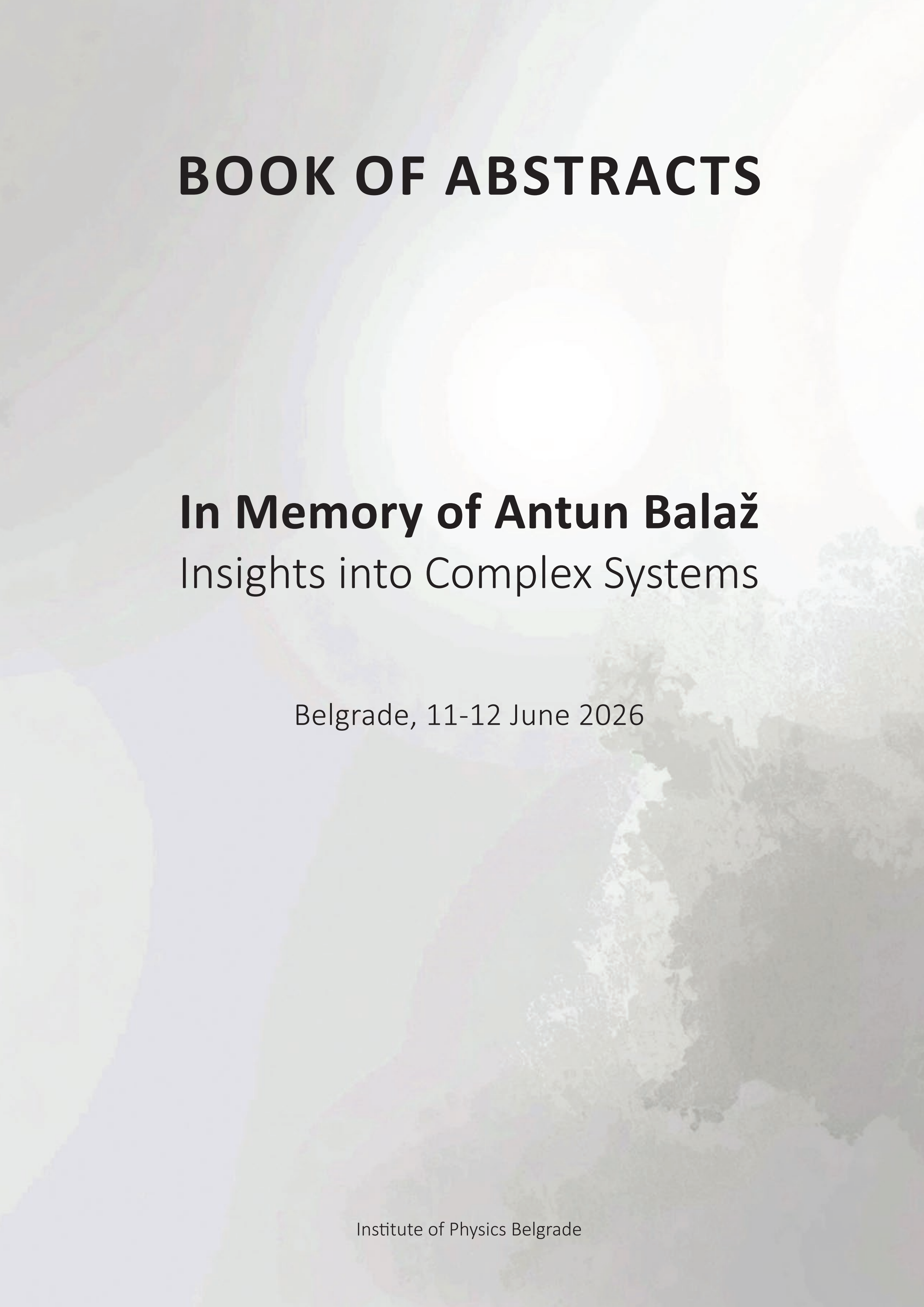

BOOK OF ABSTRACTS

In Memory of Antun Balaž
Insights into Complex Systems

Belgrade, 11-12 June 2026

Institute of Physics Belgrade

In Memory of Antun Balaž – Insights into Complex Systems, Belgrade 11-12 June 2026

Book of Abstracts

Institute of Physics Belgrade

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Book of Abstracts

In Memory of Antun Balaž – Insights into Complex Systems

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Welcome to the Memorial Conference:
In Memory of Antun Balaž – Insights into Complex Systems

We warmly welcome you to the memorial conference to be held at the Institute of Physics Belgrade on June 11 and 12, 2026. Deeply saddened by Antun's early passing, we have gathered, as his friends and colleagues, to honor his life and celebrate his outstanding scientific achievements, preserving the memory of Antun and the enduring legacy of his work.

Antun was a cornerstone of our community, serving as the long-time Deputy Director of the Institute of Physics Belgrade and the head of the Center for the Study of Complex Systems. This conference brings together his collaborators and friends to present joint research with him and to discuss the latest advancements in ultracold atomic gases, high-performance computing, and related fields of complex systems.

We hope that this event serves not only as a tribute to a brilliant physicist and leader but also as a platform for carrying forward the scientific excellence he so passionately championed.

We wish you a productive and inspiring conference and a pleasant time in Belgrade.

