8th Workshop on Quantum Phase Transitions in Nuclei and Many-Body Systems

Prague, June 6-9, 2016

Organized by the Institute of Particle and Nuclear Physics of the Faculty of Mathematics and Physics, Charles University in Prague (Pavel Cejnar, Pavel Stránský, Michal Kloc, Alexandra Moravcová)

Program

Monday (June 6)

9.00-12.45: Morning program

9.00-10.00 Registration

10.00-11.30 Opening Session

V. Baumruk (vice-dean of the Math.& Phys. Faculty of the Charles University): Opening address (15 min)

F. Iachello: Introduction to quantum phase transitions in nuclei and many-body systems (60 min)

Discussion (15 min)

11.30-11.45 Coffee break

11.45-12.45 Session: Microscopic approaches to quantum phase transitions, part I

(convenors: D. Vretenar, L. Robledo; times include discussion)

J. Dudek: Microscopic approaches to the nuclear shape transitions: Dynamical-, high-spin-, high temperature effects (30 min)

N. Shimizu: Shape phase transition and shell evolution in large-scale shell-model calculations (30 min)

12.45-14.15: Lunch

14.15-18.00: Afternoon session

Microscopic approaches to quantum phase transitions, part II (convenors: D. Vretenar, L. Robledo)

14.15-16.00 Talks (times include discussion)

P. Sarriguren: Signatures of nuclear shape transitions in ground-state properties of neutron-rich nuclei (30 min)

T. Niksic: Coexistence of nuclear shapes: Self-consistent mean-field and beyond (20 min)

K. Nomura: Beyond-mean-field boson-fermion model for odd-mass nuclei (20 min)

R.-D. Lasseri: Crystal-liquid transition in nuclei (20 min)

General discussion (15 min)

16.00-16.15 Coffee break

16.15-18.00 Talks (times include discussion)

K. Nomura : Shape coexistence in the microscopically guided IBM (25 min)

X. Vinas: Pasta phase transitions in the inner crust of neutron stars (20 min)

A. Severyukhin: Proton-neutron structure of first and second quadrupole excitations in ^{90}Sr (20 min)

N. Pietralla: Data on type II shell evolution in ^{96}Zr from electron scattering (20 min)

General discussion (20 min)

Tuesday (June 7)

9.00-12.45: Morning session

Experimental signatures of quantum phase transitions in nuclei (convenors: R. Casten, N. Pietralla)

9.00-10.45 Talks (times include discussion)

R.F. Casten, N. Pietralla: Introduction (5 min)

R.F. Casten: Perspective on structural evolution. Partial dynamical symmetries. Testing theories (45 min)

T. Braunroth: ^{58,60}Cr - Candidates for the E(5) limit (15 min)

T. Braunroth (on behalf of C.Müller-Gatermann): Collective structures in the neutron deficient nucleus ^{180}Pt (15 min)
J.C. Wiederhold: New *B*(M1), *B*(E2) signatures of QPT using scissors 1^+ (15 min)
General discussion (10 min)
10.45-11.00 Coffee break
11.00-12.45 Talks (times include discussion)
C. Lizarazo: HPGe-spectroscopy data on ^{90,92,94}Se, ground sequence + first off-yrasts; RIBF-EURICA results (15 min)
N. Pietralla: 2^+ lifetime in ^{98}Zr (15 min)
J. Jolie: Lifetimes in even-even Zirconium isotopes from the FATIMA & EXILL campaign (15 min)
M. Lettman: Mapping the *N*=56 sub-shell closure. SEASTAR results (15 min)
M. Klintefjord: The structure of low-lying states in ^{140}Sm (15 min)
R. Jolos: Alternating parity bands in nuclei - phase transition and stabilization of the octupole deformation with angular momentum increase (20 min)
General discussion (10 min)

12.45-14.15: Lunch

14.15-18.00: Afternoon session

Quantum phase transitions in non-nuclear systems, part I: Quantum simulators (convenors: L.D. Carr, J. Dukelsky)
14.15-16.00 Talks (times include discussion)
L.D. Carr: Feynman's vision comes true (overview of quantum simulators) (25 min)
S. Jochim: Deterministic quantum simulators with cold atoms (35 min)
S. Montangero: From the classical to the quantum Kibble-Zurek scaling (35 min)
General discussion (10 min)
16:00-16:15 Coffee break
16.15-18.00 Talks (times include discussion)
M. Fattori: QPTs with parity-symmetry breaking and hysteresis with atomic BECs in a double-well potential (35 min)
L. Santos: Power law decays and thermalization in isolated many-body quantum systems (35 min)
M.A. Bastarrachea Magnani: QPTs and microcanonical description of atom-field systems (20 min)
General discussion (15 min)

Wednesday (June 8)

9.00-12.45: Morning session

Symmetry-based approach to nuclear structure and quantum phase transitions (convenors: P. Van Isacker, A. Leviatan)
9.00-10.35 Talks (times include discussion)
V. Zelevinsky: Open quantum systems and superradiance phase transition (25 min)
J.E. García-Ramos: On the nature of the shape coexistence phenomenon in the lead region (25 min)
A. Leviatan: Symmetry-based approach to prolate-oblate coexistence in nuclei (25 min)
N. Gavrielov: First-order QPT between spherical and gamma-unstable nuclear shapes (20 min)
10.35-10.50 Coffee break
10.50-12.45 Talks (times include discussion)
J.M. Arias: Phase diagram of the two-fluid Lipkin model: A butterfly catastrophe (25 min)
J. Cseh: Cluster and shell configurations: competition and coexistence (25 min)
P. Van Isacker: The octupole solution of the shell model (25 min)
G. Stellin: Electromagnetic selection rules in the triangular alpha-cluster model of ^{12}C (20 min)
P.E. Georgoudis: Study of the Bohr Hamiltonian with sextic potentials (20 min)

12.45-14.15: Lunch

14.15-17.00: Afternoon program

14.15-16.45 **Session: Quantum phase transitions in non-nuclear systems, part II: Advanced quantum materials** (convenors: L.D. Carr, J. Dukelsky; times include discussion)
A. Keller: Universal Fermi liquid crossover and quantum criticality in a mesoscopic system (35 min)
G. Ortiz: Particle-conserving topological superfluids and the fate of Majoranas (35 min)
G. Salomon: Spin and charge resolved quantum gas microscopy of antiferromagnetic correlations in Hubbard chains (35 min)
O. Legeza: Phase separation of superfluids in the chain of four-component ultracold atoms (35 min)

General discussion (10 min)

16.45-17.00 Coffee break

17.00-18.00: **Special lecture** (Baroque refectory of the House for Professed)

J. Podolský: An outline of the history of physics and astronomy in Prague (from Brahe and Kepler to Einstein)

19.00-23.00: Social dinner

Thursday (June 9)

9.00-12.45: Morning session

Quantum phase transitions in coupled systems (convenors: F. Pérez Bernal, J.E. García Ramos)

9.00-10.45 Talks (times include discussion)

F. Pérez Bernal, J.E. García Ramos: Introduction (10 min)

M. Macek: Dispersion relations and densities of states in coupled U(2) and U(3) models (35 min)

M.A. Bastarrechea Magnani: Quantum signatures of chaos in boson-fermion systems (20 min)

J. Jolie: Partial dynamical symmetry in Bose-Fermi systems (15 min)

General discussion (25 min)

10.45-11.00 Coffee break

11.00-12.45 Talks (times include discussion)

K. Nomura: Microscopic approach to coupled quadrupole-octupole collective states (20 min)

J. Chávez Carlos: Classical chaos in atom-field systems (25 min)

M. Bermúdez-Montaña: A new point of view of the local to normal mode transition (20 min)

L. Fortunato: New interdisciplinary playgrounds for algebraic models: From molecules to hypernuclei (20 min)

R. Puebla Antunes: QPT and ESQPT in the Rabi model (20 min)

12.45-14.15: Lunch

14.15-18.00: Afternoon program

14.15-17.45 **Session: Excited state quantum phase transitions** (convenors: T. Brandes, M. Macek)

14.15-16.00 Talks (times include discussion)

T. Brandes: Introduction (5 min)

L. Carr: Bose-Einstein condensates in ring traps: Topological unwinding, strongly correlated solitons, and metastable quantum phase transitions (30 min)

P. Stránský: Classification of ESQPTs (15 min)

M.A. Bastarrachea Magnani: A thermodynamic interpretation of QPTs: A microcanonical description of the generalized Dicke Hamiltonian (15 min)

S. Lerma: The participation ratio of coherent states over energy eigenstates: a quantum measure sensitive to ESQPTs and chaos (15 min)

M. Macek: Stripe-like eigenstates at ESQPT/van Hove singularity energies in 2D lattices (15 min)

General discussion (10 min)

16.00-16.15 Coffee break

16.15-17.45 Talks (times include discussion)

R. Puebla Antunes: Irreversibilty due to the loss of symmetry-breaking information crossing an ESQPT (15 min)

P. Pérez-Fernández: ESQPTs in the two-fluid Lipkin model (15 min)

T. Mavrogordatos: QPTs in the dispersive driven dissipative Jaynes-Cummings model (15 min)

R. Sýkora: Nonequilibrium heat transport in an exactly solvable quantum-critical model (15 min)

M. Kloc: Entanglement and ESQPT in an extended Dicke model (15 min)

General discussion (15 min)

17.45-18.00 **Closing of the workshop**

Abstracts

Opening Session

Introduction to quantum phase transitions in nuclei and many-body systems

Francesco IACHELLO
Yale University, USA

Abstract: After a brief review of quantum phase transitions (QPT) and excited state quantum phase transitions (ESQPT) in nuclei and molecules, an overview of recent developments in QPT and ESQPT in algebraic models of Lattice Systems and of Cluster Systems will be given.

