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Scattering and Nuclear Matter / 2

Configuration space techniques to solve multiparticle scattering problem by using trivial boundary conditions

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The main difficulty to solve the scattering problem in configuration space is related to the fact that the scattering wave functions are not localized. One is therefore obliged to find solutions for multi-dimensional differential equations, which satisfy extremely complex boundary conditions. Finding a method which enables us to solve the scattering problem without an explicit use of the asymptotic form of the wave function is of great importance. In this talk I will present two configuration space formalisms [1-3], namely complex scaling and complex energy methods, which allow to solve rigorously scattering problem but still avoiding complex boundary conditions. Limitations of the two methods will be discussed, as well as some "lucky" cases.

Several applications will be provided for complex-scaling method proving its efficiency in describing elastic and three-body breakup reactions for Hamiltonians which may combine short-range, Coulomb as well as optical potentials. For the first time this formalism will be applied to solve four-nucleon scattering problem above the break-up threshold using realistic interactions.

[1] A. Deltuva et al., PPNP 74 (2014) 55.
[2] J. Nuttal and H. L. Cohen. Phys. Rev., 188 (1969) 1542.
[3] F. A. McDonald, J. Nuttall, Phys. Rev. Lett. 23 (1969) 361.

Molecular Systems + Nuclear Few-Body Systems / 4

Systematics of Elastic and Inelastic Deuteron Breakup

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Deuteron-induced reactions are being used to produce medical radioisotopes [1] and as surrogates to other reactions (see review [2] and references therein), among recent applications. Although they have been studied for decades [3-6], the complexity of these reactions continues to make their theoretical description challenging. The direct reaction mechanism is a major contributor to the reaction cross section due to the low binding energy of the deuteron. Competition between elastic breakup, absorption of only a neutron or a proton (stripping and inelastic breakup) and absorption of the deuteron must be taken into account to determine the formation or not of a compound nucleus and its subsequent decay. The inelastic breakup reactions –those in which either only a neutron or a proton is absorbed –are particularly complex, as they form compound nuclei with a wide range of excitation energies and angular momenta. We present the results of a theoretical study of elastic and inelastic deuteron breakup for a large selection of targets at incident deuteron energies below 100 MeV. We use the zero-range post-form DWBA approximation to calculate the elastic breakup cross section [3,4] and its extension to absorption channels to calculate the inelastic breakup cross sections [5,6]. We discuss the regularities and ambiguities in our results, as well as the irregularities in the

inelastic breakup energy and angular momentum distributions that complicate their substitution by a smooth distribution obtained from systematics.

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Reduced Dimensional Systems and Extended Efimov Physics / 8

Exploration of Efimov window in the N-body sector: Universality and Scaling

Auteur: Mario Gattobigio[1]

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In this talk I will illustrate the universal behaviour that we have found inside the window of Efimov physics for systems made of N≤6 particles [1]. We have solved the Schroedinger equation of the few-body systems using different potentials, and we have changed the potential parameters in such a way to explore a range of two-body scattering length, a, around the unitary limit, $|a| \longrightarrow \infty$. The ground and excited-state energies have been analyzed by means of a recent developed method which allows to remove finite-range effects [2]. In this way we show that the calculated ground- and excited-state energies collapse over the same universal curve obtained in the zero range three-body systems as shown in [2].

[1] M. Gattobigio and A. Kievsky, arXiv:1309.1927 (2013).
[2] A. Kievsky and M. Gattobigio, Phys. Rev. A 87, 052719 (2013).

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Charmonia and bottomonia spectroscopy

Auteur: elena santopinto[1]

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Charmonia and bottomonia spectroscopy will be discussed in an unquenched quark model.

Scaling and Universality / 11

Microscopic origin and universality classes of the three-body parameter

Auteur: Pascal NAIDON[1]

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Three particles resonantly interacting via short-range pairwise interactions experience the Efimov attraction which can bind them in an infinite series of three-body bound states. This phenomenon is well described in the zero-range theory, but this theory requires the introduction of a three-body parameter.

In this talk, I address the microscopic mechanism determining the three-body parameter from single-channel pairwise interaction potentials. I will show that it originates from a three-body deformation induced by pair correlation. This interpretation explains the universality of the three-body parameter observed for van der Waals potential, and suggest the existence of several university classes depending on the nature of the pairwise potential.

