



Newsletter

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THE PRESIDENTS' MESSAGE

IUPAP attracting New Members

At the IUPAP General Assembly in Sao Paulo in October 2017, it was decided that attracting new members would be a priority for the next six years. We had 13 members at the start in 1923, and 57 members in 2017. We should have about 60 or more in 2020 after our next General Assembly and hope to have many more members by 2023 for the 100th anniversary of the first General Assembly. To do that, the 2017 General Assembly appointed Nithaya Chetty as the Vice-President-at-Large for New Members. Thanks to his impressive and energetic work, we can be very optimistic today.

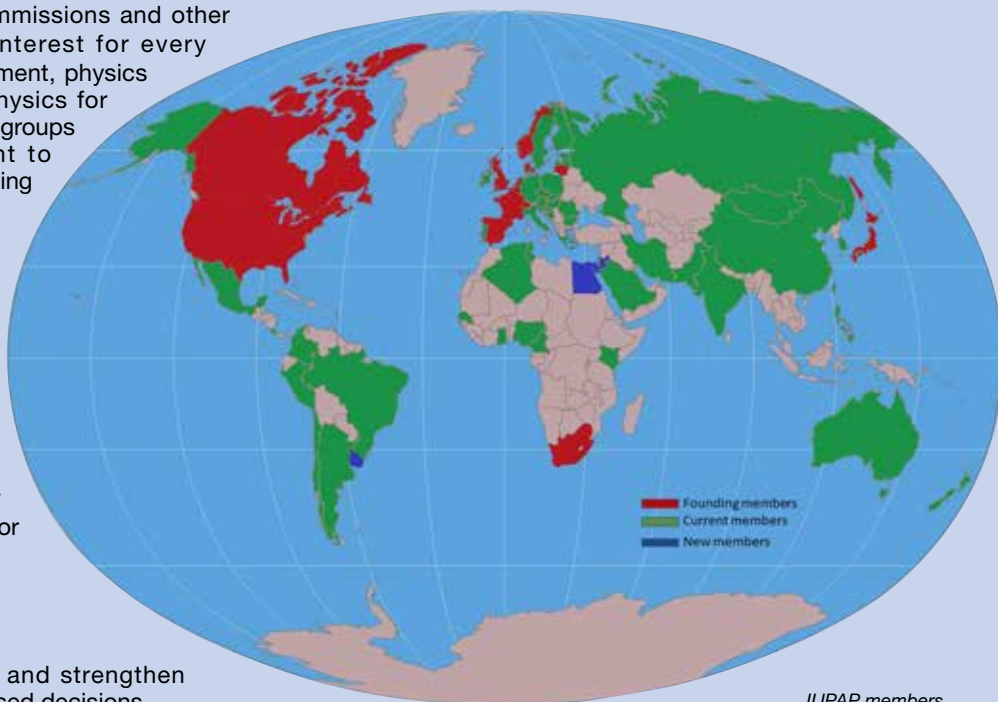
Jordan, Egypt and Uruguay have recently joined (accepted by Council, waiting for ratification by the 2020 General Assembly) and are considered as members starting in 2019. We would like to welcome these countries as members of IUPAP and are looking forward, to their full participation in the affairs of the Union for mutual benefit.

There are many reasons for countries or territories, having a physics community, to join IUPAP:

1. To be part of the “concert” of nations in Physics and so take part in the IUPAP General Assemblies and be part of the resolution making process.
2. To be part of the world physics community represented by IUPAP and thus enable scientists to cooperate freely across political boundaries.
3. To have a fair representation in commissions and other physics endeavours of general interest for every country, namely physics for development, physics and industry, physics education, physics for society, etc. To participate in working groups and committees that are relevant to addressing some specific challenge facing physics in the world.
4. To have links and networks with allied disciplines of physics through affiliated commissions and other allied international unions, and to be a part of ISC (the council of all scientific unions) through IUPAP.
5. To have a chance to host prestigious IUPAP conferences or events.
6. To receive the support of IUPAP for physics and science in their country or territory.

2. To better reach across national boundaries and ensure the free circulation of scientists through global physics cooperation in a world that is becoming more fragmented.
3. To better enable scientists to participate in decision-making processes that impact physics on an international level in significant ways.
4. To create a more international platform where scientists can raise their voices and express their views on any matter that relates to physics and the practice of physics, and in so doing, help to propose solutions and action plans to address such matters.
5. To enhance the role of physics and physics education with particular emphasis on the developing world.
6. To help better address major global societal challenges, such as environmental and energy problems, as physics will continue to underpin all science and technology for the foreseeable future.

Attracting new members is a win-win approach for the new members and for IUPAP. We count on all of you to help in this process and to approach our Vice-President-at-Large, Nithaya Chetty to help him in this challenge.



For IUPAP the benefit is:

1. To consolidate its global footprint and strengthen its position for scientific, evidence-based decisions.

Egypt re-joins the IUPAP

Nithaya Chetty (Vice President - New members)

Egypt joined the IUPAP in 1948 and had a near 70-year period of active participation in the affairs of the Union. Unfortunately, Egypt was formally excluded from the Union at the last General Assembly which took place in Brazil in 2017. The political changes in the country since 2011 made it difficult for Egypt to continue to maintain its membership in the Union.

However, the IUPAP Council has always considered Egypt as an extremely important physics nation, in Africa and in the world, and has spared no effort in working with the Egyptian Academy of Scientific Research and Technology (ASRT) to facilitate Egypt's reinstatement.

Egypt ranks amongst the top producers of international physics journal outputs on the African continent. Egypt has only recently been awarded the privilege of hosting the African Space Agency. It is noteworthy that Egypt's President Abdel Fattah al-Sisi has been elected chairperson of the African Union at the continental body's summit in Ethiopia only a month ago. The ASRT recently announced the annual Prizes for African young scientists. These awards are allocated to young (non-Egyptian) researchers from the African continent in the areas of Agriculture and Food Sciences; Health and Pharmaceutical Sciences; and Water, Energy and Environmental Sciences, with each award valued at 15,000 US dollars.

IUPAP is very supportive of the leading role that Egypt is playing in physics on the African continent, and will continue to work closely with the ASRT to support its physics endeavours.

In March 2019, the negotiations for Egypt's readmission to the IUPAP were completed to the mutual satisfaction of the IUPAP Council and the ASRT. Prof Sameh Soror of the ASRT and Prof Nithaya Chetty, Vice President of the IUPAP responsible for membership matters, signed the Memorandum of Understanding on behalf of their respective organisations that will readmit Egypt as a fully-fledged member of the IUPAP effective 01 January 2020. This will be formally confirmed at the next General Assembly, to be held later in 2020.



Prof Sameh Soror (the Egyptian Academy of Scientific Research and Technology Foreign Secretary) signs the Memorandum of Understanding to re-admit Egypt as a member of the IUPAP as Prof Nithaya Chetty (Vice President - New members) looks on.

Deciphering the collective dynamics of active particles

Alexandre Solon (2019 – C3 YSP winner)

CNRS research scientist, Sorbonne Université, Paris

Dr Solon is a theoretical physicist working at Sorbonne Université in Paris as a CNRS research scientist. His researches focus on deciphering the collective dynamics of active particles, a general name for particles that individually consume energy to propel or exert forces. Collections of many such particles, that we term active matter, are strongly driven out of equilibrium, and exhibit phenomena impossible in equilibrium. These systems are found at all scales in Nature, from the actin cytoskeleton that gives our cells their mechanical properties, to bacterial colonies and

large groups of animals such as bird flocks and fish schools. Many kinds of inert active particles are also engineered in the laboratory and used in controlled experiments. An underlying motivation to study these systems is to be able to control living systems or mimic them to use them in practical applications, for example to create new materials with original properties.

