FIRST WORKSHOP
ON SOLITON THEORY, NONLINEAR DYNAMICS AND MACHINE LEARNING

Varna Bulgaria, August 12, 2023 – August 17, 2023

Book of Abstracts

Organized by:
Institute for Advanced Physical Studies
Varna Free University

Supported by:

BULGARIAN SCIENCE FUND

VARNA FREE UNIVERSITY "CHERNORIZETS HRABAR"

INSTITUTE *for* ADVANCED PHYSICAL STUDIES

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Tentative program of the
First Workshop on Soliton Theory, Nonlinear Dynamics and Machine Learning
August 12 – 17, 2023, Varna, Bulgaria

The online participation is accessible via https://meet.google.com/skt-rvfe-zyu

August 12 – Arrival

August 13 (Sunday)

	8.30 – 9.00	Registration and Opening
R. Constantinescu	9.00 – 10.00	The attached flow method for the Dodd-Bullough-Mikhailov equation
R. Ivanov	10.00 – 11.00	Hamiltonian methods in the theory of water waves

Coffee break 11.00 – 11.30

C. Babalic	11.30 – 12.30	Overview on the generalized Volterra system: solutions and integrability

Lunch

S. Mishev	14.30 – 15.30	Multipole Moment Prediction with Symmetry-preserving Graph Neural Networks
L. Petrov	15.30 – 16.30	Application of equivariant steerable convolutional neural networks to rotated images

Coffee break 16.30 – 17.00

M. Savova	17.00 – 18.00	Neural network approximation in the Lipkin-Meshkov-Glick model
N. Nikolov	18.00 – 19.00	A First Attempt at Neural Machine Translation of Old Church Slavonic and Church Slavonic Languages

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August 14 (Monday)

M. Babalic	09.00 – 10.00	Nonlinear dynamics in two-field cosmological models with hidden symmetry
B. Kostadinov	10.00 – 11.00	On integrable spinor models and simple Lie algebras

Coffee break 11.00 – 11.30

A. Păuna	11.30 – 12.30	The Functional Expansion Approach for Solving Reaction-Diffusion Equations

Lunch

Stoytcho Yazadjiev	14.30 – 15.30	Dynamical development of fundamental fields around black holes
Daniela Doneva	15.30 – 16.30	Calculating black hole quasinormal modes with physics informed neural networks

Coffee break 16.30 – 17.00

Galin Gyulchev	17.00 – 18.00	Image of the shadow and thin accretion disk in gravity with a minimally coupled scalar field
Kalin Staykov	18.00 – 19.00	Nonlinear black hole scalarization in multi-scalar Gauss-Bonnet gravity

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August 15 (Tuesday)

M. Grinberg	09.00 – 10.00	Reinforcement Learning Models of Cooperation in the Prisoner's Dilemma Game
Y. Gorbounov	10.00 – 11.00	Achieving High Efficiency: Resource sharing techniques in neural networks for resource-constrained devices

Coffee break 11.00 – 11.30

K. Djounakov	11.30 – 12.30	Imbalanced Classification Problems

Lunch

A. Stefanov	14.30 – 15.30	Soliton-like equations with Coxeter reduction
V. Gerdjikov	15.30 – 16.30	Riemann–Hilbert problems, polynomial Lax pairs, integrable equations and their soliton solutions

Coffee break 16.30 – 17.00

V. Kozhuharov	17.00 – 18.00	The PADME Experiment at LNF-INFN: Data Reconstruction Techniques and Present Results
A. Kirkova	18.00 – 19.00	Identification of tau lepton final states in hadronic interactions

CONFERENCE DINNER

August 16 (Wednesday)

A. Isar	09.00 – 10.00	Entropy production and quantum correlations in two coupled bosonic modes interacting with a thermal environment
G. Grahovski	10.00 – 11.00	Affine Toda field theories: simple Lie algebras and real Hamiltonian forms

Coffee break 11.00 – 11.30

E. Prodanov	11.30 – 12.30	On Newton's Rule of Signs
S. Mishev	12.30 – 13.30	Nuclear matter calculations using Argonne V18 nucleon-nucleon potential

Lunch

BOAT TRIP

August 17 (Thursday)

T. Mihaescu	09:00 - 10:00	Steering witnesses for unknown Gaussian quantum states
M. Ivanov	10:00 - 11:00	A Machine Learning application in low-energy electron microscopy

Coffee break 11.00 – 11.30

P. Hristov	11.30 – 12.30	Some Applications of ML Transformers in Physics
	12.30 – 13.00	Closing

Identification of tau lepton final states in hadronic interactions

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High energy particle interactions lead to complex final states, characterized by a variety of parameters, including type of particles, momentum and angular momentum distributions etc. Using phase space parameters, machine learning can be used to identify and classify processes that lead to a desired final state, as well as separate them from the background noise. In particular, we look at simulations of ultraperipheral Pb-Pb interactions. They give rise to the process Pb + Pb $\rightarrow$ Pb + Pb + $\tau'\tau$, which can provide information on the boundaries for the value of the anomalous magnetic moment (g-2) of the tau-lepton.