Efimov Physics and Miscellaneous / 12

Protonium Formation in a Collision Between Slow Anti-Proton and Muonic Hydrogen Atom

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Recent progress in creation of ultra-slow anti-protons, $\bar{p}$, [1] is of considerable scientific interest, because of possible formation of low-energy anti-hydrogen atoms $\bar{H}$: a bound state of $\bar{p}$ and a positron e+. The main goal of the anti-hydrogen/antimatter research is to check and confirm (or not confirm) certain fundamental laws and theories of modern physics. For example, one of the most important subjects in the field is to check the charge conjugation, parity, and time reversal (CPT) symmetry of quantum electrodynamics. In other words: a charged particle and its antiparticle should have equal and opposite charges, equal masses, lifetimes, and gyromagnetic ratios. The CPT symmetry predicts that the H and $\bar{H}$ atoms should have identical spectra. In order to test these fundamental laws of physics, new experiments are in progress in the field. Together with the $\bar{H}$ physics there is a significant interest in the protonium Pn atom too: Pn is a bound state of p and $\bar{p}$. For example, Pn formation is related to charmonium - a hydrogen-like atom ($c\bar{c}$), which is a bound state of a c-quark and c-antiquark. The $p\bar{p}$ annihilation can produce ($c\bar{c}$) in the ground and excited states. It would be interesting to study how charmonium interacts with other nuclear particles. It is interesting, because charmonium is composed of quarks, which are not parts of the nuclei. Charmonium interacts with nuclear particles through exchange of gluons. It provides the strong interaction. Gluons are usually manifested in processes at high energies, but in the interaction with nuclear particles charmonium gluons can be studied at low energies. In this work, a few-body system with Coulomb and nuclear forces is considered. Specifically we compute the cross-sections and rates of the ultra-low energy collision between $\bar{p}$ and a muonic hydrogen atom, i.e. a bound state of p, i.e a proton p+, and a muon, μ−: $\bar{p} + (p\mu)_{1s} \longrightarrow (p\bar{p})_\alpha + \mu^-$. (1)
Here, α=1s, or 2s/2p is Pn's quantum atomic state. In the low-energy muonic reaction (1) protonium is formed in a very compact, small size ground and "almost"ground states α, in which the hadronic nuclear force between p and $\bar{p}$ should be extremely pronounced. For example, in the atomic case of the reaction (1), i.e. $\bar{p} + (pe)_{1s} \longrightarrow (p\bar{p})_{\alpha'} + e^-$, Pn would be formed at highly excited "crumbly" states with $\alpha' \approx 30$. In the current work, a detailed few-body approach based on a Faddeev-Hahn-type equation formalism [2] is applied.

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G.B. Andresen (ALPHA Collaboration) et al., Phys. Rev. Lett. 105 (2010) 013003.
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Scaling and Universality + Atomic Systems / 13

Monte Carlo Simulations of the Unitary Bose Gas

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We investigate the zero-temperature properties of a diluted homogeneous Bose gas made of N particles interacting via a two-body square-well potential by performing Monte Carlo simulations. We tune the interaction strength to achieve arbitrary positive values of the scattering length and compute by Monte Carlo quadrature the energy per particle E/N and the condensate fraction N_0/N of this system by using a Jastrow ansatz for the many-body wave function which avoids the formation of the self-bound ground-state and describes instead a (metastable) gaseous state with uniform density. In the unitarity limit, where the scattering length diverges while the range of the inter-atomic potential is much smaller than the average distance between atoms, we find a finite energy per particle (E/N=0.70 hbar^2(6\pi^2 n)^{2/3}/2m, with n the number density) and a quite large condensate fraction (N_0/N=0.83).

Cold Atoms, Few- and Many-Body Physics / 14

Integrability and weak diffraction in a one-dimensional two-particle Bose-Hubbard model

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We study the one dimensional two-particle Bose-Hubbard model with a defect site. The continuum case of the model was claimed by McGuire to be nonintegrable fifty years ago, but now it is shown that the odd parity sector is integrable. More precisely, the odd-parity eigenstates are all in the Bethe-form.

Interestingly, this model offers a long-sought kind of exotic bound state: Bound state in the continuum. This kind of state was shown by von Neumann and Wigner eighty years ago to exist, but for the first time, we have found such a state with simple wave function and in a simple, realistic model.

We also show explicitly that the even-parity eigenstates are not in the Bethe form. However, some of them are close to the Bethe form and can be considered weakly diffractive. As a by-product, we bring up a method based on the Prony algorithm to check whether a numerically obtained wave function is in the Bethe form or not, and if so, to extract parameters from it. This algorithm is applicable to many other Bethe ansatz relevant models.

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Scaling and Universality / 15

Universal physics with three or four particles

Auteur: Chris Greene[1]

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Recent studies using the adiabatic hyperspherical representation have helped to provide an understanding of the universal three-body parameter for both homonuclear and heteronuclear systems characterized by van der Waals plus short-range interactions. This talk will discuss the current state of theoretical analyses of this important aspect of the universal Efimov effect, and what has been learned from recent experimental studies of the three-body parameter. Extensions of these hyperspherical ideas to handle four-body systems will also be presented, including a recent exploration of charge transfer collisions in the polyelectron system consisting of two electrons and two positrons.