With best regards,

The Organizing Committee

Biography of Dr Antun Balaž

Antun Balaž was born on December 27, 1973, in Zrenjanin, where he completed his early education and graduated from Zrenjanin Gymnasium as the top student of his generation. Upon completing his military service, he continued his education at the Faculty of Physics, University of Belgrade, where he graduated in 1997 with a degree in Theoretical and Experimental Physics with an average grade of 9.93 out of 10. He defended his master's thesis entitled "New Recursive Formula for Path Integrals in Quantum Mechanics: Analytical and Numerical Properties" in May 2004 at the Faculty of Physics, University of Belgrade. He completed his PhD on the topic "Speeding up the Convergence of Path Integrals" under the supervision of Dr Aleksandar Bogojević in December 2008. He was the recipient of the "Prof. Dr. Lj. Ćirković" award for best undergraduate thesis, the Annual Award of the Institute of Physics Belgrade for best master's thesis (2005), and the Annual Research Award of the Institute of Physics (2014).

In 2004, Antun was one of the founders of the Scientific Computing Laboratory (SCL) where he played a highly active role from the very beginning, engaged at every step of its development. Even before completing his PhD, he provided invaluable support to younger colleagues, guiding them through their first steps in scientific research. In 2014, he became the Head of SCL and, shortly thereafter, took over the leadership of the accredited Center for the Study of Complex Systems, of which the lab is a central part. He ensured that every lab member had optimal working conditions and felt like a valued part of the team. He also oversaw the maintenance of the PARADOX computing cluster, making it a vital resource for researchers across Serbia.

In the early stages of his career, his research focused on the application of effective actions in the path integral formalism within quantum field theory. He later turned to independent research in ultracold quantum gases and Bose–Einstein condensation, establishing collaborations with groups in Germany, Austria, Romania, Brazil, and India. His work covered collective and nonlinear excitations of Bose–Einstein condensates, including the effects of dipole–dipole interactions and disorder. In 2015, he opened a new research direction on ultracold dipolar fermions, developing a quantum Boltzmann formalism to describe Fermi surface deformation. Throughout his career, he developed numerous parallel numerical algorithms and software, having published approximately 60 papers in leading international journals, and delivered many invited lectures worldwide.

Antun led a wide array of scientific projects. From 2015 to 2019, he was principal investigator of a basic research project funded by the Ministry of Science, involving nearly all members of SCL. He also led several bilateral projects with Germany and Austria. He was highly active in leading the Serbian team in several FP6, FP7, Horizon 2020, Horizon Europe and Digital Europe projects in the fields of high-performance computing, high-performance data analysis, distributed, and grid computing. Through these initiatives, he contributed to building and strengthening of high-performance computing infrastructure in Southeastern Europe.

Antun served as the leader of Grid operations for the SEE-GRID-2 and SEE-GRID-SCI projects and represented Serbia in the EGI-InSPIRE initiative. He managed Serbia's participation in the European Grid Initiative and was the technical manager for Serbia's National Grid Initiative, AEGIS. He also coordinated the Serbian team's efforts in the PRACE projects and served as a deputy member of the PRACE Council. Additionally, he served on the Board of Directors of the European Open Science Cloud (EOSC). In the EuroHPC program, he led the national high-performance computing competence center, HPC Serbia.

Since his undergraduate days, Antun was deeply dedicated to fostering young scientific talent and introducing students to scientific work. He was an associate and a lecturer in the physics and astronomy programs at the Petnica Science Center and a mentor for many student projects. Many of our colleagues fondly recall their first steps into science beyond the school curriculum through Antun's lectures or projects in Petnica. In recent years, he also formally supported Petnica as a member of its Management Board. He was a member of the national committee for high school physics competition several times and participated in preparation of students for international competitions. As the team leader, he led Serbian teams at the International Physics Olympiads in 2002 and 2003. Additionally, he coauthored physics textbooks for the 6th and the 7th grade of elementary school.

His academic teaching career was equally distinguished. From 2002 to 2005, he was a teaching assistant at the Faculty of Physics in Belgrade, where he was known for his dedication to high-quality coursework in Quantum Field Theory, Quantum Electrodynamics and Theory of Elementary Particles. He later served as an Assistant Professor at the Faculty of Sciences in Novi Sad (2009–2014) and taught in the PhD program at the Faculty of Physics in Belgrade from 2015. Since 2017, he was a member of the Doctoral Studies Council at the Faculty of Physics.

He mentored five defended doctoral dissertations—three at the Faculty of Physics in Belgrade (in 2011 and two in 2019), one at the Faculty of Sciences in Novi Sad (2017), and one at the Faculty of Technical Sciences in Novi Sad (2017). He also supervised many master’s and undergraduate theses and contributed to two doctoral dissertations at the Free University of Berlin in Germany.

From 2015 onward, he had served as Deputy Director of the Institute, responsible for science. In that role, he made significant contributions to the development of the Institute’s research capacity and the launch of numerous research projects. Even prior to taking on this role, he was widely regarded as the go-to person for advice on preparing and managing research projects and academic promotions.

Since 2017, he had served on the Scientific Board for Physics under the Ministry in charge of science, and as its Chair since 2022. In this capacity, he helped refine the evaluation criteria for scientific work and tirelessly advocated for better conditions for scientific research. He also contributed to the work of other scientific institutions. Since 2010, he had been a member of the Management Board of the Astronomical Observatory and served as its Chair from 2014 to 2018, playing an important role in the realization of the Vidojevica Astronomical Station project. He was a member of the Optical Society of Serbia, the European Physical Society, and the German Physical Society. He pursued his commitment to better science and a better society both within institutional frameworks and, when needed, beyond them.

The highest recognition of his work came in 2024, when he was elected Corresponding Member of the Serbian Academy of Sciences and Arts.

Antun passed away suddenly on July 4, 2025, while attending a scientific conference in Szeged, Hungary. His legacy endures through his extensive scientific accomplishments, the high-performance computing infrastructure he helped build across Southeastern Europe, and the many scientists he guided with his unique vision, generosity and profound kindness.

