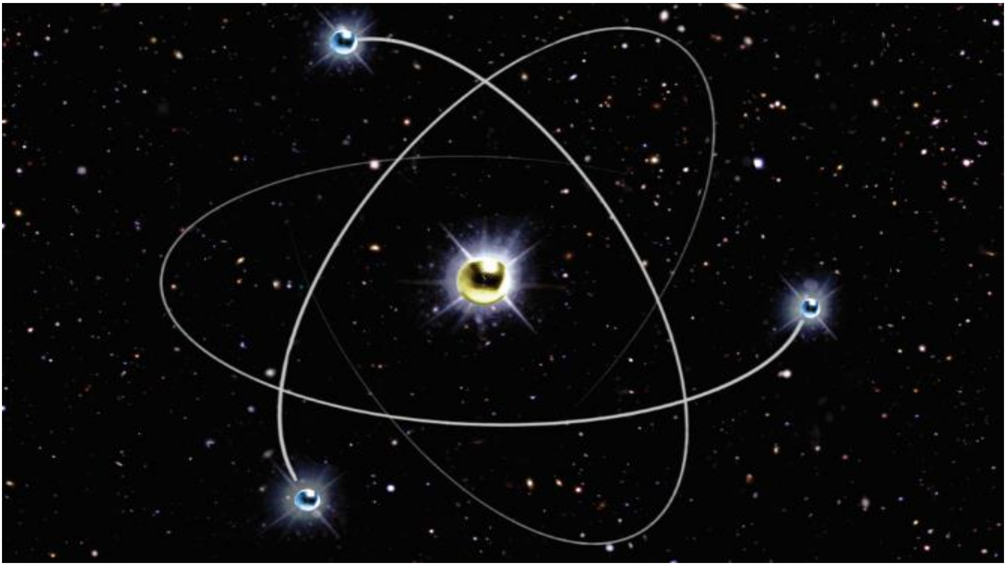


COLD ATOMS AND BEYOND ABSTRACTS

AARHUS UNIVERSITY
AARHUS INSTITUTE OF ADVANCED STUDIES

VENUE

AARHUS INSTITUTE OF ADVANCED STUDIES, AIAS
HØEGH-GULDBERGS GADE 6B
8000 AARHUS C
BUILDING 1630-1632

WWW. AIAS. AU.DK

Abstracts

Yusuke Nishida
Tokyo Institute of Technology, Japan

‘New analogies between cold atoms and high-energy physics’

I will present two of my works on cold atoms that are motivated by some analogy with high-energy physics. One is about the analogue of "hard probes" in cold atoms (arXiv:1110.5926). I will discuss how an energetic atom can be useful to probe many-body properties of strongly-interacting atomic gases. The other is about the analogue of "quark-hadron continuity" in cold atoms (arXiv:1207.6971). I will discuss that a three-component Fermi gas can exhibit a new type of crossover physics in which a Fermi surface of atoms smoothly changes into that of trimers in addition to the usual BCS-BEC crossover of condensed pairs.

Jan Arlt
Aarhus University, Denmark

‘Correlations and entanglement in spinor quantum gasses’

Recent experiments have demonstrated the production of squeezing and entanglement in neutral atoms using various techniques. I will show how spin dynamics can be used to create such non-classical ensembles and how their properties can be measured. In particular I will present a criterion for estimating the amount of entanglement based on a measurement of the global spin and show that Dicke-like states at least 28-particle -11.4(5) dB squeezing can be produced. Moreover I will show how spin dynamics in 2D can possibly be employed for the creation of EPR pairs.

Jean-Philippe Brantut
ETH Zürich, Switzerland

‘Observation of Quantized Conductance in Neutral Matter’