Microscopic approaches to quantum phase transitions, part I

convenors: Dario VRETENAR, Luis ROBLEDO

Microscopic approaches to the nuclear shape transitions: Dynamical-, high-spin-, high temperature effects

Jerzy DUDEK, I. Dedes, K. Mazurek* and D. Rouvel
Université de Strasbourg, IPHC, 23 rue du Loess, 67037 Strasbourg, France
* The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Kraków, Poland

Abstract: The issue of the nuclear shape transitions (sometimes referred to as evolution) is strongly related to the issue of the nuclear shape coexistence. These are the coexisting equilibrium or quasi-equilibrium shapes which determine the way the shapes evolve under the influence of certain external conditions. The very word 'transition' covers (or hides) diverse possible mechanisms or ways of interpreting facts which in turn have different quantum mechanical origin. Indeed, whereas sometimes one may refer to the shape evolution as the changes in shape induced by certain specific excitation conditions as for instance varying spin, or varying temperature, another way of perceiving the transition will be to follow those changes as functions of the nucleon numbers. We address both these issues. The term 'equilibrium deformation(s)' is used in reference to either ground-state, or shape-coexisting minima on the potential energy surfaces in sufficiently rich deformation spaces. The excited-states giving rise to the potential minima – in order to be considered – are expected to be surrounded by the sufficiently well pronounced potential barriers thus giving rise to the isomeric states and therefore opening the way to the experimental tests. We pay attention to the condition that the deformation spaces used for the modelling of the shape phenomena are sufficiently rich to avoid the situations in which certain excited 'minima' in reality are just e.g. the saddle points, when the more adequate deformations spaces are used [illustrative examples are given]. For certain purposes it may be sufficient to use the information about the shape transitions deduced from the collection of the results of modelling the static equilibrium deformations (e.g. employing microscopic methods). We present the extensions of such considerations to include the dynamical shape effects caused by collective motion in the deformation spaces, studied with the help of the collective Schrödinger equation. An important opening of the perspective comes from the distinction between the static, as opposed to the 'dynamic' (most probable) deformations calculated with the help of the collective wave-functions. Those are particularly relevant in, e.g., transitional nuclei whose potential energy landscapes are relatively flat and the minima are not well pronounced thus giving raise to the large amplitude motion. We discuss certain new, microscopic results in this context. Finally we address the issue of uncertainties of theoretical modelling from the perspective of the mathematical Inverse Problem Theory - including the application of stochastic and Monte-Carlo methods. The well established techniques of Appled Mathematics related to critical approach to the parameter adjustment methods allow estimating the predictive power of the modelling given the uncertainties of both the models themselves and the experimental sampling.

Shape phase transition and shell evolution in large-scale shell-model calculations

Noritaka SHIMIZU
Center for Nuclear Study, the University of Tokyo, Japan

Abstract: Nuclear shape is one of the central subjects of nuclear structure physics. Quadrupole collective states and their competing situation bring about various structures such as the gradual transition of shapes and shape coexistence. For the microscopic description of these structures including beyond-mean-field correlations, we adopt the large-scale shell model calculation. Recently developed shell-model code [1] enables us to perform the large-scale shell model calculations in medium-heavy nuclei. Moreover, the intrinsic analysis of the wave function of the Monte Carlo shell model provides us with the discussion of the intrinsic shape and its quantum fluctuation [2]. In this contribution, we discuss the low-lying collective states of Xe and Ba isotopes around A=134 in terms of shell-model calculations. These isotopes show the shape transition from the spherical shape to the triaxial deformation. The structure of the modest triaxial deformation is further studied by the intrinsic

analysis of the Monte Carlo shell model. The shell evolution of neutron-rich Ni isotopes are also discussed connected to the shell evolution driven by the first-order tensor force [3].

[1] N. Shimizu, arXiv:1310.5431 [nucl-th]
[2] N. Shimizu, T. Abe, Y. Tsunoda, Y. Utsuno, T. Yoshida, T. Mizusaki, M. Honma, and T. Otsuka, Prog. Theor. Exp. Phys. 2012, 01A205 (2012).
[3] Y. Tsunoda, T. Otsuka, N. Shimizu, M. Honma and Y. Utsuno, Phys. Rev. C 89 031301(R) (2014).

Microscopic approaches to quantum phase transitions, part II

convenors: Dario VRETENAR, Luis ROBLEDO

Signatures of nuclear shape transitions in ground-state properties of neutron-rich nuclei

Pedro SARRIGUREN[1], R. Rodriguez-Guzman[2], and I.M. Robledo[3]
[1] Instituto de Estructura de la Materia, IEM-CSIC, Serrano 123, E-28006 Madrid, Spain
[2] Physics Department, Kuwait University, Kuwait 13060, Kuwait
[3] Departamento de Física Teórica, Universidad Autónoma de Madrid, 28049-Madrid, Spain

Abstract: The nuclear structural evolution as a function of the number of nucleons is a subject of increasing interest in nuclear physics, which is supported by very intense activity on both theoretical and experimental sides [1]. Specially interesting are those cases where the nuclear structure changes rapidly between neighbor nuclides, leading to sudden variations of particular properties that can be used as a signature of the transition. This is the case of the neutron-rich isotopes with masses *A*∼100. Westudytheisotopicevolutionoftheground-statenuclearshapesinvariousneutron-rich nuclei in this mass region, namely, Kr, Rb, Sr, Y, Zr, Nb, and Mo isotopic chains. Both even-even and odd-*A* nuclei are included in the analysis. For the latter we also study the systematics of their one-quasiparticle low-lying configurations. The theoretical approach is based on a selfconsistent Hartree-Fock-Bogoliubov formalism with finite range Gogny energy density functionals. Neutron separation energies, charge radii, and the spin-parity of the ground states are calculated and compared with available data. Shape-transition signatures are identified around *N*=60 isotones as discontinuities in both charge radii isotopic shifts and spin-parities of the ground states [2]. The nuclear deformation including triaxiality and the shape coexistence inherent to this mass region are shown to play a relevant role in the understanding of the bulk and spectroscopic features of the ground and low-lying one-quasiparticle states. Comparison with the available data from laser spectroscopy [3] demonstrates the quality of the Gogny-HFB description that is able to reproduce the main features of the measurements. The signatures found are a common characteristic for nuclei in the mass region studied and they are robust, consistent to each other, and in agreement with experiment. We point out that the combined analysis of these observables could be used to predict unambiguously new regions where shape transitions might develop.

[1] P. Cejnar, J. Jolie, and R.F. Casten, Rev. Mod. Phys. 82, 2155 (2010).
[2] R. Rodriguez-Guzman et al., Phys. Lett. B691, 202 (2010); Phys. Rev. C 82, 044318 (2010); Phys. Rev. C 82, 061302(R) (2010); Phys. Rev. C 83, 044307 (2011).
[3] B. Cheal and K.T. Flanagan, J. Phys. G 37, 113101 (2010).

Coexistence of nuclear shapes: Self-consistent mean-field and beyond

Tamara NIKSIC
Physics Department, Faculty of Science, University of Zagreb, Croatia

Abstract: A quantitative analysis of the evolution of nuclear shapes and shape phase transitions, including regions of short-lived nuclei that are becoming accessible in experiments at radioactive-beam facilities, necessitate accurate modeling of the underlying nucleonic dynamics. Important theoretical advances have recently been made in studies of complex shapes and the corresponding excitation spectra and electromagnetic decay patterns, especially in the “beyond mean-field” framework based on nuclear density functionals. Interesting applications include studies of the structure of lowest 0^+ excitations in deformed *N*=90 rare-earth nuclei, and quadrupole and octupole shape transitions in thorium isotopes.

Beyond-mean-field boson-fermion model for odd-mass nuclei

Kosuke NOMURA
Physics Department, Faculty of Science, University of Zagreb, Croatia

Abstract: We present a novel method for calculating spectroscopic properties of medium-mass and heavy atomic nuclei with an odd number of nucleons, based on the framework of nuclear energy density functional theory and the particle-core coupling scheme. The deformation energy surface of the even-even core, as well as the spherical single-particle energies and occupation probabilities of the odd particle(s), are obtained in a self-consistent mean-field calculation determined by the choice of the energy density functional and pairing interaction. This method uniquely determines the parameters of the Hamiltonian of the boson core, and only the strength of the particle-core coupling is specifically adjusted to selected data for a particular nucleus. The approach is illustrated in a systematic study of low-energy excitation spectra and transition rates of axially deformed odd-mass Eu isotopes.

