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東京大学 大学院　理学系研究科・理学部
物理学教室

II

Summary of group activities in 2007

1 Theoretical Nuclear Physics Group

Subjects: Structure and reactions of unstable nuclei, Monte Carlo Shell Model, Molecular Orbit Method, Mean Field Calculations, Quantum Chaos
Quark-Gluon Plasma, Lattice QCD simulations, Structure of Hadrons, Color superconductivity
Relativistic Heavy Ion Collisions, Relativistic Hydrodynamics, Color Glass Condensate

Member: Takaharu Otsuka, Tetsuo Hatsuda, Tetsufumi Hirano, Noritaka Shimizu and Shoichi Sasaki

In the nuclear theory group, a wide variety of subjects are studied. The subjects are divided into three major categories: Nuclear Structure Physics, Quantum Hadron Physics and High Energy Hadron Physics.

Nuclear Structure Physics

In Nuclear Structure group (T. Otsuka and N. Shimizu), nuclear structure physics is studied theoretically in terms of the quantum many-body problem. The major subjects are the structure of unstable exotic nuclei, shell model calculations including Monte Carlo Shell Model, reactions between heavy nuclei, Bose-Einstein condensation, symmetries and quantum chaos, etc. The structure of unstable nuclei is the major focus of our interests, and examples of the current subjects are the disappearance of conventional magic numbers and appearance of new ones, as studied extensively by using the Monte Carlo Shell Model [1, 2]. These phenomena are due to the change of the shell structure (shell evolution), and are largely due to nuclear forces such as the tensor force and the three-body force. We have proposed a new type of ab initio calculations. This method is designed for the description of heavier nuclei, and its application has been made for exotic carbon isotopes. Abnormally small B(E2) value of 16C has been reproduced, and predictions have been made [3]. We are working on the relation between symmtries and quantum chaos. A regularity occuring in a single-j-shell of the shell model calculation has been explained in a simple and basic way [4].

Quantum Hadron Physics

In Quantum Hadron Physics group (T. Hatsuda and S. Sasaki), many-body problems of quarks and gluons are studied theoretically on the basis of the quantum chromodynamics (QCD). Main research interests are the quark-gluon structure of hadrons, lattice gauge theories and simulations, matter under extreme conditions, quark-gluon plasma in relativistic heavy-ion collisions, high density matter, neutron stars and quark stars, chiral symmetry in nuclei, and color superconductivity. Highlights in research activities of this year are listed below.

1. Lattice QCD studies of hadron structure [5]
2. Lattice QCD study of the nuclear force [6]
3. Lattice QCD study of the quark-gluon plasma [7]
4. Phase transition in high density quark matter [8]
5. Study of the confinement proof in Yang-Mills theory
6. Heavy quark diffusion in the quark-gluon plasma

High Energy Hadron Physics

In High Energy Hadron Physics group (T. Hirano), the physics of the quark-gluon plasma and dynamics of relativistic heavy ion collisions are studied theoretically based on relativistic hydrodynamics and relativistic kinetic theories. Main subjects include (1) hydrodynamic description of the space-time evolution of the quark-gluon plasma, (2) transport description of hadrons and their dissipation (3) analyses of the quark-gluon plasma through hard probes such as jets and heavy quarks/quarkonia [9], and (4) color glass condensate for high energy colliding hadrons/nuclei.

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2 Theoretical Particle and High Energy Physics Group

Research Subjects: The Unification of Elementary Particles & Fundamental Interactions

Member: Tohru Eguchi, Tsutomu Yanagida, Yutaka Matsuo, Koichi Hamaguchi
Yuji Sugawara, Yosuke Imamura, Teruhiko Kawano, Taizan Watari

The main research interests at our group are in string theory, quantum field theory and unification theories. String theory, supersymmetric field theories, and conformal field theories are analyzed relating to the fundamental problems of interactions. In the field of high energy phenomenology, supersymmetric unified theories are extensively studied and cosmological problems are also investigated.

We list the main subjects of our researches below.

1. Superstring Theory.
   1.1 Calabi-Yau and T-fold compactifications [1, 10, 16, 17]
   1.2 Topological strings and matrix models [12, 18, 20]
   1.3 Black holes and string theory [14, 15]
2. Gauge theories and gauge/string duality
   2.1 Superconformal field theories and AdS/CFT [11, 21, 9]
   2.2 Spin chains and classical strings [8, 13]
3. High Energy Phenomenology.
   3.1 Phenomenology of beyond the standard models [6, 19]
   3.2 Particle cosmology [2, 5, 7]
   3.3 String inspired models [3, 4, 22, 23]

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3 Sakai (Hideyuki) Group

Research Subjects: Experimental Nuclear Physics

Member: Hideyuki Sakai, Kentaro Yako

We are aiming to explore nuclear structure as well as nuclear reaction mechanisms by using an intermediate energy beam from accelerators. Particular emphasis is placed on the study of the spin degrees of freedom in nuclei. Our expertise is various "spin-polarizations": spin-polarized beams ($\vec{p}$, $\vec{n}$ and $\vec{d}$), spin-polarized targets ($\vec{p}$ and $^3\vec{\mathrm{He}}$), and spin-polarization analysis of reaction products ($\vec{p}$, $\vec{n}$ and $\vec{d}$).

Major activities during the year are summarized below.

ICHOR project: Isospin-spin responses in CHarge-exchange exOthermic Reactions

—SHARAQ spectrometer

Spin-isospin response of nucleus is a unique excitation mode since it is related with mesons in nuclei and consequently it provides valuable information on nuclear forces. So far the research has been performed by using endothermic reactions by a stable beam such as (p,n) or (n,p), which is inevitably accompanied by a finite momentum transfer to nucleus. Such reactions hamper the study of spin-isospin responses in highly excited regions. We will try to overcome this difficulty by using exothermic reactions by an unstable beam such as (^{12}N, ^{12}C) or (^{12}B, ^{12}C). With this new experimental means, we pursue the study of spin-hasping responses in the highly excited region. Aiming to identify new spin excitation modes, we are constructing a high energy resolution spectrometer SHARAQ dedicated to the exothermic reactions by unstable beams. In this year, we installed the analyzer magnets of SHARAQ and started measurement of the magnetic field of each element.

—First test of exothermic reaction—

In order to confirm the usefulness of the exothermic charge-exchange reaction for the spin-isospin response study, we performed the measurement of the exothermic reaction ^{13}C(^{12}N, ^{12}C)^{13}N* as well as the endothermic reaction ^{13}C(^{12}C, ^{12}B)^{13}N* at 100A MeV at zero degrees. Since the reaction Q value is different by 30 MeV, the cross section going to the excited 1^+ state at 15.1 MeV relative to that going to the 3.5 MeV 1^+ state will be enhanced in the exothermic reaction. The measurement was carried out at the National Superconducting Cyclotron Laboratory, Michigan University. The data analysis is in progress.

—Intermediate states involved in nuclear double beta decay

The double β decay of nuclei is the rarest process confirmed so far in nature. It is a second-order weak process, described by successive virtual Gamow-Teller transitions from the mother nucleus to the intermediate nucleus, and then from the intermediate to the daughter nucleus, emitting two neutrinos. Therefore GT strength distributions give information through which intermediate states the decay occurs. The intermediate GT states of double-beta decay nuclei, ^{116}Cd and ^{48}Ca, have been studied by the ^{116}Cd(p,n) / ^{116}Sn(n,p) and ^{48}Ca(p,n) / ^{48}Ti(n,p) measurements, respectively, at Research Center for Nuclear Physics, Osaka University. The GT strength distributions in the continuum region up to 30 MeV exciation energy have been derived for the first time. It has been found that for the present theoretical calculations underestimate the GT strength especially in the continuum in the (n,p) channel, which suggests that the contribution of the GT giant resonance region is underestimated.

