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Ecole Normale Superieure and University of Tokyo

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Hongo Campus, University of Tokyo
ENS-UT Workshop on Physics

November 25-26, 2019

Hongo Campus, University of Tokyo

Faculty of Science, Building No.4, Room 1320 (3rd floor)
Workshop Program

November 25, 2019

9:30- Welcome coffee

9:50-10:00 Welcome address

10:00-10:30 Jakob Reichel
“Spin Squeezing at a Metrologically Relevant Level”

10:30-11:00 Hidetoshi Katori
“Transportable Optical Lattice Clocks to Test Gravitational Redshift”

11:00-11:30 Sébastien Gleyzes
“Cat States and Quantum Metrology with Rydberg Atoms”

11:30-12:00 Masahito Ueda
“Discrete Time-crystalline Order in Cavity and Circuit QED Systems”

12:00-13:30 Lunch

13:30-14:00 Kazuhiko Hirakawa
“Terahertz Spectroscopy of Electron - vibron Coupling in Single Molecules”

14:00-14:30 Robson Ferreira
“Graphene Quantum Dots in the THz domain”

14:30-15:00 Ryo Shimano
“Electron-hole Bardeen-Cooper-Schrieffer State in a Photoexcited Semiconductor”

15:00-15:30 Synge Todo
“Data Assimilation in Materials Science - crystal Structure Prediction Supported by Incomplete Experimental Data”

15:30-16:00 Break

16:00-16:30 Matthieu Delbecq
“Sensing a Synthetic Spin Texture with Cavity Photons”
16:30-17:00  Kensuke Kobayashi
“Non-equilibrium Fluctuations in Correlated Quantum Liquids”

17:00-17:30  Gwendal Fève
“Microwave Photons Emitted by Fractionally Charged Quasiparticles”

17:30-18:00  Seigo Tarucha
“Quantum Non-demolition Measurement of Single Spins”

November 26, 2019

10:00-10:30  Satoshi Yamamoto
“Why Chemistry in Astronomy?”

10:30-11:00  Edith Falgarone
“A Tale of Turbulence and Gravity”

11:00-11:30  Naoki Yoshida
“Cosmological Simulations of Galaxy Formation”

11:30-13:00  Lunch

13:00-13:30  Yasushi Okada
“Dissecting the Molecular Mechanisms of Axonal Transport Through Single Molecule and Super-resolution Imaging”

13:30-14:00  Frederic Pincet
“In Vitro Recapitulation of Synaptic Transmission with Model Physiological Membranes”

14:00-14:30  Tetsuya Kobayashi
“Understanding Biological Sensing and Its Optimality”

14:30-15:00  Jean François Allemand
“Some Single DNA Micromanipulation Experiments”

15:00-15:30  Takahiro Sagawa
“Thermodynamics of Information”

15:30-15:45  Closing
Long-lived spin squeezing and quantum phase magnification

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The spectacular progress of atomic clocks has turned them into the most precise of all physical instruments available today. Beyond metrology, this precision also opens a new window on many-body physics in ultracold atomic ensembles, much of which occurs on energy scales that only these instruments can resolve. These clocks, and indeed all sensors utilizing uncorrelated particles are ultimately limited by quantum projection noise, as is already the case for some state-of-the-art instruments today. This so-called standard quantum limit (SQL) can be overcome by preparing the particles in a many-body entangled state, such as a spin-squeezed state. Atomic spin-squeezing has been generated in spectacular proof-of-principle experiments. In these experiments, however, the entanglement was rather short-lived (typical coherence times on the order of milliseconds), precluding clock measurements in any metrologically relevant regime. In a collaboration with the French time and frequency laboratory SYRTE (Observatoire de Paris), we have now produced spin-squeezed states with coherence times on the order of a second in the experimental platform of a trapped-atom clock on a chip. Besides the metrological perspective of enabling quantum-enhanced clock measurement in the range of $10^{-13}$ s^{-1/2} (the regime of next-generation compact atomic clocks), these long coherence times reveal a surprising quantum phase magnification effect resulting from a subtle interplay of spin dynamics and non-demolition measurement of the collective spin.
Transportable Optical Lattice Clocks to Test Gravitational Redshift

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An “optical lattice clock” proposed in 2001 [1] benefits from a low quantum-projection noise by simultaneously interrogating a large number of atoms trapped in optical lattices tuned to the “magic frequency” [2] that largely cancels the light shift perturbation of the lattice trap. About a thousand atoms enable such clocks to achieve $10^{-18}$ instability in a few hours of operation, which allows intensive investigation of systematic uncertainties and finding new applications.