Crystal-liquid transition in nuclei

Raphael-David LASSERI[1], J.P. Ebran[2], E. Khan[1], N. Sandulescu[3], D. Vretenar[4]
[1] Institut de Physique Nuclaire, Université Paris-Sud, IN2P3-CNRS, F-91406 Orsay, France
[2] CEA,DAM,DIF, F-91297 Arpajon, France
[3] National Institute of Physics and Nuclear Engineering, P.O. Box MG-6, Magurele, Bucharest, Romania
[4] Physics Department, Faculty of Science, University of Zagreb, Bijenicka 32, Zagreb 10000, Croatia

Abstract: During past years the description of nuclear structure using relativistic energy density functionals has shown its powerfullness and its ability to explain a wide spectrum of phenomena. It has been shown that among them the clustering phenomenon has been particularly well described [1]. Nuclei can display two very different kinds of behavior. When long-range correlations prevail, they behave as quantum liquids while in other cases, they exhibit crystalline properties [2]. We will discuss these phenomena in terms of quantum phase transitions and analyze some of the necessary conditions to the emergence of clusters. We will also discuss the effects of two and four body correlations, namely pairing and quarteting, on the global structure of the nucleus, and especially on clustering [3]. We will then conclude on the possibility to use the formalism of quantum phase transition in order to develop a unified description of several phenomenological aspects in nuclear physics.

[1] J.P. Ebran, E. Khan, D. Vretenar, T. Niksic, Nature 487,341344 (2012).
[2] J.P. Ebran, E. Khan, T. Niksic, D. Vretenar, PRC 89,031303(R) (2014).
[3] R.D Lasseri, J.P. Ebran, E. Khan, N. Sandulescu, D. Vretenar, in preparation.

Shape coexistence in the microscopically guided IBM

Kosuke NOMURA
Physics Department, Faculty of Science, University of Zagreb, Croatia

Abstract: Shape coexistence has been a subject of great interest in nuclear physics for many decades. In the context of the nuclear shell model, intruder excitations may give rise to remarkably low-lying excited 0+ states associated with different intrinsic shapes. In heavy open-shell nuclei, the dimension of the shell-model configuration space that includes such intruder excitations becomes exceedingly large, thus requiring a drastic truncation scheme. Such a framework has been provided by the interacting boson model (IBM). We discuss the phenomenon of shape coexistence and its relevant spectroscopy from the point of view of the IBM. A special focus is placed on the method developed recently, which makes use of the link between the IBM and the self-consistent mean-field approach based on the nuclear energy density functional. The method is extended to deal with various intruder configurations associated with different equilibrium shapes. I will demonstrate the predictive power of the method by considering illustrative examples in the neutron-deficient Pb region, and present a recent application to more challenging cases of neutron-rich Zr-Sr nuclei.

Pasta phase transitions in the inner crust of neutron stars

Xavier VIÑAS
Dep. de Física Quantica i Astrofísica and Inst. de Ciencies del Cosmos Facultat de Física, Univ. de Barcelona, Spain

Abstract: In the inner crut of neutron stars, at baryon densities between 1.5 × 1014 g/cm^3 and 4.0 × 1011 g/cm^3, matter consists of neutron, protons and electrons. The positive charges are concentrated in individual clusters of charge Z and form a solid lattice to minimize the Coulomb repulsion among them. This lattice is permeated by a gas of free neutrons an a background of electrons, such that he whole system is charge neutrl. In his region the nucler clusters may addopt non-spherical shapes, generically referred as nuclear pasta. Although sophisticated quantal calcuations can be done to deal with such exotic nuclear structures, they are complicted owing the presence of the neutron gas and they are, usually, very time consuming. As a result, large scale calculations of the inner crust and pasta phases are quite often performed using semiclasssical techniques, such as the Compressible Liquid Drop Model (CLDM) [1] and Thomas-Fermi (TF) type approaches [2,3] using effective forces. In this contribution I will discuss pasta phase transitions using the CLDM and the self-consistent TF method [4] using modern Skyrme forces and the BCPM energy density functional [5] comparing with another calculations available in the literature. The EOS corresponding to the inner crust of neutron stars and its impact on the mass-radius relationship are also presented.

[1]. F. Douchin and P. Haensel, A&A 380, 151 (2001).
[2]. P. Haensel, A. Potekhin and D.G. Yakolev ”Neutron Stars I: Equation of State and Structure”, (New York, Springer) .
[3]. N. Chamel and P. Haensel, LivRel.Relat 11, 10 (2008).
[4]. B.K. Sharma, M. Centeelles, X. Vinas, M. Baldo and F.G. Burgio, A&A 584, A103 (2015).
[5]. M. Baldo, L.M. Robledo, P. Schuck and X. Vinas, Phys.Rev C87, 064305(2013).

Proton-neutron structure of first and second quadrupole excitations in ^{90}Sr

Alexey P. SEVERYUKHIN
Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
Abstract: Starting from a Skyrme interaction we study the properties of the $2^+_{1,2}$ excitations in ^{90,92}Zr and ^{88,90}Sr. The coupling between one- and two-phonon terms in the wave functions of excited states are taken into account. We use the finite-rank separable approximation which enables one to perform the QRPA calculations in large two-quasiparticle spaces. Using the Skyrme force f_- together with the volume pairing interaction, we describe available experimental data and give the prediction for ^{90}Sr, $g(2_2^+)=-0.14$ in comparison to $g(2_1^+)=-0.07$, $B(M1;2_2^+\rightarrow 2_1^+)=0.61\mu_N^2$.

Data on Type II Shell Evolution in ^{96}Zr from electron scattering

Norbert PIETRALLA
Institut fuer Kernphysik, Technische Universität, Darmstadt, Germany
Abstract: Type II shell evolution has recently been identified as a microscopic cause for nuclear shape coexistence. Experimental evidence for T2SE comes from excitation energies in ^{68}Ni. The sharp shape phase transition in neutron-rich Zr isotopes is expected to be caused by T2SE, too. We report on the first measurement of the intra-band E2 transition rates of the rotational band on top of the first excited 0^+ state of ^{96}Zr. The data were obtained from electron scattering at the S-DALINAC and provide evidence for T2SE for the first time based on absolute transition strengths.

Experimental signatures of quantum phase transitions in nuclei

convenors: Richard CASTEN, Norbert PIETRALLA

Perspective on structural evolution. Partial Dynamical Symmetries. Testing Theories

Richard CASTEN
Yale University, USA
Abstract: This introductory talk will cover three diverse but related topics. A) An empirical perspective on how nuclear structure evolves using a variety of observables, informed by simple idealized models. B) A discussion of Partial Dynamical symmetries and recent tests of their predictions, including a discussion of the implications for the evolution of collective structure with nucleon number. C) Some remarks on appropriate and inappropriate approaches to testing theories, including the concept of theoretical uncertainties and the dangers of blind statistical tests.

^{58,60}Cr - candidates for the E(5) limit

Thomas BRAUNROTH
Institute for Nuclear Physics, University of Cologne, Germany
Abstract: The E(5) limit [1] describes nuclei at the critical point of the shape phase transition from a vibrator to a γ soft structure. So far, ^{134}Ba [2] and ^{128}Xe [3] are the most prominent candidates for the E(5) limit. Motivated by ratios between various level energies, e.g. $R = E(4^+)/E(2^+)$, ^{58}Cr was proposed as a candidate for the E(5) limit [4]. Lifetimes of low-lying yrast states in ^{58,60,62}Cr were measured with the RDDS technique at NSCL, MSU (USA) to deduce model independent B(E2) values [5]. Our results show a rapid increase in quadrupole collectivity from ^{58}Cr to ^{62}Cr. In particular, quadrupole deformation in ^{58,60,62}Cr appear to be more pronounced compared to the even-even Fe isotones. In addition, ratios of experimental B(E2) values, e.g. $B = B(E2;4^+_1\rightarrow 2^+_1)/B(E2;2^+_1\rightarrow 0^+_1)$, show that ^{60}Cr is in reasonable agreement with the E(5) limit. In this contribution experimental details of this experiment will be presented and corresponding results will be discussed in the IBM-2 framework.
[1] F. Iachello, PRL 85, 3580 (2000)
[2] R.F. Casten and N.V. Zamfir, PRL 85, 3584 (2000)
[3] R.M. Clark et al., PRC 69, 064322 (2004)
[4] N. Marginean et al., PL B 633, 696 (2006)
[5] T.Braunroth et al., PRC 92, 034306 (2015)

Collective structures in the neutron deficient nucleus ^{180}Pt

Thomas BRAUNROTH (on behalf of C. MÜLLER-GATERMANN)
Institute for Nuclear Physics, University of Cologne, Germany
Abstract: The X(5) limit [1] describes nuclei at the critical point of shape phase transition from a vibrator to an axial rotor. A good example for X(5) is given by the neutron-deficient nucleus ^{178}Os, whose low-lying excitation energies and corre sponding transition properties are in good agreement with this critical point symmetry. We performed lifetime measurements using the RDDS and the Fast-Timing technique to investigate in more detail the collective structures in the neighbouring even-even

isotone ^{180}Pt [2]. These experiments were further motivated by the fact that already existing experimental data are to some extend in disagreement [3, 4]. In qualitative terms, our results classify ^{180}Pt as a prolate rotor with a certain degree of γ-softness. In this contribution we present experimental details and compare the experimental B(E2) values to IBA calculations.