Spin correlation in entangled two-nucleon system

In 1935, Einstein, Podolsky and Rosen presented a paradox to quantum correlations and concluded that the quantum mechanical description of nature is incomplete. So-called hidden variables are introduced in the classical approach to describe the correlation. The Bell's inequality shows that correlation produced by the hidden variables is weaker than that predicted by quantum mechanics. Having completed the study of the spin correlation between the two-proton system as one of the first severe tests in hadronic systems, we tested the quantum mechanical correlation in the proton-neutron system by measuring the spin correlation between the proton-neutron pair in $[^1S_0]$ produced by the $^1H(d,pn)$ reaction at $E_d = 270$ MeV. The measurement was performed by using the magnetic spectrograph SMART at the RIKEN accelerator research facility, employing two polarimeters EPOL and SMART-NPOL. The S value in CHSH type of the Bell's inequality is obtained as $S_{\rm exp}(45°) = 3.47 \pm 1.80$. Although this value is rather near to the prediction of quantum mechanics ($S = 2.82$), it is also within the 1σ error from the local reality limit ($S \leq 2$) due to the difficulty in the polarization measurement. If deuteron beam with a higher energy becomes available, the spin analysis at the polarimeter becomes more effective.

4 Hayano Group

Research Subjects: Precision spectroscopy of exotic atoms and nuclei

Member: Ryugo S. Hayano & Takatoshi Suzuki

1) Precision X-ray spectroscopy of kaonic atoms

The X-ray spectroscopy of kaonic atoms is a unique tool to pin down the strength of kaon-nucleus strong interaction. The advent of silicon drift detector (SDD), a new type of high-resolution x-ray detector, enables us to study kaonic hydrogen and kaonic helium atoms with unprecedented precision.

1. X-ray spectroscopy of kaonic helium 4 - solution to the long-standing kaonic helium puzzle [1].
   It has been known since many years that there exists a large discrepancy between measured (-43 ± 8 eV) and calculated (~ 0 eV) values of the $2p$-level strong interaction shift of the K^--^{4}He atom. We used the SDDs and sophisticated background-reduction and calibration techniques to measure the $3d \rightarrow 2p$ X-rays of kaonic helium 4 at the KEK proton synchrotron, and determined the shift to be $+2 \pm 2$ (stat.) $\pm$ 2 (syst.) eV, and thus solved the long-standing "kaonic helium puzzle".

2. X-ray spectroscopy of kaonic helium 3.
   The same technique will be used to study kaonic helium 3 in the J-PARC E17 experiment, which is the first experiment to be carried out at J-PARC in 2008-2009. Construction of the setup is in progress.

3. X-ray spectroscopy of kaonic hydrogen.
   SDDs will be also used to measure kaonic hydrogen x rays at the DAΦNE e^+e^- collider (Frascati, Italy).

2) Study of kaonic nuclei

1. Study of kaonic nucleus and multi-nucleon absorption processes via the stopped K^- reaction in helium 4 [2, 3].
   In the ^{4}He$(K^-_{stopped}, YN/Yd)$ spectra measured in the KEK-PS E549 experiment , we have identified clearly the non-mesonic multinucleon absorption processes of K^- at rest on ^{4}He. The isospin dependence of the two-nucleon absorption process has been revealed, and the three-nucleon absorption process has been experimentally identified for the first time. On the spectra, we have observed yet unresolved wide strength which are well separable from those simple multi-nucleon absorption processes, and they could be the signal of non-mesonic YN/YNN decay of strongly-bound $\bar{K}NN/\bar{K}NNN$ states.

2. Search for K^-pp and K^-pn deeply-bound kaonic states at J-PARC.
   The J-PARC E15 experiment (under construction, to be scheduled after E17) will use the ^{3}He$(K^-, n/p)$ reaction to search for K^-pp and K^-pn. E15 is a kinematically complete experiment in which we measure both missing mass (n/p time of flight) and invariant mass (e.g., $\Lambda - p$) spectra, so as to provide decisive information on the nature of the much-debated "deeply-bound kaonic states".

3) Antimatter study at CERN's antiproton decelerator

1. Determination of proton-to-electron mass ratio using the precision laser spectroscopy of antiprotonic helium atoms [4, 5, 6].
   In 2007, using a Doppler-suppressed two-photon spectroscopy of antiprotonic helium, we succeeded to determine the (anti)proton-to-electron mass ratio with a precision of 10^{-9}, almost as precise as the known proton-to-electron mass ratio. We anticipate that this precision can be further improved in coming years, so that our measurement can provide the most precise value of m_p/m_e, an important fundamental constant.

2. Antihydrogen [7, 8, 9].
   Antihydrogen atoms can now be abundantly produced by mixing antiprotons and positrons in a Penning trap. By superimposing an octupole magnetic field, we are now attempting to trap the produced antihydrogen atoms.

4) Precision spectroscopy of pionic atoms.

Precision spectroscopy of the $1s$ level of pionic atoms using the (d,^{3}He) reaction is a powerful method to study the $\langle q\bar{q}\rangle$ condensate, and to understand why the proton is so heavy compared to its constituents, the u, d quarks. A new experimental setup based on a dispersion-matched optics is being constructed at the BigRIPS facility of RIBF.

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5 Ozawa Group

Research Subjects: Experimental study of non-perturbative QCD

Member: Kyoichiro Ozawa

We have three research activities.

- Study of quark-gluon-plasma and hadronic matter under high-temperature and high density condition at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory
- Study of mechanism of hadronic mass generation at KEK and J-PARC
- R&D of new detector for future J-PARC experiment

Study of quark-gluon-plasma at RHIC

In 6 years operation of Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), many new phenomena related to hot and dense nuclear matter have been discovered. We performed the PHENIX experiment at RHIC and produced many new results on a wide range of physics subjects, including charged and neutral hadron production, single electron production, event isotropy, and many other topics.

In spite of these fruitful results, there are still remaining questions to be answered to further characterize the state of matter formed at RHIC. In particular, chiral properties of the dense matter produced has not been obtained, and should be provided. For the study of the chiral properties, $\phi(1020)$ is an interesting meson because the restoration of approximate chiral symmetry at high temperature may modify its mass and width. These modifications can be shown directly in the line shape of the $\phi \longrightarrow e^+e^-$ peak. In addition, it can affect the branching ratio of e^+e^- and K^+K^- decays, since $\phi \longrightarrow K^+K^-$ has very small Q-value. To realize such measurements, baseline measurements in $p + p$ collisions are important for comparison. In this year, we focused on the analysis of $\phi \longrightarrow e^+e^-$ in $p + p$ collisions. Figure 2.1.7 shows the comparison of transverse momentum distribution of ϕ mesons between e^+e^- and K^+K^- decays. Results shows good consistency between both decay modes.

Study of mechanism of hadronic mass generation at J-PARC

Recently, the chiral property of QCD in hot(T$\neq$ 0) or dense($\rho \neq 0$) nuclear matter has attracted wide interest in the field of hadron physics. The dynamical breaking of chiral symmetry in the QCD vacuum induces an effective mass of quarks, known as constituent quark mass, which then determines the known mass of all the hadrons. In hot and/or dense matter, this broken symmetry is subject to be restored either partially or completely and, hence, the properties of hadrons can be modified. To observe such an effect, measurements of the in-medium decay of vector mesons are highly desirable for the direct determination of the meson properties in matter. We performed an experiment at KEK and are planning two new experiments at J-PARC to measure vector mesons at normal nuclear density.

One new experimet aim to collect 100 times larger statistics of ϕ meson than that collected by the KEK experiment. We can discuss the velocity dependence of the mass spectra of vector mesons more pricisely and compare with the theoretical predictions. We are also able to use larger and smaller nuclear targets as lead and proton,

In another experiment, we propose combined measurements of nuclear ω bound state and direct ω mass modification. Nuclear ω bound states are measured in p(π^-, n)ω reaction and decays of generated ω meson are also measured with $\omega \rightarrow \pi^0\gamma$ mode. Such exclusive measurement can supply essential information to establish partial restoration of the chiral symmetry in nucleus.