Efimov Physics and Miscellaneous / 16

Efimov Resonances in a Mixture with Extreme Mass Imbalance

Auteurs: Juris Ulmanis[1]; Rico Pires[1]

Co-auteurs: Alda Arias [1]; Eva Kuhnle [1]; Marc Repp [1]; Matthias Weidemüller [1]; Stephan Häfner [1]

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We present the observation of two consecutive heteronuclear Efimov resonances in an ultracold Fermi-Bose mixture of Li-Cs by measuring magnetic field dependent three-body loss coefficients and atom loss spectra near a broad Feshbach resonance. The first Efimov resonance is found at a scattering length of a(0)=-320(10)a0, corresponding to approximately 7(3) times the Li-Cs (Cs-Cs) van der Waals range. The second resonance appears at a(1)=-1870(390)a0, close to the unitarity-limited regime at the sample temperature of 450 nK. Indication of a third resonance is found in the atom loss spectra. The scaling factor of the resonance positions of 5.8(1.0) is close to the predicted universal value of 4.9 for zero temperature mixtures. The refined Feshbach resonance position agrees excellently with an extensive interpretation of the recently observed interspecies Li-Cs Feshbach resonances by three different theoretical models: coupled channels calculation, asymptotic bound state model, and multi-channel quantum defect theory.

Reduced Dimensional Systems and Extended Efimov Physics / 17

Extended Efimov scenario: Boson droplets without and with an impurity

Auteur: D. Blume[1]

Co-auteur: Yangqian Yan [1]

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Three identical bosons at zero temperature exhibit the Efimov effect if the magnitude of the s-wave scattering length is much larger than the other length scales of the underlying two-body potentials. This talk discusses extensions of the Efimov scenario to more than three particles. Two different systems are considered: First, the properties of N identical bosons interacting through zero-range two-body potentials are discussed. Particular emphasis is placed on investigating how the N-boson properties depend on the regularization scheme employed in the three-body sector. Second, motivated by recent experimental investigations of Cs-Cs-Li Efimov resonances, the few-body properties of N-1 non-interacting identical heavy bosons, which interact with a light impurity through a large s-wave scattering length, are investigated. For Cs-Cs-Cs-Li, the existence of two four-body states, which are universally linked to the energy of the n-th Cs-Cs-Li Efimov trimer, is predicted.

Nuclei Close to Drip Line / 18

Capture reactions in Halo Effective Field Theory

Auteur: Renato Higa[1]

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Loosely bound nuclei far from the stability region emerge as a quantum phenomenon with many universal properties. The connection between these properties and the underlying symmetries can be best explored with halo/cluster EFT, an effective field theory where the softness of the binding momentum and the hardness of the core(s) form the expansion parameter of a given perturbative approach. In this talk I will present a few examples where these ideas were applied, with emphasis in capture reactions.

Light hypernuclei + Scaling and Universality / 19

At the threshold of the Efimov effect

Auteur: Yvan Castin[1]

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The three-body Efimov effect leads, for a binary interaction of infinite s-wave scattering length and no dimer state, to an infinite number of trimer states, which is quite remarkable for a short-range interaction. Of particular conceptual interest would thus be a system where a control parameter alpha allows to continuously switch on and off the Efimov effect. When alpha crosses the critical value alpha_c the system would then exhibit an intriguing transition from a finite number to an infinite number of trimer states. However Efimov's universal theory alone cannot in principle fully characterize this transition, as it cannot predict the behavior of the three-body parameter nor the energy of the ground state trimer.

With cold atoms, one may realize such a system, with two same-spin-state fermions of mass m resonantly interacting with a lighter impurity of mass M. Then the mass ratio alpha=m/M constitutes the desired knob controlling the Efimov effect, with alpha_c=13.6069… When the impurity-fermion resonant interaction is realized on an ultra-narrow Feshbach resonance, a fully microscopic model

can be used, as proposed by Petrov, involving the so-called Feshbach length R_*, an effective range for the interaction.

Extending to fermions a technique developed by Mora, Gogolin, Egger for bosons, one can then determine analytically the three-body parameter and fully characterize the emergence of the infinite number of trimer states beyond alpha=alpha_c.