[1] F. Iachello, PRL 87, 052502 (2001)
[2] C. Muller-Gatermann, to be published
[3] M.J.A. de Voigt et al., NP A 507, 472 (1990)
[4] E. Williams et al., PRC 74, 024302 (2006)

New *B*(M1), *B*(E2) signatures of QPT using scissors 1^+

Johannes C. WIEDERHOLD
Institut für Kernphysik - Technische Universität Darmstadt, Germany

Abstract: Starting from the Interacting Boson Model and the *Q*-phonon scheme a relation between the branching ratio of the 1^+ scissors mode to the first 0^+-states and the branching ratio of the first 2^+-state to these 0^+-states can be derived. Multiplying this equation with the empirical correlation $B(M1;0^+_1\text{->} 1^+$ scissors mode) ≈ $B(E2;0^+_1\text{->}2^+_1)$ squared, results in a relation between a product of *B*(M1)-strengths and a product of *B*(E2)-strengths. It could be shown that the *B*(M1)-product is a possible signature for a quantum phase transition (QPT) and peaks at N=90 for the Gadolinium isotopes. So also the product of *B*(E2) should be a hitherto unknown signature for a QPT. There is peak for the Samarium isotopes at N=90. But unfortunately there is no known M1-data for the transition of the scissors-mode to the second 0^+-state of the Sm-isotopes. In the sequence of Gd-isotopes, there is no peak. Noteworthy is the big uncertainty for ^{152}Gd. This uncertainty stems mainly from the literature value of the lifetime $\tau(0^+_2)$ of ^{152}Gd. To improve this value a fast-timing experiment has been carried out at the IFIN-HH in Bucharest. Excited states of 152Gd were populated via a ^{149}Sm(α,n)^{152}Gd reaction and the deexcitation gamma-rays were detected using the RoSphere detector array in a configuration with 14 HPGe- and 11 LaBr3-detectors.

HPGe-spectroscopy data on ^{90,92,94}Se, ground sequence + first off-yrasts; RIBF-EURICA results

Cesar LIZARAZO
Institut für Kernphysik - Technische Universität Darmstadt, Germany

Abstract: The evolution on nuclear deformation for neutron-rich nuclei in the region of Z≈40, N≈60, has been extensively studied over the last decades. In particular, the change of the deformation from ^{96}Zr (N=56) to ^{98}Zr (N=58) is one of the more extreme shape transitions in the entire chart of nuclides. Extensive efforts have been conducted previously to measure spectroscopic information (such as the 2^+ and 4^+ transition energies) for the very exotic nuclei in the vicinity, revealing that this sudden shape evolution is also present for Kr, Sr, Mo isotopes at N=58. Nevertheless, the question of the shape evolution is still open for cases such as Se or Ge, since no information of the nuclear transitions for these isotopes has been reported yet. In this talk, I present the first results of the transition energies found for ^{92,94}Se measured with the EURICA setup in the scope of the 2nd campaing of the SEASTAR project conducted in RIKEN, Japan, in May 2015. The nuclei of interest where produced via fragmentation of 238U @ 345MeV/A and selected using the high resolution BigRIPS fragment separator. The selected fission products passed through a LH2 secondary target where (*p,2p*), (*p,np*), (*p,p'*) reactions took place, and the final products were precisely indentified via TOF, energy loss and magnetic rigidity measurements using the ZeroDegree spectrometer. Finally, the nuclei were implanted on the AIDA silicon stopper, where de-excitation from isomeric states previously populated took place. The gamma rays emited during the de-excitation process where detected using the high-resolution gamma-ray setup EURICA. We will report on the gamma-ray spectroscopic information on ^{92,94}Se.

2^+ lifetime in ^{98}Zr

Norbert PIETRALLA
Institut für Kernphysik, Technische Universität, Darmstadt, Germany

Abstract: Heavy Zirconium isotopes are considered to exhibit the most rapid quadrupole shape-phase transition in nuclear physics from ^{98}Zr(spherical) to ^{100}Zr(deformed). This is based on the evolution of $R_{4/2}$ ratios. Unfortunately, the $B(E2;\, 0^+_1 \rightarrow 2^+_1)$ value for ^{98}Zr is unknown. We report on an attempt to measure it using COULEX on a beam of radioactive ^{98}Zr nuclei from the CARIBU facility at the Argonne National Lab. A small upper limit for $B(E2;\, 0^+_1 \rightarrow 2^+_1) < 11$ W.u. is obtained supporting the conclusions drawn before from level energies.

Lifetimes in even-even Zirconium isotopes from the FATIMA & EXILL campaign

Jan JOLIE
Institute of nuclear physics, University of Cologne, Germany

Abstract: During the FATIMA&EXILL campaign at the ILL, Grenoble, cold neutrons induced fission of ^{235}U and ^{241}Pu [1]. Using an array of eight Compton shielded EXOGAM Clover detectors and 16 LaBr3(Ce) scintillators Ge gated Labr3(Ce)-LaBr3(Ce)

coincidences were used to determine lifetimes of excited states in the shape transitional ^{98,100,102}Zr isotopes [2]. We present the results of these experiments obtained using the generalised centroid difference method [3].

[1] J.-M Régis et al. NIM A763 (2014) 210.
[2] S. Ansari master thesis university of Cologne (2016).
[3] J.-M Régis et al. NIM A726 (2013) 191.

Mapping the *N*=56 sub-shell closure. SEASTAR results

Marc LETTMAN
Institut für Kernphysik - Technische Universität Darmstadt, Germany

Abstract: In the chain of Zr isotopes a large $E(2^+)$ for stable ^{96}Zr could be observed, indicating a sub-shell closure at N=56. In this nucleus, shape coexistence between a spherical ground band and a collective deformed band was identified [Kremer]. This first experimentally confirmed case of Type-II shell evolution highlights the importance of ^{96}Zr for the frequently discussed phase transition in the Zr isotopes. So far it is unknown if the sub-shell closure N=56 is valid for proton-deficient nuclei. A near-constant behavior of the $E(2^+)$ for the Sr isotopic chain could be observed. On the other hand, a slight increasing $E(2^+)$ for ^{92}Kr was noticed. This leads to the question if the N=56 sub-shell closure vanishes for lighter, more neutron rich isotopes, which can be investigated in the Se and Ge isotopic chains. First results for the Ge isotopic chain could be obtained during the SEASTAR campaign 2015. Using BigRIPS and ZeroDegree spectrometer at the RIKEN Nishina Center, it was possible to select the reaction channels ^{87}As(p,2p2n)^{84}Ge, ^{87}As(p,2p)^{86}Ge and ^{89}As(p,2p)^{88}Ge. Using the NaI array DALI2 the energies of the yrast 2^+ and 4^+ states, providing the $R_{4/2}$ ratio, could be observed for all the three cases. The first 2^+ energy in ^{88}Ge and the 4^+ transition in ^{86,88}Ge could be measured for the first time. In addition, a candidate for the second 2^+ state in ^{86}Ge, which has a direct impact on conclusions of the gamma-softness in the Ge isotopes, could be observed for the first time.

The structure of low-lying states in ^{140}Sm

Malin KLINTEFJORD
University of Oslo, Norway

Abstract: The nucleus ^{140}Sm is located in a transitional region between spherical shape at the N=82 shell closure and strongly deformed prolate shapes for N<74. Theoretical models furthermore predict a transition of the ground-state shape for N=78 isotones from prolate to oblate with increasing Z. Lifetimes of low-lying states in ^{140}Sm were previously unknown due to the occurrence of two isomeric 10^+ states. A Coulomb excitation experiment with radioactive 140Sm beam was performed at the ISOLDE facility at CERN, using the MINIBALL spectrometer coupled to a DSSSD array. Three excited states in ^{140}Sm were populated during the experiment: the 2^+ and 4^+ states of the ground-state band and a non-yrast state at 990 keV excitation energy. The Coulomb excitation analysis with the code GOSIA yielded transition probabilities between these states and the spectroscopic quadrupole moment for the first 2^+ state The state at 990 keV excitation energy was previously interpreted as a 0^+ state. A measurement of gamma-gamma angular correlations following the beta decay of ^{140}Eu at the Heavy Ion Laboratory in Warsaw found the spin-parity of the state to be 2^+. In addition, the previously assigned 2^+ state at 1699 keV excitation energy was found to have spin-parity 0^+. The experimental B(E2) values and quadrupole moments are compared with theoretical calculations using beyond mean-field models, the shell model, and algebraic models. The results show that the triaxial degree of freedom is important for the shape transition. The analysis of the excitation spectrum and the transition probabilities using the interacting boson model suggests that ^{140}Sm exhibits many of the features expected for a nucleus with approximate E(5) critical point symmetry.