We report recent topics including 1) an “operational magic condition” [3, 4] to reduce the clock uncertainty to $10^{-19}$ by cancelling out the higher-order light shifts than that given by the electric-dipole interaction, 2) transportable Sr-based clocks with an uncertainty of $10^{-18}$ that were being operated outside a laboratory, and 3) testing of the gravitational redshift using 450-m-high tower.

References
Quantum Metrology with Rydberg Atoms

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Rydberg states correspond to electron wave function localized at a very large distance from the nucleus. These giant atoms are extremely sensitive to their electromagnetic field environment. It is possible to prepare state with very large electric dipole to probe the amplitude of the electric field, or states with very large angular momentum, able to detect very small magnetic field. As often in quantum metrology experiment, the limit of the sensitivity is set by the quantum fluctuations associated with the state of the atom. To reach the ultimate sensitivity set by the law of quantum mechanics, called the Heisenberg limit, it is necessary to prepare the atom in a non-classical states, like a Schrödinger cat state.

Our system is a Rydberg atom with a large quantum principal number \( n \sim 50 \). In the presence of a small electric field defining the quantization axis, the degeneracy between levels with the same \( n \) is lifted. The new eigenstates, called Stark levels, are defined by the magnetic quantum number \( m \), which remains a good quantum number, and the parabolic quantum number \( n_1 \), with \( 0 \leq n_1 \leq n-|m|-1 \). Since \( m \) remains a good quantum number, it is possible, using a radio frequency field with a well-defined \( \sigma^+ \) polarization, to restrict the evolution of the atom to a subspace of the Stark manifold where the system behaves like a large spin \( J = (n-1)/2 \), whose frequency is proportional to the local amplitude of the electric field. We have used this effective spin to perform a quantum-enabled measurement of the static electric field. We prepare a Schrödinger cat state of the Rydberg atom, quantum superposition of two classically distinct wavefunction with very different electric dipole, and observe how the relative phase between the two components of the quantum superposition provides a very sensitive signal to measure the variation of the static electric field [1]. We achieve a precision that exceeds the SQL and approaches the fundamental Heisenberg limit (HL). The single-shot sensitivity reaches 0.3 mV/cm for a 200 ns interaction time, (8 \( \mu \)V/cm/\( \sqrt{\text{Hz}} \) at a 3 kHz repetition rate). This highly sensitive, non-invasive space- and time-resolved field measurement extends the realm of electrometric techniques and could have important applications.

Driving the Rydberg atom with a combination of \( \sigma^+ \) and \( \sigma^- \) polarization also open the way to explore the full set of Stark level, and in particular prepare quantum superposition of state with same parabolic number but opposite value of \( m \). Such states are very interesting for magnetic metrology, as they correspond to microscopic probe with up to 100 \( \mu \)B magnetic moment, while at the same time being impervious to electric field noise [2].

References
Discrete Time-Crystalline Order in Cavity and Circuit QED Systems

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We propose an open-system setup to realize the discrete time-crystalline (DTC) order based on a modified open Dicke model, which can be implemented in cavity and circuit QED systems [1]. It is well-known that the open Dicke model, which describes a collective light-atom interaction in the presence of photon loss, exhibits a superadiant phase transition in the strong-coupling regime. We show that a DTC order can be realized by simply switching on and off a strong light-atom interaction periodically. In the thermodynamic limit with infinite atoms, we find a rich variety of dynamical phases with different types of DTC orders, which turn out to be related to bifurcation theory. In the deep quantum regime with few atoms, we show a clear transient DTC order stabilized by photon loss. These theoretical predictions are testable in light of the state-of-the-art experiments in atomic, molecular and optical physics.

