NITheCS

National Institute for
Theoretical and Computational Sciences

NITheCS MINI-SCHOOL:

An Introduction to Solitons and Solitary Waves in Physics and Mathematics

Wednesday 8, 15, 22 and 29 March 2023
14h00 – 15h00 SAST (note: the 22 March lecture starts at 14h15)

ABSTRACT

This mini-school offers a basic introduction to solitons and solitary waves in physics and mathematics. The focus is on applications and therefore renowned scientists working on solitons in very different branches have been invited to lecture on their fields of expertise.

In mathematics and physics, a soliton (or solitary wave) is a wave-like solution to nonlinear field equations that maintains its shape while it propagates at a constant velocity. Apart from that propagation, solitons are characterised by possessing localised energy densities. They have a wide range of applications in different branches of science, including optics, condensed matter, nanophysics, biology and nuclear & high energy physics.

In the course of this mini-school, lecturers from these different disciplines will explain how these various solitons are constructed from non-linear equations and how they feature in describing various aspects of nature.

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SPEAKERS

8 March @14h00
'Multidimensional Solitons'
Prof Boris Malomed (Tel Aviv University)

15 March @14h00
'Spatially localized and delocalized nonlinear vibrations in the lattices'
Prof Sergey Dmitriev (Russian Academy of Sciences)

22 March @14h15
'Chiral soliton models for baryons'
Prof Herbert Weigel (Stellenbosch University)

29 March @14h00
'Scattering and collisions of solitons in (1+1) dimension'
Dr Danial Saadatmand (Stellenbosch University)

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SPEAKERS' ABSTRACTS

'Multidimensional Solitons'

Prof Boris Malomed (Tel Aviv University)

It is commonly known that the interplay of linear and nonlinear effects gives rise to solitons, ie self-trapped localized structures, in a wide range of physical settings, including optics, Bose-Einstein condensates (BECs), hydrodynamics, plasmas, condensed-matter physics etc. Nowadays, solitons are considered an interdisciplinary class of modes, which feature diverse internal structures.

While most experimental realizations and theoretical models of solitons have been elaborated in one-dimensional (1D) settings, a challenging issue is prediction of stable solitons in 2D and 3D media. In particular, multidimensional solitons may carry an intrinsic topological structure in the form of vorticity. In addition to the "simple" vortex solitons, fascinating objects featuring complex structures, such as hopfions, i.e., vortex rings with internal twist, have been predicted too.

A fundamental problem is the propensity of multidimensional solitons to be unstable (naturally, solitons with a more sophisticated structure, such as vortex solitons, are more vulnerable to instabilities). Recently, novel perspectives for the creation of stable 2D and 3D solitons were brought to the attention of researchers in optics and BEC. The present talk aims to provide an overview of the main results and ongoing developments in this vast field. An essential conclusion is the benefit offered by the exchange of concepts between different areas, such as optics, BEC, and hydrodynamics.

'Spatially localized and delocalized nonlinear vibrations in the lattices'

Prof Sergey Dmitriev (Russian Academy of Sciences)

Nonlinear lattices support Delocalized Nonlinear Vibrational Modes (DNVMs), which are exact solutions to the dynamical equations of motion. DNVMs are determined by considering only the symmetry of the lattice, so they exist for any type of interparticle interaction and any amplitude. On the other hand, nonlinear lattices support spatially localized vibrational modes called discrete breathers (DBs). This talk will describe the DNVMs of 2D and 3D lattices and demonstrate the relationship between DNVMs and DBs. It will be shown that DNVMs can be used to solve the problem of fitting interatomic potentials employed for molecular dynamics modeling of crystalline solids.

'Chiral soliton models for baryons'

Prof Herbert Weigel (Stellenbosch University)

We start from Witten's large-Nc argument that baryons emerge as solitons in an effective meson theory for quantum chromodynamics. Taking chiral symmetry as the main building principle for this effective theory leads to the Skyrme soliton. Good nucleon (proton & neutron) quantum states are generated from this soliton by collective quantization of the flavor SU(2) degrees of freedom. We discuss the resulting predictions for the nucleon properties, ranging from radii over magnetic moments to pion-nucleon scattering. We extend the quantization to flavor SU(3) and show that the Skyrme soliton carries half-integer spin. We briefly comment on extensions of the model by adding vector mesons or constituent chiral quarks.