R&D of new detector for future J-PARC experiment

We have performed an R&D for future J-PARC experiment. The development of new detector based on Gas Electron Multiplier (GEM), which is originally developped at CERN. Using GEM, we are imvestigating 2 dimentional tracker for high rate counting. A prototype is reconstructed and reasonable signals are observed as shown in Fig. 2.1.8. Detailed evaluation of postion resolution is under way.

6 Komamiya group

Research Subjects: (1) Preparation for an accelerator technology and an experiment for the International linear e^+e^- collider ILC; (2) Data analysis for the BES-II experiment at BEPC-I, and TOF detector construction for BES-III experiment at BEPC-II; (3) Detector development for studying gravitational quantum effects and searching for new medium range force using ultra-cold neutron beam; (4) Preparation for physics analyses in the ATLAS experiment at the LHC pp collider; (5) Data analyses for the OPAL experiment at the LEP e^+e^- collider;

Member: Sachio Komamiya, Yoshio Kamiya (Tomoyuki Sanuki: up to June 2007)

We, particle physicists, are entering an exciting period in which new paradigm of the field will be opened on the TeV energy scale by new discoveries expected in experiments at high-energy frontier colliders, LHC and ILC.

1) Preparation for the International e^+e^- Linear Collider ILC: ILC is the energy frontier machine for e^+e^- collisions in the near future. In 2004 August the main linac technology was internationally agreed to use superconducting accelerator structures. In 2007 March, the Reference Design Report was issued by the Global Design Effort (GDE) and hence the project has been accelerated as an international big-science

project. We are working on ILC accelerator related hardware development, especially on the beam delivery system. We are developing the Shintake beam size monitor for the ATF2, which is a test accelerator system for ILC located at KEK. Also beam position monitors with a nano-meter position accuracy were developed with the KEK accelerator laboratory. Also we have been studying possible physics scenario and the large detector concept (ILD) for an experiment at ILC.

2) BES-II/-III experiment at IHEP: The group has considered the BES-III experiment at the Beijing e^+e^- collider BEPC-II as the candidate for the middle term project before ILC. We have made a research and development for TOF detector for the BES-III experiment together with IHEP, USTC. We successfully completed a test of over 500 photomultipliers in 1[T] magnetic field and they are already installed to the BES-II detector. We have studied the data analysis of baryon-pair production in $J\psi$ decay using 5.8M BES-II J/ψ events.

3) Detector development for studying gravitational quantum bound states and searching for new medium range force using ultra-cold neutron beam: A detector to measure gravitational bound states of ultra-cold neutrons (UCN) is under way. We decided to use CCD's for the position measurement of the UCN's. The CCD is going to be covered by a Li layer to convert neutron to charged nuclear fragments. The simulation studies on the quantum effects of UCN in a narrow slit with 100 [μ] height is also done. In 2008 we will test our neutron detector at ILL Grenoble.

4) ATLAS experiment at LHC: The epoc of new paradigm for particle physics is going to open with the experiments at LHC. LHC is going to be operated in 2008. The ATLAS detector is almost ready. Some of our students work on the preparation for physics analysis at LHC. Search for supersymmetric particles with the missing transverse energy, and detector related and physics background are under study.

5) OPAL experiment at LEP: It is the experiment at the highest energy e^+e^- collider LEP of CERN. The data taking with the OPAL detector was completed in the end of 2000. Important physics subjects at LEP are (a) Higgs boson searches, (b) Supersymmetric particle searches and (c) W-boson physics. We have extensively searched for the Higgs boson at LEP. The Higgs boson was driven to a narrow mass range of 114-200 GeV. For supersymmetric particles searches the lower mass limit of the lightest neutralino, which is the most important candidate of the dark matter material, was set to be 38.0 GeV. The W boson mass was determined to be 80.412$\pm$ 0.042 GeV (statistical and systematic errors combined).

7 Minowa-Group

Research Subjects: Experimental Particle Physics without Accelerators

Member: MINOWA, Makoto and INOUE, Yoshizumi

Various kinds of astro-/non-accelerator/low-energy particle physics experiments have been performed and are newly being planned in our research group.

We are running an experiment to search for axions, light neutral pseudoscalar particles yet to be discovered. Its existence is implied to solve the so-called strong CP problem. The axion would be produced in the solar core through the Primakoff effect. It can be converted back to an x-ray in a strong magnetic field in the laboratory by the inverse process. We search for such x-rays coming from the direction of the sun with the TOKYO AXION HELIOSCOPE. The axion helioscope consists of a cryogen-free 4 T superconducting magnet with an effective length of 2300 mm and PIN photodiodes as x-ray detectors. Previously, we put upper limits of $g_{a\gamma\gamma} < (6.8 - 10.9) \times 10^{-10}\mathrm{GeV}^{-1}$ to axion - photon coupling constant for the axion mass less than 0.27 eV.

We just started the third phase measurement in which we scanned the mass region around 1 eV using the upgraded apparatus to withstand higher pressure gas. After checking if everything with the system is working fine the mass scan will be continued to cover still wider mass range around 1 eV.

Another long-running project of our group is the direct experimental search for supersymmetric neutralino dark matter in an underground cell of the Kamioka Observatory. The search has been suspended for the improvement of the CaF_2(Eu) scintillation detector in order to get still higher sensitivity for the possible feeble neutralino signals. The improvement includes the pulse shape analysis for the discrimination between nuclear recoil events and electron recoil events. It has been commonly used for other scintillators like NaI(Tl) but not established for the CaF_2(Eu) yet. We are also studying a possibility of wavelength discrimination for the scintillation light. It is also confirmed with a certain kind of scintillators but not for the CaF_2(Eu) yet.

The third project is an R and D of a resonance ionization mass spectroscopy, RIMS , aiming at neutrino detection by a trace analysis of an exotic atomic element produced by charged current interaction of an electron neutrino or an anti-electron neutrino on a nucleus in the target material. We first started with an analysis of metal contamination on a silicon wafer, which is a big issue in contemporary semiconductor industry and could potentially be improved by a use of RIMS, too. We introduced a blue LASER diode for the resonant excitation and a red LASER diode for the ionization, and successfully examined the effectiveness of the method by trying to detect a small amount of potassium vapor. The next step is to find out a way to get a high detection efficiency.

We also started a new R and D of a compact anti-electron neutrino detector with plastic scintillator to be used at a nuclear reactor station, for the purpose of monitoring the power and plutonium content of the nuclear fuel. It can be used to monitor a reactor from outside of the reactor containment with no disruption of day-to-day operations at the reactor site. This unique capability may be of interest for the reactor safeguard program of the International Atomic Energy Agency(IAEA), as well as for the precision monitoring of the antineutrino flux in the close vicinity of a reactor in a short baseline neutrino oscillation experiment for the determination of the mixing angle θ_{13}.

We have done a performance test of a plastic scintillator module, which is to be used as a building block of the detector. The basic design has been mostly completed with a help of computer simulation program.

8 Aihara Group

Research Subjects: Study of CP-Violation and Search for Physics Beyond the Standard Model in the B Meson System (Belle), Long Baseline Neutrino Oscillation Experiment (T2K), Dark Energy Survey at Subaru Telescope (Hyper Suprime-cam), and R&D for Hybrid Photodetectors and the ILC Silicon Detector Concept (SiD).

Members: H. Aihara, M. Iwasaki, H. Kakuno, T. Abe, N. Hastings and T. Uchida

One of the major research activities has been a study of CP-violation in the B meson system using the KEK B-factory (KEKB). This past year we presented a measurement of CP violating asymmetries in the neutral B meson decaying to two neutral Kaons (K^0_S's). It was based on a data sample containing 657M $B\bar{B}$ pairs. In this study, one neutral B meson was fully reconstructed in the $B^0 \to K^0_S K^0_S$ decay mode, and the flavor of the accompanying B meson was identified by its decay products. The CP-violating parameters were measured from the asymmetry in the distributions of the proper-time interval between the two B decays: $S = -0.38^{+0.69}_{-0.77}(\text{stat}) \pm 0.09(\text{syst})$ and $A = -0.38 \pm 0.38(\text{stat}) \pm 0.05(\text{syst})$, consistent with the Standard Model prediction. We have also started to develop the beamline simulation for the KEKB luminosity upgrade.