PhD Theses Supervised by Dr Antun Balaž

Dušan Vudragović
“Faraday Waves in Ultracold Dipolar Bose Gases”
University of Belgrade, Faculty of Physics (2019)

Vladimir Veljić
“Quantum Kinetic Theory for Ultracold Dipolar Fermi Gases”
University of Belgrade, Faculty of Physics (2019)

Vladimir Lončar
“Hybrid Parallel Algorithms for Solving Nonlinear Schrödinger Equation”
University of Novi Sad, Faculty of Sciences (2017)

Bogdan Satarić
“Parallel Data Transposition in Numerical Algorithm for Solving the Gross-Pitaevskii Equation”
University of Novi Sad, Faculty of Technical Sciences (2017)

Ivana Vidanović (presently Ivana Vasić)
“Numerical Study of Quantum Gases at Low Temperatures”
University of Belgrade, Faculty of Physics (2011)

List of journal publications by Dr Antun Balaž

A. Hudomal, A. Daniel, T. Santiago do Espirito Santo, M. Kornjaca, T. Macrì, J. C. Halimeh, G.-X. Su, A. Balaz, Z. Papic
“Ergodicity Breaking Meets Criticality in a Gauge-theory Quantum Simulator”
arXiv: 2512.23794

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“Spin-1 Spin-orbit- and Rabi-coupled Bose-Einstein Condensate Solver”
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Abstracts

Completing Feynman’s Path Integral Program: Lagrangian Path Integral Measure

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A general classical theory is non-singular if its Hessian matrix (second derivatives of the Lagrangian with respect to the velocities) is invertible, making it possible to calculate the velocities in terms of the momenta $p = \partial L / \partial \dot{q}$ to define the corresponding Hamiltonian as the Legendre transformation $H = p\dot{q} - L(q, \dot{q})$ and obtain the phase space equations of motion. Here we discuss how this can be extended to the case of quantum theory by looking at Schwinger-Dyson equations satisfied by the generating function in the Lagrangian and Hamiltonian formalisms.

Path Integrals at Warp Speed: Reporting to my Captain for Quarter-Century

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This presentation honors the legacy of Antun Balaž by reflecting on his early contributions to the advancement of path integral methods, particularly the development of techniques to accelerate convergence and enhance numerical precision. In our collaborative research, I applied the effective action approach to the anharmonic oscillator, providing high-precision numerical results that validated the method's efficiency. By utilizing this framework to analytically derive higher-order discretized actions, I demonstrated a significant acceleration in the convergence of path integrals for both transition amplitudes and energy spectra. These applications, implemented through our SPEEDUP software suite, proved that the method could resolve the complexities of the anharmonic potential using substantially fewer time slices than traditional algorithms. My work focused on bridging theory and practice, showcasing the framework's robustness through this rigorous numerical benchmark.

Acknowledgment: *I first entered Antun's orbit in the year 2000, and five years later I officially joined his crew at the Scientific Computing Laboratory. While our 'away mission' into the specifics of path integrals only lasted a few years, his role as my commanding officer and mentor spanned my entire career. I am eternally grateful for his unwavering support over the years, for being available even when busy, for his professional and personal guidance that pushed me to do better, work harder and be wiser. He introduced me to the world of theoretical physics and high-performance computing, but the greatest gift he gave me was his friendship. He believed in our shared mission and treated the SCL team like a family, ensuring we always had a safe starbase and the best environment for the encounters with the unknown. It was a great honor to serve on his bridge.*

Bosonic Dynamics in Optical Lattices

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Cold atoms in optical lattices provide a clean and highly tunable realization of the Hubbard model [1], making them a powerful platform for quantum simulations of strongly correlated quantum phases. Motivated by recent experimental advances, we investigate several dynamical regimes of strongly interacting bosonic atoms confined in optical lattices.

First we investigate stability of a bosonic Laughlin state in a small atomic sample exposed to driving [2]. Strong synthetic magnetic fields have been successfully implemented in periodically driven optical lattices [3]. However, the interplay of the driving and interactions introduces detrimental heating. By performing a numerical study, we identify an optimal regime of microscopic parameters, in particular interaction strength and the driving frequency, such that the stroboscopic dynamics supports the Laughlin state [4].

Next, we investigate the optical conductivity in the Bose-Hubbard model and focus on the regime of strong interactions and high temperatures, away from any ordering instabilities. We identify a regime of T-linear resistivity and establish the relation of the leading coefficient to the tunneling amplitude [5]. At very strong coupling and half filling, we identify a separate linear-resistivity regime at lower temperature, corresponding to the hard-core boson regime [6].

In this talk, I would like to express my sincere gratitude to my PhD supervisor, Dr. Antun Balaž, for introducing me to the field of cold atoms, for his guidance throughout my research, and for sharing his persistence and optimism in dealing with both physics and real-life challenges.

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On the open-dissipative nature of photon Bose-Einstein condensates

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Photon condensation was first observed in 2010 within a dye-filled microcavity at room temperature and gained interest since then. A deeper understanding is particularly needed as to whether the stationary states are of equilibrium or non-equilibrium nature.

To this end we examine at first how the driven-dissipative nature of a photon Bose–Einstein condensate modifies the condensation process [1]. In particular, we consider a rate-equation model, which can be derived microscopically [2]. It depends on external parameters such as emission and absorption rates as well as cavity photon losses. In steady state, the photon occupation follows an open-dissipative Bose–Einstein distribution whose chemical potential is set self-consistently by the dye’s ground- and excited-state populations. We show that driven-dissipative parameters strongly alter the distribution and use these results to distinguish photonic condensation from both atomic condensation and lasing.