In a conductance measurement the quantum nature of matter becomes directly evident when changes in conductance occur only in discrete steps, with a size determined solely by Planck’s constant h. The observations of quantized steps in the electric conductance have provided important insights into the physics of mesoscopic systems and allowed for the development of quantum electronic devices. Even though quantized conductance should not rely on the presence of electric charges, it has never been observed for neutral massive particles. In its most fundamental form, the phenomenon requires a quantum degenerate Fermi gas, a ballistic and adiabatic transport channel, and a constriction with dimensions comparable to the Fermi wavelength. Here we report on the observation of quantized conductance in the transport of neutral atoms. We employ ultra-high resolution lithography to shape light potentials that realize either a quantum point contact or a quantum wire for atoms. These constrictions are imprinted on a quasi two-dimensional ballistic channel connecting two adjustable reservoirs of quantum degenerate fermionic lithium atoms. By tuning either a gate potential or the transverse confinements of the constrictions, we observe distinct plateaus in the conductance for matter. The conductance in the first plateau is found to be equal to 1/ h, the universal conductance quantum. For low gate potentials we find good agreement between the experimental data and the Landauer formula with all parameters determined a priori. Our experiment constitutes a quantum simulation of a mesoscopic device and can be readily extended to more complex geometries and interacting quantum gases.

Tilman Enss
University of Heidelberg, Germany

'Universal quantum transport in ultracold Fermi gases'

The unitary Fermi gas describes strongly interacting fermions ranging from ultracold atoms near a Feshbach resonance to dilute neutron matter, which share a common universal phase diagram. Its universal thermodynamics has recently been measured and computed with unprecedented precision. I will present results on the shear viscosity, or internal friction, for mass transport and show that the strongly interacting Fermi gas is an almost perfect quantum fluid. On the other hand, if particles of different spin move in opposite directions, the dynamics are governed by spin diffusion. One can distinguish longitudinal diffusion, when atomic clouds of different spin collide, and transverse diffusion, which occurs when the magnetization is wound up as a helix in a spin-echo experiment. Medium scattering and spin rotation have a strong effect on spin diffusion, and I will discuss how spin transport becomes very slow at strong coupling in the quantum degenerate regime and reaches a quantum limit of diffusion.

[1] T. Enss, R. Haussmann, and W. Zwerger, Viscosity and scale invariance in the unitary Fermi gas, Ann. Phys. 326, 770–796 (2011).
[2] T. Enss and R. Haussmann, Quantum mechanical limitations to spin diffusion in the unitary Fermi gas, Phys. Rev. Lett. 109, 195303 (2012).
[3] T. Enss, Transverse spin diffusion in strongly interacting Fermi gases, Phys. Rev. A 88, 033630 (2013).
[4] M. Bauer, M. M. Parish, and T. Enss, Universal equation of state and pseudogap in the two-dimensional Fermi gas, Phys. Rev. Lett. 112, 135302 (2014).

Sebastian Diehl
University of Innsbruck, Austria

‘Non-Equilibrium Universality in the Heating Dynamics of Interacting Luttinger Liquids’

Heating mechanisms are ubiquitous in experiments with cold atomic systems, calling for a proper treatment of such settings as driven open quantum systems. Wereport on a new non-equilibrium scaling regime in the short time evolution of one-dimensional interacting open quantum systems subject to a generic heating mechanism. This dynamical regime is characterized by uncompensated phonon production and a subdiffusive, universal scaling of quasiparticle lifetimes with momentum, distinct from finite and zero temperature cases. It is separated from a high momentum regime by a time dependent scale fading out universally as well. In the latter region we observe thermalization to an effective time-dependent equilibrium with linearly increasing temperature. By mapping out the dynamical phase diagram and computing the dynamical structure factor within an open system Keldysh functional integral approach, we show how these predictions can be explored in cold atom experiments by means of Bragg spectroscopy.

Matteo Zaccanti
LENS, Florence, Italy

‘Ultracold Fermi mixtures with resonant interactions’

Ultracold mixtures of two different fermionic species open exciting and qualitatively new scenarios when compared with the well-established homonuclear ones. At the few-body level, a sufficiently large mass ratio can give rise to the appearance of novel cluster states with universal properties. At the many-body level, mass imbalance is predicted to facilitate the access to elusive and strongly debated phases, primarily in the context of superfluidity and of magnetism. Here, I will describe recent experiments performed on a 6Li-40K mixture in the FeLiKx lab in IQOQI, Innsbruck. In particular, I will discuss the observation of a strong atom-dimer attractive interaction on the BEC side of a K-Li Feshbach resonance, and its potential implications within a many-body context. I will finally outline possible new directions in the research field of ultracold Fermi-Fermi mixtures.