To abstract from the complexity of living systems, one has to study simple models that can reproduce a given phenomenon. In

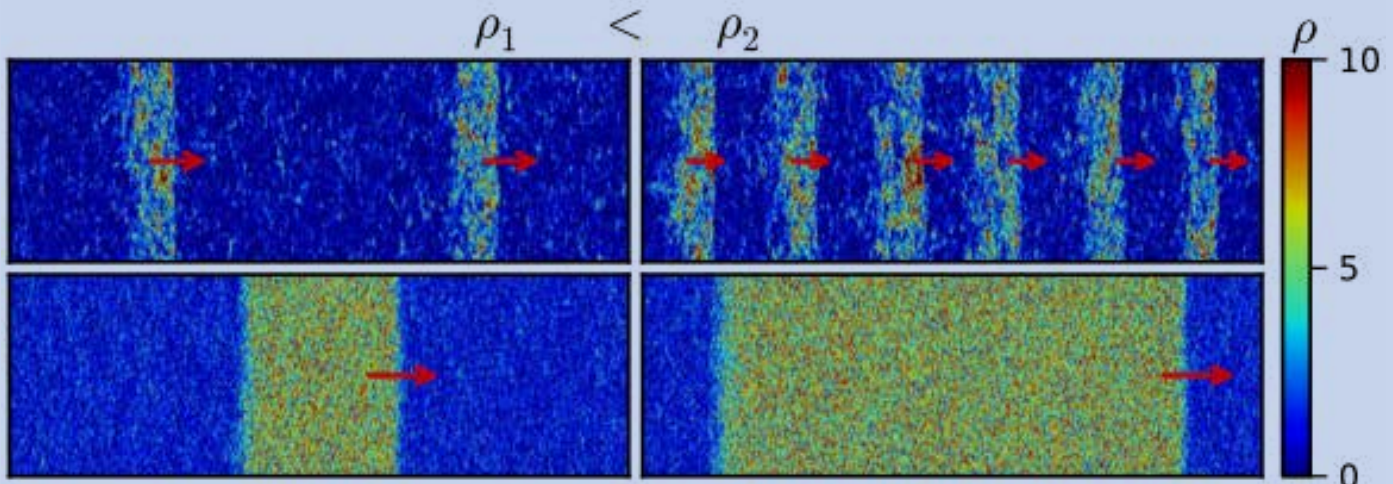


Figure 1. Phase coexistence in models of polar aligning particles. The high density bands are ordered and thus move in the disordered background. Top: Vicsek model, akin to an Active XY model, showing microphase separation in bands of finite size. Bottom: Active Ising model in which that particles self-propel only to the left or right (and just diffuse symmetrically in the vertical direction), showing full phase separation. Reproduced from [Phys. Rev. Lett. 114, 068101 (2015)].

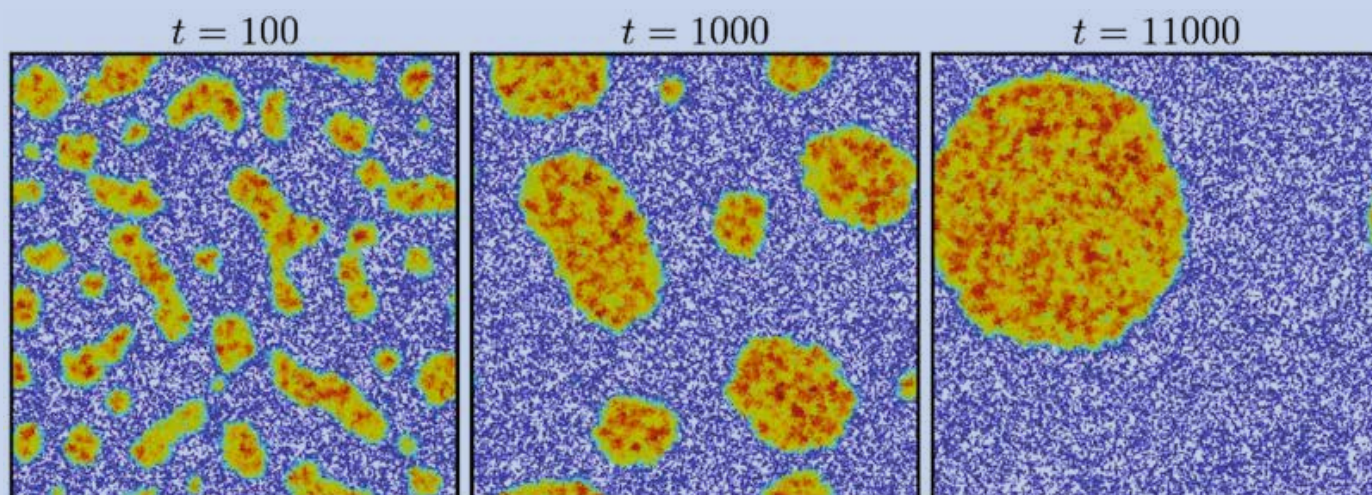


Figure 2. Coarsening in motility-induced phase separation. Warmer colors denote higher density. The many clusters formed at short time coarsen through Ostwald ripening until full phase separation is reached. Reproduced from [Eur. Phys. J. Special Topics 224, 1231-1262 (2015)].

this way, Dr Solon has studied several aspects of active matter. The most characteristic one is probably collective motion: the ability of many individuals to align and move coherently in a self-organized manner, without external supervision or leader. For a long time, the transition between disordered and collective motion was thought to be a type of ferromagnetic transition. Dr Solon and collaborators showed that it is actually akin to a liquid-gas phase separation, between a dilute disordered gas and a denser ordered liquid. The phase coexistence region depends on the symmetry of the interactions and can take unusual forms such as a periodic array of small propagating bands for particles interacting with polar alignment (see Figure 1). Although the coexistence phases can be very different, this liquid-gas framework allows to understand the phase diagram of many systems exhibiting collective motion in a unified manner.

Because of energy dissipation, the forces exerted by active systems can be very different from passive ones that are tied by the conservation of energy and momentum. For example, Dr Solon and collaborators have shown that in general the mechanical pressure (the force per unit area exerted on the contain) does not follow an equation of state in active system. As opposed to equilibrium systems, the mechanical pressure

cannot be simply measured in the bulk since it depends on the (possibly complex) interactions at the boundary. Pressure thus depends on the instrument used to measure it.

Similar conclusions were obtained about motility-induced phase separation. This phenomenon, also characteristic of active system, appears because collisions impede the motion of active particles. For very persistent particles, this leads to full phase separation between a gas of fast-moving particles and a liquid of slow movers. The coarsening process is shown in Figure 2. The phenomenology appears at first sight very similar to an equilibrium phase separation, except that here cohesive phases are obtained in absence of any attractive interaction. Dr Solon has shown that this type of phase separation can be described in a manner similar to equilibrium ones but using generalized thermodynamic functions (free energy, chemical potential, pressure). There are still fundamental differences. In particular, the thermodynamic functions are not quantities measurable in the bulk, they depend on the physics at the interfaces, as opposed to the passive case for which the all interface contribution are subdominant in a large system and thus do not contribute to the phase diagram.

Tackling the structural, dynamical and functional complexity of systems of systems

M. De Domenico¹ (2019 – C3 YSP winner)

¹Complex Multilayer Networks Laboratory (CoMuNeLab), Fondazione Bruno Kessler, Italy

Many natural and artificial systems are characterized by networked structure and dynamics which lead to a broad class of emergent phenomena. However, a classical description in terms of a single complex network does not provide, often, a good model of empirical systems. Dr. De Domenico has extensively shown that a new level of complexity must be taken into account to cope with the structure of many social, biological and engineering systems.

In this new class of models, known as multilayer networks, each pairs of nodes might interact in different ways, simultaneously (Fig. 1). At the molecular scale, this is the case of gene-protein interactions due to physical, chemical or genetic functional relationships. In the human brain, the functional connectivity between different areas is better described by disentangling functional relationships with respect to time and frequency. At the scale of urban transportation, adjacent geographic areas of

a city are usually connected by multimodal transportation means such as bus, trains or underground.

The challenge was to develop new theoretical and computational tools to analyze the structure and the function of this broad class of complex systems far from equilibrium, as well as to characterize their dynamics. To this aim, Dr. De Domenico developed a general tensorial formulation of multilayer interactions allowing to encode, within a unifying framework, the higher complexity of this type of systems [1]. The most fundamental object in this framework is the multilayer adjacency tensor $M_{\beta\delta}^{\alpha\gamma}$, a real tensor [1, 2] accounting for interactions between a node α in layer γ and node β in layer δ , with some abuse of notation.