Although open-dissipative quantum fluids have extensively been studied numerically, analytical descriptions are rare. Here we show that generalizing the standard optimization method for closed systems yields a projection optimization method, which is applicable for open-dissipative systems [3]. As an example we analyze a complex Gross–Pitaevskii equation that heuristically models a harmonically trapped photon Bose–Einstein condensate. Together with established methods from hydrodynamics, we obtain an approximate dynamical vortex solution and demonstrate how open-dissipative parameters affect both vortex size and stability. The resulting information is useful for possibly realizing vortices in photon Bose-Einstein condensates.

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Dipole-Induced Fermi-Surface Anisotropy in Strongly Dipolar Quantum Gases

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Interactions fundamentally shape the behavior of quantum-degenerate gases, and recent advances have brought long-range, anisotropic dipole-dipole interactions to the forefront of research. Strongly magnetic lanthanide atoms such as erbium and dysprosium, as well as polar molecules, now enable the exploration of dipolar Bose and Fermi systems far beyond the contact-interaction regime. In dipolar Fermi gases, many-body effects compete with the large kinetic energy near the Fermi surface, leading to subtle but measurable phenomena. Experiments have recently observed a dipole-induced deformation of the Fermi surface, motivating the development of a generalized Hartree–Fock theory for arbitrarily oriented dipoles in triaxial traps. This framework reveals universal stability conditions governed solely by trap geometry and dipole orientation. Extending the analysis to dynamics, a quantum-kinetic Boltzmann approach captures the full range of expansion regimes and enables reconstruction of the momentum-space deformation from real-space measurements. Comparison with erbium experiments shows excellent agreement and predicts that, for even stronger dipoles, the Fermi surface not only reorients with the dipoles but also softens depending on trap anisotropy and dipole alignment.

Faraday and resonant waves in dipolar cigar-shaped Bose-Einstein condensates

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Faraday and resonant density waves appear in Bose-Einstein condensates due to the harmonic excitation of the system [1-3]. These nonlinear excitations result from interactions that couple collective oscillation modes and the presence of parametric resonances. Using both variational mean-field and comprehensive numerical methods, we examine density waves in dipolar condensates at zero temperature [1], where anisotropy in the dipole-dipole interaction causes symmetry breaking. We develop variational equations of motion to describe the dynamics of a driven dipolar system and identify the most unstable modes, which correspond to Faraday and resonant waves. Additionally, we derive analytical formulas for the spatial periods of these density waves as functions of contact and dipole-dipole interaction strengths. Finally, we compare these variational results with extensive numerical simulations solving the 3D dipolar Gross-Pitaevskii equation.

I would like to express my sincere gratitude to Antun Balaž for his support, inspiration, and friendship throughout the years. His guidance and influence will always remain an important part of both my scientific and personal life.

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Sound in Ring Dipolar Supersolids

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A supersolid is a state of matter characterized by the spontaneous and simultaneous breaking of global phase symmetry and continuous translational symmetry, resulting in the non-intuitive coexistence of superfluid and crystalline features. This phase has recently been realized experimentally in dipolar Bose-Einstein condensates. In one-dimensional ring geometries, supersolids exhibit two Goldstone modes, which can be excited by the sudden removal of a weak periodic perturbation. We numerically investigate the resulting collective oscillations using the extended Gross-Pitaevskii theory and extract the corresponding sound velocities. By comparing these velocities with predictions from supersolid hydrodynamic theory, we determine the superfluid fraction, a key parameter characterizing the supersolid phase. In the presence of persistent currents, the excitation spectrum is modified by the Doppler effect, resulting in splitting of the sound velocities for co- and counter-propagating modes. We find that the Doppler shifts are mode dependent, with analytical hydrodynamics predictions in good agreement with Gross-Pitaevskii simulations.

Nonthermalizing Dynamics and Quantum Criticality in Programmable Rydberg Atom Arrays

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Recent advances in quantum simulators have opened a new window into the behavior of complex quantum systems far from equilibrium. Using QuEra's programmable Rydberg atom arrays, we investigate how quantum criticality influences thermalization and ergodicity by simulating a one-dimensional model with kinetic constraints [1]. We map out the dynamical phase diagram of this model and reveal a tunable regime of ergodicity breaking due to quantum many-body scars [2-4], a set of atypical eigenstates that prevent the system from rapidly reaching thermal equilibrium. Remarkably, these nonthermalizing dynamics, manifested as long-lived coherent oscillations, persist across a much broader range of parameters than previously observed, including at the quantum critical point [5]. We further analyze the defects generated during state preparation via the Kibble-Zurek mechanism, which strongly affect the subsequent dynamics. Our results provide new insights into the interplay between ergodicity breaking and quantum criticality and establish Rydberg atom arrays as a powerful platform for probing such phenomena.

I would like to express my sincere gratitude to Antun Balaž for his continuous support and guidance over the years. This work represents the final publication of his remarkable scientific career.

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The Quantum Age: From Atoms and Photons to Quantum Computers

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Arrays of individually trapped neutral atoms, laser cooled to temperatures only a tad above absolute zero, are arising as a new tool for many applications in the emerging world of quantum technologies. Uses of atomic arrays range from atomic clocks and quantum communication networks to quantum simulation and computing. I will discuss the basic principles of trapping individual atoms in arrays of light beams and describe two applications: the coupling of single atoms to single photons in high-quality cavities and quantum computing using neutral atoms. In the latter systems, neutral atoms are used to encode the quantum generalized version of classical bits, so-called qubits. Quantum processing with atomic qubits becomes possible via laser control by exciting atoms to high-energy states (Rydberg states).

