MajuLab/CQT/NUS workshop on Localization, Quantum Chaos and Topology with Matter Waves
Tuesday 20 March & Wednesday 21 March

Workshop Organizers:

- Gong Jiangbin, NUS Physics Departement;
- Christian Miniatura, MajuLab;
- Evon Tan, CQT.

Tuesday 20th March

- Talk 1: Simulating quantum disorder with ultracold atoms
  By Jean-Claude Garreau

Abstract:
Quantum simulation is one of the most active trends in ultracold-atom physics. A quantum simulator is a “simple” system that mimics the dynamics of a more complicate one. The Anderson model is a paradigm for quantum disorder, originally introduced in the helm of solid-state physics; however, solid-state disordered systems are very difficult to study experimentally and even numerically. The kicked rotor, in contrast, is a very simple system, easy to simulate and also relatively simple to realize experimentally with cold atoms even in a deep quantum regime. The resulting setup is simple, clean and controllable. Amazingly, the kicked rotor can be mathematically mapped onto an Anderson model, and is thus a quite subtle quantum simulator for disordered systems. In this talk I will describe a series of experiments taking advantage of this correspondence to investigate experimentally the Anderson model, and in particular the metal-insulator transition.
About the speaker:
I got my PhD in 1989 from Université Paris VI, my thesis research subject was a high-precision measurement of the Rydberg constant using atomic hydrogen, in the (now called) Laboratoire Kastler-Brossel of ENS, under the supervision of François Biraben. I then spent two years at the research labs of France Télécom studying quantum noise manipulation (squeezing) in optical systems. In 1991 I joined Laboratoire PhLAM in Lille, where I created a new research group focused on the physics of cold and ultra-cold atoms. Since 1998 this group has been working experimentally and theoretically on simple ultracold-atom systems as the atomic kicked rotor and the Wannier-Stark system. In 2015 I was awarded the Leconte prize of the Académie des Sciences for these works.

- Talk 2: Generalized Thouless Pump: theory and experimental realization
  By Longwen Zhou

Abstract:
Adiabatic cyclic modulation of a one-dimensional periodic potential will result in quantized charge transport, which is termed the Thouless pump. In contrast to the original Thouless pump restricted by the topology of the energy band, we introduce a generalized Thouless pump that can be extensively and continuously controlled. The extraordinary features of the new pump originate from interband coherence in nonequilibrium initial states, and this fact indicates that a quantum superposition of different eigenstates individually undergoing quantum adiabatic following can also be an important ingredient unavailable in classical physics. The quantum simulation of this generalized Thouless pump in a two-band insulator is achieved by applying delicate control fields to a single spin in diamond. The experimental results demonstrate all principal characteristics of the generalized Thouless pump. Notably, the pumping is most pronounced around a band-touching point, which suggests an alternative means to detect quantum or topological phase transitions.

- Talk 3: From Quantum Chaos to Topological Matter
  By Jiangbin Gong

Abstract:
In this talk I review a few early quantum chaos studies in my group at NUS, which eventually led us to ongoing fruitful investigations of Floquet topological phases and their possible applications. I shall begin with a double-kicked rotor model with Hofstadter's butterfly-like Floquet spectrum, a finding strongly suggesting the usefulness of quantum chaos models to explore topological matter. I then discuss a few important aspects of Floquet topological phases, followed by some detailed results on a spin-half double kicked rotor that is within reach of today's cold-atom experiments.

References (only those related to kicked rotor is listed):

About the speaker:
Prof. Gong Jiangbin obtained his Ph.D from the University of Toronto in 2001. He joined NUS in 2006 after postdoctoral studies at the University of Toronto and the University of Chicago. Prof. Gong's theoretical research interests include nonlinear dynamics and quantum chaos, quantum control, quantum thermodynamics, non-Hermitian quantum mechanics, and recently, topological matter. Prof. Gong is appointed as Deputy Head (research) of the Department of Physics of NUS since July 2017. He recently won the NUS Faculty of Science Outstanding Scientist Award 2016, the prestigious Singapore National Research Foundation Investigatorship Award 2017, and the IPS (Institute of Physics) Singapore Medal 2017.