Capitalizing on this elegant formulation, Dr. De Domenico described the dynamics of diffusion and random walks in multilayer systems [1, 3], accounting simultaneously, for

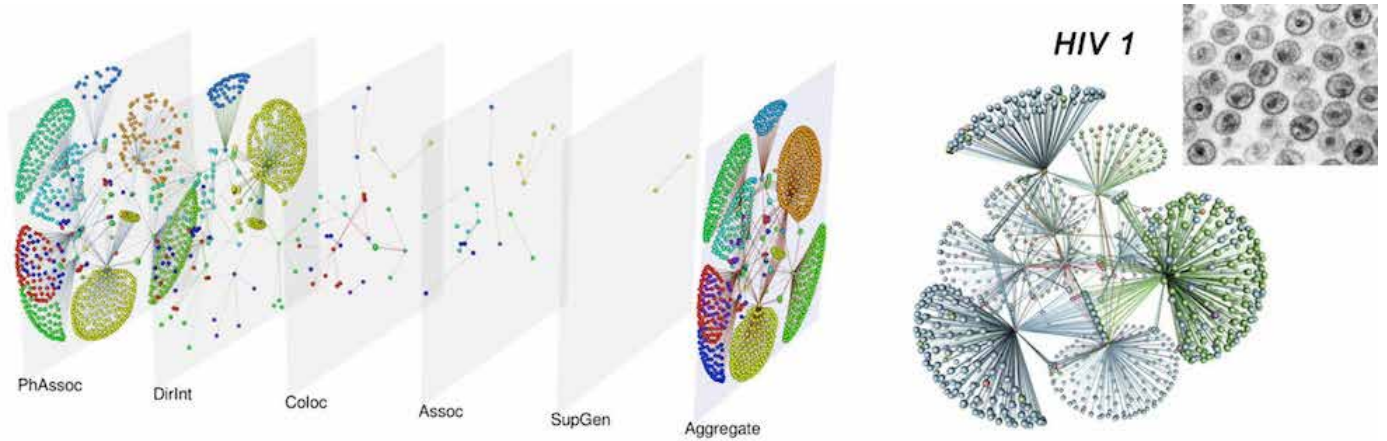


Fig. 1. Multilayer structure of the human immunodeficiency virus of type I. Different types of gene-protein inter-actions are encoded by distinct layers (left panel). A more compact representation of the same system is shown in the right panel. Empirical multilayer systems are characterized by topological correlations that can dramatically alter their response to external perturbations.

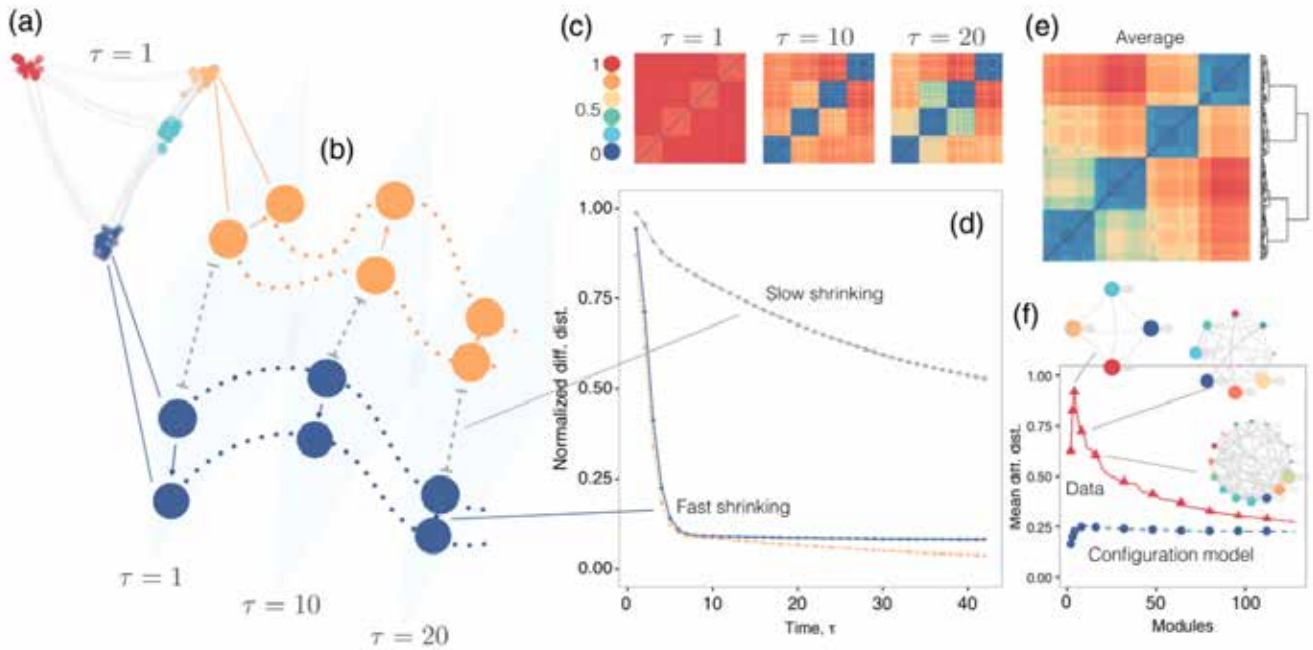


Fig. 2. Functional clusters in diffusion space. (A) A system with four clusters, embedded at time $\tau = 1$. (B) Units within a cluster are closer than units between clusters. (C) Mesoscale structure becomes more evident as time goes by. (D) The rate at which distance between units shrinks is used to probe the mesoscale at different resolutions. (E) Persistence of mesoscale across time is used to unveil hierarchies. (F) The most representative mesoscale structure is the one where the average diffusion distance among clusters is maximized. Figure from [4].

transitions between systems' units within and across layers. If $X_{\alpha\tilde{\gamma}}(t)$ indicates the state tensor of units in each layer at time t , the manifestly covariant diffusion equation is

$$\partial_t X_{\beta\tilde{\delta}}(t) = -L_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}} X_{\alpha\tilde{\gamma}}(t), \quad (1)$$

where $L_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}}$ is the multilayer generalization of the combinatorial Laplacian tensor, the discrete counterpart of the well-known differential operator. Similarly, the master equation for multilayer random walks can be obtained. If $T_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}}$ indicates the tensor of probabilities for stochastic transitions between pairs of nodes – within and across layers – in the system, and the state tensor $P_{\alpha\tilde{\gamma}}(t)$ en-codes the probability to find the walker at a particular node in a particular layer, the master equation governing between pairs of nodes – within and across layers – in the system, and the state tensor $P_{\alpha\tilde{\gamma}}(t)$ en-codes the probability to find the walker at a particular node in a particular layer, the master equation governing its dynamics is given by $P_{\beta\tilde{\delta}}(t+1) = T_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}} P_{\alpha\tilde{\gamma}}(t)$, which in continuous-time approximation, leads to Eq. (1) with

$X_{\alpha\tilde{\gamma}}(t) = p_{\alpha\tilde{\gamma}}(t)$ and $L_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}} = \delta_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}} - T_{\beta\tilde{\delta}}^{\alpha\tilde{\gamma}}$ the normalized Laplacian tensor. Dr. De Domenico used random walks to quantify the navigability of empirical systems, such as the public transport of London, and characterize their resilience to unexpected perturbations such as random failures [3].

According to Murray Gell-Mann, complex systems exhibit very different structural and dynamical features but resemble each other in the way they process information. By modeling information flowing through the backbone of a system in terms of stochastic processes, Dr. De Domenico mapped the underlying functional relationships to a geometric space where it was easier to determine the mesoscale organization during collective phenomena such as synchronization or consensus [4] (Fig. 2). By compressing flows through an information-theoretic approach, Dr. De Domenico characterized the functional organization of social and biological multilayer systems [5].

By capitalizing on random flows [6], Dr. De Domenico developed a quantum-inspired statistical mechanics of networks based

on density matrices to represent network states and quantify their information entropy, showing that it can be used to coarse-grain the complex structure of many biological, social and transportation multilayer systems while preserving their most salient physical properties [7, 8].

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Role of orbital physics in iron-based high-temperature superconductors

Ming Yi (2019 – C10 YSP winner)

Assistant Professor, Physics and Astronomy Department, Rice University

High temperature superconductivity (HTSC) remains one of the long-standing mysteries of condensed matter physics. On the one hand, room-temperature superconductors hold the tantalizing potential to revolutionize technological advancements. On the other hand, the microscopic description of HTSC requires a deep understanding of emergent phenomena in strongly-correlated electron systems - a challenge that pushes the boundary of fundamental physics.