Soliton-like equations with Coxeter reduction

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We review some multicomponent soliton-like equations with a Coxeter reduction and Lax operator, linear in the spectral parameter. It is well known that those equations are related to Kac-Moody algebras and while most of the low dimensional cases were examined by Drinfeld and Sokolov [1] there were some omissions that were filled by some of our recent works [2]. We also examine their generalization to polynomial Lax operators.

[1] V.G. Drinfel'd and V.V. Sokolov, Lie algebras and equations of Korteweg-de Vries type, Sov. J. Math. **30**, 1975-2036 (1985).

[2] V.S. Gerdjikov, A.A. Stefanov, I.D. Iliev, et al., Recursion operators and hierarchies of mKdV equations related to the Kac–Moody algebras $D_4^{(1)}, D_4^{(2)}$, and $D_4^{(3)}$. Theor Math Phys **204**, 1110–1129 (2020).

The Functional Expansion Approach for Solving Reaction-Diffusion Equations

A. M. Păuna

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This report is based on papers [1],[2] and offers solutions for equations of reaction-diffusion type using a non-linear second-order auxiliary equation; it also creates opportunities for investigating more complex nonlinear PDEs.

[1] Cimpoiasu, R.; Constantinescu, R.; Pauna, A.S. Solutions of the Bullough–Dodd Model of Scalar Field through Jacobi-Type Equations. Symmetry 2021, 13, 1529. https://doi.org/10.3390/sym13081529.

[2] Ionescu, C.; Babalic, C.N.; Constantinescu, R.; Efrem, R. The Functional Expansion Approach for Solving NPDEs as a Generalization of the Kudryashov and G'/G Methods. Symmetry 2022, 14, 827. https://doi.org/10.3390/sym14040827.

Image of the shadow and thin accretion disk in gravity with a minimally coupled scalar field

Galin Gyulchev

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We study possible observable images of a black hole and naked singularity described by rotating geometry in Einstein gravity, minimally coupled to a scalar field. We consider a Kerr-like (KL) alternative to the rotating Fisher-Janis-Newman-Winicour solution. Our study includes analytical and numerical calculations of equatorial circular orbits, shadow images, and radiation from thin accretion disks for various values of the object's angular momentum and scalar charge. The KL solution cannot be ruled out by the observations for small values of the scalar charge either. As the scalar charge increases, the optical properties change dramatically. The photon region does not hide the singularity, so it should be classified as a strong singularity. The shadow of the compact object can become multiply connected and strongly oblate. This qualitatively new feature can be used to distinguish observationally black holes from naked singularities via the contemporary Very Long Baseline Interferometry experiments at short wavelengths.

Affine Toda field theories: simple Lie algebras and real Hamiltonian forms

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We will start with a brief introduction to conformal and affine Toda models related to simple Lie algebras. Then we will present real Hamiltonian forms of 2-dimensional Toda field theories related to exceptional simple Lie algebras [1], and the spectral theory of the associated Lax operators. Real Hamiltonian forms [2] are a special type of "reductions" of Hamiltonian systems, similar to real forms of semi-simple Lie algebras. Examples of real Hamiltonian forms of affine Toda field theories related to exceptional complex untwisted affine Kac-Moody algebras will be presented.

Along with the associated Lax representations, we will also discuss the relevant Riemann-Hilbert problems and derive the minimal sets of scattering data that determine uniquely the scattering matrices and the potentials of the Lax operators.

[1] V. S. Gerdjikov and G. G. Grahovski, *On reductions and real Hamiltonian forms of affine Toda field theories*, J Nonlin. Math. Phys. **12** (2005), Suppl. 3, 153–168;
V. S. Gerdjikov and G. G. Grahovski, *Real Hamiltonian Forms of Affine Toda Models Related to Exceptional Lie Algebras*, SIGMA **2** (2006), paper 022 (11 pages).

[2] V. S. Gerdjikov, A. V. Kyuldjiev, G. Marmo and G. Vilasi, *Complexifications and Real Forms of Hamiltonian Structures*, European J. Phys. B **29** (2002) 177–182;
V. S. Gerdjikov, A. V. Kyuldjiev, G. Marmo and G. Vilasi, *Real Hamiltonian forms of Hamiltonian systems*, European Phys. J. B. **38** (2004) 635–649.

[3] V. S. Gerdjikov, G. G. Grahovski and A. A. Stefanov, *Real Hamiltonian forms of affine Toda field theories: spectral aspects*, Theor. Math. Phys. **212** (2022) 1053–1072.

