Symposium Efimov Physics (SYEP)

jointly organized by
the Quantum Optics and Photonics Division (Q),
the Atomic Physics Division (A), and
the Hadronic and Nuclear Physics Division (HK).

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Overview of Invited Talks and Sessions

(Lecture room: C/gHS)

Invited Talks

SYEP 1.1	Mon	11:30–12:00	C/gHS	**Few-body physics with ultracold atoms: What we learned from cesium** — •Rudolf Grimm
SYEP 1.2	Mon	12:00–12:30	C/gHS	**Universality in halo nuclei** — •Daniel Phillips
SYEP 2.1	Mon	14:30–15:00	C/gHS	**Efimov Physics from Quantum Field Theory** — •Eric Braaten
SYEP 2.2	Mon	15:00–15:30	C/gHS	**Efimov physics with multiple spin substates** — •Chris H Greene

Sessions

SYEP 1.1–1.4	Mon	11:30–13:00	C/gHS	**Symposium Efimov Physics I**
SYEP 2.1–2.6	Mon	14:30–16:30	C/gHS	**Symposium Efimov Physics II**

SYEP 1: Symposium Efimov Physics I

Time: Monday 11:30–13:00 Location: C/gHS

Invited Talk SYEP 1.1 Mon 11:30 C/gHS

Few-body physics with ultracold atoms: What we learned from cesium — •Rudolf Grimm — Institute of Experimental Physics, Univ. Innsbruck, Austria — IQOQI Innsbruck, Austria

The first experimental evidence for the existence of Efimov quantum states was obtained almost a decade ago in a gas of ultracold cesium atoms. Since then, experiments relying on the special interaction properties of ultracold cesium have provided us with much deeper insights into the few-body problem, concerning not only Efimov's original scenario of trimer states but also few-body phenomena beyond that. In my talk I will review the key developments in the field with emphasis on the cesium experiments, drawing an essentially complete picture of Efimov physics in single-species bosonic quantum gases. I will present the current state-of-the-art of the field and discuss future prospects of few-body physics with ultracold atoms.

Invited Talk SYEP 1.2 Mon 12:00 C/gHS

Universality in halo nuclei — •Daniel Phillips — Institute of Nuclear and Particle Physics and Department of Physics and Astronomy, Ohio University, Athens, OH 45701, USA

In the limit of a large two-body s-wave scattering length the properties of quantum-mechanical few-body systems become insensitive to details of the two-body potential. This leads to the emergence of universality: relations between different observables which rely for their validity only on the presence of a sizable scattering length. These relations apply across a wide range of scales: to hadrons, light nuclei, clusters of atoms, and to cold atomic gases with tunable interactions. The Efimov effect is one example of a universal phenomenon, but many other universal correlations also exist.

In this talk I will show that this type of universality provides an organizing principle for the physics of halo nuclei. These are systems in which a few nucleons are weakly bound to a nuclear core. They can thus be treated in a "clustered" description in which the core and the "halo" nucleons are the degrees of freedom. Since the halo nucleons are weakly bound universal correlations between observables exist. This unifies the physics of a diverse set of halo nuclei.

I will also discuss the ways in which details of nuclear interactions refine, but do not destroy, a universal description. Applications to the possibility of Efimov states in halo nuclei, as well as results for observables in halo systems where the unitary limit is close to being realized, will be displayed.

SYEP 1.3 Mon 12:30 C/gHS

Observation of the Efimov state of the helium trimer — •Maksim Kunitski[1], Stefan Zeller[1], Jörg Voigtsberger[1], Anton Kalinin[1], Lothar Schmidt[1], Markus Schöffler[1], Achim Czasch[1], Wieland Schöllkopf[2], Robert E. Grisenti[1], Till Jahnke[1], Dörte Blume[3], and Reinhard Dörner[1] — [1]IKF, Goethe-Universität Frankfurt am Main — [2]Fritz-Haber-Institut, Berlin — [3]Washington State University, Pullman, WA, USA

In 1970 Vitali Efimov predicted remarkable counterintuitive behavior of a three-body system made up of identical bosons. Namely, a weakening of pair interaction in such a system brings about in the limit appearance of infinite number of bound states. These three-body states possess universal properties, which are determined primarily by the s-wave scattering length and a single three-body parameter but do not depend on a particular short-range interaction. Helium trimer has been suggested to be an only native molecular system having an excite state of Efimov nature. Though many theoretical works predict the existence of this state in Helium trimer, it has not been observed experimentally so far. Here we report the first experimental observation of the excited state of He trimer by means of Coulomb explosion imaging. We show spatial images of an Efimov state, confirming the predicted size and a structure where two atoms are close to each other with the third one being far away. This structure is believed to be universal to all Efimov systems from nuclear and atomic physics to condensed matter and biology.