Brian Møller Andersen
Niels Bohr Institute, Copenhagen, Denmark

'Unconventional superconductivity in correlated electron systems – the role of competing phases'

The presentation will be divided into two main parts. First I will discuss the status of our understanding of unconventional superconductivity in correlated bulk electron systems, including both Cu- and Fe-based high-Tc superconductors, and heavy fermion systems. This part will be intended for a rather broad audience including non-exerts in this particular field. I will highlight the imortance of electronic inhomogeneity. In the second part, I will exhibit several of our recent results of how various electronic ordered phases get easily intertwined in these systems.

Leticia Tarruell
ICFO, Barcelona, Spain

'Short-range quantum magnetism of ultracold fermions in an optical lattice'

We report on the observation of nearest-neighbor magnetic spin correlations emerging in the many-body state of a thermalized Fermi gas in an optical lattice [1]. The key to obtaining short-range magnetic order is a local redistribution of entropy within the lattice structure. This is achieved in a tunable-geometry optical lattice, which also enables the detection of the magnetic correlations. We load a low-temperature two-component Fermi gas with repulsive interactions into either a dimerized or an anisotropic simple cubic lattice. For both systems the correlations manifest as an excess number of singlets as compared to triplets consisting of two atoms with opposite spins. For the anisotropic lattice, we determine the transverse spin correlator from the singlet-triplet imbalance and observe antiferromagnetic correlations along one spatial axis. Our results are in good agreement with state-of-the-art numerical simulations of the anisotropic Fermi-Hubbard model, and confirm that we can achieve temperatures in the lattice below the exchange energy [2,3].

[1] D. Greif, T. Uehlinger, G. Jotzu, L. Tarruell, and T. Esslinger, Science 340, 1307-1310 (2013).
[2] J. Imriška, M. Iazzi, L. Wang, E. Gull, D. Greif, T. Uehlinger, G. Jotzu, L. Tarruell, T. Esslinger, and M. Troyer, Phys. Rev. Lett. 112, 115301 (2014).

Jonas Larson
Stockholm University, Sweden

'Towards new states of matter with atoms and photons'

The advent of optical lattices made it possible to experimentally access quantum many-body lattice models frequently appearing in condensed matter theories. The optical light field is seen as simply generating an external potential for the atoms. If the lattice would be formed from only a few photons one would not be able to think of the lattice as a static external potential, but one would need to treat it on a quantum level. In free space such a situation is not achievable because the atom-light interaction would be too weak for the atoms to even feel the presence of the photons. By confining the atoms inside an optical resonator the situation is changed and here the atomic state can be altered from a few photons inside the cavity. The atoms are "dressed" with photons and the states of these systems are thereby entangled mixtures between matter and light. As such, these systems are different from Hubbard models and alikes. In this talk, I will review this field of research and give some prospects for future explorations.

Richard Schmidt
Harvard University, USA

'Field-theoretical Study of the Bose Polaron – Challenges for Quantum Simulation with ultracold Atoms'

In this talk we review our recent study of the Bose polaron, an impurity strongly interacting with a Bose-Einstein condensate, using a field-theoretic approach. In our work we make predictions for the spectral function and various quasiparticle properties that can be tested in experiment. We find that most of the spectral weight is contained in a coherent attractive and a metastable repulsive polaron branch. Additionally we show that the qualitative behavior of the Bose polaron is well described by a non-selfconsistent T-matrix approximation by comparing analytical results to numerical data obtained from a fully selfconsistent T-matrix approach. The latter takes into account an infinite number of bosons excited from the condensate. Also we discuss how our results can be tested in experimentally using radio frequency spectroscopy. Finally we comment on the implications of our results for an attempted quantum simulation of the Froehlich Hamiltonian using ultracold atoms.

Reference: S. P. Rath, R. Schmidt, Phys. Rev. A 88, 053632 (2013).

Pietro Massignan
ICFO, Barcelona, Spain

'Efimov physics under strong confinement'

While three identical bosons in three dimensions can support an infinite tower of Efimov trimers, only two universal trimers exist in the two dimensional case. I will discuss how these two limits are connected by considering the problem of three identical bosons confined by a harmonic potential along one direction. As we will see, the confinement breaks the discrete Efimov scaling symmetry and destroys the weakest bound trimers, but the two deepest trimers persist under arbitrarily strong confinement as they hybridize with the two-dimensional trimers. Our results suggest a way to use strong confinement to engineer more stable Efimov-like trimers, which have so far proved elusive.