Light hypernuclei + Scaling and Universality / 20

New results on light hypernuclei

Auteur: Jean-Marc Richard[1]

Co-auteurs: Qian Wang [2]; Qiang Zhao [3]

[1] *IPNL*

[2] *Juelich, Germany*

[3] *IHEP, Beijing*

We revisit the spectroscopy and some production mechanisms of light hypernuclei with single or double strangeness. There is already an abundant literature on the subject [1-4], and we generally recover the published results. We first review the rigorous limits on the possibilities of "Borromean" binding, i.e., bound
states whose subsytems and unbound, and discuss whether novel possibilities exist of critically-bound systems containing nucleons and hyperons. We stress the role of the the effective range when designing tool potentials that mimic more elaborate meson-exchange models fitting the data. Some production mechanisms involving deuteron beams and/or targets are investigated.
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[2]H. Nemura, Y. Akaishi, and Khin Swe Myint, Phys.Rev., C67:051001, 2003.
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Nuclei Close to Drip Line / 22

The far side of the neutron dripline at RIKEN

Auteur: Miguel Marques[1]

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The Radioactive Isotope Beam Factory (RIBF) at RIKEN, Tokyo, has become the world's most powerful machine for the production of exotic nuclei. At intermediate masses, it is pushing the frontier of existence towards areas until now inaccessible, and below Fluorine it is leading us even beyond. After a brief description of the facility, we will see the very preliminary results of the first SAMURAI campaign, in which we have created systems as exotic as Boron 20 and Oxygen 26, and conclude with our plans to extend the neutron detector NEBULA for the measurement of Oxygen 28 in 2015.

Nuclei Close to Drip Line / 23

Low-energy reactions involving halo nuclei

Auteur: Pierre Descouvemont[1]

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Owing to the unusually large radius of halo nuclei, their interaction with a target extends to large distances, in comparison with non-halo nuclei. This property has important consequences on the calculation of the cross sections. On the other hand, halo nuclei are weakly bound, and present a low breakup threshold. Consequently, breakup channels must be included for a realistic description of the elastic cross sections.

Recent examples, involving 11Be, 9Be or 8B at energies close to the Coulomb barrier, will be presented.

Molecular Systems + Nuclear Few-Body Systems / 24

Tunneling, diffusion, and dissociation of Feshbach molecules in optical lattices

Auteur: Carlos Bertulani[1]

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The quantum dynamics of an ultracold diatomic molecule tunneling and diffusing in a one-dimensional optical lattice exhibits unusual features. While it is known that the process of quantum tunneling through potential barriers can break up a bound-state molecule into a pair of dissociated atoms, interference and reassociation produce intricate patterns in the time-evolving site-dependent probability distribution for finding atoms and bound-state molecules. We find that the bound-state molecule is unusually resilient against break up at ultralow binding energy Eb (Eb much smaller than the barrier height of the lattice potential). After an initial transient, the bound-state molecule spreads with a width that grows as the square root of time. Surprisingly, the width of the probability of finding dissociated atoms does not increase with time as a power law.

Molecular Systems + Nuclear Few-Body Systems / 25

Proton Ejection from Molecular Hydride Clusters

Auteur: Jan Michael Rost[1]

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Exposed to intense X-ray pulses, molecular Hydride clusters eject protons thereby reducing the charge imbalance generated by the X-ray photo ionisation. The consequence is a transient stabilisation of the heavy ions of the cluster backbone leading to a delayed Coulomb explosion. The mechanism behind the effect will be explained which will also elucidate why this peculiar dynamics only occurs for intermediate, experimentally realised, intensities of the X-ray pulse.

Pierfrancesco Di Cintio, Ulf Saalmann, and Jan-Michael Rost, Phys. Rev. Lett. 111, 123401 (2013).

Molecular Systems + Nuclear Few-Body Systems / 26

Few-Nucleon Systems in a Quirky World

Auteur: Ubirajara van Kolck[1]

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I will show how nuclear structure can be predicted from lattice QCD through low-energy effective field theories (EFTs), using as an example simulations of a world with relatively heavy quarks. At distances scales much larger than the inverse pion mass few-nucleon systems are described by an EFT where the leading interactions are contact two- and three-body forces, which explicitly incorporate the universality of weakly bound systems. After matching to the results of lattice simulations for few-nucleon systems, the solution of the EFT with ab initio methods, such as effective-interaction hyperspherical harmonics and auxiliary-field diffusion Monte Carlo, allows the calculation of properties of larger systems.

Scaling and Universality + Atomic Systems / 27

Few-body universality: from Efimov effect to super Efimov effect

Auteur: Yusuke Nishida[1]

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Physics is said to be universal when it emerges regardless of microscopic details. The most remarkable example is the Efimov effect, which predicts the emergence of an infinite tower of three-boson bound states in three dimensions with binding energies obeying the universal exponential scaling. In this talk, I will discuss our recent proposal for its condensed matter realization, namely, the Efimov effect in quantum magnets [1]. Also, I will discuss our recent discovery of new few-body universality, the super Efimov effect, which predicts the emergence of an infinite tower of three-fermion bound states in two dimensions with binding energies obeying the universal doubly exponential scaling [2].
[1] Y. Nishida, Y. Kato, and C. D. Batista, Nature Physics 9, 93-97 (2013).
[2] Y. Nishida, S. Moroz, and D. T. Son, Phys. Rev. Lett. 110, 235301 (2013).