In 2008, a new class of HTSC materials based on iron were discovered, ending the copper oxides' two decades of monopoly as the only family of HTSC materials. These new materials became known as the iron-based superconductors (FeSCs). In the decade that followed, a wide range of systematic studies of FeSCs were carried out, in the effort to compare and contrast the FeSCs with the copper oxides, towards the goal of identifying the minimal ingredients for HTSC. One of the main differences between the two families is that copper oxides are effectively single-band systems while FeSCs is a multi-orbital system, where the low-energy physics involves all five Fe 3d orbitals. Using spectroscopy tools such as angle-resolved photoemission, my work has made contributions in elucidating the remarkable role played by the orbital degree of freedom in the FeSCs in two main developments of research directions in the field—electronic nematicity and orbital selectivity.

Electronic nematicity—the breaking of rotational C4 symmetry driven by the electronic degree of freedom—has now been established to be a ubiquitous companion approximal to FeSC superconductivity. Macroscopically, it is manifested in a small lattice orthorhombicity observed across a large region of the underdoped phase diagram. Our observation via angle-resolved photoemission spectroscopy of the anisotropy between the d_{xz} and d_{yz} orbitals with an energy scale almost an order of magnitude larger than that accountable by the lattice degree of freedom [PNAS 108, 6878 (2011)] was one of the key experimental evidences for the electronic origin of this order (Fig. 1). Subsequent work established this nematic orbital anisotropy to be a universal feature of underdoped FeSCs where the orbital anisotropy energy scale is shown to be a direct measure of the order parameter of the electronic nematicity in FeSCs [NJP 14, 073019 (2012); Nat. Comm. 5, 3711 (2014)]. This work was enabled by our development of the first *in-situ* mechanical strain device for photoemission. Such an order is a correlation-driven electronic instability and provides an important tie between the magnetic ground state and superconductivity in this class of materials.

Orbital-selectivity—the differentiation in electron correlation

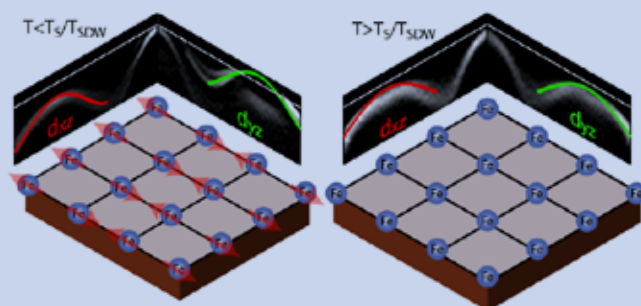


Fig. 1. ARPES measurement of band dispersions along the orthogonal directions of a $Ba(Fe_{1-x}Co_x)_2As_2$ single crystal in the C_2 nematic state (top) versus the C_4 normal state (bottom), showing the orbital anisotropy in the lifted degeneracy between the d_{xz} and d_{yz} orbitals. [PNAS 108, 6878 (2011)]

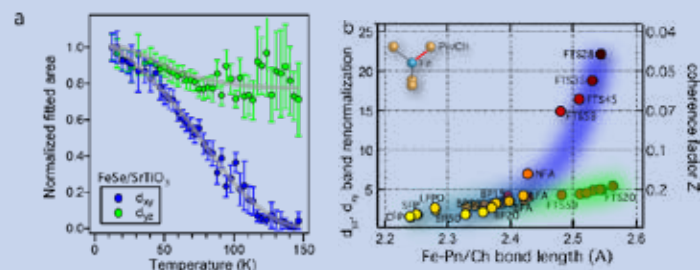


Fig. 2. (a) observation of a temperature-induced crossover into an orbital-selective Mott phase in an iron-chalcogenide superconductor. [Nat. Comm. 6, 7777 (2015)] (b) Orbital-selective correlation trends across all available FeSC literature. [npj Quantum Materials 2, 57 (2017)]

strength between different Fe 3d orbitals—is also a concept beyond that of the copper-oxide superconductors. Initially, we found evidence of such orbital selectivity in an iron chalcogenide superconductor, where the d_{xy} orbital was much strongly localized beyond that of the d_{xz} and d_{yz} orbitals. Furthermore, with increasing temperature, we identified a crossover into an orbital-selective Mott phase, where the d_{xy} orbital became completely localized while the d_{xz} and d_{yz} orbitals remained itinerant, all within the same electronic system (Fig. 2a) [PRL 110, 067003 (2013)]. Subsequent, our follow-up work identified a systematic trend of such behaviors across FeSC material families (Fig. 2b) [Nat. Comm. 6, 7777 (2015); npj Quantum Materials 2, 57 (2017)]. These observations of strong orbital-selective correlation effects in FeSCs helped drive the inclusion of orbital-selectivity in established theoretical frameworks for FeSCs. The end-result, demonstrated by recent theoretical works, shows promising improvements for describing the superconducting properties among FeSCs.

Probing the exotic nuclear structure via high-resolution laser spectroscopy

Xiaofei Yang (2019 – C12 YSP winner)

Peking University, China

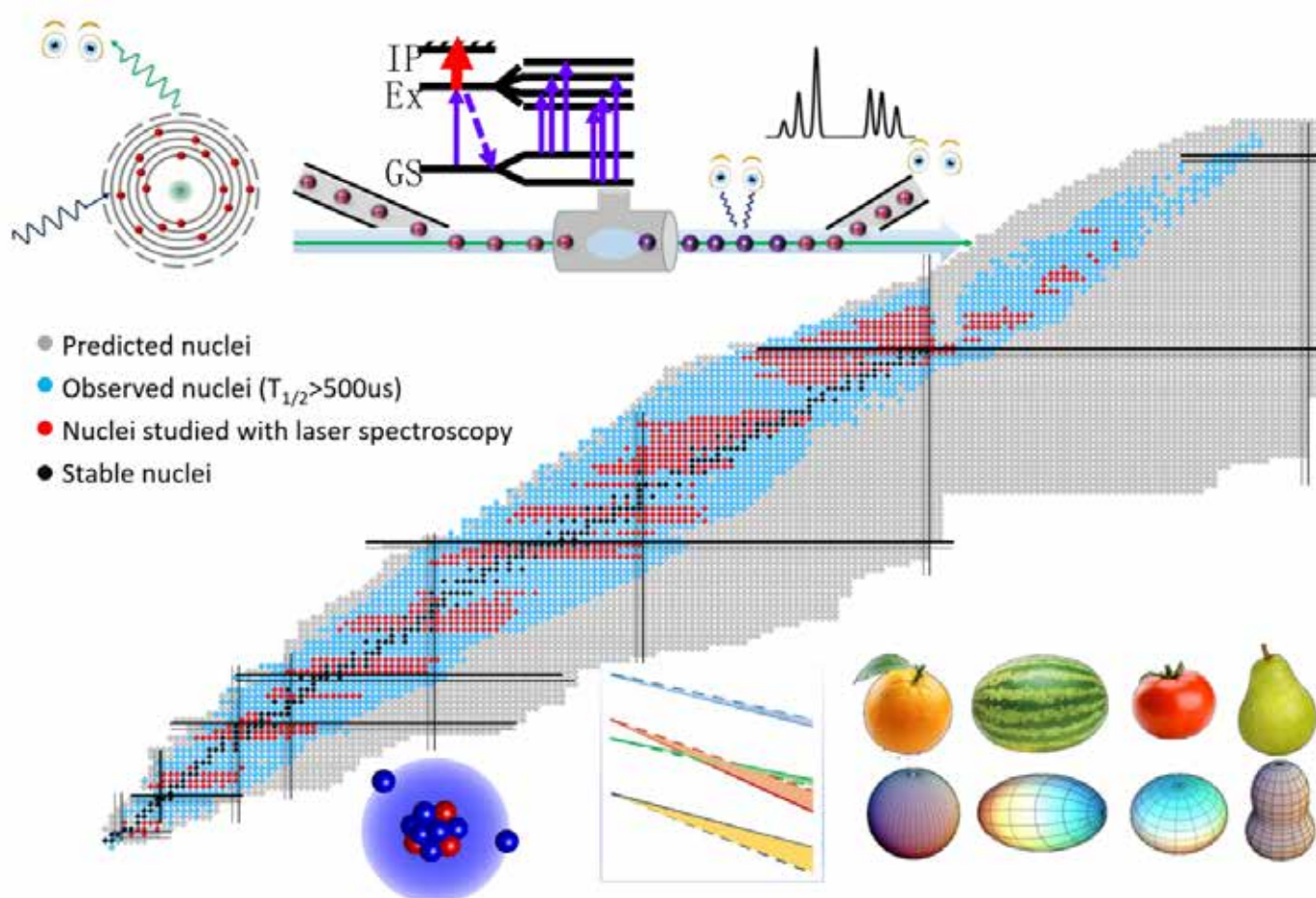
Investigating the exotic nuclear properties and structure of unstable nuclei far from the β -stability line remains a cornerstone of nuclear physics research. This has been triggered continuously by the unexpected phenomena observed in nuclei with an unusual proton to neutron ratio. Some examples are the changes of magic numbers, the inversion or intrusion of quantum orbits, halo and cluster structures, exotic nuclear shapes and so on, which were investigated under the joint effort of experimental and theoretical nuclear physicists.