References
Terahertz Spectroscopy of Electron - vibron Coupling in Single Molecules

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Clarifying electronic and vibronic properties of individual molecules provides key insights to future tailor-made medicine, chemistry, nanoelectronics, and quantum information technologies. Terahertz (THz) spectroscopy has been developed as a powerful tool for clarifying vibrational dynamics of various kinds of molecules. Because of the long-wavelength nature of the THz radiation (typically, ~100 microns), however, spectral information was obtained only for ensemble average of a huge number of molecules. It has been a formidable challenge to overcome the diffraction limit and focus THz radiation on a single molecule. Furthermore, the number of mobile charges that can absorb THz radiation in a single molecule is very few, which makes THz absorption by a single molecule extremely small.

Here, we report on the THz spectroscopy of single molecules by using the single molecule transistor (SMT) geometry [1]. Using the source and drain electrodes separated by a sub-nm gap as a THz antenna [2], we focused the THz radiation onto a single fullerene molecule trapped in the nanogap electrodes and measured THz-induced photocurrent in the SMT. A great advantage of the present SMT geometry is that the electrostatic potential and the number of electrons on the molecule can be precisely controlled. We have observed low energy vibrational modes due to the center-of-mass nanomechanical motion of the fullerene molecule. Furthermore, we found that the observed peaks are finely split into two, reflecting the difference in the van der Waals potential profile experienced by the molecule on the metal surface when the number of electrons on the molecule fluctuates by one during the single electron tunneling process. Such an ultrahigh-sensitivity to the electronic/vibronic structures of a single molecule upon adding/removing a single electron has been achieved by using the THz spectroscopy in the SMT geometry. This SMT scheme provides a novel opportunity for investigating ultrafast THz dynamics of sub-nm scale systems.

References
Graphene Quantum Dots in the THz Domain

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The energy spectrum of graphene quantum dots presents pronounced discretization effects and is highly sensitive to lateral disorder, because of its usually large perimeter to surface ratio. We have performed calculations of the electron spectrum and optical absorption of graphene quantum dots. We discuss the emergence of bulk-like features in the spectrum and its polarization-dependent optical response, for model QDs of increasing size, in the low energy (THz) domain.
Electron-hole Bardeen-Cooper-Schrieffer state in photoexcited semiconductors

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Concept of a Cooper pair plays a key role in quantum condensation phenomena in many-body systems. After the original Bardeen-Cooper-Schrieffer (BCS) theory for superconductivity, many kinds of fermionic condensates where particles other than electrons form Cooper pairs have been unveiled, e.g. in the superfluid \textsuperscript{3}He, fermionic ultracold atomic gases, and theoretically in quark matters. An electron-hole (e-h) system in photoexcited semiconductors offers another fascinating arena to explore the pair condensation phenomena. In the low-density region, electrons and holes are strongly bound to form quasi-bosonic elementally excitations, called excitons, which have been expected to undergo Bose-Einstein condensation (BEC) at sufficiently low temperatures. On the other hand, in the high-density region where electrons and holes can form degenerate fermionic gases, a BCS-type condensation consisted of weakly bound e-h Cooper pairs has long been anticipated, referred to as the e-h BCS state, while its experimental verification has remained elusive over decades. We tackled this problem by the resonance excitation of 1S exciton across the excitonic Mott insulator-to-metal transition density [1-4]. The optical pump-probe spectroscopy shows that under the relatively low density region, the 1S exciton absorption line splits into two lines which are interpreted in terms of the dressed states(Rabi splitting) of excitons. The high-energy branch of the excitonic dressed states is shown to evolve into an pronounced absorption edge above the band-gap. Comparing the experimental result with a simulation based on semiconductor Bloch equations, we demonstrate that the dressed state in such a high-density region is viewed as e-h BCS state [5].