Alternating parity bands in nuclei - phase transition and stabilization of the octupole deformation with angular momentum increase

Rostislav JOLOS
Joint Institute for Nuclear Research, Dubna, Russia

Abstract: Low-lying octupole collective excitations play an important role in describing the structure of nuclei in different regions of the nuclide chart. Ground state alternating-parity rotational bands combining both positive- and negative-parity states are known in several nuclei. The experimental data indicate that octupole deformation becomes stable with increase of the angular momentum. A nondimensional characteristic of the spectra of the ground state alternating-parity bands is introduced and applied to investigation of a stabilization of the octupole deformation with increase of the angular momentum. We analyze the experimental data on the energies of the states belonging to the alternating-parity bands based on the ratio of the interpolated and the experimental energies of the negative-parity states. Interpolated energies are determined by the experimental energies of the neighboring positive-parity states assuming smooth dependence on the angular momentum. The values of the ratio of the interpolated and the experimental energies of the negative-parity states belonging to the ground state alternating-parity bands of many nuclei are evaluated.   It is shown that the angular-momentum dependence of the ratio of the interpolated and the

experimental energies of the negative-parity states belonging to the ground state alternating-parity bands indicates stabilization of the octupole deformation with angular-momentum increase. The results obtained indicate on universality of this dependence. Comparison of this universal behavior with the Debye relaxation phenomena in composite systems is done.

Quantum phase transitions in non-nuclear systems, part I: Quantum simulators

convenors: Lincoln D. CARR, Jorge DUKELSKY

Feynman's vision comes true: An overview of quantum simulators

Lincoln D. CARR
Department of Physics, Colorado School of Mines, Golden, Colorado, USA

In 1981 Feynman, inspired by concepts of cellular automata, proposed a universal quantum computer, a quantum simulator. 25 years later, many of the elements in Feynman's original proposal have been realized in the now over 100 working quantum simulators worldwide built on a wide variety of platforms. In this session, we cover a diverse grouping of quantum simulators treating quantum phase transitions and related dynamics. Starting with small systems of spin-1/2 fermions and double well experiments, we work our way up to the Kibble-Zurek mechanism, thermalization dynamics, coupled quantum dots, topological superfluids, and spin 3/2.

Deterministic quantum simulators with cold atoms

Selim JOCHIM
University of Heidelberg, Germany

Abstract: Experiments with ultracold gases have been extremely successful in studying many body physics, such as Bose Einstein condensates or fermionic superfluids. These are deep in the regime of statistical physics, where adding or removing an individual particle does not matter. An essential challenge for current experiments is to reach low enough entropies to observe low-temperature phases such as magnetically ordered states. In our work we deterministically prepare generic model systems containing a precise number of few ultracold fermionic atoms with tunable interaction. We have started the exploration of such few-body systems with a two-particle system that can be described with an analytic theory. As we increase the system size atom by atom, we have been working in a one-dimensional framework allowing us to describe the system as a Heisenberg spin chain at strong repulsion. This allowed us to deterministically prepare a finite antiferromagnetically ordered state. It is our vision is to use our tunable few-body systems as microscopic building blocks to assemble deterministic quantum systems that allow for the simulation of complex many-body models close to zero temperature.

From the classical to the quantum Kibble-Zurek scaling

Simone MONTANGERO
University of Ulm, Germany

Abstract: Tensor network methods are a powerful numerical tool that allows to investigate equilibrium and non-equilibrium properties of critical systems. In this talk I review recents developments in this field and present some novel results on the the Kibble-Zurek (KZ) hypothesis. The KZ hypothesis identifies the relevant time scales in out-of-equilibrium dynamics of critical systems employing concepts valid at equilibrium: It predicts the scaling of the defect formation immediately after quenches across classical and quantum phase transitions as a function of the quench speed. Here we study the crossover between the scaling dictated by a slow quench, which is ruled by the critical properties of the quantum phase transition, and the excitations due to a faster quench, where the dynamics is often well described by the classical model. For the specific case of a φ4 model we demonstrate that the two regimes exhibit two different power-law scalings, which are in agreement with the KZ theory when applied to the quantum and to the classical case. This result contributes to extending the prediction power of the Kibble-Zurek mechanism and to provide insight into recent experimental observations in systems of cold atoms and ions.

Quantum phase transitions with parity-symmetry breaking and hysteresis with atomic BECs in a double-well potential

A. Trenkwalder[1], G. Spagnolli[2], G. Semeghini[2], S. Coop[2,3], M. Landini[1], P. Castilho[1,4], L. Pezzè[1,2,5], G. Modugno[2], M. Inguscio[1,2], A. Smerzi[1,2,5] , Marco FATTORI[1,2]
[1]Istituto Nazionale di Ottica-CNR, 50019 Sesto Fiorentino, Italy
[2]LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, 50019 Sesto Fiorentino, Italy
[3]ICFO-Institut de Ciences Fotoniques, 08860 Castelldefels (Barcelona), Spain
[4]Instituto de Fisica de Sao Carlos, Universidade de Sao Paulo, 369, 13560-970 Sao Carlos, Brazil
[5]Quantum Science and Technology in Arcetri, QSTAR, 50125 Firenze, Italy

Abstract: In this work we report the experimental observation of the full phase diagram across a transition where the spatial parity symmetry is broken [1]. Our system consists of an ultra-cold gas of 39K with tunable interactions trapped in a double-well potential. At a critical value of the interaction strength, we observe a continuous quantum phase transition where the gas localizes in one well or the other, thus breaking the underlying symmetry of the system. Furthermore, we show the robustness of the asymmetric state against controlled energy mismatch between the two wells. This is the result of hysteresis associated with an additional discontinuous quantum phase transition that we fully characterize. Our results pave the way to the study of quantum critical phenomena at finite temperature, the investigation of macroscopic quantum tunneling of the order parameter in the hysteretic regime and the production of quantum entangled states at critical points including Schroedinger cat states with macroscopic atom number.
[1] A. Trenkwalder, G. Spagnolli, G. Semeghini, S. Coop, M. Landini, P. Castilho, L. Pezzè, G. Modugno, M. Inguscio, A. Smerzi, M. Fattori, Nature Physics (2016) doi:10.1038/nphys3743

Power law decays and thermalization in isolated many-body quantum systems

Lea SANTOS
Yeshiva University, USA

Abstract: I will discuss the short- and long-time dynamics of isolated many-body quantum systems, using for this the survival probability of the initial state. The results are general, applying to systems that are integrable and chaotic, interacting and noninteracting, disordered and clean. Specifically, the decay of the survival probability at short times can be very fast, even faster than exponential when the system is strongly perturbed out of equilibrium. At long times, however, the evolution of any quantum system with bounded spectrum slows down and shows a powerlaw decay. The powerlaw exponent contains information about the shape and filling of the energy distribution of the initial state. An exponent greater than or equal to 2 indicates that the distribution is ergodically filled and that the system will eventually thermalize.

Quantum phase transitions and microcanonical description of atom-field systems

Miguel A. BASTARRECHEA MAGNANI
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de Mexico

Abstract: The Dicke model describes a system of *N* two-level atoms interacting with a single monochromatic electromagnetic radiation mode within a cavity. In the language of quantum information and quantum computation it can also describe a set of *N* qubits from quantum dots, Bose-Einstein condensates, or QED circuits. A paradigmatic example of quantum collective behavior in quantum optics, the Dicke model has gained increased interest in the last years not only for its possible applications but also because it exhibits critical phenomena like the Ground-State and Excited Quantum Phase Transitions. It is not clear, however, how these properties from its spectrum are explained from a thermodynamical point of view because there is no direct framework to employ zero temperature techniques to analyze finite temperature problems. In order to develop an approach which let us to interpret critical features in the spectrum of quantum many-body systems with few collective degrees of freedom, in this work, we employ a semi-classical approximation to calculate the thermodynamics of a extended Dicke model in the microcanonical ensemble. Then, we compare this approach with the results in the canonical ensemble in order to explore the connection between the description of isolated quantum systems and the statistical ensemble one. As a result we can give a straightforward thermodynamical explanation to some features of the critical phenomena in the spectrum of the Dicke model beyond zero temperature.

Symmetry-based approach to nuclear structure and quantum phase transitions

convenors: Piet Van ISACKER, Amiram LEVIATAN

Open quantum systems and superradiance phase transition

Vladimir ZELEVINSKY
Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA

Abstract: The center of interest in nuclear structure and nuclear astrophysics is currently in physics of loosely bound nuclei out of the valley of stability. Here standard many-body theoretical approaches are not sufficient, one has to account for the continuum effects, the system becomes open, structure and reactions are unseparable. One of the convenient theoretical tools here is the effective non-Hermitian Hamiltonian. I show briefly how it works and discuss the relation of this approach to physics of superradiance in quantum optics. At strong coupling to continuum, an open system undergoes a phase transition with sharp segregation of short-lived (super-radiant) and long-lived (trapped) states. Examples cover broad applications from many-body physics to disordered condensed matter.