Cold Atoms, Few- and Many-Body Physics / 28

EXCITATION OF A TRAPPED BEC: GENERATION OF TURBULENCE AND ITS CHARACTERIZATION

Auteur: Vanderlei Salvador Bagnato[1]

Co-auteur: Mônica Andrioli Caracanhas [1]

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Turbulence is characterized by chaotic spinning flow regimes which appear in many important processes in nature. Vorticity, in superfluid systems, may present the simplest form of turbulence, and be a gateway to the study of this phenomenon in quantum gases. A 87Rb Bose condensate is used to observe and investigate quantum turbulence, by means of a weak, off-axis, magnetic field gradient, which perturbs the BEC and pushes kinetic energy onto it. This creates vortices on the condensed-thermal interface of the BEC and set up experimental conditions to the emergence of turbulence. Once the turbulent regime is set, the condensate is then released and expands under free fall. The atomic density profile is acquired using resonant absorption imaging, after 15 ms of time-of-flight. The calibrated images were used to determine the in situ momentum distribution of the BEC. We have observed that, the perturbed density profiles differ from the nonperturbed BEC. We have seen strong evidences of power law in the measured momentum and energy distributions. Additional characteristics of the system, such as the condensate's finite number, size and temperature, may play a role on the energy injection mechanism and will be discussed.

Reduced Dimensional Systems and Extended Efimov Physics / 29

Mass-imbalanced three-body systems in 2D: bound states and the one-body density

Auteur: Filipe Furlan Bellotti[1]

Co-auteurs: Aksel Jensen [2]; Dmitri Fedorov [2]; Marcelo Yamashita [3]; Nikolaj Zinner [2]; Tobias Frederico [4]

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Quantum systems composed of three particles with attractive zero-range pairwise interactions are considered for general masses and interaction strengths in two dimensions (2D). The number of bound states in a 2D three-body system increases without bound as the mass of one particle becomes much lighter than the other two. The adiabatic approximation provides an analytic form of the effective potential between the heavy particles, which explicitly shows the mass-dependence of the number of bound energy levels. An exact analytic expression for the asymptotic behavior of the spectator function in the Faddeev equation is derived, with that the large momentum form of the one-body density of the mass imbalanced system is studied. The coefficients of the leading and sub-leading order in the large- momentum expansion of the one-body density, that are called two- and three-body contact parameters, are defined and the two-body parameter is found to be independent of the quantum state in some specific 2D systems.

Scattering and Nuclear Matter / 30

Spectral and entanglement properties of the Gaussian quantum dot

Auteur: Anna Okopińska[1]

Co-auteur: Arkadiusz Kuroś [1]

[1] *Jan Kochanowski University*

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The stability of the quasi one-dimensional quantum dot composed of two Coulombically interacting electrons confined in an inverse Gaussian potential is discussed. Apart from bound states, the

system exhibits resonances that are related to the autoionization process. Employing the complex-coordinate rotation method, we determine the resonance widths and energies and study their dependence on the longitudinal confinement potential and the lateral radius of the quantum dot. The entanglement properties of the system are analyzed in relation to its stability.

Scaling and Universality + Atomic Systems / 31

Strongly-interacting few-fermion systems in a trap

Auteur: Christian Forssén[1]

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Small open quantum systems are intensely studied in various fields of physics. The properties of such systems are profoundly affected by their environment, such as the continuum of decay channels. In spite of their specific features, they also display generic properties that are common to all weakly bound/unbound systems close to threshold. This implies that similar universal few- and many-body phenomena can be studied, and that concepts and methodologies from different fields of physics can be used.
Recent progress in the field of cold atomic gases offers new opportunities to study universal questions related to the behavior of strongly interacting Fermi gases. These systems can be prepared with very high fidelity, and relevant parameters such as particle numbers, interaction strengths and dimensionality can be tuned. In this talk we will mainly be concerned with a one-dimensional system of trapped two-component fermions; and we will present very accurate theoretical models, for which we employ sophisticated many-body techniques from nuclear physics, that allows to understand the structure of such systems as a function of the interaction strength, as well as the decay of particles in the situation where the trapping barrier is lowered.

Scaling and Universality + Atomic Systems / 32

Finite range effects in two-body and three-body interactions

Auteur: Servaas Kokkelmans[1]

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Efimov physics in ultracold gases is described very well by the universal scaling laws, based on the scattering length and van der Waals length. The first can be tuned magnetically via a Feshbach resonance, the second is constant and connected to the radial range of the potential. However, experimental hints at non-universal behavior, when going away from resonance, are quite badly understood. The next leading coefficient in the scattering phase shift, the effective range parameter, gives an indication of this non-universality, but at the same time it can also be strongly dependent on the magnetic field. Moreover, higher-order terms take over quickly when increasing the collision energy. We show how the finite range corrections can be understood by making the connection to more fundamental parameters of the two-body physics, and use this description to derive a better criterion for entering the non-universal regime.

