*Book of Abstracts*

# Quo vadis quantum simulators?


**Wilczek Quantum Center**

School of Physics and Astronomy

Shanghai Jiao Tong University

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*Workshop*

November 13th - 15th, 2019

## What’s on this document?

# Quo vadis quantum simulators?

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Shanghai Jiao Tong University
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## Presentation

In a visionary colloquium nearly sixty years ago, Richard Feynman proposed to construct, in a bottom up approach, the so-called quantum simulators: systems that can be engineered and manipulated at will, and might serve as a tool to verify model Hamiltonians and ultimately lead to the understanding of other more elusive quantum systems. Although it took some decades for the field to take off, during the last years there has been an explosion of activities in designing matter using different platforms.

The aim of this multidisciplinary workshop is to gather experts on different fields of quantum simulators, to foment discussions among different communities and foster cross linking inspiration. Among other topics, the workshop will cover theoretical and experimental results in the following fields: ultracold atoms, photonics, superconducting circuits, electronic systems, and topological classical systems.

## Special guests

Frank Wilczek

Peter Zoller

## Invited Speakers

Tim Byrnes (New York University Shanghai, China)

Shuai Chen (University of Science and Technology of China - Shanghai)

Laura García-Álvarez (Chalmers University of Technology, Gothenburg, Sweden)

Alejandro González-Tudela (Institute of Fundamental Physics, Madrid, Spain)

Ying Hu (Shanxi University, China)

Jin-Feng Jia (Shanghai Jiao Tong University, China)

Xianmin Jin (Shanghai Jiao Tong University, China)

Gerhard Kirchmair (Inst. of Quantum Optics and Quantum Information, Innsbruck, Austria)

Xiaopeng Li (Fudan University, Shanghai, China)

Xiong-Jun Liu (Peking University, Beijing, China)

Ling Lu (Institute of Physics, Beijing, China)

Anja Metelmann (Free University of Berlin, Germany)

Gloria Platero (Instituto de Ciencia de Materiales de Madrid, Spain)

Sylvain Ravets (Université Paris Saclay, France)

Marc Serra-Garcia (ETH Zurich, Switzerland)

Tao Shi (Institute of Theoretical Physics, Beijing, China)

Zhong Wang (Tsinghua University, Beijing, China)

Matthias Weidemüller (Heidelberg University, Germany)

Jing Zhang (Shanxi University, China)

## Contributed Speakers

Sayan Choudhury (University of Pittsburgh, USA)

Lei Cong (Shanghai University, China)

Jian Cui (Beihang University, China)

Myung-Joong Hwang (Duke Kunshan University, China)

Kunkun Wang (Beijing Computational Science Research Center, China)

# Schedule Overview

| Wednesday Nov 13 | | Thursday Nov 14 | | Friday Nov 15 | |
|---|---|---|---|---|---|
| 9:00 - 9:30 | Frank Wilczek's welcome | 9:00 - 9:35 | Anja Metelmann | 9:00 - 9:35 | Jing Zhang |
| 9:30 - 10:05 | Xianmin Jin | 9:35 - 10:10 | Jin-Feng Jia | 9:35 - 10:10 | Álex González-Tudela |
| 10:05 - 10:40 | Sylvain Ravets | 10:10 - 10:30 | Jian Cui | 10:10 - 10:30 | Myung-Joong Hwang |
| 10:40 - 11:10 | break | 10:30 - 11:00 | break | 10:30 - 11:00 | break |
| 11:10 - 11:45 | Ling Lu | 11:00 - 11:35 | Matthias Weidemüller | 11:00 - 11:35 | Marc Serra-Garcia |
| 11:45 - 12:20 | Tao Shi | 11:35 - 12:10 | Ying Hu | 11:35 - 12:10 | Zhong Wang |
| 12:20 - 14:15 | Lunch & discussion time | 12:10 - 13:30 | Lunch & discussion time | 12:10 - 14:00 | Lunch & discussion time |
| 14:15 - 14:30 | Group picture | 13:30 - 14:05 | Gerhard Kirchmair | 14:00 - 14:35 | Tim Byrnes |
| 14:30 - 15:05 | Shuai Chen | 14:05 - 14:40 | Laura García-Álvarez | 14:35 - 15:10 | Xiaopeng Li |
| 15:05 - 15:40 | Gloria Platero | 14:40 - 16:00 | Peter Zoller & Discussion session | 15:10 - 15:30 | Sayan Choudhury |
| 15:40 - 16:00 | Kunkun Wang | | | 15:30 - on | Vincent Liu's closing remarks |
| 16:00 - 16:30 | break | 16:00 - on | Shuttle bus and banquet | | |
| 16:30 - 17:05 | Xiong-Jun Liu | | | | |
| 17:05 - 17:25 | Lei Cong | | | | |
| 17:25 - 19:00 | Poster session | | | | |
| 19:00 - on | Dinner | | | | |

# Titles overview

| Wednesday | | |
|---|---|---|
| 09:30 - 10:05 | **Xianmin Jin** | 3D Photonic Quantum Chip: Towards Large-Scale Quantum Computing and Quantum Simulation |
| 10:05 - 10:40 | **Sylvain Ravets** | Synthetic matter with light in semiconductor lattices |
| | | |
| 11:10 - 11:45 | **Ling Lu** | Dirac-vortex topological optical cavities |
| 11:45 - 12:20 | **Tao Shi** | New Macroscopic States of Matter in Attractive BECs and Quantum Droplets |
| | | |
| 14:30 - 15:05 | **Shuai Chen** | Explore topology of quantum gases by quench dynamics |
| 15:05 - 15:40 | **Gloria Platero** | Simulation of chiral topological phases in driven quantum dot arrays |
| 15:40 - 16:00 | **Kunkun Wang** | Dynamic topological phenomena in parity-time-symmetric quench dynamics |
| | | |
| 16:30 - 17:05 | **Xiong-Jun Liu** | Quantum phase transition of fracton topological orders |
| 17:05 - 17:25 | **Lei Cong** | Quantum Simulation of Light-matter Interactions with Trapped Ions |

| Thursday | | |
|---|---|---|
| 09:00 - 09:35 | **Anja Metelmann** | Interplay of Dissipative and Coherent Processes in Engineered Quantum Systems |
| 09:35 - 10:10 | **Jin-Feng Jia** | Majorana zero mode for topological quantum computing |
| 10:10 - 10:30 | **Jian Cui** | Optimal control of quantum simulators |
| | | |
| 11:00 - 11:35 | **Matthias Weidemüller** | Universal Glassy Dynamics in a Rydberg Spin System |
| 11:35 - 12:10 | **Ying Hu** | Quantum Sensing with Rydberg Atoms |
| | | |
| 14:30 - 15:05 | **Gerhard Kirchmair** | Quantum Simulation with Superconducting Qubits |
| 15:05 - 15:40 | **Laura García-Álvarez** | Quantum simulations of fermionic models with superconducting circuits |

| Friday | | |
|---|---|---|
| 09:00 - 09:35 | **Jing Zhang** | Artificial gauge field of one-dimensional superradiance lattices in ultracold atoms |
| 09:35 - 10:10 | **Alejandro González-Tudela** | Analogue quantum chemistry simulator with ultra-cold atoms |
| 10:10 - 10:30 | **Myung-Joong Hwang** | Universality in the Decay and Revival of Loschmidt Echoes |
| | | |
| 11:00 - 11:35 | **Marc Serra-Garcia** | Simulating topological matter with mechanicss |
| 11:35 - 12:10 | **Zhong Wang** | Non-Hermitian skin effect, non-Bloch band theory, and generalized bulk-boundary correspondence |
| | | |
| 14:00 - 14:35 | **Tim Byrnes** | Investigating cosmic inflation with the massive Schwinger model |
| 14:35 - 15:10 | **Xiaopeng Li** | Dynamical emergence of a Potts nematic superfluid in a hexagonal sp-2 optical lattice |
| 15:10 - 15:30 | **Sayan Choudhury** | Routes to maximize the lifetime of discrete time crystals in the absence of disorder |