[1] N. Auerbach and V. Zelevinsky, Super-radiant dynamics, doorways and resonances in nuclei and other open mesoscopic systems. Rep. Prog. Phys. 74, 106301 (2011).
[2] V. Zelevinsky and A. Volya, Chaotic Features of Nuclear Structure and Dynamics: Selected Topics. Physica Scripta 91, 033006 (2016).

On the nature of the shape coexistence phenomenon in the lead region

José Enrique GARCÍA-RAMOS
University of Huelva, Spain

Abstract: The lead region is considered as a paradigm of the shape coexistence phenomenon and several decades of experimental effort have supported this belief. In particular, long chains of the Pb, Hg, Pt and Po isotopes have been measured and a rich experimental body of data concerning excitation energies, electromagnetic transition rates, radii, magnetic g-factors, alpha-hindrance factors and Coulomb excitation reactions has been obtained. In the case of Pb and Hg, the presence of intruder states is self-evident inspecting the parabolic energy systematics of the intruder states. However, in the case of Pt and Po, the presence and influence of intruder states is not obvious. In this contribution, we try to clarify the situation using a set of Interacting Boson Model calculations. We show that in order to understand the systematics of the large set of observables in this mass region, we can resort to simple arguments based on the strength of the interaction between regular and intruder configurations and, moreover, on the energy difference between both types of configurations.

Symmetry-based approach to prolate-oblate coexistence in nuclei

Amiram LEVIATAN
Racah Institute of Physics, Hebrew University, Jerusalem, Israel

Abstract: We present a symmetry-based approach for prolate-oblate and spherical-prolate-oblate shape coexistence in nuclei [1]. The proposed IBM Hamiltonian with cubic terms, conserves the SU(3) and $\overline{\mathrm{SU(3)}}$ symmetry for the prolate and oblate ground bands and the U(5) symmetry for selected spherical states. Quadrupole moments and *B*(E2) transition rates, involving these states, are calculated in closed form and isomeric states are identified by means of selection rules. The purity of particular subsets of states, in the presence of other mixed states, demonstrates the relevance of partial dynamical symmetries to shape-coexistence in nuclei.
[1] A. Leviatan and D. Shapira, Phys. Rev. C, in press, arXiv:1605.00782 [nucl-th]

First-order QPT between spherical and gamma-unstable nuclear shapes

Noam GAVRIELOV
Hebrew University, Jerusalem, Israel

Abstract: We introduce a three-body interaction within the IBM framework which produces a novel first-order QPT between spherical to γ-unstable nuclear shapes. From the derived three-body energy surface we obtain a complete phase diagram and explore its different regions, concentrating on the critical line and identifying spectral signatures along it.

Phase diagram of the two-fluid Lipkin model: A butterfly catastrophe

J.E. García-Ramos, P. Pérez-Fernández, E. Freire, and José M. ARIAS
University of Seville, Spain

Abstract: The phase diagram of a two-fluid Lipkin model that resembles the nuclear proton-neutron interacting boson model Hamiltonian is established using both numerical results and analytic tools. The order of the different phase-transition lines and surfaces is determined using a catastrophe theory analysis. There are two first order surfaces in the phase diagram, one separating the spherical and the deformed shapes, while the other separates two different deformed phases. A second order line, where the later surfaces merge, is found. This line finishes in a singular transition point in which a divergence in the second order derivative of the energy appears.

Cluster and shell configurations: competition and coexistence

Jozsef CSEH
MTA ATOMKI, Debrecen, Hungary

Abstract: The discussion of nuclear clusterization in terms of symmetry-based models reveals the different kinds of clustering (for a two-cluster-system): molecule-like, shell-like, and weak-coupled (somewhat similarly to the three kinds of quadrupole collectivity of rotation, vibration and gamma-unstable). Therefore, the phase diagram is two-dimensional [1]. The possible phase-transitions have been studied by schematic calculations both in the simple vibron model [2], and in the cluster model (of coupled degrees of freedom [3]. The phase diagram of the shell model can also be illustrated by a triangle [4], and it matches with that of the cluster model at the U(3) dynamical symmetry [1]. Different shell and cluster model calculations lead to the

conclusion that the ground-state band of ^{20}Ne is located very close to this intersection [5], indicating the importance of shell-like clusterization. The multichannel dynamical symmetry [6] establishes a connection between the ground as well as excited states of the shell and cluster approaches. A complete high-energy cluster spectrum can be projected out from the shell description [7], and its similarity to the observed one suggests the importance of shell-like clusterization also in the highly excited region.

[1] J. Cseh, J. Phys. Conf. Ser. 205 (2010) 012021.
[2] P. Cejnar, F. Iachello, J. Phys. A 40 (2007) 581; Zhang Y et al. 2008 Phys. Rev. C 78 (2008) 024314.
[3] H. Yepez-Martinez et al, Phys. Rev. C 74 (2006) 024319, 85 (2012) 014316, 014317.
[4] P. Van Isacker, Nucl. Phys. A 704 (2002) 232c.
[5] J. Darai, J. Cseh, J. Phys. Conf. Ser. 580 (2015) 012057.
[6] J. Cseh Phys. Rev. C 50 (1994) 2240; J. Cseh, K. Kato, Phys. Rev. C 87 (2013) 067301.
[7] J. Cseh, Phys. Lett. B 743 (2015) 213; J. Cseh, G. Riczu, Phys. Lett. B in press, arXiv 1504.04480 [nucl-th] 2015.

The octupole solution of the shell model

Piet Van ISACKER
GANIL, Caen, France

Abstract: Elliott's treatment of deformed nuclei relies on the symmetry of SU(3). Elliott's model is important since it establishes a link between the spherical shell model and the quadrupole component of the geometric collective model. A quadrupole interaction acting in a single major oscillator shell *N* induces a deformed mean field and leads to rotational behaviour in the context of the spherical shell model. In this talk a generalization of the SU(3) model is discussed by including several major shells and an application to ^{20}Ne is presented. Furthermore, it is shown that a symmetry exists, analogous to SU(3), which is induced by an octupole interaction acting in two major oscillator shells $N-1$ and N. This leads to the octupole-deformed solution of the spherical shell model. In the limit of large oscillator shells, $N\rightarrow\infty$, the algebraic octupole interaction tends to that of the geometric collective model.

Electromagnetic selection rules in the triangular alpha-cluster model of ^{12}C

Gianluca STELLIN

Abstract: The implications of point-group symmetries on the states and quantum numbers of a triangular structure of three structureless alpha particles are analysed in detail, recovering the old results of Wheeler for the ^{12}C. The approximations of the model along with the application of group theoretical techniques lead to particular selection rules (e.g. the prohibition of the E1 and M1 transitions in all the bands and of M2 and M3 ones in certain excited bands), which turn to be useful for the interpretation of the ^{12}C γ-ray spectrum.

Study of the Bohr Hamiltonian with sextic potentials

Panagiotis E. GEORGOUDIS
Racah Institute of Physics, Hebrew University, Jerusalem, Israel

Abstract: Critical (sextic) potentials emerging from the Classical Limit of the IBM with cubic terms are applied to the γ-unstable Bohr equation. The SU(1,1)×SO(5) Spectrum Generating Algebra (Algebraic Collective Model) produces an O(6)-like ground state band and a U(5)-like excited band.

Quantum phase transitions in non-nuclear systems, part II: Advanced quantum materials

convenors: Lincoln D. CARR, Jorge DUKELSKY

Universal Fermi liquid crossover and quantum criticality in a mesoscopic system

Andrew KELLER
California Institute of Technology, USA

Abstract: A quantum dot tunnel-coupled to a metallic grain can host a non-Fermi liquid two-channel Kondo state, where a spin-1/2 impurity is exchange-coupled to two independent electron reservoirs. The two-channel Kondo state occurs at the critical point of a second-order quantum phase transition, which surprisingly has exact theoretical descriptions both at and away from the critical point, even at finite temperature. We confirm transport signatures of quantum criticality as first reported by Potok, et al. (Nature 446, 167–171 (2007)), and then go further by quantitatively validating a universal theory for the crossover to a Fermi liquid (Nature 536, 237–240 (2015)). The universality of this crossover in the presence of arbitrary symmetry-breaking perturbations is a consequence of emergent symmetry at the non-Fermi liquid fixed point.