Large quantum systems are highly susceptible to noise processes that can, however, be mitigated by error correction. First steps towards quantum error correction have only recently been demonstrated [1,2], ushering in a new era of circuits with logical qubits that are each comprised of many atomic qubits.

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Photons in a dye-filled cavity: quantum-optical system interpolating between Bose-Einstein condensates and laser-like states

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It is well known that photons in a dye-filled cavity exhibit a Bose-Einstein condensate (BEC) of light [1]. We generalized the microscopic non-equilibrium Kirton-Keeling model [2] of such a system by carefully considering the interplay of coherent and dissipative dynamics within the Lindblad master equation framework. The resulting equations of motion of both photonic and matter degrees of freedom were then used to study the steady-state properties of the system. We demonstrated that this system can interpolate between photon BEC and laser-like states, depending on whether the dissipative or coherent influence of the environment is dominant [3]. In the former case, we showed that the cavity modes of different energies are essentially uncorrelated. In the laser-like regime, some cavity mode acquires macroscopic occupation, while the populations of other cavity levels strongly deviate from the Bose-Einstein distribution. Additionally, the steady state contains a rather high degree of correlations between the different cavity modes. We will discuss the complexity of various conceptual and practical obstacles, as well as how they were successfully overcome due to the expertise of our dear, late colleague Antun Balaž.

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Unconventional topological phases in some lattices

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I will present hidden multitopological phases mediated by constrained intercell coupling [1] and the concept of sub-symmetry protected topological phases [2]. Topological phases of matter and their boundary states had great influence on condensed matter physics, photonics, and materials science. These topological phases are typically characterized by their energy bands through topological band theory. However, certain topological materials exist that do not fit within this framework, exhibiting unique boundary states that remain relatively obscure and under-researched. In Ref. [1], we introduce a novel category of topological phases known as "multi-topological phases" (MTPs), which arise from constrained inter-cell coupling in lattice systems. We provide experimental evidence for these phases using a photonic platform. The MTPs display multiple sets of boundary states, each corresponding to a different topological invariant. In Ref. [2], we introduce a concept of sub-symmetry (SubSy) protected topological phases; SubSy means that the symmetry (operator) equation holds only in part of the Hilbert space describing the system. Nevertheless, in some models topological boundary states are safeguarded by these weaker symmetries. This reframes our understanding of symmetry protected topological phases across various physical platforms.

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A universal speed limit for spreading of coherence

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Discoveries of fundamental limits for the rates of physical processes, from the speed of light to the Lieb–Robinson bound for information propagation, often lead to breakthroughs in the understanding of the underlying physics. We have observed such a limit for a paradigmatic many-body phenomenon, the spreading of coherence during the formation of a weakly interacting Bose–Einstein condensate. We study condensate formation in an isolated homogeneous atomic gas that is initially far from equilibrium, in an incoherent low-energy state, and condenses as it relaxes towards equilibrium. Tuning the interatomic interactions that drive condensation, we show that the spreading of coherence through the system is initially slower for weaker interactions and faster for stronger ones, but always eventually reaches the same limit, at which the square of the coherence length grows at a universal rate given by the ratio of Planck's constant and the particle mass, or, equivalently, by the quantum of velocity circulation associated with a quantum vortex. These observations are robust to changes in the initial state, the gas density, and the system size. Our results provide benchmarks for theories of universality far from equilibrium, are relevant for quantum technologies that rely on large-scale coherence, and invite similar measurements in other systems.

Pattern-forming instabilities in BECs: An homage to Antun Balaž

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I review a series of results regarding the emergence of nonlinear waves in Bose-Einstein condensates (BECs), with emphasis on how the experimental development were mirrored by computational and theoretical results that allowed for unprecedented insight into the nonlinear dynamics of BECs. My talk will follow the development of the nonlinear waves community from the perspective of the analytics (mainly variational) and computational tools (mainly solvers of the Gross-Pitaevskii equation with various levels of OpenMP/MPI/CUDA optimization) developed as part of the collaboration with Antun Balaž. I will end my presentation with the story of the sword presented by Mihailo Obrenovic to Alexandru Ioan Cuza in recognition of his support for the Serbian people’s struggle for liberation from the Ottoman rule. The words engraved on the sword (Amicus certus in re incerta) best describe Antun Balaž.

Mach-Zehnder interferometer for in-situ characterization of atom traps

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Manipulating cold atoms in traps is a key tool for numerous realizations of quantum simulators and quantum sensors. They require accurate modelling and characterization of the underlying trapping potentials. We introduce a technique based on the Mach-Zehnder interferometer for in-situ characterization of weakly anharmonic potentials [1]. By simulating the interferometer in an optical dipole trap, we can accurately determine its trap frequency and upper bounds onto anharmonicity magnitudes.

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Solitons on the surface of a sphere

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The recent realization of ultracold quantum gases in a shell geometry [1] paves the way towards a Bose-Einstein condensate (BEC) that is trapped tightly onto the surface of a sphere. We investigate the existence and stability of solitons appearing in this system with the two-dimensional (2D) Gross-Pitaevskii equations (GPE). Comparing our results to the 2D plane, we find that the scale invariance of the GPE is broken due to the curvature and compactness of the shell geometry. Consequently, the familiar Townes solitons [2] appear only when the BEC is strongly localized in a small region of the sphere surface.