Calculating black hole quasinormal modes with physics informed neural networks

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Machine learning takes an important place in gravitational physics. It has developed as an important tool in gravitational wave data analysis and it also aids the generation of gravitational waveforms in various ways. In the present talk, we will briefly review the topic, putting an emphasis on surrogate models based on numerical relativity waveforms of merging compact objects. We will also discuss ways of employing physics-informed neural networks for solving differential equations describing the final stage of the merger, namely the quasinormal mode ringing.

On Newton's Rule of Signs

Emil M. Prodanov

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Until the early nineteenth century, algebra was, essentially, a theory of polynomials. Starting with Descartes' Rule of Signs from 1637, the counting of the real roots of a polynomial has always been in its main focus. Presented in this talk is a relatively unknown but highly interesting method, proposed without proof by Newton in [1], which analyses the double sequence of the so-called simple and quadratic elements of a polynomial to limit the number of its real roots. It took close to 200 years to prove Newton's Rule of Signs (Sylvester [2]).
Newton's method will be introduced in this talk and, following [1], a modification will be proposed with which a stricter upper limit on the number of real roots of the polynomial could be found: instead of analysing the discriminants of all quadratic polynomials formed by 3 consecutive terms of the original polynomial, one can study all *cubic sectors* of the polynomial, namely, the cubic polynomials that can be formed by any four consecutive coefficients. It will be demonstrated how this works and will also be illustrated with the so-called Siebeck–Marden–Northshield triangle [2] — an exquisite geometrical construction.

[1] I. Newton, *Arithmeticae Universalis Liber Primus*, notes deposited to the Cambridge University library late in 1683 or early in 1684;
translated from Latin as *Universal Arithmetick or, a Treatise of Arithmetical Composition and Resolution* by Ralphson and Cunn, London (1719).

[2] J.J. Sylvester, *On an Elementary Proof and Generalization of Sir Isaac Newton's Hitherto Undemonstrated Rule for Discovery of Imaginary Roots*, in: *Proceedings of the London Mathematical Society I* 1–16 (1865–1866).

[3] Emil M. Prodanov, *On Newton's Rule of Signs*, Journal of Computational Mathematics and Data Science **6**, 100076, (2023).

[4] Emil M. Prodanov, *The Siebeck–Marden–Northshield Theorem and the Real Roots of the Symbolic Cubic Equation*, Results in Mathematics **77**, 126 (2022).

Imbalanced Classification Problems

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What is an imbalanced classification problem and what are the challenges associated with making good predictive models for it? Imbalanced classification problem covers all the cases where the distribution of examples across the classes is not equal. We can see that for each example in the minority class, there may be one hundred or even one thousand examples in the majority class. Imbalanced classifications pose a challenge for predictive modeling as most of the ML algorithms used for classification are designed around the assumption of an equal number of examples for each class. This results in models that have poor predictive performance, specifically for the minority class. Many real-world classification problems have an imbalanced class distribution, such as fraud detection, spam detection, and churn prediction. This requires some not so straight forward data preparation techniques, learning algorithms, and performance metrics After the introduction of the problem the main focus points of the presentation will be: Algorithms, data preparations techniques and evaluation metrics most suitable for imbalanced datasets. How they help for getting a better predictions and what potential drawbacks they have. Creating and using a systematic framework based on the problem we need to solve. Starting with selecting a suitable metric, testing different algorithms and finally hyperparameter tuning for the ones with the highest performance.

Nonlinear black hole scalarization in multi-scalar Gauss-Bonnet gravity

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A process of scalarization, called nonlinear scalarization, in which the Schwarzschild black hole is linearly stable and can coexist with a stable scalarized solution was demonstrated to exist for scalar Gauss-Bonnet theories in the recent years. In the present talk we extend the search for black hole with nonlinear scalarization in the case of multi-scalar Gauss-Bonnet gravity – a class of theories which allow for scalarized compact objects with vanishing scalar charge, hence there are no constraints from the binary pulsar observations. We demonstrate numerically the existence of such black hole solutions with nonlinear scalarization in the multi-scalar Gauss-Bonnet theories with exponential coupling functions of third and fourth leading order in the scalar field.

Application of equivariant steerable convolutional neural networks to rotated images

Lachezar Petrov

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Convolutional neural networks (CNNs) are the most popular choice of architecture when it comes to computer vision. Classical CNNs naturally offer equivariance in their feature maps under translations and reflections of the input, however they usually don't perform so well when it comes to rotations. Equivariant steerable convolutional neural networks (ESCNNs) additionally provide equivariance with respect to rotations of the input. We evaluate the performance of a classical CNN and an ESCNN on several datasets, to compare how both deal with rotations.