Particle-conserving topological superfluids and the fate of Majoranas

Gerardo ORTIZ
Indiana University, USA

Abstract: What distinguishes topologically trivial from non-trivial superfluids in interacting many-body systems with a conserved number of particles? What is the meaning and fate of Majorana zero-energy modes in interacting fermionic superfluids? These are questions that require a concrete operational answer if one seriously considers using these physical systems for quantum information processing purposes. Most of what we know about topological superfluids and Majorana excitations is based on a mean-field approximation, the Bogoliubov-de Gennes approach, that breaks particle-number conservation and, by construction, displays a particle-hole symmetry and thus a zero mode structure. I will attempt to answer the questions above from both basic physics principles, and concrete models perspectives. I will illustrate ideas by analyzing the Richardson-Gaudin-Kitaev wire, an interacting number-conserving variation of the Kitaev model that displays a topological phase transition from a topologically trivial to a non-trivial superfluid phase.

Spin and charge resolved quantum gas microscopy of antiferromagnetic correlations in Hubbard chains

Guillaume SALOMON, M. Boll[1] T.A. Hilker[1], A. Omran[1], I. Bloch[1,2], C. Gross[1]
[1]Max-Planck-Institut f¨ur Quantenoptik, Garching, Germany,
[2]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany

Abstract: Ultracold fermions in optical lattices allow for the simulation of the Hubbard Hamiltonian with a unique control over kinetic energy, interactions and dimensionality. However the study of the onset of magnetic ordering at low temperature turns out to be challenging when looking at trap averaged quantities. We will present our recent experimental study of spin correlations in spin 1/2 Hubbard chains using a quantum gas microscope. We revealed antiferromagnetic correlations at distances up to three sites corresponding to a local entropy well below *ln*2. Our ability to measure both charge and spin opens exciting perspectives for studying the interplay between magnetic ordering and doping in ultracold fermion systems.

Phase separation of superfluids in the chain of four-component ultracold atoms

Ors LEGEZA
Wigner Research Centre for Physics, Budapest, Hungary

Abstract: We investigate the spin-polarized chain of ultracold fermionic atoms with spin-3/2 which interact by s-wave attractive contact potentials. The competition of bound pairs, trions, quartets and unbound atoms is studied analytically and by the density matrix renormalization group (DMRG) method. For attractive couplings, we find that the ground state is a mixture of two distinct superfluid phases, spin-carrying pairs and singlet quartets, which form alternating domains in case of strong enough mass imbalance. For a special parametrization of the interactions, the system becomes an SU(4) symmetric Hubbard-like model and several distinct phases of bound particles coexisting with the ferromagnetic state of unpaired fermions are observed. In particular, an exotic inhomogeneous Fulde-Ferrell-Larkin-Ovchinnikov (FFLO)-type superfluid of quartets in a magnetic background of uncorrelated atoms is found for weaker interactions. We show that the system can be driven from this quartet-FFLO state to a molecular state of localized quartets which is also reflected in the static structure factor. For strong enough coupling, spatial segregation between molecular crystals and ferromagnetic liquids emerges due to the large effective mass of the composite particles.

[1] G. Barcza, E. Szirmai, J. Solyom, O. Legeza, arXiv:151206669v1 (2015). The European Physical Journal, Special Topics, 224, Issue 3, pp 533-538 (2015).
[2] E. Szirmai, G. Barcza, J. Solyom, O. Legeza, arXiv:151206669v1 (2015).

Quantum phase transitions in coupled systems

convenors: Francisco PÉREZ BERNAL, José Enrique GARCÍA RAMOS

Dispersion relations and densities of states in coupled U(2) and U(3) models

Michal MACEK
ISI, CAS Brno and IPNP, Charles University Prague, Czechia

Abstract: We discuss energy dispersion relations (EDRs) and densities of states (DoSs) for multi-phonon vibrational states in coupled U(2) and U(3) bosonic models. We consider bosons (phonons) placed on 1D linear chains and 2D square lattices of both finite and infinite sizes. Some generalizations are made for hypercubic lattices. We study effects of anharmonicities and point out also the singularities in DoSs, related to Excited State Quantum Phase Transitions.

Quantum signatures of chaos in boson-fermion systems

Miguel A. BASTARRECHEA MAGNANI
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de Mexico

Abstract: Quantum chaos is associated with the quantum description of a system whose classical counterpart exhibit chaos, and with a Wigner distribution of nearest neighbors energy differences. In this work we introduce a method to quantify quantum chaos in quantum systems whose algebraic structure allows to obtain a classical phase space through coherent states. We employ the participation ratio (PR) of a coherent state spanned in the Hamiltonian eigenstate basis. We compare this quantity with the Lyapunov exponent over different energy regions and we show it allows for a detailed exploration of the semi-classical phase space employing only quantum tools. In order to test the method, we take advantage of the algebraic and critical features of the Dicke Hamiltonian, one of the simplest models of spin-boson interaction, originally meant to describe a system of *N* two-level atoms interacting with a single monochromatic electromagnetic radiation mode within a cavity, which in the quantum computing framework can also describe a set of *N* qubits from quantum dots, Bose-Einstein condensates, or QED circuits. The Hamiltonian exhibits not only a second-order ground-state quantum phase transition (QPT) and excited-state quantum phase transitions (ESQPT), but also quantum signatures of chaos along its spectrum. This proposal could help to gain understanding on the connection between ESQPT and quantum chaos, which has been suggested it is dependent on the particular system of study.

Partial dynamical symmetry in Bose-Fermi systems

Jan JOLIE
Institute of nuclear physics, University of Cologne, Germany

Abstract: We generalize the notion of partial dynamical symmetry (PDS) to a system of interacting bosons and fermions. In a PDS, selected states of the Hamiltonian are solvable and preserve the symmetry exactly, while other states are mixed. As a first example of such novel symmetry construction, spectral features of the odd-mass nucleus ^{195}Pt were analyzed [1].

[1] P. Van Isacker, J. Jolie, T. Thomas and A. Leviatan, Physical Review C 92, 011301(R) (2015)

Microscopic approach to coupled quadrupole-octupole collective states

Kosuke NOMURA
Physics Department, Faculty of Science, University of Zagreb, Croatia

Abstract: I will present some of our recent studies on the quadrupole-octupole collective states in rare-earth nuclei. The quadrupole-octupole deformation energy surface calculated with the constrained self-consistent mean-field method using the Gogny force is mapped onto the equivalent interacting-boson Hamiltonian. The resulting Hamiltonian is used to calculate spectroscopic properties identifying the impact of octupole correlation on the shape phenomena in Sm and Gd isotopes. The method gives reasonable description of available data and also has the same level of predictive power as the symmetry-projected GCM approach.

Classical chaos in atom-field systems

Jorge CHÁVEZ CARLOS
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de Mexico

Abstract: The relation between the onset of chaos and the critical phenomena, like Quantum phase transitions (QPT) and Excited State Quantum Phase transitions (ESQPT), is analyzed for atom-field systems. While it has been speculated that the onset of hard chaos is associated with ESQPT based in the resonant case, the off-resonant cases show clearly that both phenomena, ESQPT and chaos, respond to different mechanisms. The results are supported in a detailed numerical study of the dynamics of the semiclassical Hamiltonian of the Dicke model. The appearance of chaos is quantified calculating the largest Lyapunov exponent for a wide sample of initial conditions in the whole available phase space for a given energy. The percentage of the available phase space with chaotic trajectories is evaluated as a function of energy and coupling between the qubit and bosonic part, allowing to obtain maps in the space of coupling and energy, where ergodic properties are observed in the model. Different sets of Hamiltonian parameters are considered, including resonant and off-resonant cases.

A new point of view of the local to normal mode transition

Marisol BERMÚDEZ-MONTAÑA
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de Mexico

Abstract: The use of the normal mode picture has played a fundamental role in the description of molecular vibrational excitations. On the other hand, a local mode scheme also provides a reasonable description when large mass differences are involved. When molecules with normal behaviour are studied in the local scheme, the description should include polyad breaking. In this work, the local to normal mode transition is analyzed for two interacting Morse oscillators parametrized in

terms of their structure and force constants. It is shown that the fidelity, entropy and Poincaré sections detect the polyad breaking process manifested in the transition from local to normal mode behaviors. Additionally Poincaré sections show a transition to chaos where the polyad cannot be defined.

New interdisciplinary playgrounds for algebraic models: From molecules to hypernuclei

Lorenzo FORTUNATO
Università degli Studi di Padova, Italy

Abstract: In the spirit of workshop to spur new ideas and connect different areas of physics, I will discuss the newly found applications of algebraic theories to very diverse quantum systems from supramolecular chemistry to hypernuclear physics. The parallelism I wish to make is between hydrogen molecules endohedrally confined in fullerenes (H2@C60) on one side and the interaction of Lambda particles in the nuclear environment on the other. I will also try to suggest the relevance of quantum phase transitions in these systems.