Laser spectroscopy, as one of the powerful experimental tools, has made significant contribution to investigations of the aforementioned nuclear phenomena. This is realized by measuring multiple nuclear properties in a nuclear-model-independent way, such as nuclear spins, magnetic dipole and electric quadrupole moments and charge radii. Although standard laser spectroscopy techniques have been established at various facilities around the world, more advanced techniques are continuously needed, especially for high resolution and high efficiency measurement of exotic isotopes at very low production yield, which allows the exploration of new nuclear structure and dynamics in the vicinity of the nuclear driplines. Our research interests have been focused on the development of such high-precision and high sensitivity laser spectroscopy techniques and the associated exotic nuclear structure studies of unstable nuclei being pushed closer towards the proton and neutron-dripline.

Examples for such developments in our collaborations are the realization of a unique laser spectroscopy technique "OROCHI"

to be applied at the projectile-fragmentation (PF)-type radioactive isotope beam facility at RIBF, RIKEN [1] and the optimization of the collinear resonance ionization spectroscopy (CRIS) technique at the ISOL-type facility ISOLDE-CERN [2-4]. These developments have led to, for example, the first successful online measurement of the double resonance laser spectra of radioactive Rb isotopes trapped in superfluid helium [1]; a world record in sensitivity for high resolution laser spectroscopy of ^{78}Cu at 20 ions/s production rate using the CRIS method [3]; and a higher precision and sensitivity measurement by using beta-tagging in combination with CRIS for the study of very exotic ^{52}K isotopes [4].

For the exotic nuclear structure studies using the laser spectroscopy technique, one example of our recent work is the investigation of dramatic level changes in the region towards the doubly magic nucleus ^{78}Ni . By using the collinear laser spectroscopy setup at ISOLDE-CERN, we discovered the long-lived nature of an isomeric state in ^{79}Zn and firmly assigned its spin/parity as $1/2^+$. Based on the new measurement of the nuclear moments of the ground and the isomeric states, as well as the isomer shift, we proposed the first experimental signature of shape coexistence near ^{78}Ni [5-6]. This has opened up many lines of investigation around the $N = 50$ and $Z = 28$ shell closure. Additional investigations along the same isotopic chain are the revelation of a triaxial shape in the long-lived isomeric state of ^{73}Zn isotope [7] and the observation of the sensitive correlation between the nuclear charge radii and proton cross-shell excitations [8].



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Quantitative Characterization of Quark-Gluon Plasma Properties

Chun Shen (2019 – C12 YSP winner)

Assistant Professor, Wayne State University, Detroit, USA

For a few microseconds after the Big Bang, the universe was filled with an astonishingly hot and dense soup made of elementary particles called Quark-Gluon Plasma (QGP), a precursor of the matter we know today. Colliding atomic nuclei at the Relativistic Heavy Ion Collider (RHIC) in the U.S. and the Large Hadron Collider (LHC) in Europe is the only way to reproduce those conditions in the laboratory. Those collisions create tiny “fireballs” with temperatures that can achieve several trillion degrees Kelvin within a few yoctoseconds after the collision. The QGP exhibits near perfect (inviscid) fluidity emerged from many-body effects of quarks and gluons whose interactions are governed by Quantum Chromodynamics (QCD). In the last decade, relativistic hydrodynamics, including lattice QCD-based equation of state (EoS), viscosity, and initial state event-by-event fluctuations, has developed and has successfully predicted and described particle production and correlations in the measurements. These achievements have led to a standardized theoretical framework, which provides quantitative constraints on the magnitude of the QGP specific shear viscosity η/s through phenomenological model-to-data comparisons.

The next major step in the field of high-energy nuclear physics is to fully characterize the QGP transport properties, namely its shear and bulk viscosity and charge diffusion constants, their temperature and chemical potential dependence, and elucidate the phase structure of QCD matter. Fig. 1 sketches the dynamical evolution of relativistic heavy-ion collisions. As the fireballs evolve through multiple phases, they can

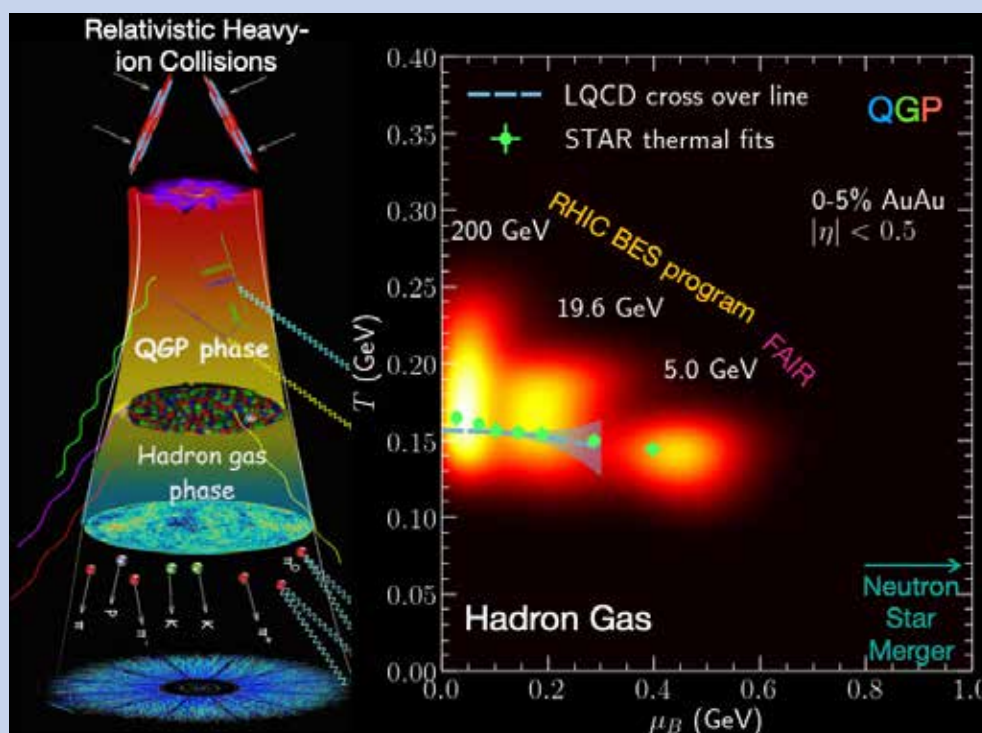


Fig. 1 As relativistic heavy-ion collisions evolve through multiple phases governed by different types of physics, they explore the phase diagram of hot and dense QCD matter. Lattice QCD calculations identified a smooth cross-over between QGP and hadron gas for $\mu_B < 250$ MeV. The chemical freeze-out points extracted from thermal model fits at RHIC are shown. The three blobs represent fireball trajectories of central Au+Au collisions at RHIC BES energies mapped onto the QCD phase diagram event-by-event using our dynamical framework. The brightness of these blobs is proportional to the fireball space-time volume weighted by T^4 .

probe a wide portion of the QCD phase diagram. In particular, experiments in the current RHIC Beam Energy Scan (BES) and future Facility for Antiproton and Ion Research (FAIR) programs can produce a baryon rich QGP, where the excess of quarks over antiquarks in the incoming nuclei is essential. The QCD critical point and its associated first-order phase transition line is a landmark on the nuclear matter phase diagram. Because of the sign problem at finite baryon chemical potential, it is not yet reliably known whether QCD has a critical point, nor where on its phase diagram it may reside. First principles lattice calculations

for baryon rich QGP remain an outstanding challenge, in spite of recent progress. Along the phenomenology direction, we recently implemented the propagation of net baryon current and its dissipative diffusion in the state-of-the-art relativistic hydrodynamic framework. This advance extended the successful fluid paradigm established at high energy collisions down to RHIC BES and future FAIR experiments. With this dynamical framework, relativistic heavy-ion collisions can be mapped to the nuclear matter phase diagram event-by-event as shown in Fig. 1. The existence of a critical point in a heavy-ion

collision should lead to strong correlations and enhanced local fluctuations of conserved densities. By modeling the dynamics of stochastic fluctuations in a realistic expanding medium, we will identify the most relevant experimental observables. This quantitative framework will be indispensable to turn high precision experimental data anticipated in the upcoming years into precise information on the QCD critical point.