Neural network approximation in the Lipkin-Meshkov-Glick model

Margarita Savova[2] and Stoyan Mishev[1,2,3]

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[3]Varna Free University Chernorizets Hrabar, Yanko Slavchev 84, Chaika Resort, 9007 Varna, Bulgaria

The quasispin models in quantum mechanics provide one of the simplest theoretical settings capable of embracing both the gross properties of significantly more complex and realistic systems and some of their structural particularities. Being exactly solvable, they serve as a testbed for exploring the qualities of different approximation schemes for solving the quantum many-body problem. In our contribution, we present an approximation to the wave function of two- and three-level Lipkin-Meshkov-Glick models using neural networks in the form of a restricted Boltzmann machine and feed-forward architectures. We further explore the ability of our solution to reproduce system properties such as deformation and spontaneous symmetry breaking.

Reinforcement Learning Models of Cooperation in the Prisoner's Dilemma Game

Maurice Grinberg

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The Prisoner's dilemma (PD) game is considered a good framework to study cooperation in a wide range of social dilemmas. The game models a social dilemma in the sense that the individualistic behaviour of a player can lead to the highest payoff of the game at the expense of the other player if the latter cooperates. On the other hand, if both players behave individualistically the payoffs they are getting are lower than if they both cooperated. The latter however is related to the risk that one of the players unilaterally will become individualistic tempted by the highest payoff. Despite the complexity of the situation, behavioural experiments show that people cooperate quite often in the PD game and the possible reasons for such a behaviour has attracted continuous interest and exploration. The talk presents two reinforcement learning models that can simulate high cooperation rates similar to the observed in behavioural experiments based on two approaches. The first of them implements prediction of the moves of the opponent and selective attention to the available payoffs and a threshold based convergence mechanism. The second targets repeated decision making in a mixture of strongly cooperative and non cooperative situations, e.g., a mixture of PD with only very low and very high cooperation indexes, and explores the possible role of Simpson's paradox effects on sustainable cooperation in one-shot PD games.

A Machine Learning application in low-energy electron microscopy

Matyo Ivanov, Juan Pereiro Viterbo
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The Low-energy electron microscope (LEEM) is a powerful crystal surface characterization tool, which uses a parallel beam of electrons at small energies of 0-10 eV to observe a crystal surface. With this, LEEM enables unprecedented sensitivity towards the surface, not only enabling the capturing of the surface morphology in real space, but also its structure in reciprocal space using diffraction. Building on this property, we explore the benefits of imaging a diffraction pattern by creating a convergent beam on a single spot on the surface, instead of the standard illumination of a large area. This enables the imaging of Convergent-beam low-energy electron diffraction (CBLEED) patterns (Figure 1). With it, we localize the information from the surface to a single small point and become sensitive to very fine- grained structural changes.

The result of such imaging is a very abstract and convoluted CBLEED pattern, which nonetheless has been shown to be extremely sensitive to the surface structure, down to the sub-angstrom level [1]. To enable the practical application of this technique, we developed an unsupervised Autoencoder-based neural network which is able to capture the underlying data structure in the CBLEED patterns (Figure 2). We demonstrate its ability to capture sub-angstrom changes in atomic displacements with enough performance to enable real-time pattern interpretation during experiments. With this, we hope to streamline the adoption of this new and powerful experimental technique.

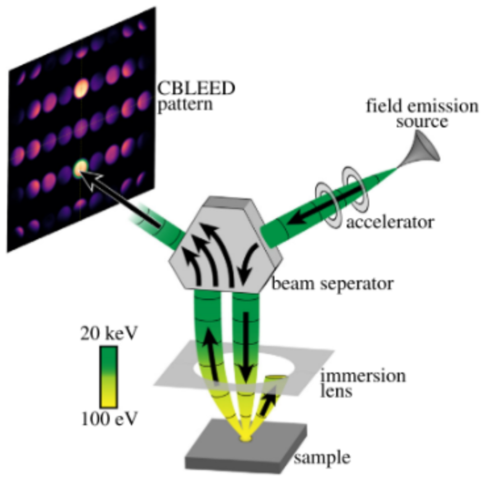

Figure 1. A schematic of CBLEED formation in conventional LEEM.

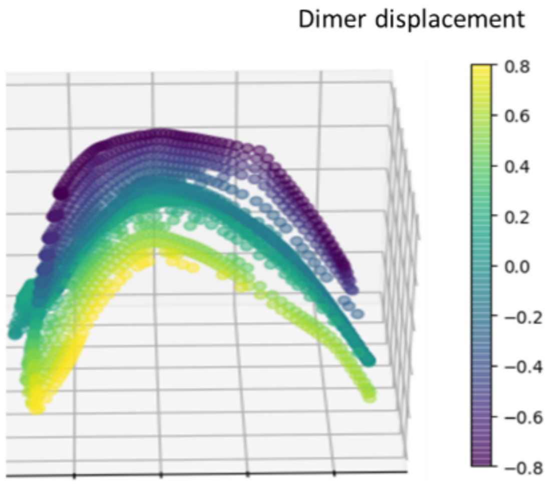

Figure 2. The captured data structure in the latent space of the Autoencoder Convolutional Neural Network.