References

Data Assimilation in Materials Science –
Crystal Structure Prediction Supported by Incomplete Experimental Data

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Prediction of crystal structure from chemical composition has been a long-standing challenge in natural science. Although various numerical methods have been developed over last decades, it remains still difficult to numerically predict crystal structures comprising more than several tens of atoms in the supercell due to the many degrees of freedom, which increase exponentially with the number of atoms. Here, we propose a new “data assimilation” approach for crystal structure prediction from numerical simulations with support of X-ray diffraction experimental data [1]. We show that even if the experimental data is totally insufficient for conventional structure analysis, it can still support and substantially accelerate structure simulation. In particular, we formulate a cost function based on a weighted sum of interatomic potential energy and a penalty function referred to as “crystallinity”, which is defined by using limited X-ray diffraction data. We apply this method to well-known polymorphs of SiO$_2$ and other materials with up to 108 atoms in the simulation cell and show that it reproduces the correct structures efficiently with very limited information of diffraction peaks.

We also propose a novel optimization method for the joint optimization of two or more cost functions [2]. Unlike the conventional joint optimization schemes, which try to find minima in a weighted sum of cost functions, the present algorithm explores search space for common minima shared by all the cost functions. Given a set of multiple cost functions that have qualitatively different distributions of local minima with each other, the proposed method finds the common minima with a high success rate without the help of any metaheuristics.

References
Implementation of an Inhomogeneous Large Spin-orbit Interaction at the Nanoscale

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A strong spin-orbit interaction in low dimensional conductors is instrumental for the realization of non-trivial topological phases of matter. In particular, it is a necessary ingredient for the engineering of Majorana zero modes in condensed matter systems which could allow one to study excitations with particle/antiparticle duality and non-abelian statistics. Most of the experimental setups with nanoscale circuits use semiconducting nanowires with strong spin-orbit interaction connected to superconductors, under a finite magnetic field. Theoretical proposals have suggested autonomously inducing the spin-orbit coupling and the Zeeman field through a magnetic texture. This especially opens the possibility to release the constrain on the nanoconductor and use nearly ideal 1D conductor like carbon nanotubes. However revealing even a strong spin orbit interaction in a conventional transport experiment setup is challenging because of its weak effect in most of the phase diagram of an electronic system.

Here we show that it can be sensed thanks to the high spectroscopic resolution of circuit QED techniques. Specifically, we investigate a carbon nanotube double quantum dot (DQD) coupled to a microwave cavity and fabricated above a magnetic texture inducing a large synthetic spin orbit interaction. We probe the internal transitions of the DQD, which are resonant with the microwave resonator, with the cavity photons and reveal the spin-texture. The observed spectrum shows orbital dependent non-monotonic dispersions of the DQD energy levels with an external magnetic field with highly renormalized electron g factors up to 50 [1]. Alternatively, the coupling of the carbon nanotube to superconducting contacts also reveals a strong spin-orbit interaction of at least 1.1 meV through the evolution of spin textured Andreev bound states [2]. These findings are encouraging for the development of advanced experiments with Majorana zero modes, including microwave spectroscopy and braiding operations.

References
Non-equilibrium Fluctuations in Correlated Quantum Liquids

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Quantum liquids are macroscopic ensembles of interacting particles dense enough for quantum statistics to manifest itself. For fermions, it is known that, around equilibrium, all the quantum liquids can be universally described within a single theory, so called Landau Fermi liquid theory. The idea is that they can be treated as an ensemble of free “quasi-particles”. This conceptual framework has been applied to many physical systems, such as liquid helium 3, normal metals, heavy fermions, neutron stars, and cold gases, where their properties in the linear-response regime have been successfully described by the theory. However, non-equilibrium properties beyond this regime still remain a key issue of many-body physics.

Here, we show a precise experimental demonstration of Landau Fermi-liquid theory extended to the non-equilibrium regime in a 0-D system [1, 2, 3]. Combining transport and sensitive current noise measurements, we have identified the SU(2) and SU(4) symmetries of quantum liquid in a carbon nanotube tuned in the Kondo regime. We find that, while the electronic transport is well described by the free quasi-particle picture around equilibrium just as the Fermi liquid theory tells us, a two-particle scattering process due to residual interaction shows up in the non-equilibrium regime [4, 5, 6]. The effective charges $e^*$, which characterize this peculiar scattering, are determined to be $e^*/e = 1.7 \pm 0.1$ for SU(2) and $e^*/e = 1.45 \pm 0.1$ for SU(4) [1], being in perfect agreement with theory ($e$: electron charge) [4-6]. From these values, by using the extended Fermi-liquid theory, we obtain the interaction parameter “Wilson ratio” to be $1.95 \pm 0.1$ for SU(2) and $1.35 \pm 0.1$ for SU(4) cases [1, 6], which are the most precise determination of the Wilson ratios that has ever been demonstrated. This result, in perfect agreement with theory, provides a strong quantitative experimental background for further developments of the many-body physics. Moreover, we discovered a new scaling law for the effective charge, signaling as-yet-unknown universality in the non-equilibrium regime.