- Talk 4: Non-Abelian adiabatic geometric transformations in a cold Strontium gas
  By David Wilkowski

Abstract:
Topology, geometry, and gauge fields play key roles in quantum physics as exemplified by fundamental phenomena such as the Aharonov-Bohm effect, the integer quantum Hall effect, the spin Hall, and topological insulators. The concept of topological protection has also become a salient ingredient in many schemes for quantum information processing and fault-tolerant quantum computation. The physical properties of such systems crucially depend on the symmetry group of the underlying holonomy. We present our work on a laser-cooled gas of strontium atoms coupled to laser fields through a 4-level resonant tripod scheme. By cycling the relative phases of the tripod beams, we realize non-Abelian SU(2) geometrical transformations acting on the dark-states of the system and demonstrate their non-Abelian character. We also reveal how the gauge field imprinted on the atoms impact their internal state dynamics. It leads to a new thermometry method based on the interferometric displacement of atoms in the tripod beams.

- Talk 5: Chaos-induced spin topological structure in kicked rotor
  By Chushun Tian

Abstract:
The kicked rotor is a “standard model” in studies of nonlinear dynamics. The kicked rotor without spin degree of freedom nowadays has been well studied. In this talk, I will present our recent result for a kicked rotor with spin degree of freedom. We find a dynamical phenomenon mathematically equivalent to the integer quantum Hall effect occurs, where Planck’s quantum mimics the magnetic field. I will show that this phenomenon is of chaos origin.

About the speaker:
Prof Tian received his bachelor and master degrees in plasma theory in Fudan University in Shanghai. From 2000-2005 he did his Ph.D. study in University of Minnesota and KITP at Santa Barbara under the supervision of late Professor Anatoly Ivanovich Larkin. After that he moved to Koeln, Germany working with Professor Alexander Altland as a postdoc. From 2011-2017 he was a faculty member of professorial rank in Institute for Advanced Study, Tsinghua University in Beijing. Since 2017 he has been a full professor in Institute for Theoretical Physics, Chinese Academy of Sciences. Prof. Tian's recent research interests include critical and topological phenomena in quantum chaos, foundations of statistical mechanics and quantum thermalization, wave transport in disordered photonic and electronic systems, strongly correlated electronic systems, and condensed matter field theory.

**Talk 6:** Quantum Dynamical, Spectral, and Topological Manifestations of Generic Superweak Chaos
By Itzhack Dana

**Abstract:**
Classical kicked Hall systems (KHSs), i.e., periodically kicked charges in the presence of uniform electric and magnetic fields that are perpendicular to each other and to the kicking direction, have been introduced and studied recently [M. Ben-Harush and I. Dana, Phys. Rev. E 93, 052207 (2016)]. It was shown that KHSs exhibit, under generic conditions, the phenomenon of superweak chaos (SWC), i.e., for small kick strength $\kappa$ a KHS behaves as if this strength were effectively $\kappa^2$ rather than $\kappa$. Here we investigate several quantum manifestations of this generic SWC (I. Dana and K. Kubo, to be published). We first derive general expressions of quantum effective Hamiltonians for the KHSs. We then show that the phenomenon of quantum antiresonance (QAR), i.e., frozen quantum dynamics with flat quasienergy (QE) bands, takes place for integer values of a scaled Planck constant $\hbar_s$ and under the same generic conditions for SWC. This appears to be the most generic occurrence of QAR in quantum systems. The vicinity of QAR is shown to correspond semiclassically to SWC. In the case of standard (cosine) potentials, SWC is manifested by the fact that a scaled QE spectrum, as function of $\hbar_s$ and at fixed small value of $\kappa/\hbar_s$, is approximately given by a universal (parameters-independent) double Hofstadter butterfly. The latter has topological properties basically different from those of the ordinary Hofstadter butterfly. Also, for standard potentials and for small $\hbar_s$ (semi-classical regime), the evolution of the kinetic energy expectation value exhibits a relatively slow quantum-diffusive behavior having universal features, as predicted by the effective Hamiltonian.