Nonlinear light generation in topological nanostructures

Sergey Kruk (2019 – C17 YSP winner)

Research Fellow, Nonlinear Physics Centre, Australian National University

Isaac Asimov once famously wrote that the most exciting phrase to hear in science is not “Eureka!” but “That’s funny...” This project started with a bit of a “that’s funny...” moment when we performed two seemingly identical experiments in Australia and in Russia, and the opposite results were yielded. Our first explanation was that, geographically speaking, from an Australian perspective, some things in Russia are made upside down. This commonplace joke has turned out to be literally the explanation of our experiments. It became clear that we witnessed an example of optical nonreciprocity at the nanoscale facilitated by topology.

We have been studying topological states of light – peculiar localisations of light that are unusually robust against various perturbations. Being inspired by the recent developments in condensed matter physics, photonic topological states have emerged as a new frontier in optics. Our research was headed towards new horizons in topological optics by introducing strong nonlinear effects in a topological structure. More specifically, we were generating a third-harmonic signal from localised topological edge states of a one-dimensional zigzag array of silicon nanoresonators known to have the Z2 topological invariant.

Our first set of measurements were performed at the Australian National University. We observed the expected effect: a strong third-harmonic signal from the localised mode associated with

topological state. Our colleagues then conducted a seemingly identical experiment at the Moscow State University, where an opposite effect was observed. We were cross-checking the experimental arrangements and procedures for a possible fault in one of the experiments and found that the only difference was the direction of propagation of light in the two experiments: light was propagating through the structure from top to bottom in Australia and from bottom to top in Russia. From there we understood that we hit the regime of strong optical nonreciprocity induced by nonlinear interactions.

In the resulting Nature Nanotechnology paper, we demonstrated the nonlinear generation of photons inside a nanoscale topological structure where nonlinearity triggers nonreciprocal response. We revealed that the interplay between topology and nonlinearity makes the third-harmonic generation and light localisation at the edge states dependent on the direction of the optical pump. In addition, we observed that the topological properties enhance substantially the efficiency of the nonlinear effects.

We believe this work will establish valuable cross-disciplinary links and set an important reference point for future studies of topological photonic structures.

Sergey Kruk is thankful to his co-authors. He acknowledges critical contributions of A. Poddubny, D. Smirnova, and Y. Kivshar.



Concept of nonlinear parametric topological edge states as seen from Canberra and from Moscow perspective. Third-harmonic generation from edge states in a zigzag array of silicon nanoresonators depends on the pump direction.

Ultra-fast visualization and ultra-precise modulation of laser pulse/beam profiles

Jinyang Liang (2019 – C17 YSP winner)

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Prof. Liang's research in the field of coded-aperture imaging is represented by the development of two highly innovative imaging modalities - compressed ultrafast photography and coded aperture band-limited imaging. They have allowed light-speed visualization and ultrahigh-precision control of laser pulse/beam profiles.

Compressed ultrafast photography (CUP), provides the world's fastest camera with an unprecedented imaging speed of 10 trillion frames per second (fps), has allowed real-time imaging of dynamics of single laser pulses for the first time. In ultrafast optical imaging, it is still challenging to measure the spatial and temporal profiles of single laser pulses in real time. This severe limitation prevents us from characterizing high-power, low-repetition laser systems. It also hinders our understanding of many physical, chemical, and biological mechanisms that are manifested in non-repeatable or difficult-to-produce laser-matter interactions. While working as a Postdoctoral Research Associate at Washington University in St. Louis, Prof. Liang co-invented the CUP technique that overcomes these limitations. This novel coded-aperture ultrafast imaging modality uses compressed sensing in the data acquisition to allow spatiotemporal mixing in the temporal shearing direction of the streak camera and then implements an optimization algorithm to reconstruct the movie. The resultant CUP camera, adding another spatial dimension into the streak camera, achieves sling-shot, receive-only femtophotography in real time.

Fig. 1. World's fastest camera captures light refraction (top row), temporal focusing (middle row), and propagation of photonic Mach cone (bottom row) in real time. [Nature 516, 74 (2014), Light: Sci. & Appl. 7, 42 (2018), and Sci. Adv. 3, e1601814 (2017) Prof. Liang has implemented the CUP technique for imaging of dynamics of single laser pulses in real time, including the refraction a single laser pulse [Nature 516, 74 (2014), cover story], the formation and propagation of a scattering-induced photonic Mach cone [Sci. Adv. 3, e1601814 (2017)], and temporal focusing of single femtosecond laser pulses [Light: Sci. & Appl. 7, 42 (2018)] (Fig. 1). The CUP technique has made imaging spatial and temporal profiles of laser pulses—the fastest object in the universe—a new daily routine.

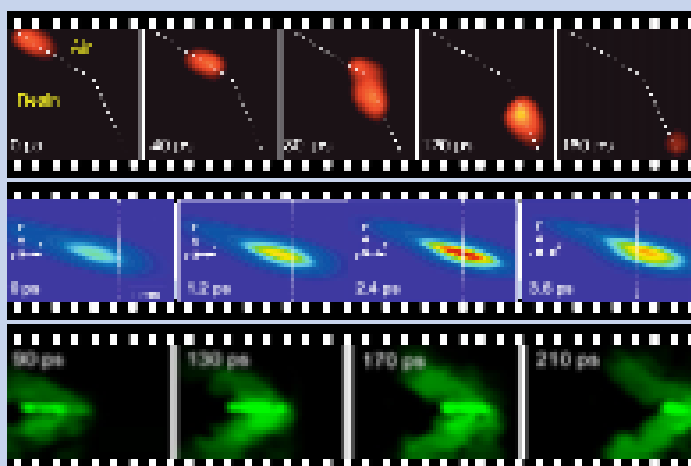


Fig. 1. World's fastest camera captures light refraction (top row), temporal focusing (middle row), and propagation of photonic Mach cone (bottom row) in real time. [Nature 516, 74 (2014), Light: Sci. & Appl. 7, 42 (2018), and Sci. Adv. 3, e1601814 (2017)

Prof. Liang has applied CUP to many new applications, including fluorescence lifetime mapping [Nature 516, 74 (2014)], encrypted quantum communication [Adv. Quantum Technol. 2018, 1800034 (2018)], and time-of-flight light radar [Sci. Rep. 5, 15504 (2015)]. Moreover, he has recently extended CUP's concept to electron imaging and diffraction [Micron 117, 47 (2019) and Phys. Rev. Appl. 10, 054061 (2018)] and to other advanced detectors [Opt. Lett 44, 1387 (2019)]. These applications testify that CUP can be readily coupled to different imaging modalities, from microscopes to telescopes, to image numerous ultrafast events occurring at all spatial scales. His ultimate goal is to develop the CUP technique toward a universal, omniscience, ultrafast imaging platform.

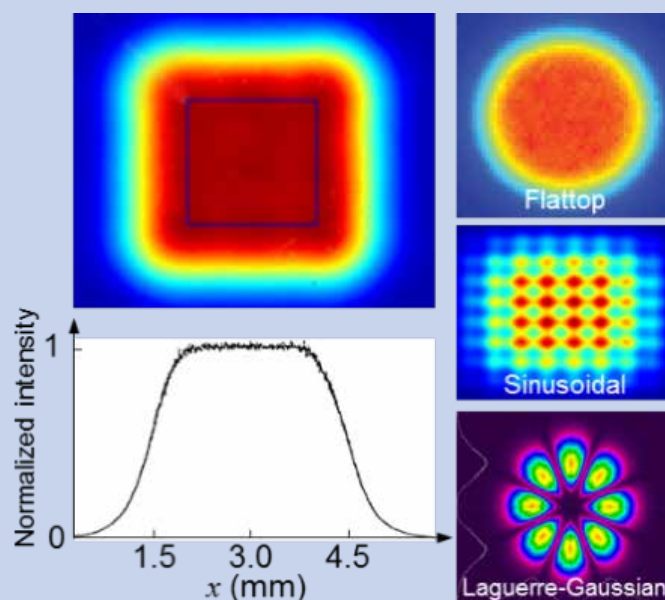


Fig. 2. World's flattest laser beam (left column) and various 2D optical potentials (right column) generated by CABI. [Appl. Opt. 49, 1323 (2010) and Opt. Eng. 51,108201 (2012)]

Coded aperture band-limited imaging (CABI) has enabled controlling laser pulse/beam profiles with unprecedented intensity accuracy and pattern flexibility (Fig. 2). Prof. Liang developed the CABI system by combining dynamic coded-aperture imaging and 4f optical processing. The ability of engineering the desired point spread function endows the CABI system with the accurate intensity controlled by the limited system bandwidth and the arbitrary profiles generated by the spatial light modulator. Using this system, Prof. Liang has demonstrated, by far, the world's flattest laser beam with a >99.7% intensity uniformity, in both visible and near-infrared spectra [Appl. Opt. 49, 1323 (2010) and Opt. Eng. 51,108201 (2012)]. CABI-based high-precision laser beam/pulse shaping has been used in free electron lasers [Opt. Exp. 21, 32013 (2013)] and atomic physics. Currently, Prof. Liang is working on applying CABI in high-speed 3D profilometry and single-pixel cameras.