Reduced Dimensional Systems and Extended Efimov Physics / 33

Tailored dynamics of strongly interacting one-dimensional few-body systems

Auteur: Nikolaj Zinner[1]

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I will present our latest progress on strongly interacting few-body systems in one-dimensional geometries. I will consider both fermionic and bosonic systems in a variety of geometries with particular emphasis on manipulation of the eigenstates and dynamics of the system by engineering the external confinement.

Efimov Physics and Miscellaneous / **34**

Dimensional transition of weakly-bound three-boson systems

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A remarkable effect related to the dimensionality of the system occurs in the spectrum of three-boson systems in the universal limit of short-range interactions when passing from three (3D) to two (2D) dimensions. In this case, for a two-body energy (E_2) equal zero, the infinite number of three-body bound states, which comes as a consequence of the Efimov effect, disappears because in 2D there is only one scale given by E_2, such that the three-body bound states (there are only two in 2D) are proportional to this two-body energy. Thus, considering this drastic effect on the energy spectrum it is not a surprise that other measurable quantities like, e.g., single-particle momentum distributions be also seriously affected by a dimensional crossover. In this presentation, we will show how different the single-particle momentum distributions for three bosons interacting by a zero-range potential can be in 2D and 3D. By "squeezing" one of the Jacobi momenta we will also show how the three-body energy spectrum changes when passing continuously from 3D to 2D.

Nuclei Close to Drip Line / **35**

Elastic scattering of halo projectiles at low energies

Auteur: Rubens Lichtenthaler[1]

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Light neutron rich nuclei such as 6He and 11Li have a pronounced halo structure with very low binding energies. These features have consequences in the shape of their elastic scattering angular distributions as well as in the total reaction cross sections. We will present experimental data of elastic scattering and reactions induced by these light exotic nuclei on targets of different masses.
The angular distributions have been analysed by four-body CDCC (Continuum Discretized Coupled Channels) calculations, and also by a simple diffractive model which displays some interesting interference phenomena. The total reaction cross sections will be compared in a systematics involving exotic and stable projectiles.

Scaling and Universality / 36

Three-body recombination at vanishing scattering length in ultracold atoms

Auteur: Lev Khaykovich[1]

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In my talk I shall overview our experimental studies of the three-body recombination process in a gas of ultracold lithium atoms. In the regime of resonant interatomic interactions we identify the characteristic features of Efimov trimers [1]. In the opposite regime of vanishingly weak interactions, where no universal bound states are expected, we discover a surprisingly simple behavior. We show that going only to the second term in the effective range expansion is sufficient to describe the rate of recombination processes [2]. We, thus, predict the behavior of the dominant mechanism of the atom loss from traps, caused by the three-body recombination, in the whole range of interatomic interactions. This knowledge, apart from being of fundamental interest, can be used in optimization of evaporative cooling to reach a Bose-Einstein condensate phase and in optimization of its lifetime.

[1] N. Gross, Z. Shotan, S. Kokkelmans and L. Khaykovich, Phys. Rev. Lett. 103, 163202 (2009)& Phys. Rev. Lett. 105, 103203 (2010); O. Machtey, Z. Shotan, N. Gross and L. Khaykovich, Phys. Rev. Lett. 108, 210406 (2012).
[2] Z. Shotan, O. Machtey, S. Kokkelmans, L. Khaykovich, Phys. Rev. Lett. 113, 053202 (2014).

Cold Atoms, Few- and Many-Body Physics / 37

Oscillating attractive-repulsive obstacle at supersonic flow of a Bose-Einstein condensate

Auteur: Arnaldo Gammal[1]

Co-auteur: Eduardo Georges Khamis [1]

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We investigate by numerical simulations the pattern formation after an oscillating attractive-repulsive obstacle inserted into the flow of a Bose-Einstein condensate. For slow oscillations we observe a complex emission of vortex dipoles. For moderate oscillations organized lined up vortex dipoles are emitted. For high frequencies no dipoles are observed but only lined up dark fragments. The results show that the drag force turns negative for sufficiently high frequency. We also successfully model the ship waves in front of the obstacle. In the limit of very fast oscillations all the excitations of the system tend to vanish.