This achievement will open up a new way to explore quantum many-body physics through fluctuations, which stands on firm ground even out of equilibrium beyond the conventional Landau Fermi liquid theory.

References
In a partially filled Landau Level, electron-electron interactions become dominant at high magnetic fields, leading to the manifestation of many-body states like the fractional quantum Hall (FQH) effect, where quasiparticle excitations carry fractional charges \( q = e/m \), \( m = 3,5,... \) [1]. The fractional charge has been successfully determined owing to low frequency shot noise measurements [2,3]. However, these methods suffer from several drawbacks. Firstly, the noise depends not only on the nature of the charge carriers, but also on the scattering properties of the conductor. Secondly, for specific filling factors of the fractional quantum Hall effect, these measurements do not provide an unambiguous determination of the charge, which is found to depend on external parameters such as electronic temperature or the conductor transmission [4]. Finally, being intrinsically low frequency, they cannot probe the characteristic frequency scales of quasiparticle transfer in contrast with high frequency measurements.

I will present the measurement of high frequency noise generated by the random transfer of fractional excitations through a potential barrier biased with a dc voltage \( V_{dc} \) [5]. At high frequencies (few GHz), the emitted noise can be interpreted as the generation of microwave photons in a coaxial measurement line weakly coupled to the sample. We observe that photons are only emitted when their frequency is smaller than the frequency threshold \( f_J = qV_{dc}/h \) called the Josephson frequency [5,6] in analogy with the Josephson relation in superconductors. This threshold provides a direct determination of the fractional charge \( q \).

High frequency characterizations of fractional excitations, in a complementary way to recent experiments of photo-assisted low frequency noise in the fractional quantum Hall regime, open the way to the exploration of the dynamical properties of anyons.

Quantum Non-demolition Measurement of Single Spins

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In the context of quantum information technologies various techniques have been developed including manipulation, initialization, and readout of quantum states. Quantum non-demolition (QND) measurement is one of them and is a special type of projective measurement that does not impose any back action on the observable. The QND measurement has been developed for various systems of quantum optics, nuclear spins in diamond colour centres, superconducting circuits, and so on but not for electron spins in quantum dots until recently. We have recently used electron spins trapped by semiconductor quantum dots forming two spin qubits, data qubit and ancilla qubit to demonstrate the all-electrical QND measurement. In the measurement protocol we entangle the data qubit with the ancilla qubit via the exchange interaction [1] and then read out the ancilla in a single shot. We observe monotonous increase of the overall measurement fidelity by repeating the protocol [2]. The QND measurement is useful not only for improving the readout fidelity but also for implementing, measurement-based quantum algorithms including high-fidelity state preparation and quantum error correction. We indeed combine the QND measurement with feedback-control to demonstrate spin-state initialization with high fidelity.

References
Why Chemistry in Astrophysics

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In understanding the history of the Universe, exploring structure formation and physical evolution processes is a fundamental task in astrophysics. For instance, the formation of the first stars, the formation of galaxies, and the formation of stars and planets in galaxies have extensively been studied. At the same time, exploring the chemical evolution of matter in the Universe is also a fundamental task. Apart from the evolution of elemental abundances due to nucleosynthesis in stars, the most important and interesting issue is molecular evolution, which is directly related to understanding the material origin of the Solar System. How are molecules formed in interstellar space? How large can molecules grow there? How are molecules incorporated into stars and planets? These questions represent the current frontiers in astronomy and astrophysics. Studies of structure formation processes and chemical evolution processes of matter are apparently two halves of the whole toward comprehensive understanding of the history of the Universe.