# Poster list

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|---|
| **Naeem Akhtar** (University of Science and Technology. Hefei) |
| *Quantum tetrachotomous states: Superposition of four coherent states on a line in phase space* |
| **Francisco Albarrán-Arriagada** (Shanghai University) |
| *Spin-1 models in the ultrastrong-coupling regime of circuit QED* |
| **Lei Cong** (Shanghai University) |
| *Tunable Phase Transitions in Anisotropic Rabi-Stark Model* |
| **Emmanouil Grigoriou** (Shanghai Jiao Tong University) |
| *Quantum phase transition in a single-mode system* |
| **Yizun He** and **Lingjing Ji** *(Fudan University, Shanghai)* |
| *Geometric control of collective spontaneous emission* |
| **Narendra Hegade** (Shanghai University) |
| *Investigation of Quantum Pigeonhole Effect in IBM Quantum Computer* |
| **Mingyong Jing** (Shanxi University) |
| *Quantum superhet based on microwave-dressed Rydberg atoms* |
| **Shubham Kumar** (Shanghai University) |
| *Observation of geometric phase in molecular Aharonov-Bohm system using IBM quantum computer* |
| **Alexey N. Pyrkov** (Institute of Problems of Chemical Physics - Russian Academy of Sciences) |
| *Solitonic fixed point attractors in the complex Ginzburg-Landau equation for associative memories* |
| **Hao Tang** (Shanghai Jiao Tong University) |
| *(a) Experimental simulation of photosynthetic energy transport in a photonic network via quantum stochastic walks on photonic lattices*<br>*(b) Experimental quantum walks to simulate dynamic localization on periodically curved photonic lattices*<br>*(c) An efficient TensorFlow solver for quantum PageRank in large-scale networks* |
| **Lei Xiao** (Beijing Computational Science Research Center) |
| *Observation of critical phenomena in parity-time-symmetric quantum dynamics* |
| **Bing Zhu** (University of Science and Technology of China, Shanghai) |
| *Ultracold strontium Rydberg atoms for quantum simulation* |

# Abstracts

## Wednesday, November 13th [WED]

| 09:30 - 10:05 [WED] | **Xianmin Jin**<br>Shanghai Jiao Tong University, China |
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*3D Photonic Quantum Chip:*

*Towards Large-Scale Quantum Computing and Quantum Simulation*

Photons can be generated, manipulated and detected comparatively easier than other quantum particles, and can be transferred in a long distance without coupling with the environment. Photons therefore are a promising candidate for realizing quantum information processing. However, the limitations of bulk optics have become key bottleneck preventing quantum technologies from realizing in practice. Alternatively, integrated photonics provides an elegant way to scale up quantum systems. In this talk, I will present our endeavours recently delivered in Shanghai Jiao Tong University on femtosecond laser direct writing of 3D photonic quantum chips, and the applications in quantum computing and quantum simulation, including experimental demonstrations of two-dimensional quantum walk, quantum fast hitting and works on quantum topological photonics.

| 10:05 - 10:40 [WED] | **Sylvain Ravets**<br>Université Paris Saclay, France |
|---|---|

*Synthetic matter with light in semiconductor lattices*

Semiconductor microcavities have recently emerged as a powerful platform to implement artificial photonic materials based on the use of exciton-polaritons [1]. Polaritons are hybrid quasiparticles resulting from the strong coupling of cavity photons and quantum well excitons. Polaritons are particularly attractive since they combine the best of two worlds: (i) they are photonic excitations that can conveniently be excited and read-out using optical spectroscopy; (ii) their interactions can be tuned and reinforced via their matter component. Moreover, at C2N, we are able to sculpt the microcavities into micron-scale photonic materials with a great variety of geometries, in order to emulate different Hamiltonians.

After a general introduction, I will describe two examples that illustrate the potential of this non-linear photonic platform for quantum simulation. (i) We recently explored the localization properties of waves in synthetic quasiperiodic lattices [2]. Using both a theoretical analysis and experiments on our devices, we evidenced the existence of a series of delocalization-localization transitions in a novel family of quasiperiodic chains. (ii) In another study, we investigated the nonlinear properties of polaritons in the gapped flatband of a 1D Lieb lattice [3]. We observed the formation of gap solitons with quantized size and abrupt edges, a signature of frozen propagation due to the quenching of kinetic energy in a flatband. Our experiments also reveal a complex multistable behavior, which is a direct consequence of the driven-dissipative nature of the platform.

Finally, I will discuss perspectives in terms of quantum simulation.

[1] Amo, A. and J. Bloch, "Exciton-polaritons in lattices: A non-linear photonic simulator", Comptes Rendus Phys. 17, 934 (2016).
[2] V. Goblot et al., "Emergence of criticality through a cascade of delocalization transitions in quasiperiodic chains", in preparation (2019).
[3] V. Goblot et al., "Nonlinear Polariton Fluids in a Flatband Reveal Discrete Gap Solitons", Phys. Rev. Lett. 123, 113901 (2019).

| **11:10 - 11:45 [WED]** | **Ling Lu**<br>Institute of Physics, Beijing, China |
|---|---|

*Dirac-vortex topological optical cavities*

The distributed feedback (DFB) and vertical-cavity surface-emitting lasers (VCSEL) are the dominant diode lasers for many applications. By recognizing that both optical resonators feature a single mid-gap mode localized at the topological defect in a one-dimensional (1D) lattice, we generalize the topological cavity design into 2D using a honeycomb photonic crystal with a vortex Dirac mass — the analogue of Jackiw-Rossi zero modes. We theoretically predict and experimentally demonstrate that such a Dirac-vortex microcavity can have a tunable mode area across a few orders of magnitudes, arbitrary mode degeneracy, robustly large free-spectral-range, vector-beam output of low divergence, and compatibility with high-index substrates. This topological cavity may enable photonic crystal surface emitting lasers (PCSEL) with stabler single-mode operation.

| **11:45 - 12:20 [WED]** | **Tao Shi**<br>Institute of Theoretical Physics, Beijing, China |
|---|---|

*New Macroscopic States of Matter in Attractive BECs and Quantum Droplets*

It has been long believed that the steady-state of BECs with attractive interactions are considered as a coherent state with small depletions. However, by using the full Gaussian theory [1,2] including the squeezing effects self-consistently, we show that the true steady-state of attractive BECs is a new macroscopic state of matter, i.e., a single-mode squeezed vacuum state, and the macroscopic wavefunction is determined by a new equation of state [3]. A first-order phase transition between the macroscopic coherent and squeezed states is signaled by the softened two-particle excitations.