Scaling and Universality / 38

On universality in three-body recombination of cold atoms into deep dimers

Auteur: Dmitri Fedorov[1]

Co-auteurs: Aksel Jensen [1]; Mathias Mikkelsen [1]; Nikolaj Zinner [1]

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The three-body recombination rates in cold atomic gases typically exhibit certain universal features — often referred to as Efimov physics — which can be described within a model-independent theory using only very few of the low-energy parameters of the inter-atomic interactions.

In this contribution we specifically consider recombination into expressly non-universal deep dimers. Even in this case the model-independent theory can quantitatively describe the rates by introducing a finite-range phenomenological 'optical potential'.

We discuss the implementation of this approach and the resulting interplay between the universal and non-universal properties of the recombination rates, particularly in the systems of atoms with different masses.

Light hypernuclei + Scaling and Universality / 40

The rare gas clusters

Auteur: Elena Kolganova[1]

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This work is devoted to the theoretical study of the properties of rare gas clusters. Spectra and wave functions are calculated for dimers of the atoms He, Ne, Ar, Kr, Xe and Rn. Calculations were performed for all possible homogeneous and heterogeneous pairs of rare gas atoms. The Tang - Toennies, Aziz and Lennard - Jones potential models are used for description the interatomic interaction. The Faddeev differential equations for a three-particle system are described. The numerical results on the binding energies of helium trimer are reviewed. The results obtained by using the Faddeev differential equations are compared with the corresponding results from other studies. Some universal correlations are discussed.

Cold Atoms, Few- and Many-Body Physics / 41

Stability and collapse of fermions in a binary dipolar Bose-Fermi 164Dy-161Dy mixture

Auteur: Sadhan Adhikari[1]

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Trapped degenerate dipolar Bose and Fermi gases of cylindrical symmetry with the polarization vector along the symmetry axis are only stable for the strength of dipolar interaction below a critical value. In the case of bosons, the stability of such a dipolar Bose-Einstein condensate (BEC) is investigated for different strengths of contact and dipolar interactions using variational approximation and numerical solution of a mean-field model. In the disk shape, with the polarization vector perpendicular to the plane of the disk, the atoms experience an overall dipolar repulsion and this fact should contribute to the stability. However, a complete numerical solution of the dynamics leads to the collapse of a strongly disk-shaped dipolar BEC as well as a Fermi superfluid. A collapse can be induced in a disk-shaped stable binary Bose-Fermi mixture by jumping the interspecies contact interaction from

repulsive
to attractive by the Feshbach resonance technique. Collapse and fragmentation in the fermions after subsequent
explosions are illustrated. The present study is carried out in three-dimensional space using realistic values of dipolar and contact interactions.

Scattering and Nuclear Matter / 42

Nuclear Matter Bulk Parameter Correlations from a Nonrelativistic Solvable Approach and Beyond

Auteur: ANTONIO DELFINO[1]

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A nonrelativistic (NR) limit of a Point-Coupling version of a Relativistic Mean-Field (RMF) is constructed to investigate nuclear matter properties. This limit allows for nuclear matter bulk parameter analytical expressions. Correlations between many-nucleon bulk parameters as
nuclear matter symmetry energy, its slope, and curvature are presented from this nonrelativistic solvable approach. This study is extended to investigate the correlation between the
nuclear matter incompresibility and the its skewness parameter. Exact RMF results, without the NR limit, support the NR proposed correlations. (In collaboration with B. M. Santos, M. Dutra and O. Louren\c co)

Light hypernuclei + Scaling and Universality / 44

Structure of neutron-rich hypernuclei

Auteur: Emiko Hiyama[1]

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Recently, we have new data on neutron-rich hypernulei, such as nnΛ and ${}^{7}_{\Lambda}$He(^{6}He+Λ). Especially, in ${}^{7}_{\Lambda}$He,
it is planned to search experiment of new excited states at JLab, which is expected to be resonant state. Then, it is requested to study these hyper nuclei to treat bound state as well as resonant states. Here, I will report the level structure of these two hypernuclei.

Scattering and Nuclear Matter / 49

Experimental evaluation of the nuclear neutron-proton contact

Auteur: Nir Barnea[1]

[1] *The Hebrew University of Jerusalem*

The nuclear neutron-proton contact is introduced, generalizing Tan's work, and evaluated from medium energy nuclear photodisintegration experiments. To this end we reformulate the quasi-deuteron model of nuclear photodisintegration and establish the bridge between the Levinger constant and the contact. Using experimental evaluations of Levinger's constant we extract the value of

the neutron-proton contact in finite nuclei and in symmetric nuclear matter. Assuming isospin symmetry we propose to evaluate the neutron-neutron contact through measurement of photonuclear spin correlated neutron-proton pairs.