We are working on the instrumentation of J-PARC beamline for T2K long baseline neutrino oscillation experiment. In particular, we have fabricated the position (Eelectrostatic) and profile (Segmentd Secondary Emission) monitors for the primary proton beams. We have also successfully developed 13-inch hybrid photodetector combining a large-format phototube technology and avalanche diode as photo-electron multiplier.

We are building a 1.5 Giga pixel CCD camera (Hype Suprime-Cam) to be mounted on the prime focus of the Subaru telescope. With this wide-field camera, we plan to conduct extensive wide-filed deep survey to investigate weak lensing. This data will be used to develop 3-D mass mapping of the universe. It, in turn, will be used to study Dark Energy.

SiD is a detector concept based on silicon tracking and a silicon-tungsten sampling calorimeter, complemented by a powerful pixel vertex detector, and outer hadronic calorimeter and muon system. Optimized forward detectors are deployed. In order to meet the ILC physics goals, we have designed the general purpose detector taking full advantage of the silicon technology. Our R&D program includes development of a silicon tracker and a 5Tesla superconducting solenoid.

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2. H. Aihara *et al.*, "Status and Upgrade Plans of The Belle Silicon Vertex Detector," Nucl. Instrum. Meth. A**582**, 709 (2007).
3. T. Tsuboyama *et al.*, "Silicon vertex detector for the KEK Super B factory," Nucl. Instrum. Meth. A**572**, 321 (2007).
4. Y. Kawai *et al.*, "Large-aperture hybrid photo-detector," Nucl. Instrum. Meth. A**579**, 42 (2007).

9 Asai group

Research Subjects: (1) Particle Physics with the energy frontier accelerators (LEP and LHC) (2) Physics analysis in the ATLAS experiment at the LHC: (Higgs, SUSY and Extra-diemnsion) (3) Particles Physics without accelerator: tabletop size (4) Positronium and QED

Member: S.Asai

- (1) LHC (Large Hadron Collider) has the excellent physics potential. Our group is contributing to the ATLAS group in the Physics analyses: focusing especially on three major topics, the Higgs boson, Supersymmetry and Extra-dimension.
  - Higgs: We are focusing on Higgs boson whose masses is lighter than 140 GeV. $H \to \gamma\gamma$ or $\tau\tau$ are the promising channel with the Vector boson fusion production processes. We are contributes on these two modes especially on (1) Background study, (2) Fake gamma estimation, (3) rapidity gap between the forward jets.
  - SUSY: We contributes SUSY study at the ATLAS experiment as a convener. We have developed methods of the data-driben background estimation for all channels, and we found out that we can estimate background number//distributions from the data itself with accuracy of 10-20% even in the early of the state.
  - Missing Et and jet calibration: We are working on performance of the mET and jet calibration of the ATLAS detector.
  - Extra-dimension If the extra-dimension is compactificated at a few TeV scale, Mini-black hole and KK excitation are interesting signals. We are study on these physics at the ATLAS experiments and have shown the ATLAS has good performance.
- (2) Small tabletop experiments have the good physics potential to discover the physics beyond the standard model, if the accuracy of the measurement or the sensitivity of the research is high enough. We perform the following tabletop experiments:
  - Search for extra-dimention with $o - Ps \to$ invisible.
  - Search for CP violation of the lepton sector using positoronium.
  - Precise measurement Search HFS of the posittronium.
  - Developing high power (>100W) stable sub THz RF source

10 Aoki Group

Subject: Theoretical condensed-matter physics

Members: Hideo Aoki, Takashi Oka

Our main interests are many-body effects in electron systems, i.e., **superconductivity, magnetism and fractional quantum Hall effect**, for which we envisage a *materials design for correlated electron systems* should be possible. Specifically we study:

- Superconductivity in repulsively interacting electron systems
  — How to optimise T_C through the "fermiology" [1]
  — Superconductivity in iron-oxypnictides with a disconnected Fermi surface [2]
  — Coexistence of electron-phonon and electron-electron interactions [3]
- Magnetism in repulsively interacting electron systems
  — Itinerant ferromagnetism in multi-orbital systems [4]
  — Flat-band ferromagnetism in a designed organic polymer
- Carbon systems
  — Quantum Hall effect in graphene: Topological aspects[5], edge states, Landau-level laser[6]
  — Giant loop current in carbon nanotubes [7]
- Electron correlation effects in strong magnetic fields
  — Many-body states in graphene [8]
  — Electron-molecule picture for quantum dots in magnetic fields [9]
- Non-equilibrium and nonlinear phenomena in correlated electron systems
  — Landau-Zener tunnelling in the breakdown of Mott's insulator [10]
  — Correlated electrons in intense laser lights
- Dynamics of superfluid-Mott insulator transition in cold atoms in optical lattices
- Electronic structure of periodic nanostrucutures
  — "Supercrystal" picture in alkali-metal-loaded zeolites
  — Electrons on periodic curved surfaces

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11 Miyashita Group

Research Subjects: Statistical Mechanics, Phase Transitions, Quantum Spin systems, Quantum Dynamics, Non-equilibrium Phenomena

Member: Seiji Miyashita and Keiji Saito

1. Novel Quantum States, Excited States, and Quantum Dynamics

In strongly interacting quantum systems, various interesting phases appear in the ground state, and also coherent motion of quantum mechanics exhibits various characteristics which are not found in classical systems. They would play important roles in controls of quantum information processing. We have studied such novel quantum phases and quantum responses.

As a novel quantum state, we have studied "super-solid state". In particular, we investigated conditions for the existence of this state. We obtained the phase diagram of the superfluid, solid, and super-solid state in the ground state, and also studied finite temperature properties of them. We also found a novel size dependence of excited states in a spin chain consisting of $S = 1/2$ and 1 in the collaboration with Professor Pati's group (JNCASR) in Bangalore. We also studied quantum effects when we carry particles by potential trap, and found the tunneling escape during carry-up procedure. We analyzed it from the view point of a successive Landau-Zener transition. Effects of the acceleration were also investigated. Energy-gap control by a transverse field in an easy-axis magnets and effects of oscillating field were also investigated. In the transverse Ising model, we studied the dynamics of magnetization under swept-field, and found a kind of quantum spinodal decomposition phenomena with a collaboration of Professor De Raedt group in Groningen University. The dynamics of itinerant magnetism as a function of filling parameter was also studied. In particular, we studied how the Mott-insulator antiferromagnetic state changes to the Nagaoka's ferromagnetism when we remove an electron. Moreover we studied magnetic states of itinerant systems with larger spins, e.g. $S = 1$ (Boson), 3/2 (Fermion), etc. Formalism for the line shapes of the electron spin resonant (ESR) in dissipative environments and also general formalism of the quantum master equation were also studied, The problem of domain wall in a uniaxial anisotropic Heisenberg spin systems was studied from the view point of quantum spin dynamics with a collaboration of Professor De Raedt. Problems of quantum annealing, qubit controls, quantum transport phenomena, and problems in quantum measurements were also studied. These studies are executed as a crest project in JST on "Quantum-mechanical cooperative phenomena and their applications".

2. Phase Transition in Spin-Crossover Materials

We studied cooperative properties of spin-crossover materials, which attract much interest because of their interesting responses to the light-irradiation. In particular, the so-called LIESST (light-induced excited spin state trapping) phenomena have been extensively studied. We have studied, the thermodynamical properties including metastable state which would play important roles for the photo-excitation. We proposed so called "generic scenario" of ordering processes, which have been found in experiments. In the last year, we studied the origin of the cooperativity of the spin transition. We pointed out that the difference of the sizes of the high-spin (HS) and the low-spin (LS) states is an important ingredient, and demonstrated that the elastic interaction of lattice distortion due to the size difference can induce a phase transition which satisfies the generic sequence. We also studied the pressure dependence of the phases in this elastic model and found the generic sequence again. Moreover, we studied the critical property of the model and we found that this model belongs to the universality class of the "mean-field model" which would be due to the effective long range interaction in the elastic interaction. We have proposed that the clusterization, which is a typical future of phase transition and causes the critical opalescence, would be strongly suppressed in this model.