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European Open Science Cloud: Enabling Open and Collaborative Research

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The journey toward open, collaborative, and reproducible research in South-East Europe and the broader Western Balkans region has been shaped by a succession of visionary infrastructure initiatives — and by the people who dedicated themselves to building them. This talk traces that journey through a series of landmark European projects: VI-SEEM [1], which established the first regional Virtual Research Environment for the SEE and Eastern Mediterranean communities; NI4OS-Europe [2], which onboarded national data and service providers into the emerging Open Science ecosystem; EOSC Future [3], which advanced the operationalization of the European Open Science Cloud as a federated data space for research; EOSC Beyond, which continues to push the boundaries of cross-domain interoperability; and Skills4EOSC [4], which addressed the human dimension of open science by building a competence framework and training network for researchers and data stewards across Europe.

Across all of these projects, the Institute of Physics Belgrade served as a cornerstone collaborating institution. Central to that contribution was the team led by Dr. Antun Balaž — a scientist of exceptional breadth whose engagement with research e-infrastructure was as deep and principled as his physics. Antun was not merely a technical collaborator; he was an architect of regional scientific culture, someone who understood that open science is, at its core, a collective human endeavor. His passing in July 2025 left a void that cannot be filled, but also a legacy that continues to guide the work.

This talk reflects on the scientific and infrastructural advances of Open Science, the evolving role of the EOSC as a backbone for European research collaboration, and the enduring importance of the regional partnerships that Antun helped to nurture. It is offered as a small tribute to a colleague whose vision reached far beyond any single project or discipline.

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Grid Computing for Large-Scale Scientific Research in a Small Country

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This presentation gives an overview of Grid computing in context of changes it introduced in a small Southeast European country and effects it had on institutions, as well as individual researchers. From the humble beginnings and small-scale triumphs of installing the first Grid cluster, over the establishment of higher quality infrastructure, to changes in perception of European research projects and the effects it had on a wider scale. While the science performed on Grid clusters was important, as was the high-speed networking introduced to support the Grid infrastructure, the real important network was the human one. Through selfless work provided by numerous members of a series of Grid computing projects, lives of countless individuals were affected in positive manner, true institutional and societal changes were implemented, and the, while projects have long ended, their effects live on even today.

From HPC and GRID infrastructures to Digital ecosystems: a rapid journey on the evolution of IT infrastructure for research and beyond

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Over the last two decades, the landscape of computing for scientific research has undergone a profound transformation. In this talk I would like to offer a rapid journey through that evolution, starting from my HPC and Grid infrastructures in the early 2000's built to serve the demanding needs of large scientific communities—toward today's integrated digital ecosystems. Drawing on my direct experience in deploying and managing advanced computing platforms, I will highlight how technological, organizational, and cultural shifts have progressively reshaped the way researchers access, share, and exploit computational resources.

High Performance Applications on heterogenous systems – benchmarking and optimisation

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When a new HPC system enters operation to serve scientific communities, it is important to ensure an efficient transition process for the various users and user groups. In this presentation we discuss our approach to transitioning from Avitohol to the newer HEMUS supercomputer system. The adaptation and validation of the complex scientific workflows in the new heterogeneous petascale environment is a daunting task without a unified approach. That is why we leveraged multiple types of benchmarks in order to streamline the whole process and gather valuable insights about the optimal way of deploying and launching applications and workflows with differing requirements. Apart from the most widely used LINPACK and HPCG benchmarks, we performed various micro-benchmarks, related to the memory and communication subsystems. In this way we obtained valuable information about the expected bottlenecks and scalability limits. Interesting results about not only performance but also energy consumption were gathered running Quantum Computing simulation tasks, as it was foreseen that research in this area will take significant portion of the resources. As the main compute power of HEMUS is in its GPU-enabled servers we show some specific GPU-oriented strategies and techniques that address challenges in achieving optimal usage of the vast compute power available in such heterogeneous system.

Building regional e-Infrastructure for advanced scientific computing

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Over the past two decades, South-East Europe has built a sustainable regional cooperation model in digital research infrastructures, linking national initiatives with European efforts in networking, high-throughput and high-performance computing, cloud services, and open science. This presentation traces this ecosystem's evolution, highlighting partnerships among NRENs, research institutions, universities, policymakers, and national computing projects that established interoperable e-Infrastructures. Key initiatives like SEEREN, SEE-GRID [1], HP-SEE [2], VI-SEEM [3], and NI4OS-Europe [4] have driven the development of national infrastructures, cross-border scientific communities, and resource-sharing platforms. The talk will also cover how these efforts support integration into European projects such as GÉANT, EGI, EuroHPC, and the European Open Science Cloud, fostering policies, capacity building, and principles like Open Science and FAIR. It will address societal impacts, including bridging the digital divide, supporting excellence, reducing brain drain, and promoting regional stability. Lastly, it will consider future trends, emphasizing EuroHPC and emerging platforms, demonstrating how regional cooperation ensures inclusivity and greater participation of smaller countries in the European Research Area.

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The Serbian AI Factory Antenna (SAIFA): Bridging High-Performance Computing with Energy and Environmental Sustainability

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The rapid evolution of Artificial Intelligence necessitates a paradigm shift in computational infrastructure, moving toward the establishment of “AI Factories” - ecosystems that integrate high-performance computing (HPC), large-scale data management, and specialized AI expertise. This session introduces the Serbian AI Factory Antenna (SAIFA), a cornerstone project within the EuroHPC Joint Undertaking designed to bridge the gap between world-leading supercomputing resources and local industrial needs. As a national hub, SAIFA provides the essential infrastructure and vertical services required to deploy complex AI models in critical sectors. This presentation focuses on the practical application of these technologies in the domains of energy and the environment. We will explore how HPC-driven AI is being utilized by the Faculty of Science, University of Kragujevac (FSUKG) and spin-off company Vodéna to solve high-stakes challenges: from platform for real-time flood prediction and prevention to sophisticated surrogate modeling for energy generation and dam safety. By utilizing distributed computing frameworks, these applications transform months of traditional calculation into actionable, real-time insights. The session also reflects on the trajectory of Serbian computational science. While we look toward a future of exascale AI, we honor the foundations laid by the pioneers of the field, most notably Antun Balaž, whose vision and dedication to scientific computing made the current era of Serbian AI innovation possible.