Achim Schwenk
Technical University Darmstadt, Germany

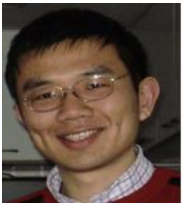
Title and abstract: TBA

Kris Van Houcke
Ecole Normale Supérieure, Paris, France

'Summing Feynman diagrams for strongly correlated fermions'

Expansion in Feynman diagrams is a standard tool of quantum many-body theory. However, one is usually restricted to a few low-order diagrams. Diagrammatic Monte Carlo is a new technique to perform the summation of (skeleton) Feynman diagrams up to high order. I will first focus on the application of this technique to the problem of a spin-down impurity strongly coupled to a spin-up Fermi sea (a so-called Fermi polaron). Conditions of zero temperature are considered for an ultracold atomic gas in two and three dimensions with resonant interactions in the zero-range limit. The convergence properties of the diagrammatic series and the role of multiple particle-hole excitations will be discussed. The polaron and molecule energy are calculated as a function of the coupling strength, revealing a transition from a polaron to a molecule in the ground state. Next I will focus on the

normal-state equation of state of the unitary gas, a prototypical example of a strongly correlated many-fermion system.
The diagrammatic series is found to be strongly oscillating but resummable thanks to sign-alternation of the diagrammatic contributions. The obtained equation of state is in excellent agreement with recent high-precision measurements done at MIT and ENS.



Zhenhua Yu
Tsinghua University, Beijing, China

'Superradiance of Fermi Gases in a Cavity'

The interaction between matter and electromagnetic field is the most fundmental and of widest applications at the energy scales relevant to human beings. Electromagnetic field in cavities has its own characteristics. We consider spinless Fermi gases placed inside a cavity. Due to the interaction between the Fermi gases and the cavity field, a super-radiance transition occurs in the system when the pumping laser field applied on the fermions reaches a critical strength. We discover that Fermi surface nesting effect can strongly enhance the superradiance tendency in comparison to a Bose gas of same density. This feature leads to interesting reentrance behavior and topologically distinct structure in the phase diagram. Away from the Fermi surface nesting regime, the Pauli exclusion principle brings about the dominant effect for which the critical pumping strength is lowered in the low-density regime and increased in the high-density regime.

Meera Parish
University College London, UK

'Fermions in two dimensions'

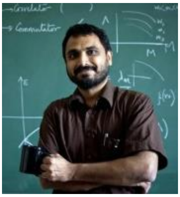
The two-dimensional Fermi gas with short-range interactions provides a basic model for understanding pairing and superconductivity in quasi-2D materials. The successful realisation of such a model system in cold-atom experiments could yield further insight into unexplained phenomena such as the pseudogap regime. I will discuss recent progress towards understanding the finite-temperature behaviour of the 2D Fermi gas and our interpretation of current quasi-2D experiments on the BCS-BEC crossover [1-3].

[1] V. Ngampruetikorn, J. Levinsen & M. M. Parish, Phys. Rev. Lett. 111, 265301 (2013)
[2] M. Bauer, M. M. Parish & T. Enss, Phys. Rev. Lett. 112, 135302 (2014)
[3] A. M. Fischer & M. M. Parish, Phys. Rev. A 88, 023612 (2013)

Selim Jochim
University of Heidelberg, Germany

‘One, two, three, many: Creating quantum systems one atom at a time’

Experiments with ultracold gases have been extremely successful in studying many body systems, 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. For a few-body system this can be dramatically different. This is apparent for example in nuclear physics, where adding a single neutron to a magic nucleus dramatically changes its properties. In our work we deterministically prepare generic model systems containing up to ten ultracold fermionic atoms with tunable short range interaction. In our bottom-up approach, we have started the exploration of such few-body systems with a two-particle system that can be described with an analytic theory. Adding more particles one by one we enter a regime in which an exact theoretical description of the system is exceedingly difficult, until the particle number becomes large enough such that many-body theories provide an adequate approximation. Our vision is to use our deterministically prepared tunable few-body systems as microscopic building blocks to prepare model systems that might help to gain insight into complex many-body systems in condensed matter or even QCD.