3. Slow Relaxation in Highly Frustrated Systems

Non-equilibrium phenomena are also important research topics of our group. In models with frustration, we studied slow relaxations caused by the so-called entropy-origin in which the structure of density of states plays important roles. In a model with a decorated-bonds we have pointed out that the ordering process becomes very slow due to a kind of spin-screening effect. We have studied the mechanism of the screening and estimated the time scale quantitatively. In the standard thermal annealing methods it is difficult to find the ground state of this model and we applied the quantum annealing method to it. We also studied the slow relaxation in the ordered state of the Ising-like kagome antiferromagnetic Heisenberg model. In this system, reflecting the macroscopic degeneracy of the grand state which is a characteristic of the corner-sharing frustrated systems, we found a slow relaxation process even after the magnetization reached to the equilibrium value. We studied this process by observing the number of the weathervane loops which represent degenerate configurations. We found the a kind of entropy-induced ordering process. We also studied a relaxation processes in which the order parameter moves opposite direction to the equilibrium value in the early stage of the relaxation. We studied this problem from a view point of eigenvalue problem of time evolution operator, and demonstrated examples explicitly in simple systems.

12 Ogata Group

Research Subjects: Condensed Matter Theory

Member: Masao Ogata, Youichi Yanase

We are studying condensed matter physics and many body problems, such as strongly correlated electron systems, high-T_c superconductivity, Mott metal-insulator transition, magnetic systems, low-dimensional electron systems, mesoscopic systems, organic conductors, unconventional superconductivity, and Tomonaga-Luttinger liquid theory. The followings are the current topics in our group.

- High-T_c superconductivity

  The t-J model as a mechanism for the oxide high-T_c superconductors.[1]

  Mott metal-insulator transition and superconductivity.
- Multi-orbital superconductivity in $Na_xCoO_2{\cdot}yH_2O$ [2-4]
- Organic conductors

  Dimensional crossover and superconductivity in quasi-one-dimensional organic conductors.[5]

  Novel spin-liquid state in an organic system with geometircal frustration.[6]

  Static nonequilibrium state of the competing charge orders under an electric field.
- Theories of anisotropic superconductivity

Superconductivity and antiferromagnetism in a non-centrosymmetric system.[7,8]

FFLO superconductivity near an antiferromagnetic quantum critical point.[9]

Anderson localization and superconductivity fluctuation in an impurity band.

- Electronic and spin states in frustrated systems

  Effects of carrier doping in a Kagomé lattice.

  Numerical simulation in classical XY spin systems with frustration.

  Ground states of the frustrated quasi-two-dimensional Hubbard model.[10]

  Analysis of the rattling transition with classical Potts model.

- Kondo effect and heavy fermion systems

  Kondo effects in quantum dots.[11]

  Fermi surface reconstruction with Kondo screening at quantum critical point.[12]

- Two-dimensional ^{3}He system on graphite

  A new quantum liquid ralized in the two-dimensional t-J-K model with ring-exchange interaction.[13]

- Microscopic theory for the magnetic domail wall driving.
- Interband effects of magnetic field on Hall effects for Dirac electrons in Bismuth.[14]

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13 Tsuneyuki Group

Research Subjects: Theoretical Condensed-matter physics

Member: Shinji Tsuneyuki and Kazuto Akagi

Computer simulations from first principles enable us to investigate properties and behavior of materials beyond the limitation of experiments, or rather to predict them before experiments. Our main subject is to develop and apply such techniques of computational physics to investigate basic problems in condensed matter physics, especially focusing on prediction of material properties under extreme conditions like ultra-high pressure or at surfaces where experimental data are limited. Our principal tool is molecular dynamics (MD) and first-principles electronic structure calculation based on the density functional theory (DFT), while we are also developing new methods that go beoynd the limitation of classical MD and DFT.

Our research subjects in FY2007 were as follows:

- Structures and electronic properties of surfaces
  - Effect of strong electric field on organic molecules chemisorbed on Si surfaces
  - Stability and band profile of a SiON insulating layer on SiC(111)
  - Soft X-ray spectra of a SO_2 molecule chemisorbed on Ni
  - Strain-induced self-organization of N/Cu(001)
- Structures and electronic properties of solids
  - Potential energy surface of $Ba_{1-x}Ca_xTiO_3$
  - 3D C60 polymer
- Electronic structure analysis of proteins by the LCMO scheme
- New methods of electronic structure calculation
  - First-principles wavefunction theory for solids based on the transcorrelated method
  - First-priniciples calculation of phonon dispersion relation by a direct method

14 Fujimori Group

Research Subjects: Photoemission Spectroscopy of Strongly Correlated Systems

Member: Atsushi Fujimori and Teppei Yoshida

We study the electronic structures of strongly correlated systems using high-energy spectroscopic techniques such as photoemission spectroscopy, x-ray absorption spectroscopy and x-ray magnetic circular dichroism using synchrotron radiation. We investigate mechanisms of high-temperature superconductivity [1], metal-insulator transitions, giant magnetoresistance, carrier-induced ferromagentism, spin/charge/orbital ordering in strongly correalted systems such as transition-metal oxides [2], magnetic semiconductors [3], and their interfaces.

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15 Uchida Group

Research Subjects: High-T_c superconductivity

Member: Uchida Shin-ichi (professor), Kojima Kenji M. (research associate)

1. Project and Research Goal

The striking features of low-dimensional electronic systems with strong correlations are the “fractionalization” of an electron and the “self-organization” of electrons to form nanoscale orders. In one dimension (1D), an electron is fractionalized into two separate quantum-mechanical particles, one containing its charge (holon) and the other its spin (spinon). In two dimensions (2D) strongly correlated electrons tend to form spin/charge stripe order.

Our study focuses on 1D and 2D copper oxides with various configurations of the corner-sharing CuO_4 squares. The common characteristics of such configurations are the quenching of the orbital degree of freedom due to degraded crystal symmetry and the extremely large exchange interaction (J) between neighboring Cu spins due to large $d-p$ overlap (arising from 180 °Cu-O-Cu bonds) as well as to the small charge-transfer energy. The quenching of orbitals tends to make the holon and spinon to be well-defined excitations in 1D with quantum-mechanical character, and the extremely large J is one of the factors that give rise to superconductivity with unprecedentedly high Tc as well as the charge/spin stripe order in 2D cuprates. The experimental researches of our laboratory are based upon successful synthesis of high quality single crystals of cuprate materials with well-controlled doping concentrations which surpasses any laboratory/institute in the world. This enables us to make systematic and quantitative study of the charge/spin dynamics by the transport and optical measurements on the strongly anisotropic systems. We also perform quite effective and highly productive collaboration with world-leading research groups in the synchrotron-radiation, μSR and neutron facilities, and STM/STS to reveal electronic structure/phenomena of cuprates in real- and momentum-space.

2. Accomplishment

(1) Ladder Cuprate

Significant progress has been made in the experimental study of a hole-doped two-leg ladder system $Sr_{14-x}Ca_xCu_{24}O_{41}$ and undoped $La_6Ca_8Cu_{24}O_{41}$:

1) From the high pressure (P) study we constructed and x-P phase diagram (in collaboration with Prof. N. Môri’s group). We find that the superconductivity appears as a superconductor-insulator transition only under pressures higher than 3GPa and that the superconducting phase is restricted in the range of x larger than 10. In lower P and smaller x regions the system is insulating.

2) The pairing wave function in the superconducting phase has an s-wave like symmetry which is evidenced by a coherence peak at T_c in the nuclear relaxation rate, revealed by the first successful NMR measurement under high pressure.