Atomic solitons in optical lattices

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We investigate atomic Bose-Einstein condensates, with attraction between atoms, under the action of strong transverse confinement and periodic (optical-lattice) axial potential. Using a combination of the variational approximation, one-dimensional nonpolynomial Schrödinger equation, and direct numerical solutions of the underlying 3D Gross-Pitaevskii equation, we show that the ground state of the condensate is a bright soliton belonging to the semi-infinite bandgap of the periodic potential [1]. The soliton may be confined to a single cell of the lattice, or extend to several cells, depending on the effective self-attraction strength (which is proportional to the number of atoms bound in the soliton) and depth of the potential. It is found that, due to the 3D character of the underlying setting, the ground-state soliton collapses at a critical value of the interaction strength, which gradually decreases with the increase of the depth of the periodic potential [1]. Very recently, the experimental observation of these discrete bright matter-wave solitons made of cesium atoms in an optical lattices was achieved [2] by using an “accordion lattice” with adjustable spacing.

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Integrated quantum photonics developed with and for quantum hardware

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The emitter-cavity interaction in solid state systems is governed by physics that can both make an impact on as well as benefit from the development of quantum hardware. In one direction, systems with color center integrated in photonic devices promise to build out quantum repeaters and analog quantum simulators of condensed matter and particle physics phenomena. To meet the scalability aspect for practical applications, we develop the first wafer-scale fabrication process in quantum-grade silicon carbide [1-3]. Reversely, to properly engineer envisioned photonic systems we pursue to deepen our understanding of open quantum system cavity QED in innovative ways using the emerging quantum computing hardware. To this goal, we develop analog and digital simulation of the open Tavis-Cummings model and test it on superconducting and trapped ion quantum testbeds [4-6], exploring this niche application for the near-term computational advantage.

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Nature-inspired periodicity on optical table

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Nature's ability to derive beautiful patterns may astonish a careful observer anew every day. Among the patterns, humans tend to recognize and reproduce periodic and nearly periodic ones, from the physiological processes that drive life, to daily routines, to masterpieces of engineering, such as atomic clocks or interferometric gravimeters [1]. In the lecture, I will discuss the design and construction of photonic integrated circuits inspired by the periodic coupling of atomic orbitals, a breadth and wealth of which I had the pleasure to discuss with Antun.

Realization of Bose-Einstein condensates (BECs) has enabled fine coherent control of atoms for high-precision measurements [2]. For example, Rabi pulse coupling between Zeeman states results in a periodic population transfer, permitting the population engineering and the construction of multi-state atomic interferometers. I will discuss the first such interferometer, which we constructed in a BEC on chip [3].

Unlike atoms, the state-coupling strengths of which are fixed, optical waveguides and their couplings are fully controllable by photonic engineering [4]. We designed a range of novel waveguide networks with arbitrary commensurable eigenvalues that support periodic light propagation [5]. The linearly arranged waveguides lend themselves to the construction of super-dense interconnects, demultiplexers and couplers, demonstrated by direct laser writing [6, 7]. The circular networks, in addition, support long-range vortex transfer, e.g., through multicore optical fibres [8].

Finally, to pay full respect to the richness of Nature, and to Antun's comments on my linear determinism, I will briefly address human cardiac drive to show how commensurability is not always a welcome feature, while a dose of irregularity might be.

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Exploring lattice gauge theories with classical and quantum simulations

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Numerical and theoretical studies of gauge theories such as quantum chromodynamics or quantum electrodynamics on the lattice, based on the path integral formulation, have been remarkably successful over the past decades. However, conventional simulation methods on classical computers, relying on Monte Carlo sampling, face fundamental limitations in certain regimes, most notably the sign problem, which hinders progress in simulating lattice gauge theories at finite chemical potential, with topological terms, or their real-time dynamics. This has motivated the search for alternative approaches to explore the dynamics of lattice gauge theories. In this talk, I will discuss recent theoretical insights into anomalous thermalization of lattice gauge theories [1,2], as well as recent proposals for analog quantum simulations of U(1) gauge theory with fermions and its extensions [3].

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Atomistic Modeling of Valence Change Memory Devices: What Can We Learn from Simulations?

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The ever-increasing demand for high-speed computational resources drives the development of novel devices and architectures that enable computation and data storage at the same physical location. One prominent example is a valence charge memory (VCM), a type of memristor that relies on the oxygen vacancy filament modulation. Enhancing memristor performance requires a deep understanding of the physical mechanisms underlying resistive switching — a challenge for which atomistic simulations can provide crucial insights. In this talk, we give an overview of atomistic simulation methods and highlight which properties of the VCM cell each of them can simulate [1]. We then present a theoretical framework (Fig. 1) that combines different methods to simulate resistive switching in VCM devices based on HfO_2 [2]. Finally, we demonstrate how this framework has been applied to elucidate termination-dependent switching in $SrTiO_3$ VCM cells [3].