The full Gaussian theory also leads to the new insight into quantum droplets. We show that the phase diagram for the ground state of dipolar droplets by the Gaussian theory, which includes four quantum phases, i.e., the expansion phase, the self-bound gas phase, the self-bound mixture phase, and the self-bound liquid phase, divided by one third-order and two first-order phase transitions. In the self-bound gas and mixture phases, the system is in the single-mode squeezed state with Z_2 symmetry and single-mode coherent-squeezed state with completely U(1) symmetry breaking, respectively, which are new quantum states of matter with large particle number fluctuations. Since the ground state is totally different than the coherent state, the Gross-Pitaevskii equation with Lee-Huang-Yang corrections based on the expansion around the coherent state is not applicable. The results from the Gaussian theory not only agree with the experimental data [4] very well but also give rise to the prediction on the particle number statistics, i.e., the second-order correlation function that can be measured directly in experiments.

[1] T. Shi, E. Demler, and J. I. Cirac, Annals of Physics 390, 245 (2018).
[2] T. Guaita, L. Hackl, T. Shi, C. Hubig, E. Demler, and J. I. Cirac, Physical Review B 100, 094529 (2019).
[3] T. Shi, J. Pan, S. Yi, arXiv preprint arXiv:1909.02432.
[4] M. Schmitt, M. Wenzel, F. Bottcher, I. Ferrier-Barbut, and T. Pfau, Nature 539, 259 (2016).

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| 14:30 - 15:05 [WED] | **Shuai Chen**<br>University of Science and Technology of China - Shanghai |
|---|---|

*Explore topology of quantum gases by quench dynamics*

The centre role of quantum simulation via ultracold quantum gases is to synthesis an effective target Hamiltonian and study the evolution or the phases of the atoms in such a system. The topological quantum matter and topological phase transition attracted many of the researchers in recent years. Here, we systhesize the 2D Spin-Orbit coupled ultracold Bose gas by Raman coupling lattices. It is a "Quantum Anormelous Hall" the non-trivial topological band structure. The topology of this system is explored by quench dynamics. By quench the Raman detuning, the Band inversion surface (BIS) of the 2D topological system has been clearly observed from the time evolution of the spin-polarization pattern in the First Brillouin Zone (FBZ). The topological phase boundary has been precisely determined. By quench the phase of the Raman coupling, we have further observed the topological charge in the system and obtain the winding of the spin on the BIS, which determined the Chern number of the system. Our work provide a simple and powerful tool to explore the topological properties.

| 15:05 - 15:40 [WED] | **Gloria Platero**<br>Instituto de Ciencia de Materiales de Madrid, Spain |
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*Simulation of chiral topological phases in driven quantum dot arrays*

Recently, there is a big effort to implement long arrays of semiconductor quantum dots [1] due to the high tunability of these systems, which makes them suitable solid state platforms for quantum state transfer [2] and for quantum simulation purposes [3]. They are good quantum simulators of real molecules, as for instance dimerized molecular chains which can be model by a one dimensional tight-binding Hamiltonian with alternating tunnel matrix elements, the SSH model, It is characterized by a topological invariant, the Zak phase [4]. For finite chains in the nontrivial phase, a pair of exponentially decaying edge states emerges.

In this talk, we will first analyze the extension of this canonical model to include long range hopping, and study how this affects the topological properties of the system. We will show then that a quantum simulator for 1D chiral topological phases, including those appearing in the extended SSH model, can be obtained by periodically driving an array of quantum dots with long-range hopping. We propose a driving protocol which enables us to imprint bond-order in the lattice, while also offers tunability of the long-range hoppings. Thus the driving protocol triggers topological behaviour in a trivial setup, opening the door to the simulation of different chiral topological phases. Furthermore, we also study the time-evolution for the case of two interacting electrons, and show that the dynamics of different edge states modes can become highly correlated. This allows to discriminate between different topological phases and also opens up new possibilities for quantum state transfer protocols [5].

[1] D.M. Zayak et al., Phys. Rev. App., 6,054013 (2016).
[2] Y.Ban et al., Adv. Quantum Technol., 1900048 (2019).
[3] T. Hengsgens et al., Nature, 548, 70 (2017).
[4] M. Atala, et al. , Nat. Phys. 9, 795–800 (2013).
[5] B. Pérez-González et al., Phys. Rev. Lett. 123, 126401 (2019).

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| **15:40 - 16:00 [WED]** | **Kunkun Wang**<br>Beijing Computational Science Research Center, China |
|---|---|

*Dynamic topological phenomena in parity-time-symmetric quench dynamics*

We identify the emergent topological phenomena such as dynamic Chern numbers and dynamic quantum phase transitions (DQPTs) in quantum quenches of the non-Hermitian quantum-walk dynamics with parity-time (PT) symmetry. We construct a theoretical formalism for characterizing topological properties in non-unitary dynamics within the framework of biorthogonal quantum mechanics, and then reveal the interesting relation between different dynamic topological phenomena through the momentum-time spin texture characterizing the dynamic process. We simulate quench dynamics between distinct Floquet topological phases using quantum-walk dynamics and experimentally characterize DQPTs through interference-based measurements. Finally we experimentally detect momentum-time skyrmions in PT-symmetric non-unitary quench dynamics in quantum walks. Our work experimentally reveals the interplay of PT symmetry and quench dynamics in inducing emergent topological structures, and highlights the application of discrete-time quantum walks for the study of dynamic topological phenomena.

[1] Observation of emergent momentum-time skyrmions in parity-time-symmetric non-unitary quench dynamics, Nat. Commun. 10, 2293 (2019).
[2] Simulating dynamic quantum phase transitions in photonic quantum walks, Phys. Rev. Lett. 122, 020501 (2019).

| **16:30 - 17:05 [WED]** | **Xiong-Jun Liu**<br>Peking University, Beijing, China |
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*Quantum phase transition of fracton topological orders*

The fracton topological orders are a new type of strongly correlated topological phases hosting fractional excitations which are immobile or mobile only in restricted sub-dimensional space. In this talk, I will introduce the quantum phase transition in the fracton topological orders. A fracton topological order has ground state degeneracy which scales up with the system size. The topological transition in our study is characterized by the breaking down of the ground state degeneracy. I will introduce how to develop a theory to study the phase transition in a class of fracton topological orders, and determine the critical points of the phase transition. Some universal results will be presented.