3) The origin of the insulating phase dominating the whole $x-P$ phase diagram is most likely the charge order of doped holes or hole pairs as suggested by the presence of a collective charge mode in the x=0, $Sr_{14}Cu_{24}O_{41}$, compound in the inelastic light scattering (with G. Blumberg, Bell Lab.), microwave and nonlinear conductivity (with A. Maeda and H. Kitano, U. of Tokyo), and inelastic X-ray scattering (with P. Abbamonte and G. A. Sawatzky).

4) In the undoped compound $La_6Ca_8Cu_{24}O_{41}$ spin thermal conductivity is remarkably enhanced to the level of silver metal along the ladder-leg direction due to the presence of a spin gap and to a ballistic-like heat transport characteristic of 1D.

(2) Observation of Two Gaps, Pseudogap and Superconducting Gap, in Underdoped High-T$_c$ Cuprates.

The most important and mysterious feature which distinguishes cuprate from conventional superconductors is the existence of " pseudogap " in the normal state which has the same d-wave symmetry as the superconducting gap does. We employed c-axis optical spectrum of $Yba_2Cu_3O_{6.8}$ as a suitable probe for exploring gaps with d-wave symmetry to investigate the inter-relationship between two gaps. We find that the two gaps are distinct in energy scale and they coexist in the superconducting state, suggesting that the pseudogap is not merely a gap associated with pairs without phase coherence, but it might originate from a new state of matter which competed with d-wave superconductivity.

(3) Nanoscale Electronic Phenomena in the High-T_c Superconducting State

The STM/STS collaboration with J. C. Davis' group in Cornell Univ. is discovering numerous unexpected nanoscale phenomena, spatial modulation of the electronic state (local density of states, LDOS), in the superconducting CuO_2 planes using STM with sub-Å resolution and unprecedentedly high stability. These include (a) "+" or "×" shaped quasiparticle (QP) clouds around an individual non-magnetic Zn (magnetic Ni) impurity atom, (b) spatial variation (distribution) of the SC gap magnitude, (c) a "checkerboard" pattern of QP states with four unit cell periodicity around vortex cores, and (d) quantum interference of the QP. This year's highlights are as follows:

1) Granular structure of high-Tc superconductivity

The STM observation of "gap map" has been extended to various doping levels of $Bi_2Sr_2CaCu_2O_{8+\delta}$. The result reveals an apparent segregation of the electronic structure into SC domains of ∼3mm size with local energy gap smaller than 60meV, located in an electronically distinct background ("pseudogap" phase) with local gap larger than 60meV but without phase coherence of pairs. With decrease of doped hole density, the (coverage) fraction of the superconducting area decreases or the density of the number of superconducting islands decreases. Apparently, this is related to the doping dependence of superfluid density as well as the doping dependence of the normal-state carrier density.

2) Homogeneous nodal superconductivity and heterogeneous antinodal states

Modulation of LDOS is observed even without vortices, at zero magnetic field. In this case, the modulation is weak and incommensurate with lattice period, showing energy (bias voltage) dependence. The dispersion is explained by quasiparticle interference due to elastic scattering between characteristic regions of momentum-space, consistent with the Fermi surface and the d-wave SC gap determined by ARPES (angle-resolved-photoemission).

These dispersive quasiparticle interference is observed at all dopings, and hence the low-energy states, dominated by the states on the " Fermi arc " formed surrounding the gap nodes, are spatially homogeneous(nodal superconductivity). By contrast, the quasiparticle states near the antinodal region degrade in coherence with decreasing doping, but have dominant contribution to superfluid density. This suggests that the volume fraction of spatial regions all of whose Fermi surface contributes to superfluid decreases with reduced doping. The result indicates the special relationship between real-space and momentum-space electronic structure.

16 Hasegawa Group

Research Subject: Experimental Surface/Nano Physics

Members: Shuji HASEGAWA and Toru HIRAHARA

Topics in our research group are (1) electronic/mass transports, (2) atomic/electronic structures, (3) phase transitions, (4) electronic excitations, and (5) epitaxial growths of coherent atomic/molecular layers on semiconductor surfaces and nano-scale phases. Peculiar atomic arrangements and surface electronic states, characteristic of the surface superstructures and ultra-thin films, on semiconductor surfaces, are our platforms for studying physics of atomic-scale low-dimensional systems by using ultrahigh vacuum experimental techniques such as electron diffraction, scanning electron microscopy, scanning tunneling microscopy/spectroscopy (STM/S), photoemission spectroscopy, and *in-situ* 4-point-probe conductivity measurements with four-tip STM and monolithic micro-4-point probes. Main results in this year are as follows.

(1) Surface electronic transport: Metal-insulator transitions, hopping conduction, and a Mott insulator in surface states. Quantitative evaluation of surface-state conductivity from Fermi surface mapping. Conductance of individual Cobalt silicide nanowires and metal-coated carbon nanotube tips.

(2) Surface phases, ultra-thin films, and phase transitions: Order-disorder phase transition, charge-density-wave transition, Mott transition on various metal-induced surface superstructures of Si and Ge. Quantum-well state in ultra-thin Pb, Bi, and Ag films. Ge nanodots layer. Rashba effect in surface state and hybridization with quantum-well states.

(3) Construction of new apparatuses: Green's-function STM (low-temperature four-tip STM), Magneto-optical Kerr effect apparatus. Magneto-resistance apparatus.

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17 Fukuyama Group

Research Subjects: Low Temperature Physics (Experimental):

Two-dimensional (2D) quantum fluids and solids with strong correlations and

frustration,
Low temperature scanning tunneling microscopy and spectroscopy of 2D electron systems (2DES) and exotic superconductors.

Member: Hiroshi Fukuyama, Tomohiro Matsui

Our current interests are (i) new quantum phases with strong correlations and frustration in 2D ^{3}He. (ii) quantum and relativistic phenomena in Graphene, a single sheet of graphite, and (iii) electronic and vortex properties of exotic superconductors. We are investigating these phenomena at ultra-low temperatures down to 50 μK, using various experimental techniques such as NMR, calorimetry, scanning tunneling microscopy and spectroscopy (STM/STS), *etc.*

1. **Novel quantum phases in strongly correlated fermions in 2D:**

   (a) **Zero-point vacancies in 2D ^{3}He**

   The zero-point vacancies (ZPVs) are atomic vacancies hopping on crystalline lattice cites even at absolute zero. Our previous heat-capacity measurements show that the ZPVs exist in monolayer solid ^{3}He adsorbed on a graphite surface at densities (ρ) near the low-density commensurate phase (the 4/7 phase). In this fiscal year, the spin-spin relaxation time (T_2) of this possible ZPV phase has been measured with the spin-echo technique of pulsed-NMR. Two-component exponential decay of the echo amplitude was observed in a wide time range, and the longer T_2 component contributes only by 5% to the total amplitude. Because the ratio between the two components does not vary with density nor temperature in such a way expected from the twp-phase coexisting model, we speculate that the longer component is not associated with intrinsic properties of 2D ^{3}He but from extrinsic one like the mosaic angle spread of Grafoil substrate. Note that T_2 values in 2D systems are strongly anisotropic with respect to the angle between the 2D planes and the magnetic field direction. This means that the intrinsic echo signal would have the singe exponential decay with shorter T_2 which decreases linearly with increasing density towards the density of the 4/7 phase. The present result contradicts the previously believed phase-separation scenario for this phase but supports our ZPV model.

2. **STM/STS studies of Graphite-based materials:**

   (a) **Electron and hole properties in Graphene**

   Graphene is a monatomic sheet of carbon atoms densely packed in a honeycomb lattice. Its charge carriers behave as massless Dirac fermions due to the unique linear dispersion relation, which results in unusual properties such as anomalous integer quantum-Hall-effect and weak anti-localization. Since Graphene is fabricated directly on substrate surfaces, one can access to such an ideal 2D electron/hole system with the STM/STS technique.