QPT and ESQPT in the Rabi model

Ricardo PUEBLA ANTUNES
University of Ulm, Germany

Abstract: We consider the Rabi Hamiltonian, which undergoes a superradiant quantum phase transition (QPT) despite consisting only of a single--mode cavity field and a two-level atom [1]. We prove QPT by deriving an exact solution in the limit where the atomic transition frequency in the unit of the cavity frequency tends to infinity. The exact solution allows us to obtain critical exponents and the exact behavior of relevant quantities of the system. Furthermore, in the spirit of finite-size scaling theory, the effect of a finite transition frequency is studied by analytically calculating finite-frequency scaling exponents as well as performing a numerically exact diagonalization. As in other well-known models where a QPT takes place in systems with a finite number of degrees of freedom, as Dicke model or Lipkin-Meshkov-Glick model, the QPT in the Rabi model is accompanied by an excited-state quantum phase transition (ESQPT), which shows the expected features of an ESQPT with one degree of freedom. Therefore, we show that both, QPT and ESQPT, can be indeed achieved in a system consisting only of a single two-level atom coupled to a single bosonic mode.

[1] M.--J. Hwang, R. Puebla and M. B. Plenio, Phys. Rev. Lett. 115, 180404 (2015).

Excited state quantum phase transitions

convenors: Tobias BRANDES, Michal MACEK

Bose-Einstein condensates in ring traps: Topological unwinding, strongly correlated solitons, and metastable quantum phase transitions

Lincoln D. CARR
Department of Physics, Colorado School of Mines, Golden, Colorado, USA

Abstract: One-dimensional quantum gases on the 1D ring offer a highly tunable quantum many body system with the possibility of non-trivial topologies and can be studied via a plethora of methods, from analytical to numerical to experimental. Taking our model as the rotating Lieb-Liniger Hamiltonian, we show theoretically that past a critical boundary in the interaction-rotation plane a finite-size metastable generalization of a quantum phase transitions occurs: the average angular momentum per particle abruptly changes from quantized, to continuously variable. Past this boundary a superfluid can be continuously wound and unwound. We identify the Yrast states as the key players in this quantum phase transition. We explain how macroscopic features like solitons emerge from the microscopic many body physics. We find the quantum generalization of dark solitons and superflow from the weakly interacting system all the way to the most strongly interacting, Tonks-Girardeau regime.

Classification of ESQPTs

Pavel STRÁNSKÝ
IPNP, Charles University, Prague, Czechia

Abstract: An Excited-State Quantum Phase Transition (ESQPT) manifests itself as a nonanalytic behaviour of the quantum spectrum in the system's infinite limit. These non-analyticities are induced by stationary points of the Hamiltonian and affect the density of energy levels and their dynamics with varying control parameters. Non-degenerate stationary points lead to singularities in the $(f-1)$-th derivative of the density and flow of the spectrum, and can be fully classified by a pair of integers (f,r), where f is the number of degrees of freedom and r is the index of the stationary point. For degenerate stationary points, an increase of flatness shifts the singularity to lower derivatives. Additionally, finite-size systems exhibit precursors of ESQPTs in the oscillatory component of the level density, originating in lower dimension, and present in case of an effective partial separability of dynamics. The theoretical results will be demonstrated on f=2 and f=3 toy models.

A thermodynamic interpretation of quantum phase transitionms: A microcanonical description of the generalized Dicke Hamiltonian

Miguel A. BASTARRECHEA MAGNANI
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de Mexico

Abstract: A paradigmatic example of quantum collective behavior in quantum optics, the Dicke model has gained increased interest in the last years not only for its possible applications but also by cause of its critical phenomena: the Ground-State and Excited-States Quantum Phase Transitions (ESQPT). However, it is not clear how these spectral properties are explained from a thermodynamical point of view, due to the absence of a direct framework to employ zero temperature techniques to analyze finite temperature problems. In order to develop an approach which let us to interpret thermodynamically critical features in the spectrum of quantum many-body systems with few collective degrees of freedom, in this work, we employ a semi-classical approximation to calculate the thermodynamics of a generalized Dicke model in the microcanonical ensemble. As a result we can exhibit that even though critical features like the ESQPT are representative from the isolated finite systems point of view, the contribution of states on those energy regimes to the thermodynamics are negligible.

The participation ratio of coherent states over energy eigenstates: a quantum measure sensitive to ESQPTs and chaos

Sergio LERMA
University of Veracruz, Mexico

Abstract: The excited state quantum phase transitions (ESQPTs) and the transition to a chaotic regime, phenomena unambiguously defined in the semi-classic limit, are explored, in the Dicke and LipkinMeshkov-Glick models, by using the participation ratio of coherent states. Numerical results are presented that show the way this quantum measure is sensitive to both (ESQPTs and chaos) phenomena.

Stripe-like Eigenstates at ESQPT/van Hove singularity energies in 2D lattices

Michal MACEK
ISI, CAS Brno and IPNP, Charles University Prague, Czechia

Abstract: Transversal phonon eigenstates of 2D square and hexagonal lattice systems, described by Vibron or tight-binding models, are found to form peculiar 1D stripes at energies corresponding to van Hove singularities, equivalent here to ESQPTs. We study numerically the persistence of these striped states to (i) noise, and to (ii) hopping interactions of higher than nearest-neighbor range.

Irreversibilty due to the loss of symmetry-breaking information crossing an ESQPT

Ricardo PUEBLA ANTUNES
University of Ulm, Germany

Abstract: We report the existence of closed cycles involving ESQPTs in which energy is not dissipated, but still are irreversible due to the loss of an extra information regarding the symmetry-breaking state, which is eroded during the process. Indeed, the expectation value of a symmetry-breaking observable changes from a value different from zero in the initial state, to zero in the final state. This entails the unavoidable loss of a certain amount of information, and constitutes a source of irreversibility. We show that the von Neumann entropy of time-averaged equilibrium states increases in the same magnitude as a consequence of the process. We support these results by means of numerical simulations involving the ESQPT of the Lipkin-Meshkov-Glick model [1].

[1] R. Puebla and A. Relaño, Phys. Rev. E 92, 012101 (2015)

ESQPTs in the two-fluid Lipkin model

Pedro PÉREZ-FERNÁNDEZ, J.E. García-Ramos, J.M. Arias, E. Freire
University of Seville, Spain

Abstract: We investigate precursors of Excited State Quantum Phase Transitions (ESQPTs) in the two-fluid Lipkin model that resembles the nuclear proton-neutron interacting boson model Hamiltonian. We show Peres lattices for different energies and constant couplings and we link these results with the presence of chaos and regularity in the system. This is still a work in progress.

QPTs in the dispersive driven dissipative Jaynes-Cummings model

Themis MAVROGORDATOS
University College London, UK

Abstract: We discuss the behaviour of the open driven generalized Jaynes-Cummings model in the context of phase and amplitude bimodality, underpinning first and second order quantum phase transitions in the strongly dispersive regime. We follow a single quantum trajectory approach, comparing to the (averaged) solution of the master equation and to mean field results. We demonstrate simultaneous qubit and resonator switching across a wide range of driving strengths, tracing bistability from the low-excitation mean field critical point.

Nonequilibrium heat transport in an exactly solvable quantum-critical model

Rudolf SÝKORA
Department of Condensed Matter Physics, Charles University, Prague, Czechia

Abstract: We study heat transport in an exactly solvable modification of the nonequilibrium transverse-field Ising-chain model originally studied by M. Vogl, G. Schaller and T. Brandes in Phys. Rev. Lett. 109, 240402 (2012), J. Phys. Cond. Matt. 26, 265001 (2014). The spin-chain model can be fermionized by the Jordan-Wigner transform to equivalent non-interacting fermions, and consequently exactly diagonalized for any value of the model parameters, in particular, the coupling to the heat spin baths. We verify the conclusions of the approximate master-equation treatment a la Vogl et al. in the limit of very weak coupling to reservoirs, and extend those results to finite coupling strengths. It turns out that for finite couplings the fate of the quantum-phase-transition-like singularities in the heat current depends crucially on the way how the thermodynamic limit is performed, more specifically, whether the full coherence along the (infinite) chain is preserved or not. We discuss the physical interpretation of the importance of the dephasing in the transport and also comment on the relation to the "conventional" equilibrium quantum phase transition (QPT) via the behaviour of correlation functions. We argue that the nonequilibrium phenomenon appears to be actually closer to the electronic topological transitions (cf. Ya. M. Blanter et al., Physics Reports 245, 159 (1994)) than standard QPTs.

Entanglement and ESQPT in an extended Dicke model

Michal KLOC
IPNP, Charles University, Prague, Czechia

Abstract: Entanglement as a purely non-classical correlation in a quantum system belongs to one of the most striking features of quantum mechanics. Several papers linking anomalous behaviour of entanglement to quantum phase transitions were published, for example [1,2]. Regarding the concept of ESQPTs, I will focus on how these singularities in the spectrum affect entanglement. We use slightly generalized Dicke model [3] which we call 'extended'. Such a model shows a rich variety of ESQPTs of a different type and so serves as a good theoretical framework for our investigation.

[1] K. Baumann, C. Guerlin, F. Brennecke and T. Esslinger, Nature 464, 1301 (2010)
[2] N. Lambert, C. Emary and T. Brandes, Phys. Rev. Lett. 92, 073602 (2004)
[3] R. H. Dicke, Phys. Rev. 93, 99 (1954)