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**17:05 - 17:25 [WED]** **Lei Cong**

Shanghai University, China

*Quantum Simulation of Light-matter Interactions with Trapped Ions*

Quantum simulation consists of the use of an easily controllable quantum platform to simulate another interactive quantum system. In the last decades, the field has grown due to the development of quantum technologies, such as cold atoms, trapped ions, photonics and superconducting circuits [1]. Among them, the trapped-ion system [2,3] has successfully simulated the quantum Rabi model [4,5], a paradigmatic example to study the ultra-strong coupling regime [6,7] of light-matter interactions. Following these works, we have studied the generalized quantum Rabi model and we have discovered novel physical features of light-matter interactions that are realizable in trapped-ion quantum simulators.

Precisely [8], we demonstrated the emergence of selective k-photon interactions in the strong and ultra-strong coupling regimes of the quantum Rabi model with a Stark coupling term. In particular, we showed that the interplay between rotating and counter-rotating terms produces k-photon interactions whose resonance frequencies depend on the state of the bosonic mode. We developed an analytical framework to explain these k-photon interactions by using time-dependent perturbation theory. Most importantly, we proposed a method to achieve the quantum simulation of the quantum Rabi model with a Stark term by using the internal and vibrational degrees of freedom of a trapped ion, and we demonstrated its performance with numerical simulations considering realistic physical parameters.

[1] A. Trabesinger, Nature Physics 8, 263 EP (2012),
[2] D. Leibfried, R. Blatt, C. Monroe, and D. Wineland, Rev. Mod. Phys. 75, 281 (2003).
[3] R. Blatt and C. F. Roos, Nature Physics 8, 277 EP (2012).
[4] J. S. Pedernales, I. Lizuain, S. Felicetti, G. Romero, L. Lamata, and E. Solano, Scientific Reports 5, 15472 (2015).
[5] D. Lv, S. An, Z. Liu, J.-N. N. Zhang, J. S. Pedernales, L. Lamata, E. Solano, and K. Kim, Physical Review X 8, 21027 (2018)
[6] A. Frisk Kockum, A. Miranowicz, S. De Liberato, S. Savasta, and F. Nori, Nature Reviews Physics 1, 19 (2019).
[7] P. Forn-Díaz, L. Lamata, E. Rico, J. Kono, and E. Solano, Rev. Mod. Phys. 91, 025005 (2019).
[8] L. Cong, S. Felicetti, J. Casanova, L. Lamata, E. Solano, and I. Arrazola, (2019), arXiv:1908.07358

## Thursday, November 14th [THU]

| 09:00 - 09:35 [THU] | **Anja Metelmann**<br>Free University of Berlin, Germany |
|---|---|

*Interplay of Dissipative and Coherent Processes in Engineered Quantum Systems*

The concept of dissipation engineering has enriched the methods available for state preparation, dissipative quantum computing and quantum information processing. Combining such engineered dissipative processes with coherent dynamics allows for new effects to emerge. For example, we found that any factorisable (coherent) Hamiltonian interaction can be rendered nonreciprocal if balanced with the corresponding dissipative interaction.

In this talk, we will address the question if nonreciprocal systems can generate entanglement between its constituents, and show that the dissipative process by itself can yield a purely unitary evolution on one subsystem.

| 09:35 - 10:10 [THU] | **Jin-Feng Jia**<br>Shanghai Jiao Tong University, China |
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*Majorana zero mode for topological quantum computing*

Majorana zero mode (MZM) can be used in fault-tolerant quantum computation relying on their non-Abelian braiding statistics, therefore, lots of efforts have been made to find them. Signatures of the MZMs have been reported as zero energy modes in various systems. As predicted, MZM in the vortex of topological superconductor appears as a zero energy mode with a cone like spatial distribution. Also, MZM can induce spin selective Andreev reflection (SSAR), a novel magnetic property which can be used to detect the MZMs. Here, I will show you that the $Bi_2Te_3/NbSe_2$ hetero-structure is an artificial topological superconductor and all the three features are observed for the MZMs inside the vortices on the $Bi_2Te_3/NbSe_2$. Especially, by using spin-polarized scanning tunneling microscopy/spectroscopy (STM/STS), we observed the spin dependent tunneling effect, which is a direct evidence for the SSAR from MZMs, and fully supported by theoretical analyses. More importantly, all evidences are self-consistent. Our work provides definitive evidences of MFs and will stimulate the MZMs research on their novel physical properties, hence a step towards their statistics and application in quantum computing. In the second part, I will show that stanene could be a topological superconductor.

[1] Mei-Xiao Wang, et al., Science 336, 52-55 (2012)
[2] J.P. Xu, et al., Phys. Rev. Lett. 112, 217001 (2014)
[3] J.P. Xu, et al., Phys. Rev. Lett. 114, 017001 (2015)
[4] H.H. Sun, et al., Phys. Rev. Lett. 116, 257003 (2016)
[5] H.H. Sun, Jin-Feng Jia*, NPJ Quan. Mater. 2, 34 (2017)
[6] F. F. Zhu, et al., Nature Mater. 14, 1020 (2015)

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| 10:10 - 10:30 [THU] | **Jian Cui**<br>Beihang University, China |
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*Optimal control of quantum simulators*

We present optimal control protocols to prepare different many-body quantum states of Rydberg quantum simulator, a programmable quantum simulator based on neutral atom arrays with interactions mediated by Rydberg states. Specifically, we show how to prepare highly ordered many-body ground states and GHZ states within sufficiently short experimental times minimising detrimental decoherence effects. We demonstrate the deterministic generation of the Greenberger-Horne-Zeilinger (GHZ) states with up to 20 qubits in experiment.

[1] Quantum Sci. Technol. 2 (2017) 035006
[2] Science 365, 570–574 (2019)

| 11:00 - 11:35 [THU] | **Matthias Weidemüller**<br>Heidelberg University, Germany |
|---|---|

*Universal Glassy Dynamics in a Rydberg Spin System*

Out of equilibrium spin systems with disorder can show extremely slow dynamics as known, e.g., for spin glasses, where the magnetization relaxes slowly over several orders of magnitude in time. To investigate such dynamics in the presence of quantum fluctuations we implement an isolated disordered spin system composed of long-range interacting Rydberg atoms which can be described by a Heisenberg XXZ spin model [1]. We present an experiment which disentangles the role of fluctuations stemming from disorder and quantum fluctuations. The spin system is represented by two atomic Rydberg states in a “frozen” gas of ultracold atoms under the influence of dipolar interactions ranging over macroscopic distances. We find strong deviation from the mean field prediction of the magnetization. Instead, the magnetization relaxes with a universal non-exponential decay much slower than the timescale associated with the exchange coupling strength. Such dynamics, which bears similarities to spin glasses, is in good agreement with a discrete truncated Wigner approximation revealing that the evolution is determined by the build-up of entanglement driven by quantum fluctuations [2]. We will also discuss the spin dynamics under the presence of an external field.

[1] A. Piñeiro Orioli et al., Phys. Rev. Lett. 120, 63601 (2018).
[2] A. Signoles, T. Franz et al., arXiv:1909.11959.