   We have succeeded in fabricating Graphene samples of 50 μm wide by micro-mechanical cleavage on oxidized silicon wafers. The thickness of the samples was checked by several different ways: atomic force microscopy, gate voltage dependence of the Hall conductivity, and optical contrast measurements. STM/STS measurements for graphene are now going at very low temperatures and in high magnetic fields.

(b) **Quasi particles in graphite surfaces**

The magnetic field dependence of the Landau levels (LLs) of the quasi-2D electron system at graphite surfaces (HOPG and Kish graphite) was studied in detail. The measured LLs are categorized into two types; LLs with the linear field (B) dependence and those with the $\sqrt{B}$ dependence. Interestingly, the field dependence of the latter type of LLs at graphite surfaces is the same as that of the LLs of the massless Dirac fermion in Graphene. All the measured LLs converge on the lowest LL, whose energy is nearly field independent, in the limit of $B \rightarrow 0$ T.

3. **STM/STS studies of exotic superconductors:**

(a) **Tunneling spectroscopy on $CeCoIn_5$**

There are several experimental indications that $CeCoIn_5$, a heavy-fermion superconductor, has an FFLO phase at temperatures below 500 mK and in magnetic fields above 4.5 T. Because the superconducting order parameter is spatially modulated in the FFLO state, STS should be a powerful tool to verify this hypothesis from real-space spectroscopy of the vortex state. In this year, we started tunneling spectroscopy measurements of cleaved surfaces of single crystal $CeCoIn_5$. Preliminary data show an clear superconducting energy gap of $2\Delta \sim 1.5$ meV which disappears in the normal state.

18 Okamoto Group

Research Subjects: Experimental Condensed Matter Physics,

Low temperature electronic properties of two-dimensional systems.

Member: Tohru Okamoto and Ryuichi Masutomi

We study low temperature electronic properties of semiconductor two-dimensional systems.
The current topics are following:

1. Two dimensional electrons at cleaved semiconductor surfaces:
At the surfaces of InAs and InSb, conduction electrons can be induced by submonolayer deposition of other materials. Recently, we have performed in-plane magnetotransport measurements on in-situ cleaved surfaces of p-type substrates and observed the quantum Hall effect which demonstrates the perfect two dimensionality of the inversion layers. Research on the hybrid system of 2D electrons and adsorbed atoms has great future potential because of the variety of the adsorbates as well as the application of scanning probe microscopy techniques.

In this year, we study the magnetic properties of submonolayer Fe films on InAs via transport measurements on the 2DESs formed in the surface inversion layers. The results can be understood in terms of spin glass ordering in the Fe films. The main observations are as follows: (1) At low temperatures (~ 2 K), clear hysteresis is observed in the magnetoresistance curve between 0 T and 9 T. It appears only in a narrow coverage range around 0.4 monolayer (ML). It becomes very small in the coverage ranges below 0.3 ML and over 0.5 ML. The coverage dependence of the width of the hysteresis loop was found to be reproducible in different experimental runs. Since the electron density and mobility do not significantly change in this range, we believe that the magnetism of the Fe film affects on electron scattering in the inversion layer and causes the hysteresis behavior of the magnetoresistance. (2) The hysteresis becomes weaker as the temperature increases and disappears above 9 K. We also obtained results indicating that the remanent magnetization can be completely removed by annealing at 10 K. (3) We observed the relaxation behavior with long time constant on the order of 100 sec. The relaxation time decreases rapidly with increasing temperature. This is another typical feature of spin glass systems.

We also performed low temperature Hall measurements on two-dimensional electron systems induced by deposition of Cs or Na on *in situ* cleaved surfaces of p-type InAs. The surface donor level, at which the Fermi energy of the 2DES is pinned, is calculated from the observed saturation surface electron density using a surface potential determined self-consistently. The results are compared to those of previous photoelectron spectroscopy measurements.

2. Strongly correlated two dimensional systems:
   We performed systematic magnetotransport measurements on a very high mobility Si 2DES in the vicinity of the coincidence of the spin-up and spin-down LLs with $n = 0$ and 1, respectively. In order to sweep the pseudospin effective field, which is proportional to $\hbar\omega_c - g^*\mu_B B_{\rm tot}$, the data were obtained by continuously changing θ at a fixed magnetic field. The resistance peak at the coincidence exhibits a strong anisotropy with respect to the angle φ between the in-plane magnetic field and direction of the electric current. The anisotropy factor reaches up to 50 at 50 mK. Large hysteresis, which demonstrates the Ising QH ferromagnetism, was observed at low temperatures while it disappears as T increases. In the paramagnetic regime ($T \gtrsim 0.5$ K), the resistance peak is split into two peaks. Using the mean field approach for the T-dependent peak positions, we deduced that strong electron scattering occurs when the pseudospin is partially polarized. We also studied the current-voltage characteristics. A wide voltage plateau observed at 0.37 K was explained in terms of the breakdown of the uniform current distribution.

19 Shimano Group

Research Subjects: Optical and Terahertz Spectroscopy of Condensed Matter

Member: Ryo Shimano and Shinichi Watanabe

We study light-matter interactions and many body quantum correlations in: 1)optically excited high density electron-hole systems in semiconductors, low dimensional systems such as 2) carbon nanotubes, 3) quasi-1D organic conductors, 4)superconductors, and 5) multi-ferroic materials. In order to investigate the role of electron correlations on the excited state as well as the ground state, we are focusing on the low energy electromagnetic responses in terahertz(THz) (1THz∼4meV) frequency range where quasi-particle excitations and various collective excitations exist. The research summary in this year is as follows.

1. **High density electron-hole system :**

Photo-excited electron-hole system in semiconductors exhibits various phases depending on their density and temperature, such as exciton gas, electron-hole plasma, electron-hole liquid (droplets). Insulator-metal transition in e-h system, namely the exciton Mott transition has long been one of the central issues, while the role of Coulomb correlation is yet to be solved problem. We approach this problem by terahertz spectroscopy which can directly reflect the effect of electron correlation with high temporal resolution. For this purpose, we developed optical pump and terahertz probe measurements setup which covers broad frequency range from 2 to 24meV. We applied the scheme to Si, the most well-known material which is also attractive for the study of high density e-h phenomena due to relatively long carrier lifetime and also due to the existence of electron-hole droplets. Temporal evolution of 1s-2p Lyman transition of exciton in indirect semiconductor was for the first time observed. The behavior in high density region around Mott transition is currently under the investigation.

2. **Quasi-1D organic conductor :**

   We studied the optical responses of quasi-1D organic conductor $(TMTSF)_2PF_6$ which shows metal-insulator transition below 12K accompanied by spin density wave formation. Since the single particle excitation energy in SDW phase is located in terahertz frequency range, it is possible to investigate the spin and charge dynamics of SDW phase under photo-excitation by terahertz time domain spectroscopy. We have developed a reflection type measurement system with diffraction-limitted spatial resolution, which allows one to determine the complex dielectric function of small samples less than 1mm that is typical for organic conductor single crystals. A clear SDW gap is observed in optical conductivity spectrum in b'-axis direction.

3. **Vortex dynamics in superconductor :**

   Transmission type terahertz polarization spectroscopy setup combined with 7T superconductor magnet was developed to investigate the complex diagonal and off diagonal conductivity of materials. By using the developed system, vortex dynamics in superconductor NbN film was investigated. The change of conductivity spectrum around 1.1THz(the BCS gap of NbN) under the magnetic field was observed. We analyzed the results based on effective medium theory and determined the magnetic field dependence of the volume fraction of vortex. The results were well explained by taking into account the dissipation due to quasi-particles in vortex and also the dissipation caused by vortex motion.

4. **Multiferroics :**

   Low energy(1-10meV) electromagnetic dynamics of spin excitations in multi-ferroic rare-earth manganites $RMnO_3$,(R=$Eu_{1-x}Y_x$,Tb,Dy) were investigated by terahertz time domain spectroscopy. Electric-dipole active pronounced absorptions were observed in all the above materials when electric field vector was along a-axis. The possible origin of the observed absorption was discussed in terms of 2-magnon excitations and dipole active 1-magnon excitation(electromagnon).