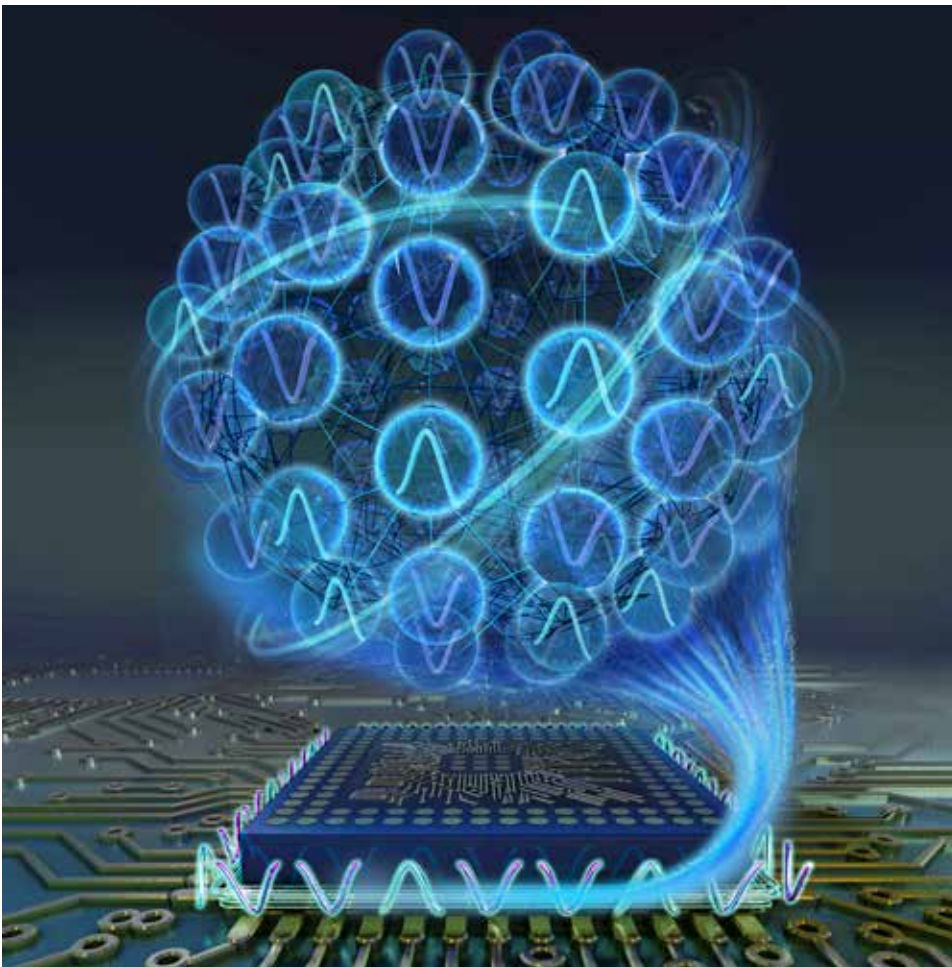
Networks of Optical Parametric Oscillators: From Ising Machines to Quantum Photonic Engineering

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In the past few years, networks of optical parametric oscillators (OPOs) have been successfully used to simulate the classical Ising Hamiltonian leading to a platform that may be used as a special-purpose computer. Some of the fundamental properties of OPOs at degeneracy that enabled simulation of the Ising Hamiltonian were experimentally demonstrated in 2012 [1, 2]. Later in 2013, numerical investigation of the idea led to promising results [3]. One of the key concepts for successful experimental realization of these networks has been the idea of time-division multiplexing of OPOs which was used in the first demonstration of OPO-based Ising machines in 2014 [4]. Time-division multiplexing in combination with the measurement-feedback architecture and guided-wave implementation of OPOs led to a special implementation of large-scale Ising machines in 2016 [5, 6] that are being studied extensively [7]. Numerical studies suggest that OPO networks have potential in realization of a wide range of quantum states, from the well-known squeezed vacuum and multi-mode entangled states [8] to less-explored highly-desired Cat states [9] and indicate a path toward scalable quantum photonic engineering using them. Recent numerical studies of ultra-short pulse OPOs in the highly-nonlinear quantum regime [10] illustrate some of the practical benefits associated with using them as the building block of a quantum photonic platform. These theoretical studies and experimental demonstrations promise that OPO networks can potentially be useful for a broad range of applications.

- [1] A. Marandi et al., “Coherence properties of a broadband femtosecond mid-IR optical parametric oscillator operating at degeneracy,” *Optics Express* 20.7 (2012): 7255-7262.
- [2] A. Marandi et al., “All-optical quantum random bit generation from intrinsically binary phase of parametric oscillators,” *Optics Express* 20.17 (2012) 19322-19330.
- [3] Z. Wang et al., “Coherent Ising machine based on degenerate optical parametric oscillators,” *Physical Review A* 88.6 (2013): 063853.
- [4] A. Marandi et al., “Network of time-multiplexed optical parametric oscillators as a coherent Ising machine,” *Nature Photonics* 8.12 (2014): 937-942.
- [5] P. McMahon*, A. Marandi* et al., “A fully programmable 100-spin coherent Ising machine with all-to-all connections,” *Science* 354.6312 (2016): 614-617.
- [6] T. Inagaki et al., “A coherent Ising machine for 2000-node optimization problems,” *Science* 354.6312 (2016): 603-606.
- [7] R. Hamerly*, T. Inagaki*, P.L. McMahon*, et al., “Experimental investigation of performance differences between Coherent Ising Machines and a quantum annealer,” arXiv:1805.05217 (2018).



An artistic illustration of optical Ising machine

- [8] K. Takata et al., “Quantum correlation in degenerate optical parametric oscillators with mutual injections,” *Physical Review A* 92.4 (2015): 043821.
- [9] M. Wolinsky, H. J. Carmichael, “Quantum noise in the parametric oscillator: from squeezed states to coherent-state superpositions,” *Physical Review Letters* 60(18):1836 (1988).
- [10] T. Onodera*, E. Ng*, et al., “Nonlinear quantum behavior of ultrashort-pulse optical parametric oscillators,” arXiv:1811.10583 (2018).

Computational approaches to the ab-initio modelling of thermal transport

Jesús Carrete Montaña (2019 - C20 YSP winner)
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Dr. Jesús Carrete Montaña was awarded the 2019 IUPAP Young Scientist Prize in Computational Physics “for his original contributions and development of pioneering computational methods in the emerging field of ab-initio thermal transport, enabling the parameter-free prediction of thermal conduction properties of solid materials, and opening these novel methods to the broader scientific community through open source codes.”

Technological progress demands advanced materials tailored to specific requirements, and thermal transport considerations often determine the suitability of a material for a particular application. For example, a high thermal conductivity is desirable to keep the operating temperatures of electronic devices low to prolong their lifetimes, whereas high thermoelectric efficiencies require a combination of low thermal conductivities and favorable electrical properties. Many of these applications involve crystalline semiconductors, where phonons are the dominant heat carriers.

A convenient theoretical tool to deal with phonon thermal transport, the Peierls-Boltzmann transport equation (BTE), has existed for close to a century; however, a direct approach to its solution was considered impossible for many decades, with applications limited to semi-empirical approximations with little quantitative value. Viable numerical solution algorithms started appearing in the late 90s, and the first predictive thermal conductivity calculations based on ab-initio results were published in the following decade by pioneers like N. Mingo and D. Broido.