Vijay Shenoy
Indian Institute of Science, Bangalore, India

‘Fermions in synthetic non-Abelian gauge fields: From Rashbon condenstates to Novel Hamiltonains'

I shall discuss the physics of interacting fermions in the presence of uniform non-Abelian gauge fields. Such gauge fields induce a generalized spin-orbit interaction for the two component fermions. I shall demonstrate that on increasing the strength of the spin-orbit coupling, a BCS superfluid that is realized in the presence of weak attraction in the absence of the gauge field, is driven to BEC state. The BEC state is a condensate of a new kind of nematic bosons, which we call "rashbons", whose properties are determined solely by the gauge field and not by the strength of the attraction between the fermions. The rashbon-BEC is shown to have a transition temperature of the order of the Fermi temperature suggesting a route to enhancing the transition temperature in weakly attracting systems using spin-orbit interaction. I shall then show that the rashbon-BEC is described by a

Bogoliubov theory and show that the rashbon-rashbon scattering length which is 'independent' of the scattering length between the constituent fermions. I will also discuss the possibility of an FFLO state, and the physics of Feshbach resonance in a non-Abelian gauge field, both of which will be relevant to recent experiments. Finally, I will make a proposal of using a non-Abelian gauge field in a conjunction with another potential for the realization of interesting condensed matter Hamiltonians such as that due to a magnetic monopole.
Work done in collaboration with J. P. Vyasanakere(IISc) and Sudeep Ghosh(IISc)
References: cond-mat:1101.0411, 1104.5633, 1108.4872, 1109.5279, 1201.5332, 1211.1831, 1212.2858
Supported by DST, DAE, India.

Nathan Goldman
Ecole Normale Superieure, Paris, France

'Gauge fields and topological phases with cold atoms: Baby, you can drive my cloud!'

Topological states of matter constitute one of the hottest disciplines in quantum physics, demonstrating a remarkable fusion between elegant mathematical theories and promising technological applications. Topology, which guarantees the robustness of unique properties, can be intrinsic to a material. Alternatively, it can be induced externally by subjecting the system to well-designed electromagnetic fields or mechanical deformations. In this talk, I will present a general framework that thoughtfully describes driven quantum systems. It enables one to identify versatile and practical driving schemes generating topological properties. A special emphasis will be set on the possibility to generate spin-orbit couplings in driven cold-atom systems.

Edward Taylor
McMaster University, Hamilton, Canada

'The angular momentum problem in Helium-3 and topological superconductors: Using cold atoms to solve a 40 year old problem'

Major predictions of the mean-field BCS theory of chiral p-wave superfluidity include the existence of topologically protected Majorana edge states as well as a spontaneous edge current due in part to such states which gives rise to a macroscopic angular momentum. Long been debated theoretically, so far no evidence has been found for such currents or angular momentum in experiments done on superfluid Helium-3 or the putative chiral p-wave superconductor Strontium Ruthenate. This seeming absence raises questions about the validity of mean-field BCS theory to describe topological superfluids and, in particular, the prediction of Majorana bound states. In this talk, I discuss the generally non-universal, non-topological nature of the edge current, meaning that in Strontium Ruthenate at least, it can in principle be very small while still being consistent with chiral p-wave order and the existence of Majorana bound states. On the other hand, for a chiral p-wave atomic gas superfluid confined in a harmonic trap, the edge current and hence, angular momentum, is topological, meaning that it is proportional to the Chern number which counts the number of Majorana bound states. Realizing a chiral p-wave superfluid in an atomic gas would thus provide a way to definitively test predictions for Majorana edge states.

Hans Peter Büchler
University of Stuttgart, Germany

'Majorana modes and p-wave superfluids for fermionic atoms in optical lattices'

The quest for realisations of non-Abelian phases of matter, driven by their possible use in fault-tolerant topological quantum computing, has been spearheaded by recent developments in p-wave superconductors. The chiral $p_x + i p_y$-wave superconductor in two-dimensions exhibiting Majorana modes provides the simplest phase supporting non-Abelian quasiparticles and can be seen as the blueprint of fractional topological der. Alternatively, Kitaev's Majorana wire has emerged as an ideal toy model to understand Majorana modes. Here, we present a way to make the transition from Kitaev's Majorana wires to two-dimensional p-wave superconductors in a system with cold atomic gases in an optical lattice. The main idea is based on an approach to generate p-wave interactions by coupling orbital degrees of freedom with strong s-wave interactions. We demonstrate how this design can induce Majorana modes at edge dislocations in the optical lattice and we provide an experimentally feasible protocol for the observation of the non-Abelian statistics.