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| **11:35 - 12:10 [THU]** | **Ying Hu**<br>Shanxi University, China |
|---|---|

*Quantum Sensing with Rydberg Atoms*

Progress in atomic, optical and quantum science has led to rapid progress in quantum sensing. In this talk, we present achievement of the first significant step en route to realizing the long sought-after electromagnetic-wave quantum sensors, which offer quantum projection noise limited sensitivity, SI-traceability, as well as capabilities of phase and frequency resolutions. Right now, quantum sensing of microwave (MW) fields primarily relies on atom-based electrometers only enabling amplitude measurement. Moreover, state-of-the-art sensitivity of atom-based electrometers is limited to few microvolts per centimeter per square root hertz. Here we develop a conceptually new approach for detection of MW field based on microwave-dressed Rydberg atoms and tailored optical spectrum. Firstly, we show it allows for a drastic sensitivity improvement even with a modest experiment setup, with the minimum detectable MW field being three orders of magnitude smaller than prior art. Equally remarkable is the low measurement uncertainties even when the signal is so small as few hundreds nanovolt per centimeter. Finally, it enables simultaneous resolution of the phase and frequency of MW reflected from moving objects. We envision a further sensitivity boost when combining our approach with quantum resources (such as quantum entanglement). Our innovative technique will benefit a wide range of fields including quantum simulation, quantum metrology, and astronomical explorations.

| **14:30 - 15:05 [THU]** | **Gerhard Kirchmair**<br>Inst. of Quantum Optics and Quantum Information, Innsbruck, Austria |
|---|---|

*Quantum Simulation with Superconducting Qubits*

In this talk, I want to present the research activities of the Superconducting Quantum Circuits group at the Institute for Quantum Optics and Quantum Information in Innsbruck.

In the first part, I will introduce circuit quantum electrodynamics and the 3D architecture. I will show how we are using this architecture to realize a platform for quantum many body simulations. Our basic building blocks are 3D Transmon qubits where we use the naturally occurring dipolar interactions to realize interacting spin systems. The ability to arrange the qubits on essentially arbitrary geometries allows us to design spin models with more than nearest-neighbor interaction in various geometries.

Combining these ideas with our waveguide architecture, will allow us to study open system dynamics with interacting spin systems. The platform will allow us to investigate the interplay between short-range direct interactions, long-range photon mediated interaction via the waveguide and the dissipative coupling to an open system.

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| 15:05 - 15:40 [THU] | **Laura García-Álvarez**<br>Chalmers University of Technology, Gothenburg, Sweden |
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*Quantum simulations of fermionic models with superconducting circuits*

In this talk, I will introduce digital-analog and purely digital methods for quantum simulations of fermionic models. The digital-analog approach provides a higher degree of scalability than purely digital or purely analog techniques, and it is suitable for implementing quantum simulations of interacting fermions and bosons in condensed matter, and quantum field theories [1]. I will provide examples of purely digital quantum simulations in the context of superconducting circuits, and particularly I will focus on the use of few-qubit quantum processors for the simulation of the Hubbard model [2,3], and an AdS/CFT duality [4].

[1] L. García-Álvarez et al., Fermion-fermion scattering in quantum field theory with superconducting circuits, Phys. Rev. Lett. 114, 070502 (2015).
[2] R. Barends et al., Digital quantum simulation of fermionic models with a superconducting circuit, Nat. Commun. 6, 7654 (2015).
[3] J. M. Kreula et al., Few-qubit quantum-classical simulation of strongly correlated lattice fermions, EPJ Quantum Technology 3, 11 (2016).
[4] L. García-Álvarez et al., Digital quantum simulation of minimal AdS/CFT, Phys. Rev. Lett. 119, 040501 (2017).

## Friday, November 15th [FRI]

| **09:00 - 09:35 [FRI]** | **Jing Zhang**<br>Shanxi University, China |
|---|---|

*Artificial gauge field of one-dimensional superradiance lattices in ultracold atoms*

There have been significant recent advances in realizing band structures with geometrical and topological features in experiments on cold atomic gases. We experimentally realize one-dimensionally superradiance lattice (SL) with 87Rb Bose-Einstein condensate (BEC) based on electromagnetically induced transparency (EIT). Based on one-dimensional SL in standing wave-coupled electromagnetically induced transparency, a far-detuned standing wave field is introduced to synthesize a magnetic field. The relative spatial phase between the two standing wave coupling fields introduces a magnetic flux in the sawtooth loop transitions of the lattice. This flux determines the moving direction of excitations created in the SL and results in nonsymmetric reectivities when the SL is probed in two opposite directions. Our work demonstrates an in-situ technique to synthesize and detect topological matter in cold atoms.

[1] L. Chen, P. Wang, Z. Meng, L. Huang, H. Cai, D.-W. Wang, S.-Y. Zhu, J. Zhang "Experimental observation of one-dimensional superradiance lattices in ultracold atoms" Phys. Rev. Lett. 120, 193601 (2018)
[2] P. Wang, L. Chen, C. Mi, Z. Meng, L. Huang, H. Cai, D.-W. Wang, S.-Y. Zhu, J. Zhang "Synthesized magnetic field of a sawtooth superradiance lattice in Bose-Einstein condensates" submitted

| **09:35 - 10:10 [FRI]** | **Alejandro González-Tudela**<br>Institute of Fundamental Physics, Madrid, Spain |
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*Analogue quantum chemistry simulator with ultra-cold atoms*

Solving quantum chemistry problems with a quantum computer is one of the most exciting applications of future quantum technologies. Current efforts are focused on finding on efficient algorithm that allow the efficient simulation of chemistry problems in a digital way. In this talk, I will present a complementary approach to the problem which consists in simulating quantum chemistry problems using ultra-cold atoms. I will first show how to simulate the different parts of the Hamiltonian, and then benchmark it with simple molecules.

[1] Nature 574, 215-218 (2019)

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| 10:10 - 10:30 [FRI] | **Myung-Joong Hwang**<br>Duke Kunshan University, China |
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*Universality in the Decay and Revival of Loschmidt Echoes*

A system exhibiting a quantum phase transition may exhibit critical behavior not only in their ground state, but also in their non-equilibrium dynamics. Understanding the latter through the lens of universality is an important challenge. In this talk, I will present a recent work [1] demonstrating that the decay of Loschmidt echo, a dynamical analogue of quantum fidelity measuring the overlap between a ground state and a time-evolved quantum state following a sudden quench, follows power-law scaling in the system size and the distance from a critical point with equilibrium critical points. It has long been pointed out that the Loschmidt echo may exhibit a sharp decay near a critical point, but our work provides a quantitative dynamical scaling law governing such a critical decay of Loschmidt echo. I will outline the construction of dynamical scaling functions and demonstrate numerically the validity of the predicted scaling laws with a diverse range of critical models such as Ising spin models with a short and long range interaction as well as a finite-component system phase transition. I will also introduce how our strategy can be used to characterize the universality of out-of-time-ordered correlators (OTOC) in critical systems [2].