[1] P. C. Constantinou and D. E. Jesson, “On the sensitivity of convergent beam low energy electron diffraction patterns to small atomic displacements,” Appl. Surf. Sci., vol. 489, no. January, pp. 504–509, 2019, doi: 10.1016/j.apsusc.2019.05.274.

Nonlinear dynamics in two-field cosmological models with hidden symmetry

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In the absence of cosmological perturbations, a classical two-field (or multifield) cosmological model is defined by a nonlinear geometric dynamical system [1]. Despite their crucial conceptual and theoretical importance, multifield cosmological models are poorly understood, mainly because their dynamics can be extremely nontrivial already in the two-field case [2-5]. We describe the dynamics of two-field cosmological models with complete scalar manifold and hidden Noether symmetries, showing that their target space metric is hyperbolic and their scalar potential has a special form which we give explicitly. We present the solutions to cosmological equations and some graphic representations for various cases and choices of parameters involved.

[1] C. I. Lazaroiu, C. S. Shahbazi, Generalized two-field α-attractor models from geometrically finite hyperbolic surfaces, Nucl. Phys. B 936 (2018) 542-596.

[2] L. Anguelova, E. M. Babalic, C. I. Lazaroiu, Hidden symmetries of two-field cosmological models, JHEP 09 (2019) 007.

[3] L. Anguelova, E. M. Babalic, C. I. Lazaroiu, Two-field Cosmological α-attractors with Noether Symmetry, JHEP 04 (2019) 148.

[4] E. M. Babalic, C. I. Lazaroiu, The infrared behavior of tame two-field cosmological models, Nucl. Phys. B 983 (2022), 115929.

[5] C. I. Lazaroiu, Dynamical renormalization and universality in classical multifield cosmological models, Nucl. Phys. B 983 (2022), 115940.

Overview on the generalized Volterra system: solutions and integrability

Nicoleta-Corina Babalic

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We present the recent results obtained, using the Hirota bilinear formalism, on the semi-discrete and discrete forms of generalized Volterra system with any number of coupled equations. The bilinear forms and the multi-soliton solutions are presented for the differential-difference multi-component Volterra system and for the fully discretized version. For some particular cases of the general differential-difference Volterra system, graphical representations of solitons are displayed.

A First Attempt at Neural Machine Translation of Old Church Slavonic and Church Slavonic Languages

Nikolay Nikolov

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In our talk we present first attempts to use Neural Machine Translation (NMT) techniques, based on the transformer architecture, to perform translations between Bulgarian, Church Slavonic and Old Church Slavonic. We will discuss in detail how the developed models were trained, evaluated and implemented using corpora of Church Slavonic and Old Church Slavonic texts. Topics of discussion will also include the mechanisms for improving the accuracy and fluency of translation, and the development of the web environment in which the models are implemented. It will consider how neural machine translation technology can open up new paths to cultural, historical and religious heritage, while providing opportunities for future research and applications. Finally, the prospects for further development of the project will be discussed, including the challenges and opportunities that lie ahead for those involved in machine translation and linguistics as it relates to Church Slavonic and Old Church Slavonic.

The attached flow method for the Dodd-Bullough-Mikhailov equation

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This report continues the work done by the same authors in [1] where the attached flow method was introduced. The case of the reaction-diffusion equation with $C(u) = 0$ is analyzed here, using as specific example the Dodd Bulough Mikhailov model. The key issue of the attached flow method consists in a decomposition of the term without derivatives, decomposition which allows us to reconsider the Abel equation and integrate it to obtain the explicit solution. We will show that for the reaction-diffusion equations with $C(u) = 0$ this decomposition has to be more carefully done.

[1] C. Ionescu, R. Constantinescu, Solving Nonlinear Second-Order Differential Equations through the Attached Flow Method, Mathematics 2022, 10(15), 2811.

Hamiltonian methods in the theory of water waves

R. I. Ivanov

School of Mathematics and Statistics,
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Grangegorman Lower, Dublin D07 ADY7, Ireland

In 1968 V. E. Zakharov in his famous work [9] demonstrated that the equations for the surface waves of a deep inviscid irrotational water have a canonical Hamiltonian formulation. This result has been extended in various directions - for example to models with finite depth and flat bottom [6, 8], for internal waves between layers of different density [7] as well as waves with added shear for constant vorticity [5, 3, 4, 1, 2].

In this presentation we illustrate the Hamiltonian approach by considering a single incompressible, inviscid, irrotational fluid medium bounded by a free surface and a flat bottom. The Hamiltonian of the system could be conveniently expressed in terms of the so-called Dirichlet-Neumann operators. Then the equations for the surface waves are presented in Hamiltonian form, which is useful for various studies. For example, a specific scaling of the variables could be selected, so that the model equations are the well known long-wave approximations of Boussinesq or KdV type.

The use of the Hamiltonian approach, the Dirichlet-Neumann operators and their expansions turns the model derivation process into an algorithm that is technically easy to follow and that is advantageous to other methods using ad-hoc approximations and assumptions.