**About the speaker:**
Prof. I. Dana received all his academic degrees from the Technion, Haifa. His Ph.D. Thesis, under the supervision of Prof. J. Zak and completed in 1984, was on theoretical solid-state physics, "Bloch electrons in a magnetic field and Von-Neumann lattices", including the quantum Hall effect in perfect crystals. In the academic year 1983-1984, he started his research work at the Technion in the field of "Classical Hamiltonian Chaos", in collaboration with Prof. S. Fishman. He continued his research in this field in his postdoctoral works, first at the University of Pennsylvania, Philadelphia (1984-1986, in collaboration with Prof. W.P. Reinhardt) and then at Queen-Mary College, University of London (1986-1988, in collaboration with Prof. I.C. Percival). In the years 1988-1990, he was a researcher at the Weizmann Institute of Science, Rehovot, still working on Classical Hamiltonian Chaos.
In the years 1990-1997, he was a researcher at Bar-Ilan University, Ramat-Gan, working on Classical Hamiltonian Chaos and Quantum Chaos. In these years and in 1998, he made some of the first works in the subject of topological properties of quasienergy states of Floquet (time-periodic) systems (that are classically nonintegrable). This subject has become quite fashionable in condensed-matter physics in the recent years. In 1997, he became a faculty member of the Department of Physics at Bar-Ilan University. Since then, he works on Classical Hamiltonian Chaos, Quantum Chaos, and related topics in condensed-matter physics, including topological quantum numbers.

- **Talk 7**: Discrete time crystals in smoothly driven spin chain
  Raditya Weda Bomantara

Abstract:
Initially proposed in 2012, time crystals constitute a new phase of matter which spontaneously breaks time translational symmetry. In particular, time crystals in time periodic systems, termed discrete time crystals (DTCs), have since stimulated various theoretical studies and two recent experimental realizations. Up to date, most of the existing proposals for the observation of DTCs involve the use of kicked systems. While the simplicity of such systems provides some understanding on the formation of period-doubling DTCs in spin systems, they may not be suitable for future real life applications since kicked systems do not normally arise naturally. To resolve this, I examine the formation of DTCs in a smoothly driven spin chain, which replaces the Dirac delta term commonly used in existing studies with a harmonic driving term. Due to the more complex structure of the one-period propagator, finding a parameter regime which admits DTCs in such a system is not a trivial task. In this talk, I will elucidate a means to accomplish this by studying the system’s Poincare surface of section in its semi-classical limit. In addition to finding period-doubling DTCs commonly observed in many previous proposals, DTCs with fourth and sixth times the driving period are also identified.

- **Talk 8**: Probing quantum interferences and symmetries in the weak and strong localization regimes: first observation of Coherent Forward Scattering
  Radu Chicireanu

Abstract:
The symmetry characteristics of the disordered system are expected to greatly affect its localization and transport properties – yet few experimental results in this direction are available today. Here we will present a novel technique which allows the realization an artificial gauge field in a synthetic (temporal) dimension of a disordered, periodically driven (Floquet) quantum system. Our remarkably simple technique is used experimentally to control the Time-Reversal Symmetry properties of the quantum kicked rotor [1], and leads to two novel experimental observations, representing 'smoking-gun' signatures of this symmetry breaking. The first consists in the first observation of the “Coherent Forward Scattering” (CFS) [2], a direct interferential signature of the Anderson localization. The second is the measurement of the scaling function \(\beta(g)\) [3] in the weak localization regime, with a test of the one-parameter scaling hypothesis, and of its universality in two different symmetry classes.
Experimental investigation of the symmetry (a) and temporal (b) properties of the CBS and CFS peaks

![Graph showing CBS and CFS peaks](image)


**About the speaker:**
I obtained my PhD degree in 2007 in Laboratoire de Physique des Lasers (Université Paris Nord). During my thesis, I built a new apparatus for producing BECs with strong dipole-dipole interactions using chromium atoms. I then spent 2 years in NIST Githersburd, in the group of Bill Philips and Trey Porto, where I worked with BECs loaded in “optical super-lattices”, with applications for quantum information and metrology. I also worked for 1 year at SYTRE (Observatoire de Paris) on an optical lattice clock with Mercury atoms, and at Institute d’Optique (Palaiseau) on single Rydberg atoms. In 2011 I joined the CNRS, and I am currently working in the ‘Quantum Chaos’ team in Laboratoire PhLAM (Lille) on quantum simulation experiments using the atomic kicked rotor, and also on the construction of a new BEC apparatus with potassium atoms, with the aim of exploring interactions effects in disordered quantum systems.