[1] Universality in the Decay and Revival of Loschmidt Echoes, arXiv:1904.09937 (2019)
[2] Dynamical Scaling Laws of Out-of-Time-Ordered Correlators, arXiv:1906.00533 (2019)

| 11:00 - 11:35 [FRI] | **Marc Serra-Garcia**<br>ETH Zurich, Switzerland |
|---|---|

*Simulating topological matter with mechanics*

The realm of theoretical physics offers a rich variety of particle and material models, from high-order or fragile topological insulators to Weyl fermions with axial fields. Some times it is difficult to find experimental examples of such systems. In this talk, I will discuss the simulation of novel phases of matter by engineering the mechanical wave propagation along metamaterial systems — For example, by tuning the flexural wave propagation in thin plates or the acoustic response of a network of cavities. In all of these examples, the mechanical realisation predated the observation of the effect in alternative simulation paradigms or in real materials. I will present strategies for the implementation of arbitrary Hamiltonians in classical wave propagation and discuss possible future directions including the automatic generation of physical systems with arbitrary dynamics.

| 11:35 - 12:10 [FRI] | **Zhong Wang**<br>Tsinghua University, Beijing, China |
|---|---|

*Non-Hermitian skin effect, non-Bloch band theory, and generalized bulk-boundary correspondence*

Non-Hermitian Hamiltonians can exhibit the counterintuitive behavior that all the eigenstates are localized at the boundary, which is dubbed the non-Hermitian skin effect. It implies a dramatic departure from the conventional Bloch band theory, for example, the failure of conventional topological invariants in predicting the topological edge modes. In this talk, we will introduce the basic idea of the non-Bloch band theory of non-Hermitian systems. In the first part, we show that the non-Bloch topological invariants defined in the generalized Brillouin zone faithfully predict the number of topological edge modes, embodying a generalized (non-Bloch) bulk-boundary correspondence. In the second part, we show that the non-Hermitian skin effect has interesting consequences in the dynamics of open quantum systems governed by the master equation. Specifically, we show that the non-Hermitian skin effect induces a "chiral damping" with novel long-time behaviors.

| 14:00 - 14:35 [FRI] | **Tim Byrnes**<br>New York University Shanghai, China |
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*Investigating cosmic inflation with the massive Schwinger model*

The prevailing theory in modern cosmology holds that shortly after the big bang, the universe underwent an extended period of extraordinarily rapid, exponential expansion known as cosmic inflation. This inflationary theory accounts for several aspects of the universe that are otherwise difficult to explain. For example, the origin of all stars and galaxies can be ultimately traced back to the magnification of small quantum effects generated during inflation. Despite the success of inflationary theory, little is known about the fundamental physics that produced the exponential growth, and how it began and came to an end. Recently, a new mechanism was proposed that accounts for the dynamical process of how vacuum energy present in space after the Big Bang gradually decreased, leading to a period of near-exponential expansion. In this so-called "unwinding inflation" theory, quantum fluctuations produce charged matter-antimatter pairs that accelerate through space, discharging the initial vacuum energy in an way analogous to the phenomenon of Schwinger pair production in quantum electrodynamics. While this mechanism has already been shown to work in certain limits where it is relatively simple to analyze, a precise evaluation of the dynamics remains to be performed. We study the dynamics of the massive Schwinger model on a lattice and find that our results support the existence of this flux unwinding phenomenon, both for initial states containing a charged pair inserted by hand, and when the charges are produced by Schwinger pair production. We also study boundary conditions where charges are confined to an interval and flux unwinding cannot occur, and the massless limit, where our results agree with the predictions of the bosonized description of the Schwinger model.

| 14:35 - 15:10 [FRI] | **Xiaopeng Li**<br>Fudan University, Shanghai, China |
|---|---|

*Dynamical emergence of a Potts nematic superfluid in a hexagonal $sp^2$ optical lattice*

Nematicity is a long-range orientational order associated with rotation-symmetry breaking in the presence of translational invariance, borne out of the description of classical liquid crystals. This order also emerges in interacting electrons and has been found to largely intertwine with multi-orbital correlation in high-temperature superconductivity, where Ising nematicity arises from a four-fold rotation symmetry $C_4$ brokendown to $C_2$. In this talk, I will present an observation of a bosonic superfluid with a three-state ($\mathbb{Z}_3$) quantum nematic order, dubbed ``Potts-nematicity", in a system of ultracold atoms loaded in an excited band of a hexagonal optical lattice described by an $sp^2$-orbital hybridized model. This Potts-nematic superfluid spontaneously breaks a three-fold rotation symmetry of the lattice, qualitatively distinct from the Ising nematicity. Our field theory analysis shows that the Potts-nematic order is stabilized by intricate renormalization effects enabled by strong inter-orbital mixing present in the hexagonal lattice.This discovery paves a way to investigate quantum vestigial orders in multi-orbital atomic superfluids.

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| 15:10 - 15:30 [FRI] | Sayan Choudhury |
| --- | --- |
| | University of Pittsburgh, USA |

*Routes to maximize the lifetime of discrete time crystals in the absence of disorder*

Motivated by the recent observation of discrete time crystals in the absence of disorder, we propose schemes to extend the lifetime of a discrete time crystal in a translation invariant Ising spin chain. We derive an analytical framework to show that by appropriately tuning the interactions, it is always possible to realize a time crystal in a finite size chain. We also obtain an expression for the optimal value of the Ising interaction that maximizes the lifetime of the time crystal. Our results hold for both short and long range interacting systems. We connect our results to the newly discovered phenomena of "Many-body Echo" and briefly discuss applications of a discrete time crystal to quantum metrology.

[1] "An eternal discrete time crystal beating the Heisenberg limit", Changyuan Lyu, Sayan Choudhury, Chenwei Lv, Yangqian Yan, and Qi Zhou, arXiv: 1907.00474
[2] "Routes to maximize the lifetime of discrete few-body time crystals", Sayan Choudhury (in preparation).

# Venue and practical information

The workshop will take **place** at the Pao Sui-Loong Library of the Xuhui campus of Shanghai Jiao Tong University, specifically at (see **Map 1**):

| | |
|---|---|
| Antai College of Economics & Management<br>Pao Sui-Loong Library, Room A511, Fifth Floor<br>Shanghai Jiao Tong University, Xuhui Campus<br>1954 Huashan Rd, 200030 Shanghai, China | 安泰经济管理学院<br>包兆龙图书馆A511平面教室<br>上海交通大学 徐汇校区<br>华山路1954号上海交通大学 2号 门 |

**Interactive campus map** at https://map.sjtu.edu.cn/m (choose Xuhui and preferred language).

**Lunch** will be served at **Canteen 2**, next to the workshop venue (see **Map 1** below).

**Dinner** on **Wednesday** will be around campus (we'll provide details on site).

Workshop **banquet** on **Thursday** will be in the **Pudong** area, which we'll reach by **shuttle** bus.

The **posters** can be put up any time during Wednesday and will be displayed for the whole duration of the workshop. A dedicated session is scheduled on Wednesday after the talks.