[1] A. Compelli, R. Ivanov. On the dynamics of internal waves interacting with the Equatorial Undercurrent. J. Nonlinear Math. Phys. **22**, 531-539 (2015). (DOI: 10.1080/14029251.2015.1113052) arXiv:1510.04096 [math-ph].

[2] A. Compelli, R. Ivanov. The dynamics of flat surface internal geophysical waves with currents. *J. Math. Fluid Mech.* **19** 329–344 (2017) (DOI: 10.1007/s00021-016-0283-4) arXiv:1611.06581 [physics.flu-dyn]

[3] A. Constantin, R. Ivanov. A Hamiltonian approach to wave-current interactions in two-layer fluids. Phys. Fluids **27**, 086603 (2015). (DOI: 10.1063/1.4929457)

[4] A. Constantin, R. Ivanov, C. I. Martin. Hamiltonian formulation for wave-current interactions in stratified rotational flows. Arch. Rational Mech. Anal. **221**, 1417–1447 (2016). (DOI: 10.1007/s00205-016-0990-2).

[5] A. Constantin, R. Ivanov, E. Prodanov. Nearly-Hamiltonian structure for water waves with constant vorticity. J. Math. Fluid Mech. **10**, 224–237 (2008). (DOI 10.1007/s00021-006-0230-x) arXiv:math-ph/0610014.

[6] W. Craig, M. Groves. Hamiltonian long-wave approximations to the water-wave problem. Wave Motion **19**, 367–389 (1994). (DOI: 10.1016/0165-2125(94)90003-5).

[7] W. Craig, P. Guyenne, H. Kalisch. Hamiltonian long wave expansions for free surfaces and interfaces. Comm. Pure Appl. Math. **58(12)**, 1587–1641 (2005). (DOI: 10.1002/cpa.20098).

[8] W. Craig, C. Sulem. Numerical simulation of gravity waves. J. Computat. Phys. **108**, 73–83 (1993). (DOI: 10.1006/jcph.1993.1164).

[9] V. E. Zakharov. Stability of periodic waves of finite amplitude on the surface of a deep fluid. J. Appl. Mech. Tech. Phys. **9**, 86-89 (1968).

Multipole Moment Prediction with Symmetry-preserving Graph Neural Networks

Stoyan Mishev[1,2,3] and Dana Tomova[2]

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Graph Neural Networks (GNNs) introduce an effective framework for representation learning of graphs. For algorithms involving graphs, there is symmetry under permutation of how the nodes and edges are ordered in computer memory. Unless specified otherwise machine learned models are not ”symmetry-aware” - they do not understand and handle the symmetry of inherent atomic structures for example. Therefore, they can be sensitive to an arbitrary choice of coordinate system or to the ordering of nodes and edges in an array. In our work we present a method that utilizes symmetries to enhance neural networks. Exploiting symmetries and invariance in data helps in making powerful predictions for a system and in achieving better generalisation with more efficiency. For example by applying transformations between layers of a graph neural network which belong to the Euclidean group (3D rotations, translations and inversion) one can construct better models for predu.

Nuclear matter calculations using Argonne V18 nucleon-nucleon potential

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Every model of finite or inifinite nuclear matter is based on a reliable quantum many-body solver and a good nucleon-nucleon potential. The most widespread potentials are ones of phenomenological origin and other having roots in the so-called effective field theory. In our work we incorporate the Argonne V18 phenomenological potential into a previosly applied coupled-cluster approach to nuclear matter calculations. Argonne V18 contains essential terms missing in the Minnesota potential which we used in the passed. We thus explore the differences between the results obtained using both potentials and evaluate the relevance of the tensor and spin-orbit terms to the nuclear matter equation of state.

Dynamical development of fundamental fields around black holes

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In my talk I will discuss the dynamical development of fundamental scalar fields around black holes. In particular I will discuss the evolution of a black hole from a small initial perturbation, throughout the exponential growth of the scalar field followed by a subsequent saturation to an equilibrium configuration. I consider in particular the dynamics within the scalar-Gauss-Bonnet gravity. I shall also discuss the gravitational core-collapse as a realistic mechanism for the formation of scalarized black holes.

Entropy production and quantum correlations in two coupled bosonic modes interacting with a thermal environment

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The Markovian time evolution of the entropy production rate as an indicator of the irreversibility, in comparison with the correlations like Rényi-2 mutual information, Rényi-2 quantum discord and entanglement is studied, in a bipartite quantum system consisting of two coupled bosonic modes embedded in a common thermal environment. The dynamics of the system is described in the framework of the theory of open systems based on completely positive quantum dynamical semigroups, for initial two-mode squeezed thermal states, squeezed vacuum states and coherent states. We show that the rate of the entropy production and the considered correlations in the non-equilibrium stationary state, as well as the time evolution of the rate of entropy production and of the correlations, strongly depend on the parameters of the initial Gaussian state (squeezing parameter and average thermal photon numbers), frequencies of the modes, the parameters characterising the thermal reservoir (temperature and dissipation rate) and the coupling between the two bosonic modes [1, 2].