SYEP 1.4 Mon 12:45 C/gHS

Limit Cycles from the Similarity Renormalization Group — •Patrick Niemann[1] and Hans-Werner Hammer[1,2] — [1]Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

Renormalization group (RG) limit cycles have been identified and studied in several systems. We investigate the limit cycle with the similarity renormalization group (SRG). In nuclear physics the SRG is applied to soften nuclear potentials in order to achieve improved numerical convergence.

We search for signatures of limit cycles in SRG evolved potentials. We examine two different systems, which exhibit the limit cycle. The first system is a two-body system with the $1/R^2$ potential and the second one is a three-body system with resonant interactions, where the Efimov effect occurs. Besides the standard kinetic energy generator we apply two other generators.

SYEP 2: Symposium Efimov Physics II

Time: Monday 14:30–16:30 Location: C/gHS

Invited Talk SYEP 2.1 Mon 14:30 C/gHS

Efimov Physics from Quantum Field Theory — •Eric Braaten — Ohio State University, Columbus, USA

The quantum-field-theory formulation of the problem of identical bosons interacting through a large scattering length provides deep insights into Efimov physics. In this approach, the zero-range limit is taken exactly, and the consequent short-distance singularities are dealt with using renormalization. The renormalization is governed by an ultraviolet limit cycle, which is reflected in low-energy physics through a 3-body parameter upon which physical observables can only depend log-periodically. In few-body physics, this feature can be exploited to obtain remarkable analytic results for some 3-body observables. One implication for many-body physics is that the momentum distribution approaches its asymptotic form C/k^4 at large momentum k though a subleading D(k)/k^5 term with a log-periodic coefficient. This effect may have been observed in recent experiments on the unitary Bose gas.

Invited Talk SYEP 2.2 Mon 15:00 C/gHS

Efimov physics with multiple spin substates — •Chris H Greene — Purdue University, West Lafayette, Indiana, USA

The Efimov effect for three particles has some novel features when each particle can reside in more than one degenerate spin substate.[1] In the context of Bose-Einstein condensation, such systems are referred to a spinor condensates, and we can similarly refer to this few-body analog as a spinor three-body problem. Some of the effects we predict for this system, in the regime of large scattering lengths, include the occurrence of multiple Efimov channels with multiple universal exponents, in addition to some multichannel spectral features. [1] V. E. Colussi et al., Phys. Rev. Lett. 113, 045302 (2014)

SYEP 2.3 Mon 15:30 C/gHS

Few-body physics induced by p-wave resonance — •Maxim A. Efremov and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm, Germany

One of the most intriguing phenomenon of few-body physics is the Efimov effect [1], which manifests itself in an infinite number of weakly bound three-body states if at least two of the three two-body subsystems exhibit a single weakly s-wave bound state or resonance.

We present novel class of purely quantum-mechanical bound states in the system of three particles provided: (i) the system consists of a light particle and two heavy bosonic ones, (ii) the heavy-light short-range potential has a p-wave resonance, and (iii) all three particles move in either three [2] or two [3] space dimensions. In the case of an

exact p-wave resonance and *three dimensions*, the effective potential between the two heavy particles is attractive and of long-range, supporting a *finite* number of bound states, with the spectrum strongly determined by the parameters of the underlying p-wave resonance. However, in *two dimensions*, the effective potential between the two heavy particles is attractive and of long-range, resulting in an *infinite* number of the universal bound states. Moreover, due to the weak dependence of the effective potential on the parameters of the planar p-wave resonance, the two-dimensional three-body bound states display a Coulomb series with a Gaussian cut-off governed solely by the mass ratio. [1] V. Efimov, Phys. Lett. B 33, 563 (1970) [2] M.A. Efremov, L. Plimak, M.Yu. Ivanov, and W.P. Schleich, PRL 111, 113201 (2013) [3] M.A. Efremov and W.P. Schleich, arXiv:1407.3352