Cold Atoms, Few- and Many-Body Physics / 50

Fragmentation, resonances and vortices in critically and sub-critically rotated Bose-Einstein condensates

Auteur: Marios Tsatsos[1]

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Superfluids are distinguished from ordinary fluids by the quantized manner the rotation is manifested in them. Precisely, quantized vortices are known to appear in the bulk of a superfluid subject to external rotation, beyond a critical velocity. In most of the studies so far the quantum fluids are considered to be coherent and condensed at all times. In this work I present two examples of rotating ultracold Bose gases that show how fragmentation, i.e. loss of coherence, evolves in time. In specific, a trapped ultracold Bose gas of N=100 atoms in two spatial dimensions is studied, that is either stirred or rotated by an external field. I use and briefly present the multiconfigurational time dependent Hartree method for bosons (MCTDHB), that extends the mainstream mean-field theory, to calculate the dynamics of the gas in real time. As the gas is rotated the wavefunction of the system changes symmetry and topology. The gas gradually fragments over various orbitals and angular momentum is absorbed by forming 'phantom vortices'. We see a series of resonant rotations as the stirring frequency is increased, that are almost always accompanied by fragmentation.

Nuclei Close to Drip Line / 53

Mahir Hussein's 70th birthday

Auteurs: Alinka Lépine-Szily[1]; Carlos Bertulani[2]; Luiz Felipe Canto[3]

[1] *U. Sao Paulo*

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Higher-Order Isospin Asymmetric Nuclear Matter Expansion for Pressure, Binding Energy and Chemical Potential

Auteur: Bianca Martins Santos[1]

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By using a nonrelativistic limit based at point-coupling versions of finite range nuclear relativistic mean-field models containing cubic and quartic self interactions in the scalar field, we derive the analytical expressions for pressure, chemical potential and energy per particle expanded up to sixth-order in isospin asymmetry parameter. In the expansion, the thermodynamic consistency afforded by the Hugenholtz-van-Hove theorem is achieved. This expansion may be of importance

for asymmetric nuclear matter at high densities. Collaboration with M. Dutra, O. Lourenco and A. Delfino.

Efimov Physics and Miscellaneous / 55

Pairing in nuclear matter and nuclei in a relativistic formalism and possible astrophysics implications for neutron star cooling

Auteur: Manuel Malheiro[1]

[1] *Instituto Tecnologico de Aeronautica*

We present some results for pairing in nuclear matter using a relativistic formalism investigating its density dependence, and also how the singlet pairing state changes with temperature for some spherical and deformed nuclei. We will discuss some astrophysical implications of these results, namely the pairing of neutron in the singlet and triplet states, which reduces the neutrino emission from neutron stars associated with the direct Urca process that dominates over other neutrino emitting processes in the star core. The nuclear paring effect on this reaction used recently to explain the temperature data observed for the neutron star Cas A cooling, over a 10 year period, will be presented.

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Triton photodisintegration in three-dimensional approach

Auteur: Mahdi Ahmadian Shalchi[1]

[1] *Instituto de Física Teórica - IFT / UNESP*

Two- and three-particles photodisintegration of the triton is investigated in a three-dimensional (3D) Faddeev approach. For this purpose the Jacobi momentum vectors for three-particles system and spin-isospin quantum numbers of the individual nucleons are considered. Based on this picture the three- nucleon Faddeev integral equations with the two-nucleon interaction are formulated without employing the partial-wave decomposition. The single-nucleon current as well as two-body currents are used in an appropriate form to be employed in the 3D approach.

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Bound states in Minkowski space in 2+1 dimensions

Auteur: Cristian Gutierrez[1]

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The Nakanishi perturbative integral representation of the Bethe-Salpeter (BS) amplitude in three-dimensions (2+1) is investigated in order to derive a workable framework for bound states in Minkowski space. The projection onto the null-plane of the three-dimensional homogeneous BS amplitude is used to derive an equation for the Nakanishi weight function. The formal development is illustrated in detail and applied to the bound system composed by two massive scalars interacting through the exchange of a massive scalar. The explicit forms of the integral equations are obtained in ladder approximation. Autors: C. Gutierrez, V. Gigante, L. Tomio, T. Frederico.

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Curvature effects on the graphene optical properties

Auteur: Wayne de Paula[1]

[1] *Instituto Tecnologico de Aeronautica*

We formulate out-of-plane displacements of graphene as a spatial-curvature and we obtain the corresponding Dirac equation for a general geometry. An analytical solution of the Dirac equation in a curved space for a general deformation along one spatial direction is derived, and it amounts to an extra phase in the electron wavefunction. This can be explored to produce interference devices of the Aharonov-Bohm type. For periodic deformations, the quantization rule for the energy levels is found from this phase. In this situation, the calculated optical conductivity for curved graphene, obtained from the Kubo Formula, can show an enhancement up to one order of magnitude in respect of flat graphene due to curvature effects. In collaboration with A. J. Chaves, O. Oliveira and T. Frederico