[1] T. Mihaescu, A. Isar. Dynamics of entropy production rate in two coupled bosonic modes interacting with a thermal reservoir. Entropy **24**, 696 (2022).

[2] T. Mihaescu, A. Isar. Entropy production and correlations in two coupled bosonic modes interacting with a thermal environment. European Physical Journal Plus (submitted).

Steering witnesses for unknown Gaussian quantum states

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We define and fully characterize the witnesses based on second moments detecting steering in Gaussian states by means of Gaussian measurements. All such tests, which arise from linear combination of variances or second moments of canonical operators, are easily implemented in experiments. We propose also a set of linear constraints fully characterizing steering witnesses when the steered party has one bosonic mode, while in the general case the constraints restrict the set of tests detecting steering. Given an unknown quantum state we implement a semidefinite program providing the appropriate steering test with respect to the number of random measurements performed. Thus, it is a "repeat-until-success" method allowing for steering detection with less measurements than in full tomography. We study the efficiency of steering detection for two-mode squeezed vacuum states, for two-mode general unknown states, and for three-mode continuous variable GHZ states. In addition, we discuss the robustness of this method to statistical errors. A similar method for entanglement detection based on covariance matrices was developed in Ref. [1].

[1] T. Mihaescu, H. Kampermann, G. Gianfelici, A. Isar, D. Bruss. Detecting entanglement of unknown continuous variable states with random measurements, New J. Phys. **22**, 123041 (2020)

The PADME experiment at LNF-INFN: data reconstruction techniques and present results

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Despite the impressive success of the Standard model (SM) in describing nature it still fails in finding the answers for a few astrophysics phenomena, including the lack of antimatter in the Universe and what Dark Matter is made of. The PADME experiment at LNF-INFN aims to search for new light states, which may act as a portal between the SM and the Dark Sector, employing positron-on-target annihilation technique. The experimental setup is exposed to huge instantaneous rate and double particle separation requires the application of novel techniques to better discriminate between background and signal. The possible usage of Machine Learning methods for reconstructing the signals from various scintillating detectors, including the energy and time reconstruction in the PADME electromagnetic calorimeter will be presented and discussed.

Riemann–Hilbert problems, polynomial Lax pairs, integrable equations and their soliton solutions

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This report is an extension of our previous results [1, 2, 3, 4].

The standard approach to integrable nonlinear evolution equations (NLEE) usually uses the following steps: 1) Lax representation $[L,M]=0$ (which nay include additional reductions); 2) construction of fundamental analytic solutions (FAS); 3) reducing the inverse scattering problem (ISP) to a Riemann-Hilbert problem (RHP); 4) soliton solutions and possible applications. Step 1) involves several assumptions: the choice of the Lie algebra $\mathfrak{g}$ underlying L and M, as well as their dependence on the spectral parameter λ. In the simplest nontrivial cases (e.g., linear dependence of L on λ) the construction of FAS is routine. The routine part of step 3) allows one to derive the corresponding RHP. Assuming that we have two FAS $\xi^{\pm}(x,t,\lambda)$ we need to pass over to the RHP $\xi^{+}(x,t,\lambda)=\xi^{+}(x,t,\lambda)G(x,t\lambda)$ on a contour Γ with sewing function $G(x,t,\lambda)$. Sometimes it is necessary to make a (gauge) transformation that ensures that the RHP is canonically normalized. There are several methods for calculating the soliton solutions. To us, once having formulated the RHP step 4 could be most efficiently executed using Zakharov-Shabat dressing method. This method has been widely used and as a result the classes of NLEE related to the generalized Zakharov-Shabat system and their reductions are by now thoroughly studied. the same is true also for some special types of Lax operators whose λ-dependence is quadratic.

Using additional methods like the resolvent of L and the generalized Fourier transforms (GFT) one can analyze the spectral properties of the Lax operators and the hierarchies of Hamiltonian structures. In some cases they allow one to derive the action-angle variables of the NLEE.

In the present paper we propose another approach which substantially extends the classes of integrable NLEE. Its first advantage is that one can effectively use any polynomial dependence in L and M. We propose to use the following steps: A) Start with canonically normalized RHP with predefined contour Γ; B) Specify the x and t dependence of the sewing function defined on Γ; C) Introduce convenient parametrization for the solutions $\xi^{+}(x,t,\lambda)$ of the RHP and use Zakharov-Shabat theorem to formulate the NLEE; D) use Zakharov-Shabat dressing method to derive their soliton solutions. E) analyze the spectral properties of the Lax operator; F) Prove the compatibility of any two Hamiltonian structures from the hierarchy.