Dr. Carrete’s contributions to this area of research have helped make such calculations mainstream and greatly extended their reach beyond single crystals to more realistic materials and into the realm of devices like LEDs and HEMTs.

The open-source ShengBTE package [Comput. Phys. Commun. 185, 1747 (2014), cited close to 600 times] has allowed hundreds

of research groups to apply first-principles-based phonon BTE calculations to both new and known materials, helping establish those as the gold standard for predicting thermal conductivities. More recently, almaBTE [Comput. Phys. Commun. 220, 351 (2017)] has integrated these techniques into a more flexible variance-reduced Monte Carlo framework capable of dealing with defect-laden materials, complex geometries and interfaces, as depicted schematically in Fig. 1. Dr. Carrete has played a central role in the design, implementation and promotion of both packages, and still runs their active user support fora.

In addition to his work on methodology and on implementations, Dr. Jesús Carrete’s production comprises many pioneering applications of the formalism, such as its use for the high-throughput screening of materials libraries [Phys. Rev. X 4, 011019 (2014), Adv. Funct. Mater. 24, 7427 (2014)] and for the quantitative characterization of the nature and abundances of defects like antisites [J. Mater. Chem. A 4, 15940 (2016)] or dislocations [Phys. Rev. B 95, 245304 (2017)], as well as accurate descriptions of physical phenomena like resonant scattering of phonons by point defects [Phys. Rev. Lett. 119, 075902 (2017)] and the effect of the isotropy of free space on the phonon dispersions of 2D systems [Mater. Res. Lett. 4, 204 (2016)]. Moreover, he has co-authored highly-cited articles on materials of such current interest as MoS2 [Appl. Phys. Lett. 105, 101907 (2014)], black phosphorus [Adv. Mater. 29, 1603756 (2017)] or SnSe [Appl. Phys. Lett. 105, 101907 (2014)].

Dr. Carrete’s current lines of research focus on the fundamental physics of phonon scattering in low dimensionality, on applications of machine learning, and on the integration with higher-level tools like TCAD packages.

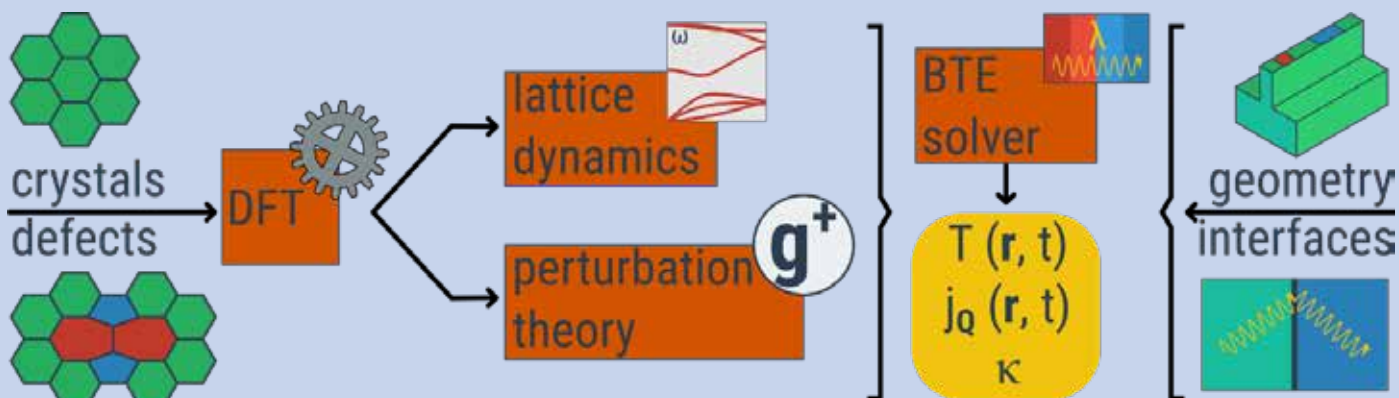


Fig.1. High-level overview of the almaBTE workflow leading from an atomistic description of the materials making up a semiconductor device, including defects such as dopants and dislocations, to a quantitative picture of thermal transport in the device.

UPCOMING SUPPORTED CONFERENCES 2019 (July – December)

- **1 - 5 July 2019** Budapest (Hungary)
GIREF-ICPE-EPEC– Eötvös Year 2019. (Research and practice in physics education to celebrate Eötvös centenary)
- **1 - 5 July 2019** Szeged, Hungary
International Conference on Attosecond Science and Technology (ICAST 2019)
- **7 - 12 July 2019** Valencia, Spain
22nd International Conference on General Relativity and Gravitation (22nd GRG)
- **7 - 12 July 2019** Valencia, Spain
13th Edoardo Amaldi Conference on Gravitational Waves (13th Eduardo)
- **8 - 12 July 2019** Buenos Aires, Argentina
27th International Conference on Statistical Physics (STATSPHY-27)
- **14 - 19 July 2019** Sapporo, Japan
International Conference on Phenomena in Ionized Gases (ICPIG 2019)
- **20 - 24 July 2019** Madrid, Spain
12th EBSA and 10th ICBP-IUPAP Biophysics Congress. Biophysics for Life and Technology (EBSA+10th ICBP-IUPAP)
- **21 - 26 July 2019** Seattle, WA, USA
30th International Conference on Defects in Semiconductors (ICDS 2019)
- **22 - 26 July 2019** Montreal, Canada
Quantum Theory and Symmetry (QTS 2019)
- **23 - 30 July 2019** Deauville, FRANCE
XXXI International Conference on Photonic, Electronic and Atomic Collisions (ICPEAC 2019)
- **24 July – 1 August 2019** Madison, WI, USA
36th International Cosmic Ray Conference (ICRC 2019)
- **28 July - 1 August 2019** Hong Kong, China
31th IUPAP Conference on Computational Physics in 2019 (CCP2019)
- **29 July – 2 August 2019** Glasgow, UK
International Nuclear Physics Conference (INPC 2019)
- **5 - 10 August 2019** Toronto, Canada
International Symposium on Lepton Photon Interactions at High Energies (ISLPIHE 2019)
- **7 - 13 August 2019** Edmonton, Canada
International Symposium on Quantum Fluids and Solids (QFS2019)
- **10 - 17 August 2019** Cologne, Germany
International Conference for Physics Students (ICPS 2019)
- **1 – 5 September 2019** Carthage, Tunisia
ICO & IUPAP-C17 Topical Meeting on OPTics and Applications to Sustainable Development (OPTISUD 2019)
- **8 - 11 September 2019** Santiago de Chile
International Conference on Medical Physics (ICMP 2019)
- **8 - 13 September 2019** Zatoka, Odessa Region Ukraine
International Workshop on "Nanomagnetic Materials, Applications & Properties" (InMAP-2019)
- **9 - 13 September 2019** Aachen, Germany
23rd International Congress on Acoustics (ICA 2019)
- **9 - 20 September 2019** Nairobi, Kenya
Biophysical approaches to macromolecules and cells: integrated tools for life sciences and medicine (BAMC 2019)
- **9 - 13 September 2019** Toyama, Japan
16th International Conference on Topics in Astroparticle and Underground Physics (TAUP 2019)
- **22 - 27 September 2019** Osaka, Japan
International Conference on Inertial Fusion and Science Applications (IFSA 2019)
- **21 - 25 October 2019** Costa Rica
XIII Latin American Symposium on Nuclear Physics and Applications (XIII LASNPA)
- **3 - 9 November 2019** Wuhan, China
Quark Matter (QM 2019)
- **2 - 6 December 2019** Sydney, Australia
2019 TeV Particle Astrophysics (TeVPA 2019)
- **15 - 20 December 2019** Portsmouth, UK
Texas Symposium on Relativistic Astrophysics (TEXAS 2019)

UPCOMING ENDORSED CONFERENCES 2019

- **11- 17 July 2019** Ghent, Belgium
European Physical Society Conference on High Energy Physics (EPS-HEP 2019)
- **15- 19 July 2019** South Korea
28th Annual International Laser Physics Workshop (LPHYS'19)
- **24- 26 July 2019** Ljubljana, Slovenia
High density DNA arrays: models, theories and multiscale simulations (HdDNA)
- **25 - 30 August 2019** Wilhelmshaven, Germany
6th International Conference on the Chemistry and Physics of Transactinide Elements (TAN 2019)
- **1 - 6 September 2019** Prague, Czech Republic
57th European High Pressure Research Group Meeting on High Pressure Science and Technology (EHPRG2019)