SYEP 2.4 Mon 15:45 C/gHS

An optically trapped mixture of metastable helium and rubidium — •Adonis Flores, Hari Prasad Mishra, Wim Vassen, and Steven Knoop — LaserLaB, Department of Physics and Astronomy, VU University Amsterdam, The Netherlands

We report on our efforts to realize an ultracold mixture of metastable triplet ^{4}He and ^{87}Rb in an optical dipole trap (ODT). This extreme mass-imbalanced mixture is interesting for investigating the Efimov trimer spectrum, in particular to test its scale invariance [1]. Recently, we have realized a BEC of ^{87}Rb in the $F = 2$, $m_F = 2$ hyperfine substate in a hybrid trap [2], consisting of a quadrupole magnetic field and a single beam ODT. We also obtain thermal clouds of 1×10^6 atoms below 1 μK in a pure single beam ODT, by ramping down the magnetic field gradient after evaporative cooling in the hybrid trap. We are currently exploring the application of the hybrid trap for metastable He. Previously, we have studied interspecies thermalization in the quadrupole magnetic trap, from which we have obtained a value of the interspecies quartet scattering length, in agreement with *ab initio* quantum chemistry calculations [3]. Once we have obtained an ultracold mixture in the ODT we will study interspecies Penning ionization for different spin mixtures and search for interspecies Feshbach resonances.

[1] R. Pires *et al.*, Phys. Rev. Lett. 112, 250404 (2014)

[2] H. P. Mishra, A. S. Flores, W. Vassen, and S. Knoop, arXiv:1411.7628

[3] S. Knoop *et al.*, Phys. Rev. A 90, 022709 (2014)

SYEP 2.5 Mon 16:00 C/gHS

Efimov physics in an ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li — •Juris Ulmanis, Rico Pires, Stephan Häfner, Alda Arias, Eva D. Kuhnle, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold Bose-Fermi mixture of Cs and Li constitute a prototypical system with mass imbalance that allows exploration of many intriguing phenomena in few- and many-body physics. One of such is the heteronuclear Efimov effect, due to which an infinite geometrical series of bound three-body states can be formed, given that the two-body interactions are resonant. Here we present the recent observations of two consecutive Efimov resonances through measurements of three-body loss coefficients near the broad Feshbach resonance [1]. In order to precisely map the applied magnetic field onto the scattering length we extend our previous analysis of Feshbach resonances [2] with radio-frequency association of LiCs Feshbach molecules. We measure the dimer binding energies close to Feshbach resonances and extract Li-Cs scattering properties from them. The new mapping allows us to obtain refined positions and scaling of the Efimov resonances, which slightly deviates from the predicted universal scaling factor for the LiCs system.

[1] R. Pires *et al.*, PRL **112**, 250404 (2014)

[2] R. Pires *et al.*, PRA **90**, 012710 (2014)

SYEP 2.6 Mon 16:15 C/gHS

Z_b-B scattering in pionless effective field theory — •Erik Wilbring[1], Hans-Werner Hammer[2], and Ulf-G. Meissner[1,3] — [1]Helmholtz-Institut für Strahlen- und Kernphysik (Theorie) and Bethe Center for Theoretical Physics, Universität Bonn, D-53115 Bonn, Germany — [2]Institut für Kernphysik, TU Darmstadt, D-64289 Darmstadt, Germany — [3]Institut für Kernphysik (IKP-3), Institute for Advanced Simulation (IAS-4) and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany

The two charged exotic mesons $Z_b(10610)$ and $Z_b'(10650)$ found by the Belle collaboration are interpreted as hadronic molecules made of two loosely-bound B-mesons. Motivated by their relatively small binding energies, we analyze their scattering off a third B-meson using a non-relativistic effective field theory without pions. In analogy to the deuteron considered as a NN bound state and the triton as the first Efimov trimer in the NNN system, we search for possible bound states of three B-mesons which originate from the Efimov effect. In addition we determine the scattering length and phase shift of different elastic Z_b–B-meson scattering processes by numerically solving the corresponding (coupled) integral equations.