**WIFI** is available through **eduroam** or the **workshop's** own network: **WQC_2019**
psswd: **WQC2019WORKSHOP**

In case of need, do not hesitate to contact:

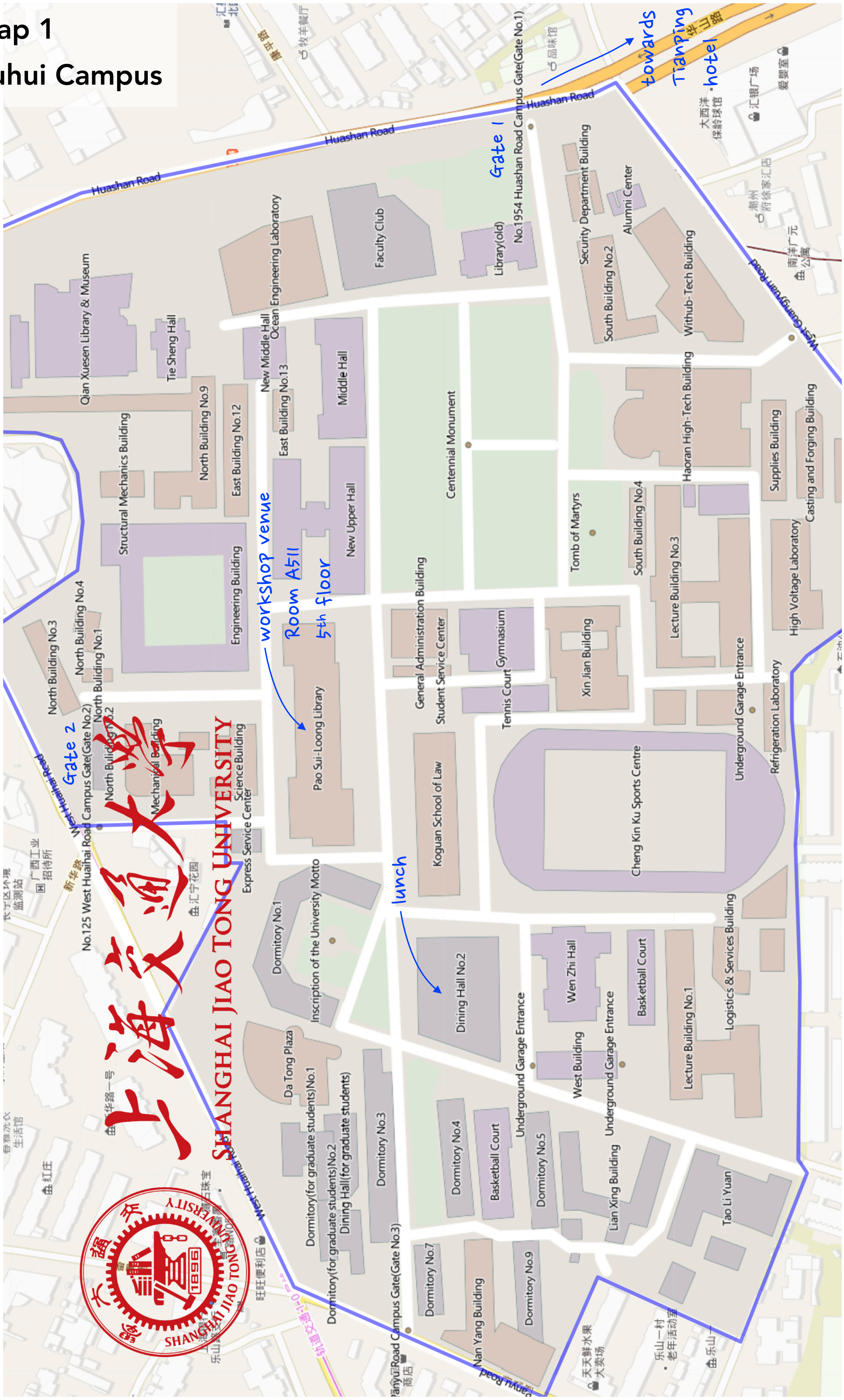
| | |
|---|---|
| Elaine (Zexin) Hu<br>+86 152 1687 3627<br>zexinhu@sjtu.edu.cn | Carlos Navarrete-Benlloch<br>+86 131 62897467<br>derekkorg@gmail.com |

Invited speakers and guests stay at the following accommodation:

| | |
|---|---|
| Tianping Hotel<br>185 Tianping Rd<br>200030 Shanghai, China<br>TEL: +86 021 54569999<br>www.tianpinghotel.com | 上海天平宾馆<br>上海市徐汇区天平路185号<br>电话: +86 021 54569999<br>www.tianpinghotel.com |

It is within walking distance (10-15 min) from the workshop venue (see **Maps 2** or **3** below).