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**Talk 9:** A view on Anderson localization from momentum space
Sanjib Ghosh

**Abstract:**
A particle moving in a disordered medium undergoes random scattering events. From the classical point of view, these scattering events induce a diffusive motion. Quantum mechanically, a strong wave-interference effect can alter this classical paradigm inducing the so-called Anderson localization: Localization of single particle wavefunctions in position space. Here, we present the signatures of Anderson localization in momentum space. In momentum space, the signatures of Anderson localization are encoded in the two coherent peaks, namely the coherent back scattering (CBS) and coherent forward scattering (CFS) peaks. More interestingly, the signature if the Anderson metal-insulator transition (MIT) are also encoded in the dynamics of these interference peaks. Since these peaks are the consequences of wave interference effects, a mere observation of them is sufficient for proving the phase coherence in the system which is a prerequisite for the occurrence of the
Anderson MIT. Finally, we show how to extract the critical properties and multifractal signatures from these peaks.

**Wednesday 21st March**

- **Talk 10:** *The Aharonov-Bohm effect in mesoscopic Bose-Einstein condensates*  
  Tobias Haug

  **Abstract:**  
The Aharonov-Bohm and its dual, the Aharonov-Casher, effects have been extremely fruitful in physics and, nowadays, they are of central importance for quantum technologies. Here, we study the Aharonov-Bohm effect for a Bose-Einstein condensate propagating out of equilibrium along a mesoscopic ring-shaped laser light potential, pierced by an effective magnetic flux. We found how the system experiences a subtle crossover between physical regimes dominated by pronounced interference patterns and others in which the Aharonov-Bohm effect is effectively washed out. We propose various applications for this system.

- **Talk 11:** *Many-body open quantum systems: role of disorder and of period doubling*  
  Dario Poletti

  **Abstract:**  
Many-body quantum systems can present interesting phases of matter and dynamics. These are significantly affected once the system is open, i.e. in contact with an environment. We discuss two particular scenarios: in the first case the system is in presence of disorder, and we show how dissipatively engineered states are sensitive to disorder, and signatures of localization; in the second case we study the steady state properties of a periodically driven many body state and show the emergence of period doubling only when studying two-time correlations.

- **Talk 12:** *Nonlinearity and Disorder in Topological Photonics*  
  Yidong Chong

  **Abstract:**  
In the first part of the talk, I discuss how optical nonlinearity alters the behavior of photonic topological insulators. In the nonlinear regime, band structures and their associated topological invariants cannot be calculated. Nonetheless, nonlinear photonic lattices can support moving edge solitons that "inherit" many properties of linear topological edge states: they are strongly self-localized and propagate unidirectionally along the lattice edge.

These solitons can be realized in a variety of model systems, including (i) an abstract nonlinear Haldane model, (ii) a Floquet lattice of coupled helical waveguides, and (iii) a lattice of coupled-ring waveguides.

Topological solitons can be "self-induced", meaning that they locally drive the lattice from a topologically trivial to nontrivial phase, similar to how an ordinary soliton locally induces its own confining potential. This behavior can be used to design nonlinear photonic structures
with power thresholds and discontinuities in their transmittance; such structures, in turn, may provide a novel route to devising nonlinear optical isolators.

In the second part of the talk, I discuss amorphous analogues of a two-dimensional photonic Chern insulator. These lattices consist of gyromagnetic rods that break time-reversal symmetry, arranged using a close-packing algorithm in which the level of short-range order can be freely adjusted. Simulation results reveal strongly-enhanced nonreciprocal edge transmission, consistent with the behavior of topological edge states. Interestingly, this phenomenon persists even into the regime where the disorder is sufficiently strong that there is no discernable spectral gap.

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**Talk 13:** *Spin-1 boson in the honeycomb lattice: SU(3) spin-orbit coupling and topological insulators*

Benoît Grémaud

**Abstract:**
In a first part, I will present the topological properties of the single-particle band structure, namely Chern numbers and edge states. I will discuss their connection to the different symmetries of the system namely the time-reversal symmetry and the sub-lattice symmetry. In a second part, I will present our recent results in the interacting regime, discussing the impact of the spin-orbit coupling on the properties of the Mott phases and the superfluid phases.