Stars and associated planetary systems are formed by the gravitational contraction of the interstellar gas. Our group is now investigating the chemical evolution during their formation processes with the state-of-the-art radio telescopes including ALMA (Atacama Large Millimeter/submillimeter Array). For the last decade, we have found that the chemical composition of the gas around the protostar shows significant diversity at a 1000 astronomical unit (au) scale (a parent gas cloud scale) to a few 10 au scale (a planetary system scale) [1-7]. This means that an initial chemical condition at the beginning of the planetary system formation is likely different from source to source. This result would be an important constraint when we consider whether our Solar system is common occurrence in the Universe. Moreover, we have found a drastic change in the chemical composition of the gas in the transition zone from an infalling-rotating envelope to a rotationally supported disk (Keplerian disk). This is likely caused by a combination of accretion shocks and protostellar heating [3,4]. Thus, the transition zone is highlighted by the chemical change. This is one of good examples showing the power of chemistry in astrophysical studies. The transition zone plays a crucial role in physical processes of star and planet formation. It can be responsible for discarding angular momentum of the infalling gas to form a disk structure. Its physical structure is likely unstable, which would cause a sporadic accretion onto a central star. Observations revealing a detailed structure of the transition zone is in progress.

References
Turbulence, fed primarily by gravity, is ubiquitous in interstellar and intergalactic baryonic matter. It has so far escaped theory because it is supersonic, magnetized and its cascade pervades multi-phase media. Its dissipation, a key issue in the star and galaxy formation processes, remains elusive. A fundamental property of turbulent dissipation is its space-time intermittency, well studied theoretically and in flow experiments. While it can only be approached with dedicated numerical simulations in the case of magneto-hydrodynamical turbulence, its non-Gaussian statistical signatures have been detected in the velocity field of galactic interstellar matter [1]. This led to the prediction that specific molecules with highly endothermic formation can be quantitative markers of the dissipation rate of cosmic turbulence [2]. The recent discovery of one of these molecules in starburst galaxies at high redshifts has been a major surprise that has modified our perspective on galaxy growth in the early universe and reveals that cosmic turbulence is less dissipative than predicted by cosmological simulations [3].

References:
Cosmological Simulations of Galaxy Formation

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We present the results from state-of-the-art computer simulations of the formation of galaxies in the universe. Our simulations follow the gravitational dynamics of dark matter and hydrodynamics, radiative transfer and chemistry of the inter-galactic and inter-stellar medium (ISM) in a self-consistent manner. In this talk, we focus on the large-scale distribution of galaxies and the inter-galactic hydrogen to be probed observationally by the next-generation telescopes such as NASA’s James Webb Space Telescope. We then discuss details of the adopted models of ISM that capture the so-called baryonic physics such as star-formation and stellar feedback. We compare a few popular models and examine how the model choice affects the morphology of galaxies, to be compared with recent observations.

Finally, we present interesting applications of machine-/deep-learning for analysis of large observational data to be collected by future satellite missions. We use a large set of cosmological simulations and generate thousands of “mock observations” that are fed to conditional neural networks as training data set. Then the trained machine (network) can denoise two-dimentional matter distributions reconstructed from observations, and can also extract designated features such as the distribution of distant galaxies from infrared intensity maps. We discuss the future prospect for astroinformatics.

References
Dissecting the Molecular Mechanisms of Axonal Transport Through Single Molecule and Super-resolution Imaging

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Advancement of structural biology technologies such as cryo-EM has enabled us to visualize the atomic details of the proteins, the molecular machineries working in the living cells. However, there still remains a huge gap in our understanding of biological phenomena at the cellular level and the atomic details of the molecular machineries. One of the biggest hurdles to fill this gap would be the lack of the dynamics and the context in those atomic structures. The atomic structure models are mostly frozen, and it is often difficult to understand the dynamics from those structures. Furthermore, the effects from the crowding environment of the cytoplasm have not been seriously examined. The concentration of protein in the cytoplasm is higher than 30%, which means that the cytoplasm is packed with proteins just like the rush-hour train, which would slow down the diffusion of molecules in the cytoplasm than in the dilute solution in vitro. This suggests that the reaction kinetics of enzymes and other molecular machineries would be affected by the crowded environment of the cytoplasm.