Step A) involves specifying the Lie group $\mathscr{G}$ to which $\xi^{+}(x,t,\lambda)$ belongs, and the contour Γ which must be compatible with the reductions of the system. For example, if we want to treat a case when both Lax operators are quadratic pencils the contour Γ must fill in both the real and imaginary axis in the complex λ-plane $\mathbb{C}$. This means that Γ must be compatible with the x and t dependence of the sewing function in step B). The parametrization in step C) is introduced using the asymptotic expansion of the solutions of RHP. In step D) we use the Zakharov-Shabat dressing method, which needs minor modifications when both Lax operators are pencils of order 2 or higher. In step E) we introduce explicit expression for the kernel of the resolvent of L in terms of the solutions of RHP. As a result we find that the poles of the dressing factors are pole singularities of the resolvent, which means that they are discrete eigenvalues of L and M. In addition the diagonal of the resolvent provides the integrals of motion of the NLEE. Using the solutions of the RHP we can define the 'squared solutions' of the Lax operator and can prove that they from a complete set of solutions in the space of allowed potentials. Using the expansions of the potential and its variation over the squared solutions we are able to prove the equivalence between the different members of the hierarchy.

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[3] V. S. Gerdjikov, A. O. Smirnov, V. B. Matveev, From generalized Fourier transforms to spectral curves for the Manakov hierarchy. I. Generalized Fourier transforms. Eur. Phys. J. Plus **135**(8), 659 (2020). https://doi.org/10.1140/epjp/s13360-020-00668-2

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On integrable spinor models and simple Lie algebras

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This talk is based on a paper that is currently in preparation. With each classical simple Lie algebra one can relate an integrable spinor model. In this case, the orthogonal algebras are considered. More precisely, the Zakharov-Mikhailov (Z-M) model, together with those proposed by Nambu–Jona-Lasinio–Vaks–Larkin and Gross–Neveu are two-dimensional spinor models that are considered important in the theoretical physics. In [1] Zakharov and Mikhailov developed a new spinor model, that is now known as the Z-M model:

$$i\frac{\partial \psi_\alpha}{\partial \xi} = \sum_{\beta=1}^{N} (\phi_\alpha \phi_\beta^* - \phi_\alpha^* \phi_\beta)\psi_\beta, \qquad i\frac{\partial \phi_\alpha}{\partial \eta} = \sum_{\beta=1}^{N} (\psi_\alpha \psi_\beta^* - \psi_\alpha^* \psi_\beta)\phi_\beta,$$

where $\psi(\xi,\eta)$ and $\phi(\xi,\eta)$ belong to the Special Orthogonal Group $SO(n)$.

The research starts with the Lax representation of the Z-M model. The corresponding Lax operator is given by:

$$L\Psi \equiv i\frac{\partial \Psi}{\partial x} + \frac{U_1(x,t)\Psi(x,t,\lambda)}{\lambda - a} = 0, \qquad U_1(x,t) = \theta J \theta^{-1},$$

where $\theta(x,t) \in SO(n)$ and $J = \mathrm{diag}(1,0,...,0,-1) \in so(n)$. Solving the direct scattering problem of L means construction of its Jost solutions The two Jost solutions are linearly related by the scattering matrix $T(t,\lambda)$ which must belong to $SO(n)$. The Lax representation allows us to derive ordinary linear equation for the time dependence of $T(t,\lambda)$. Next we apply Gauss decomposition to $T(t,\lambda)$ and using the Gauss factors $T_J^{\pm}(t,\lambda)$, $S_J^{\pm}(t,\lambda)$ and $D^{\pm}(\lambda)$ construct two sets of fundamental analytic solutions (FAS) of L: $\xi^{\pm}(x,\lambda)$ and $\tilde{\xi}^{\pm}(x,\lambda)$ where $+$ (resp. $-$) means analyticity in the upper (resp. lower) half of the complex λ-plane. Thus the Inverse Scattering Problem for L is reduced to a Riemann-Hilbert problem (RHP) for FAS. Applying Zakharov-Shabat dressing method we construct singular solutions to the RHP and soliton solutions to Z-M model.

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Achieving High Efficiency: Resource sharing techniques in neural networks for resource-constrained devices

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Artificial neural networks emerged in the early 1940s as a connectionist approach to modeling the behavior of interconnected living nerve cells within the intricate cognitive framework of the brain. Over the years, this idea has undergone unprecedented proliferation of ever-expanding application areas, accompanied by an exponential surge in the mathematical formalism employed. This prodigious growth poses severe demands on computational hardware infrastructure. The current research suggests a novel approach for optimizing artificial neural network architectures using resource-sharing techniques. It is discussed the concept of merging context-switching and time-division multiplexing in building a single-neuron artificial neural network with the aid of an FPGA device. This would benefit the significant reduction of hardware resources and the possibility of creating small yet very efficient artificial neural networks without deteriorating the dynamical system performance.

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