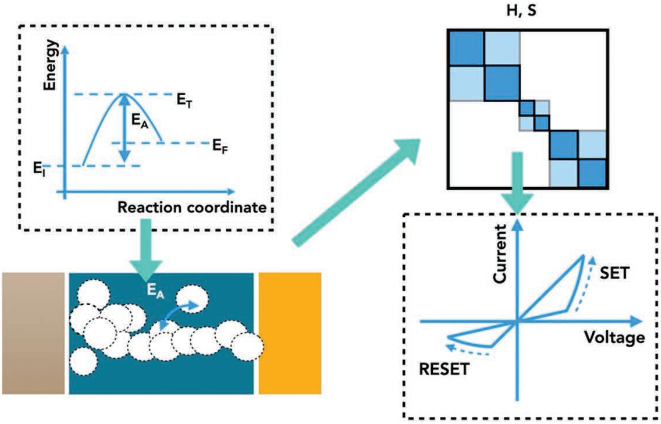

Fig. 1.
The illustration of the theoretical framework applied to resistive switching in memristors.

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Noncommutative AdS spacetime: classical limits & the boundary

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The noncommutative frame formalism, a version of noncommutative geometry, gives a good operational framework to explore noncommutative (fuzzy) extensions of the de Sitter (dS) and Anti-de Sitter (AdS) spaces. Here we define the fuzzy AdS space in d=2,3 dimensions using the algebra of SO(d,2) group, and obtain the corresponding noncommutative geometry. We further define the set od semi-classical states: using this set we discuss the classical limit of the fuzzy AdS spaces, including their boundary. We then study the free scalar field on fuzzy AdS, determine the field modes and the corresponding 1-point and 2-point functions. We show that both functions have the correct classical limits, and discuss some aspects of the AdS/CFT correspondence in the presented semi-classical model.

From classical to fuzzy de Sitter spacetime and back

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Fuzzy de Sitter space provides a noncommutative realisation of de Sitter geometry constructed from the Lie algebra of the de Sitter group SO(1,d) in unitary irreducible representations and equipped with differential geometry via the noncommutative frame formalism. Such constructions are motivated by the expectation that spacetime in the very early Universe may acquire a noncommutative structure, providing an effective description of quantum gravitational effects during the inflationary epoch. The talk presents a three-step story: from classical de Sitter spacetime to its fuzzy counterpart, and back to an emergent classical description through semi-classical limits. Free scalar field modes and invariant vacua on the Poincaré patch of de Sitter space are revisited using a coordinate choice (η, y^i) that is naturally suggested by the noncommutative construction. In this framework fuzzy coordinates and momenta are realised as operators, and the Klein–Gordon equation can be solved at the operator level in $d=2$ and $d=4$ using a compatible ordering prescription. This promotes commutative field modes to fuzzy eigen-operators and reveals genuinely noncommutative degrees of freedom that arise for $d>2$. Finally, the semi-classical regime is discussed through states that allow fuzzy operators to be related to approximate classical observables. This provides a concrete way to analyse the commutative limit of fuzzy observables and correlation functions and opens the possibility of studying late-time correlators relevant to inflation within the noncommutative framework.

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Complex Networks analysis of Belgian Railway

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The primary cause of train delays in the Belgian rail network is other trains. Initial delays propagate through the system, potentially affecting a significant proportion of all trains on a given day. This suggests that the rail network is not merely complicated but genuinely complex, and should therefore be analysed using complex network methods. Here we construct three distinct networks: a train network, a train numbers network, and a network of stations and other characteristic geographical points. Applying PageRank, we identify individual trains, as well as stations, causing the most delays at the network level — effects that are not directly visible from local inspection alone. This allows us to find “low-hanging fruit”: lower priority trains and smaller stations that are therefore less costly to address yet have a disproportionately large impact on the system. Using modularity analysis, we partition the system into smaller components that can be individually optimised.

Large Language Models as Voting Mechanisms and their Economic rationality

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Large Language Models (LLMs) are increasingly used as decision-support systems in high-stakes economic and financial environments. However, their microeconomic foundations remain insufficiently understood. These papers develops a unified framework that connects social choice theory, behavioral economics, and artificial intelligence by conceptualizing LLMs as probabilistic voting mechanisms. In this framework, each prompt constitutes an election, possible text continuations represent candidates, and the model's output probabilities correspond to empirical vote shares embedded in the training data.

Building on this interpretation, papers examine the implications of Condorcet's foundational results for AI-generated economic advice. First, through the lens of Condorcet's Paradox, we show that aggregating heterogeneous preferences can generate intransitive collective rankings, or Condorcet cycles. These cycles create potential "money pump" vulnerabilities for users who rely on AI systems for sequential economic or investment decisions. We empirically document this phenomenon by identifying millions of intransitive cycles in ChatGPT-4o's investment recommendations across S&P 100 firms. Second, drawing on Condorcet's Jury Theorem, we demonstrate that LLMs may also generate statistically superior recommendations by aggregating dispersed private signals across their training population. We show theoretically that improvements in signal quality monotonically reduce the likelihood of intransitive cycles, whereas AI-generated synthetic or "fake" data can weaken this informational advantage. The voting framework is further evaluated through empirical tests of ChatGPT-4o's economic rationality. The model displays risk-averse advisory behavior consistent with Constant Relative Risk Aversion preferences, with estimated coefficients broadly aligned with macro-finance benchmarks. We also exhibit time discounting and systematic behavioral anomalies, including gender bias and the Allais paradox, suggesting that LLMs reproduce decision-making patterns prevalent in human-generated training data. Finally, we show that common AI engineering practices act as electoral interventions. The temperature parameter operates analogously to a power-law electoral rule, shifting model behavior from proportional representation toward majoritarian, winner-take-all outcomes. Fine-tuning, similarly, can be understood as altering aggregate preferences by adding weighted votes to the training ledger. Overall, this framework shows that the biases, inconsistencies, and vulnerabilities of AI advisors are not merely technical defects, but structural consequences of probabilistic preference aggregation.

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