap potential is analyzed here with relation to the current experiments in Rice University.

1. V. A. Yurovsky, B. A. Malomed, R. G. Hulet, and M. Olshanii, Phys. Rev. Lett. 119, 220401 (2017).

2. B. Opanchuk and P. D. Drummond, Phys. Rev. A 96, 053628 (2017)

14:20 – 15:00 **Dmitry Petrov,** Universite Paris Sud

Beyond mean field in cold gases: quantum droplets and three-body interactions

petrov@lptms.u-psud.fr

(D.S. Petrov)

I will talk about beyond-mean-field effects in three- and low-dimensional gases and about the quantum-mechanical stabilization of dilute droplets in various regimes and geometries. The second part of the talk will be devoted to the case where the beyond-mean-field correction manifests itself in the form of a strong effective three-body interaction. In particular, I will discuss a peculiar one-dimensional dimerized liquid with a three-dimer repulsion.

15:00 – 15:20 **Tomasz Wasak,** Max Planck Institute for Physics of Complex Systems

Quantum Bose-Bose droplets at a dimensional crossover

trwas@fuw.edu.pl

(P. Zin, M. Pylak, T. Wasak, M. Gajda, Z. Idziaszek)

Recent advancement in the experiments with ultracold Bose-Bose mixtures led to the observation of exotic ultra-dilute quantum droplets. These are the exotic phases of the selfbound incompressible system of a two component Bose-Einstein condensate stabilized by quantum fluctuations. The existence of droplets is overlooked by the mean-field theory. A proper description of quantum droplets requires the beyond-mean-field corrections to the energy of the ground state of the system.

In the talk, I will present an analysis of liquid quantum droplets in a mixture of twocomponent Bose-Einstein condensates under a variable confinement introduced along one or two spatial dimensions. Despite the atom-atom scattering has a three-dimensional character, discreetness of the available modes in the reduced dimensions strongly influences the zero-point energy, known as the Lee-Huang-Yang term. I will show the properties of the droplets at the dimensional crossovers, and provide the conditions for accessing quasi-low dimensions.

15:40 – 16:00 **Tomasz Karpiuk,** University of Bialystok

Quantum Bose-Fermi 3D droplets

t.karpiuk@uwb.edu.pl

(T. Karpiuk)

We study stability of a zero temperature mixture of attractively interacting degenerate bosons and spin-polarized fermions in the absence of confinement. We demonstrate that higher order corrections to the standard mean field energy of the system can lead to a formation of liquid droplets -- self-bound incompressible systems in a three-dimensional space. The stability analysis of the homogeneous system is supported by numerical simulations of finite systems by explicit inclusion of surface effects. Our results indicate that Bose-Fermi droplets can be realized experimentally.

16:00 – 16:20 **Debraj Rakshit,** Institute of Physics, Polish Academy of Sciences

Low-Dimensional Bose-Fermi Droplets

debraj@ifpan.edu.pl

(D. Rakshit, T. Karpiuk, M. Brewczyk, M. Lewenstein, M. Gajda)

We recently showed that higher order quantum corrections to the standard mean field energy of the system can lead to a formation of liquid droplets in a Bose-Fermi mixture in three-dimension (arXiv:1801.00346). Here we demonstrate that Bose-Fermi droplets can exist in strictly two-dimension as well. Our stability analysis for the homogeneous two-dimensional droplets is further aided by numerical simulations of the finite systems. We also examine the possibility of formation of such droplets in strictly one-dimensional Bose-Fermi mixture.

Time	Tuesday 11.09.2018	Wednesday 12.09.2018	Thursday 13.09.2018	Friday 14.09.2018	Saturday 15.09.2018
9:00 – 9:20		Morigi	Langen	Lewenstein	Lemeshko
9:20 – 9:40					
9:40 – 10:00		Victorin	Tomza	Sierant P	Janarek
10:00 – 10:20		Ramaniuk	Śmiałkowski	Maksymov	Świsłocki
10:20 – 10:40		COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
10:40 – 11:00		Safaei	Sroczyńska	Szymański	Płodzień
11:00 – 11:20		Giergiel	Zaremba-Kopczyk	Deuar	Witkowska
11:20 – 11:40		Zegadło	Pylak	Gawryluk	Yurovsky
11:40 – 12:00			Borkowski		
12:00 – 12:20					
12:20 – 12:40					
12:40 – 13:00					
13:00 – 13:20		LUNCH		LUNCH	LUNCH
13:20 – 13:40					
13:40 – 14:00					
14:00 – 14:20			LUNCH		
14:20 – 14:40					Petrov
14:40 – 15:00					
15:00 – 15:20		Roati		Szymańska	Wasak
15:20 – 15:40	LUNCH				COFFEE BREAK
15:40 – 16:00		Majewska		Damski	Karpiuk
16:00 – 16:20		Pęcak	Konotop	Białończyk	Rakshit
16:20 – 16:40		COFFEE BREAK		COFFEE BREAK	
16:40 – 17:00		Pruvost	Rzążewski	Prośniak	
17:00 – 17:20		De Saint Vincent		Sierant A	
17:20 – 17:40	Büchler	Syrwid	COFFEE BREAK	Tura	
17:40 – 18:00		Szczepkowski	Matuszewski		
18:00 – 18:20	Efimov	Semczuk	Ziń		
18:20 – 18:40	COFFEE BREAK		Long Van		
18:40 – 19:00	Despres		Surprise		
19:00 – 19:20	Dobrzyniecki				
19:20 – 19:40					
19:40 – 20:00					
20:00 – 23:00	RECEPTION		DINNER		

September 11 - 16, 2018, Jastarnia in Hel, Poland