As a model system to examine this issue, we have been working on the axonal transport in the neurons. Neurons have a single long process, called axon, to send out the signal to the next target cells. Some axons in our body reach about 1 m in length, but the newly synthesized proteins in the cell body are packed into a 100-nm diameter vesicle and transported down in the axon to the terminal. Quite interestingly, the velocity of this transport vesicle is much faster than in vitro, although the crowded cytoplasm would pose more than 1000 times larger drag force on this transport vesicle than in the dilute solution in vitro. To solve this apparent paradox, we have been working on the development of several optical imaging technologies to examine the molecular details of this transport system. In this talk, I will discuss our recent results [1, 2]

References
In vitro recapitulation of biomimetic membranes: applications to synaptic transmission and membrane disruption in Parkinson disease

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We have recently developed a novel microfluidic setup in which stable biomimetic membranes can be fabricated [1]. Fast and sensitive electric (patch-clamp) and optical (Confocal microscopy and single particle tracking) measurements allow the monitoring of the membrane state in time. During my presentation, I will describe how this new biomimetic membrane is made and demonstrate its versatility in terms of composition and usage. Then I’ll show how this membrane can be used on two examples related to neuronal function. First, I’ll provide some hints on how sub-millisecond neurotransmission can be achieved accurately in time and space [2,3]. Second, I’ll show some neuronal damage that occur during Parkinson disease: the aggregation of a protein on the neuron plasma membrane induces thinning, piercing and freezing of the membrane which disrupt neuronal function.

References
Almost all biological organisms are equipped with sensory systems with which they obtain the information about the environment. The performance of such a sensory system is crucial for the survival of organisms in the face of dynamic and unpredictable changes in the environment.

Bacterial chemotaxis and its associated sensory machinery have been the simplest model system. Each bacterium senses the external chemical gradient by actively moving in the gradient with stochastic activations of its sensory receptors for swimming either towards sources of attractants or away from those of repellants. To obtain the information about the direction of the gradient, cells have to process the dynamic change in the receptor activities out of the stochastic and noisy background activities. Even though biochemical models of bacterial chemotaxis have been proposed, the question of how the bacterial sensory system can extract information from noise remains elusive.

In this work, we address this problem using the theory of optimal filtering. By physically modelling the way how a bacterium is exposed to the gradient, we derive optimal sensing dynamics as the optimal filtering equation. By comparing the derived equation with a biochemical model of the bacterial chemotaxis, we demonstrate that such optimal sensing is structurally implemented in the bacterial sensory system. In addition, we show that our model based on optimal filtering can reproduce an experimentally observed functional relation in the system. We will also discuss potential applications of our approaches based on optimal filtering theory.

References
Some experiments with magnetic tweezers

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Magnetic tweezers are a single molecule micromanipulation tool that allows to apply pN range forces, and torsion, on biomolecules, in particular DNA. I will illustrate two applications of magnetic tweezers in the study of:

1) PICH, a molecular motor translocating on double stranded DNA, that in conjunction with a topoisomerase, can generate positive torsion on DNA, which can be involved in the disjunction of sister centromeres [1],

2) the displacement and dissociation of oligonucleotides on a single stranded DNA forming a hairpin, a technique that can be used to obtain information on DNA sequence [2].

References
Thermodynamics of Information

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In the nineteenth century, J. C. Maxwell considered a hypothetical being that can observe and manipulate individual atoms and molecules, leading to apparent violation of the second law of thermodynamics. Such a being was named Maxwell’s demon and has been an issue of intense controversies; Nowadays, it is realized that information is the key concept to understand the role of the demon. In this decade, thermodynamics of information has attracted renewed attention from both the theoretical and experimental point of view [1]. Theoretically, a modern formulation of the second law has been established, where information contents and thermodynamic quantities, such as work and heat, are treated on an equal footing. Experimentally, Maxwell’s demon has been realized by real experiments with various systems including colloidal particles, NMR, and superconducting qubits.