Anders Mathias Lunde
Niels Bohr Institute, Copenhagen, Denmark

'Current-induced magnetization in a two-dimensional topological insulator coupled to an environment of localized spins'

First I will briefly introduce the concept of a two-dimensional topological insulator (2DTI). A 2DTI has two counter propagating helical edge states of opposite spins, such that the states of opposite wave numbers, k and -k, constitutes a Kramers pair. I will consider current carrying helical edge states in a 2DTI coupled to an environment of localized spins, which could be magnetic impurities or the nuclear spins of the host material. The localized spins mediate elastic spin-flip scattering between the helical edge states, which induces a magnetization of the localized spins for a finite current through the edge states. The magnetization appears near the boundaries of the 2DTI, while the bulk remains unmagnetized. Interestingly, the transport through the helical edge states remains ballistic, if no additional spin-flip mechanisms for the localized spins are present.

Stefan Baur
University of Cambridge, UK

'Dynamic optical superlattices with topological bands and adiabatic creation of vortex lattices of bosons'

After giving a brief introduction to some recent ideas and efforts to create strong artificial magnetic fields for neutral atoms in optical lattices, I will introduce a novel way to create strong uniform magnetic fields in driven optical lattice systems, a proposal that we call 'Dynamic Optical Super-Lattices' [1]. In the second part of the talk, I will explain how to load an interacting Bose gas adiabatically into a vortex lattice using these techniques for creating gauge potentials [2]. Finally, I will show how an interacting Fermi gas in an optical flux lattice could potentially be used as a quantum simulator for Ising nematic order of fermions [3].

[1] SKB, Monika Schleier-Smith and Nigel Cooper, "Dynamic Optical Superlattices with Topological Bands", Phys. Rev. A 89, 051605(R) (2014)
[2] SKB and Nigel Cooper, "Adiabatic preparation of vortex lattices", Phys. Rev. A 88, 033603 (2013)
[3] SKB and Nigel Cooper, "Coupled Ferromagnetic and Nematic Ordering of Fermions in an Optical Flux Lattice", Phys. Rev. Lett. 109, 265301 (2012)

Carlos Lobo
University of Southhampton, UK

‘Optical Lattices with large scattering length’

I will discuss a new proposal to go beyond the standard way of thinking of atoms in optical lattices by bringing in ideas from few-body physics. I will consider a setup where one atomic species is trapped in a lattice at full filling while another is untrapped (does not see the optical lattice) but has an s-wave contact interaction with the first one. If the interspecies scattering length a is positive and on the order of the lattice spacing d then the usual two-body bound (dimer) states overlap forming a polyatomic molecule extending over the entire lattice, which can also be viewed as a band solid for the untrapped species, where the trapped atoms play the role of ions. This setup requires large scattering lengths but minimises losses, does not need higher bands and adds new degrees of freedom which cannot easily be described in terms of lattice variables. As an example I show how to create “electron”-phonon quantum simulators for both longitudinal and transverse phonons which exhibit renormalization of the phonon frequencies due to electron-ion interactions, Peierls instability and polaron physics.

Nikolaj Zinner
Aarhus University, Denmark

‘Strongly interacting particles in one-dimensional confining geometries’

Strongly-interacting one-dimensional few-body systems provide a great playground for studying magnetic correlations. Using a combination of numerical and analytical methods, we discuss how ferro- and antiferromagnetic few-body systems can be created and manipulated in trapped cold atomic systems. Of particular interest is the role of quantum statistics and we consider multi-component bosonic and fermionic examples. If time permits, we will also consider the more exotic case of strongly-interacting anyons which allows for an interpolation between bosons and fermions.

References:
E.J. Lindgren et al.. New J. Phys. 16, 063003 (2014)
A.G. Volosniev et al.. arXiv:1306.4610 (2013)
N.T. Zinner et al., arXiv:1309.7219 (2013)
N.T. Zinner, arXiv:1406.3592 (2014)
A.S. Dehkharghani et al., in preparation

ORGANISORS

Jesper Fredenslund Levinsen, Dale T. Mortensen Junior Fellow at Aarhus Institute of Advanced Studies, AIAS, and Georg Bruun, Dep. of Physics and Astronomy, Aarhus University, Denmark