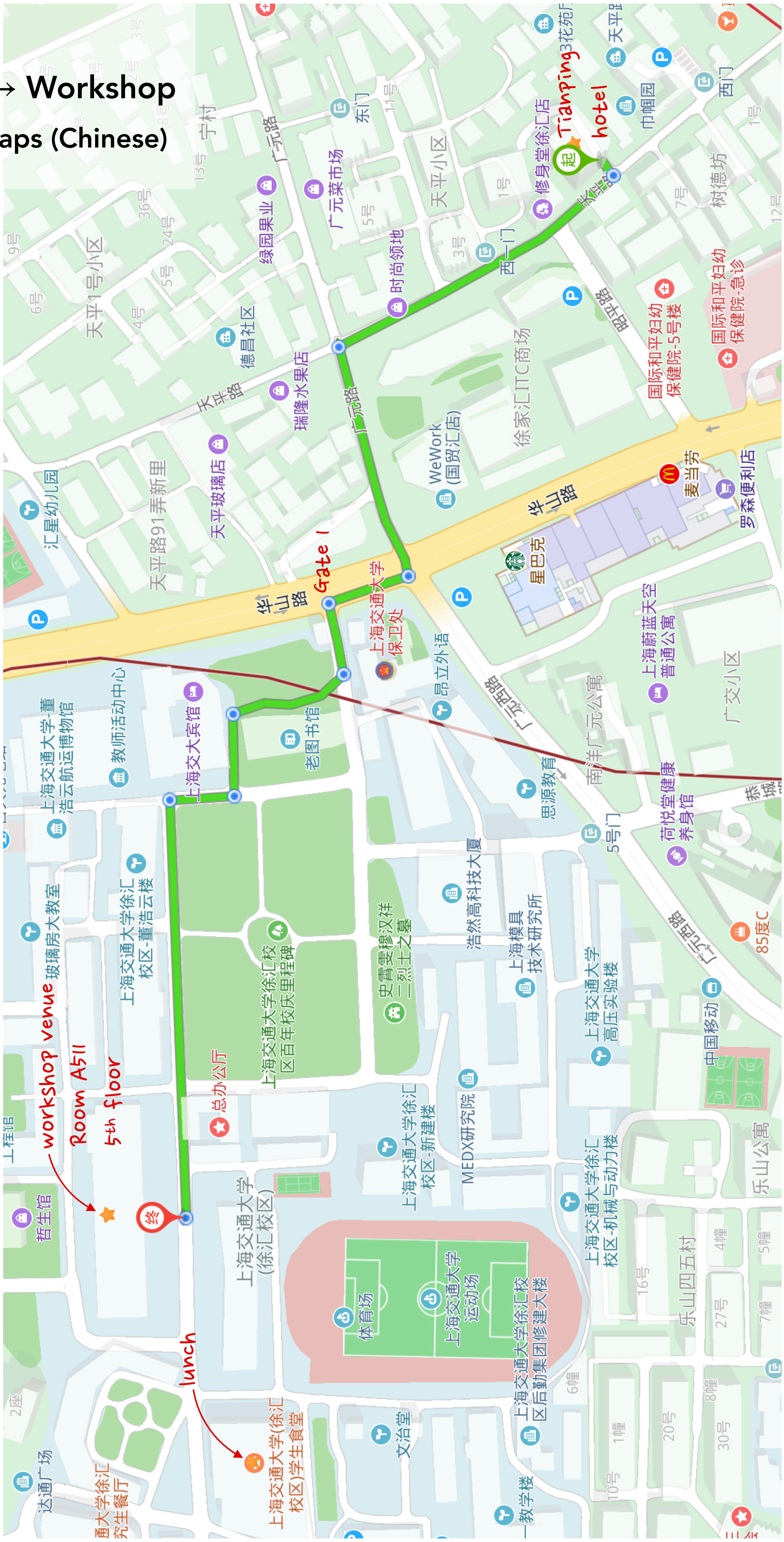
## Map 1
## Xuhui Campus



## Map 2

## Hotel ↔ Workshop

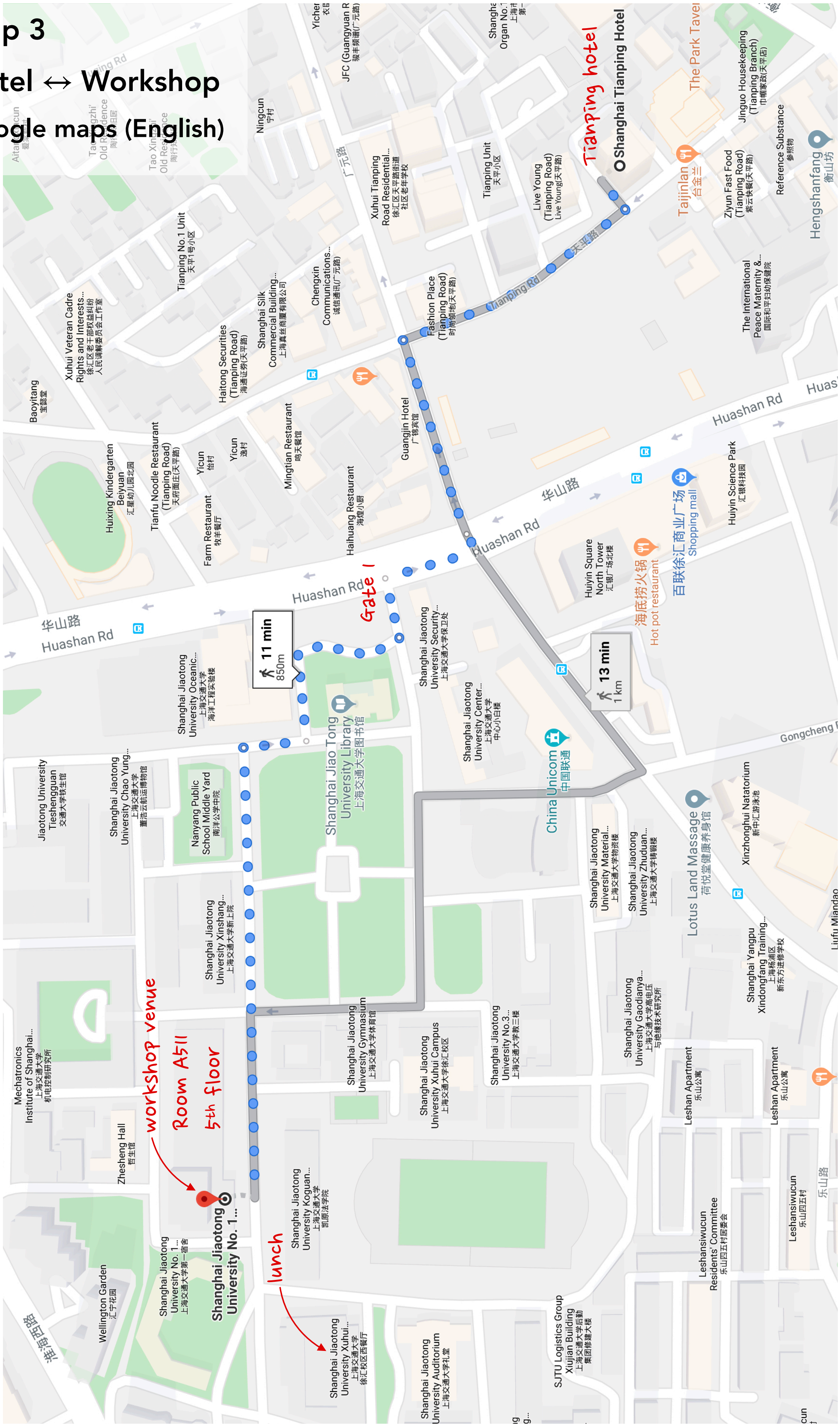
### Baidu maps (Chinese)



# Map 3

## Hotel ↔ Workshop

### Google maps (English)



### Taxis in Shanghai

Taxis are the fastest means of transportation, traffic permitting. Finding a taxi in the busy streets of the city is easy in most cases. Although most drivers are familiar with the city, being as specific as possible with directions will speed up your journey and make it cheaper. Have at hand the addresses we provided above, keeping in mind that drivers seldom understand English.

*Payment*: Tipping is not expected and cash is essentially the only means for payment for foreigners. Common Chinese payment methods (wechat, alipay, transportation card, etc) are also available. The ride from Pudong airport to the workshop area should cost around 200-250RMB and may take about an hour with traffic.

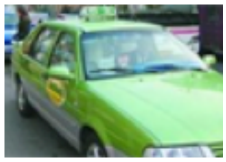
*Receipt*: Upon leaving, ask for a receipt (发票 - FA PIAO), which will show the taxi's plate and the company’s telephone number. It is very useful in case you leave something behind or you have a complaint.

*Avoid fake taxis*: Especially at the airport, do not pay attention to people offering you help finding a taxi. All train stations and airports have a proper, obvious taxi area, where you’ll typically find other people queueing. Just follow the signs to those areas.

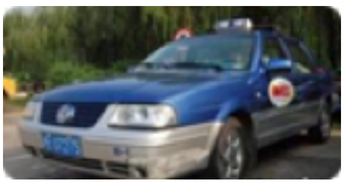
Typical taxis and hotlines:

Dazhong Taxi Company (大众)
Tel: 96822; Cyan taxis:

Qiangsheng Taxi Company (强生)
Tel: 62580000; Yellow & Green taxis:



Haibo Taxi Company (海博)
Tel: 96933; Blue taxis



Jinjiang Taxi Company (锦江)
Tel: 96961; White taxis