'Scattering and collisions of solitons in (1+1) dimension'

Dr Danial Saadatmand (Stellenbosch University)

In this talk we describe the scattering of kinks and breathers of the nonlinear Klein-Gordon (NKG) equations on a spatially localised parity-time-symmetric perturbation with a balanced gain and loss. Then, we discuss that solitons are very effective in transporting energy over great distances and collisions between them can produce high energy density spots of relevance to phase transformations, energy localization and defect formation among others. We demonstrate that the maximal energy density that can be achieved in collision of N slowly moving kinks and antikinks in the NKG models.

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SPEAKERS' BIOGRAPHIES

Prof Boris Malomed (Tel Aviv University)

Boris A. Malomed (Senior Member, IEEE) received his PhD degree from the Moscow Physico-Technical Institute, Russia, in 1981, and a Doctor of Science degree (habilitation) from the Institute for Theoretical Physics of the Academy of Sciences of Ukraine in 1989. He has been working with the Tel Aviv University since 1991 and is currently a Professor with a chair in 'Optical Solitons'. Since 2011, he has also collaborated as a consultant with the Institute of Photonic Sciences (ICFO, Spain).

He was a Divisional Associate Editor of *Physical Review Letters* (in the area of 'laser physics') in 2009–2015. He is currently the editor of *Phys. Lett. A and Chaos, Solitons & Fractals*, and an editorial board member of *J. Optics*. His research interests include the fields of nonlinear optics, Bose–Einstein condensates and matter waves, pattern formation in nonlinear dissipative media, dynamics of nonlinear lattices, etc. He is a Senior Member of OSA.

Prof Sergey Dmitriev (Russian Academy of Sciences)

Prof Sergey V. Dmitriev graduated from Tomsk State University, Russia, with an MSc degree in 1984. He completed his PhD degree in structural mechanics at Tver State University, Russia, in 1988. He gained a second PhD degree in computer modeling of incommensurate phases in dielectrics from the University of Electro-Communications, Tokyo, Japan, in 1999. He received a 'Habilitation' degree in 2008 with a thesis on solitary wave dynamics in discrete systems from Altai State Technical University.

Since 2008, Prof Dmitriev has been serving as Head of Laboratory of the Institute for Metals Superplasticity Problems of the Russian Academy of Sciences, Ufa, Russia. His scientific interests are in solitary waves in discrete systems, discrete breathers, evolution of defect structures in solids during plastic deformation, mechanical properties of graphene, and atomistic simulations.

Prof Herbert Weigel (Stellenbosch University)

Herbert Weigel is Professor of Theoretical Physics at Stellenbosch University. He received his PhD at Siegen University (Germany) under the supervision of Prof G. Holzwarth. Thereafter he spent several years as a postdoc in Syracuse (New York), Orsay (France) and Tubingen (Germany). In Tubingen he also gained his 'Habilitation' degree. He was then awarded a Heisenberg fellowship by the German Science Foundation (DFG) for five years, which he spent as a researcher at MIT, Cambridge (Massachusetts) and Tubingen. He became an Extra-curricular Professor at Siegen University before moving to Stellenbosch as Associate Professor. He was promoted to Full Professor in 2013.

Prof Weigel's research interests are centered around non-linear phenomena in (quantum) field theory. Most notably these are the so-called soliton solutions. They have a particle interpretation and can, for example, be used to model aspects of quantum-chromo-dynamics as low energy scales. He particularly investigated the relevance of strange degrees of freedom for baryons. More recently he also focused on the quantum effects for solitons (or soliton-like structures). Not only yields that study insight in the famous Casimir effect, it also shows that classically unstable field configurations can be stabilized quantum mechanically. In other cases these quantum effects may cause classically stable configurations to fade away.

Prof Weigel has (co)authored more than 100 research publications, about six review articles and two monographs on his research projects.

Dr Danial Saadatmand (Stellenbosch University)

Dr Danial Saadatmand is a postdoctoral researcher of Theoretical Physics at Stellenbosch University. He received his PhD in elementary particle physics from Ferdowsi University of Mashhad under the supervision of Prof K. Javidan in 2015. He spent one year as a researcher at the Russia Academy of Science, Ufa, and five years as an assistant Professor of physics at the University of Sistan and Baluchestan, Iran. Dr Saadatmand has (co)authored more than 30 research publications.