In this talk, I will focus on basic ideas in thermodynamics of information and the generalized second law that incorporates mutual information obtained by the measurement of the demon. I will also discuss how the “paradox” of Maxwell’s demon is understood in light of the modern theory of thermodynamics. I will also briefly mention the recent progress in this field, especially possible application to biochemical signal transduction.

References
ENS-UT Special Lectures on Physics

November 27-29, 2019

Hongo Campus, University of Tokyo
Lecture Program

November 27 (Wed)  Faculty of Science, Building No.1, Room 207

9:30-11:30  Marc Mezard
“From Spin Glasses to Statistical Inference” (1)
13:00-16:00 Gwendal Feve
“Electronic Transport in Ballistic Quantum Conductors” (1)
16:30-18:30 Koji Hukushima
“Monte Carlo Approach to Statistical Physics and Bayesian Inference”

November 28 (Thu)  Faculty of Science, Building No.1, Room 207

9:00-12:00  Marc Mezard
“From Spin Glasses to Statistical Inference” (2)
13:30-15:30 Seigo Tarucha
“Quantum Coherence and Entanglement of Electron Spins - Preparation, Manipulation and Detection”
16:00-18:00 Simona Cocco
“Statistical Physics, Inference and Applications to Biology” (1)

November 29 (Fri)  Faculty of Science, Building No.1, Room 201b

9:00-12:00  Simona Cocco
“Statistical Physics, Inference and Applications to Biology” (2)
13:30-15:30 Gwendal Feve
“Electronic Transport in Ballistic Quantum Conductors” (2)
16:00-18:00 Chikara Furusawa
“Universal Biology of Evolution and Development: Theoretical and Experimental Approaches”

Lecture time: 5 hours for ENS professors, 2 hours for UT professors
How to get to your hotel

Forest Hongo
address: 6-16-4 Hongo, Bunkyo-ku, 113-0033 Tokyo
phone: +81-(0) 3-3813-4408

+ Hotel Info: https://www.forest-hongo.com/en/location/
+ How to get to the hotel:
Haneda Airport – (monorail) – Hamamatsu-cho – (JR Yamanote Line) – Tokyo
--(Tokyo Metro Marunouchi Line: red) – Hongo san-chome – (10 min walk or taxi) – Hotel
(You can also take a taxi cab from Tokyo station; 20 min or so)

Suigetsu Hotel
address: 3-3-21 Ikenohata, Taito-ku, 110-0008 Tokyo
phone: +81-(0)3-3822-4611

+ Hotel Info: https://ohgai.co.jp (Japanese web page only)
+ How to get to the hotel:
Haneda Airport – (monorail) – Hamamatsu-cho – (JR Yamanote Line) – Tokyo – (walk)
-- Nijubashi-mae or Otemachi – (Tokyo Metro Chiyoda Line: green) – Nezu --(walk)
--Hotel
Some notice about the ENS-UT workshop/special lectures

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<tr>
<td>Nov. 25 (Mon)</td>
<td>Workshop at Rm 1320, Faculty of Science Bldg 4</td>
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<tr>
<td>Nov. 26 (Tue)</td>
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<tr>
<td>Nov. 27 (Wed)</td>
<td>Special Lecture at Rm 207, Faculty of Science Bldg 1</td>
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<td>Nov. 28 (Thu)</td>
<td>Special Lecture at Rm 207, Faculty of Science Bldg 1</td>
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<td>Nov. 28 (Fri)</td>
<td>Special Lecture at Rm 201b, Faculty of Science Bldg 1</td>
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Shop & Services

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</tr>
<tr>
<td>住所</td>
<td>1-1-1 University of Tokyo, Bunkyo-ku, Tokyo 113-8550</td>
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東京大学

本郷地区キャンパスへの案内 Getting to the Hongo Campus

1. 本郷駅出入口に沿って東京大学駅を南面する。
2. 大楼B館を通り、大学通りを東に進む。
3. 本郷駅を通り、大学通りを南に進む。

バス利用者

京成バス / えちご交通 / 京成電鉄の各駅から、大学通りを西に進む。

駅前店

駅北口：京成電鉄東京駅前店 / 駅南口：京成電鉄豊川駅前店

参考

東京大学<br>本郷地区キャンパス / 上野八幡橋前駅前行/上野駅前駅前行