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20 Theoretical Astrophysics Group

Research Subjects: Particle Astrophysics, Relativistic Astrophysics, Physics of Supernovae and High Density Matter, Observational Cosmology

Member: Katsuhiko Sato, Yasushi Suto, Atsushi Taruya, & Shinji Mukohyama

The Theoretical Astrophysics Group carries out a wide range of research programmes. However, astrophysics is a very broad field of research, and it goes without saying that our group alone cannot cover all the various important astrophysical research topics on hand; we therefore place particular emphasis on the following three areas of research - "Physics of the Early Universe", "Observational Cosmology", and "Paricle and Nuclear Astrophysics". Let us delve into the specifics of these areas below.

The understanding of the very early universe saw a sort of renaissance in 1980's by applying the ideas of particle physics around the epoch close to the Planck time, of which the prime example is the inflationary universe scenario. On the basis of such recent development, "Physics of the Early Universe" aims at describing the birth of the universe within the language of physics. Our group activities include inflationary universe models, cosmological phase-transition and topological defects, big-bang nucleosynthesis, the cosmic no-hair conjecture and the fundamental problem of general relativity.

"Observational Cosmology" attempts to understand the evolution of the universe on the basis of the observational data in various wavebands. The proper interpretation of the recent and future data provided by COBE, ASCA, the Hubble telescope, SUBARU, and large-scale galaxy survey projects is quite important both in improving our understanding of the present universe and in determining several basic parameters of the universe which are crucial in predicting the evolutionary behavior of the universe in the past and in the future. Our current interests include nonlinear gravitational evolution of cosmological fluctuations, formation and evolution of proto-galaxies and proto-clusters, X-ray luminosity and temperature functions of clusters of galaxies, hydrodynamical simulations of galaxies and the origin of the Hubble sequence, thermal history of the universe and reionization, prediction of anisotropies in the cosmic microwave background radiation, statistical description of the evolution of mass functions of gravitationally bound objects, and statistics of gravitationally lensed quasars.

"Particle and Nuclear Astrophysics" explores the interfaces between particle physics, nuclear physics, and astrophysics. We place particular attention on the physics of supernovae. This includes a rich variety of micro- and macro-physics, for example, neutrino transport, equation of state of high density matter, r-process nucleosynthesis, convective instability, fast rotation of a stellar core, strong magnetic field, gravitational radiation, and so on. In particular, the mechanism of the Type II supernovae itself has not been properly explained for more than 40 years. It is, therefore, important to make clear the physics of supernova phenomena not only for astrophysics but also for other fields of elementary physics. We are currently working on the multi-dimensional aspects of supernovae such as rotating core collapse, asymmetric neutrino emission, convective energy transfer near the neutrino sphere, possibility of r-process nucleosynthesis in the hot bubble region, and gravitational radiation from an asymmetrically bouncing core. Additionally, we have also recently been working on the effects of magnetic fields and those of nuclear structural transitions on the explosion mechanism.

Let us summarize this report by presenting recent titles of the doctor and master theses in our group;
2007

- The Rossiter effect of extrasolar transiting planetrary systems – perturbative approach and application to the detection of planetary rings
- Stability of flux compactifications and de Sitter thermodynamics
- Study of core-collapse supernovae in special relativistic magnetohydrodynamics
- Spectroscopic Studies of Transiting Planetary Systems
- The relation of the Galactic extinction map to the surface number density of galaxies
- Brane Inflation in String Theory

2006

- Numerical studies on cosmological perturbations in braneworld
- Inflationary braneworld probed with primordial black holes
- Galaxy Biasing and Higher-Order Statistics
- Probing circular polarization of Gravitational Wave Background with Cosmic Microwave Background Anisotropy
- Gravitational Collapse of Population III Stars

2005

- Brane gravity and dynamical stability in warped flux compactification
- Neutrino Probes of Galactic and Cosmological Supernovae
- Detectability of cosmic dark baryons through high-resolution spectroscopy in soft X-ray band
- Propagation of Ultra-High Energy Cosmic Rays in Cosmic Magnetic Fields
- The study of nuclear pasta investigated by Quantum Molecular Dynamics

2004

- Strong Gravitational Lenses in a Cold Dark Matter Universe
- Effect of Rotation and Magnetic Field on the Explosion Mechanism and Gravitational Wave in Core-Collapse Supernovae
- "Bulk Fields in Braneworld"
- "Gravitational collapse and gravitational wave in the brane-world"

- Magnetohydrodynamical Simulation of Core-Collapse Supernovae
- A Search for the Atmospheric Absorption in the Transiting Extrasolar Planet HD209458b with Subaru HDS
- Baryogenesis and Inhomogeneous Big Bang Nucleosynthesis
- The large-scale structure of SDSS quasars and its cosmological implication

2003

- Non-Gravitational Heating of Galaxy Clusters in a Hierarchical Universe
- Discoveries of Gravitationally Lensed Quasars from the Sloan Digital Sky Survey
- One, Two, Three – measuring evolved large scale structure of the Universe
- Higher-order Statistics as a probe of Non-Gaussianity in Large Scale Structure
- Primordial black holes as an imprint of the brane Universe
- Probing the Extra Dimensions with Gravitational Wave Background of Cosmological Origin

2002

- Nuclear "pasta" in dense stars and its properties
- Supernova Neutrinos: Their Relic Background and Resonant Spin-Flavor Conversion
- Arrival Distribution of Ultra-High Energy Cosmic Rays and Implications for Their Source Candidates
- Non-linear evolution of the cosmological large scale structure from the local collapse model

21 Murao Group

Research Subjects: Quantum Information Theory

Member: Mio Murao, Damian Markham (-August 2007)/ Peter Turner (February 2008-)

Quantum information processing seeks to perform tasks which are impossible or not effective with the use of conventional classical information, by using quantum information described by quantum mechanical states. Quantum computation, quantum cryptography, and quantum communication have been proposed and this new field of quantum information processing has developed rapidly especially over the last 10 years. Entanglement is nonlocal correlation that appears in certain types of quantum states (non-separable states) and has become considered as a fundamental resource for quantum information processing. In our group, we investigate new properties of multipartite and multi-level entanglement and the use of these properties as resources for quantum information processing. Our current projects are the following:

- Entanglement and local information access for graph states [1]
- Local encoding of classical information onto quantum states [2]

- Survival of entanglement in thermal states [3]
- The role of entanglement in quantum information and in statistical physics [4]
- LOCC and SLOCC convertibility of quantum states in infinite dimensional systems [5]
- Entanglement and group symmetries: stabilizer states, symmetric and antisymmetric states [6]
- Quantum state discrimination: a geometric approach [7]
- Remote extraction and destruction of asymmetrically spread qubit information [8]
- Thermal Robustness of multipartite entanglement of 1-D spin 1/2 XY model
- Searching for the maximally entangled state in terms of the geometric measure
- Authorized quantum computation
- Generalization of measurement based quantum computation
- Continuous variable SIC-POVMs

Please refer our webpage: http://eve.phys.s.u-tokyo.ac.jp/indexe.htm

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22 Ueda Group

Research Subjects: Bose-Einstein condensation, Fermionic superfluidity, cold molecules, mesurement theory, quantum information, quantum control

Member: Masahito Ueda and Yuki Kawaguchi

A gaseous Bose-Einstein condensate (BEC) offers an ideal testing ground for studying symmetry breaking, because a trapped BEC system is in a mesoscopic regime, and situations exist under which symmetry breaking may or may not occur. Investigating this problem can explain why mean-field theories have been so successful in elucidating gaseous BEC systems and when many-body effects play a significant role. We substantiate these ideas in four distinct situations: namely, soliton formation in attractive BECs, spontaneous magnetization in spinor BECs, and spin texture formation in dipolar BECs.

22.1 Soliton formation in a quasi-1D attractive BEC

We begin by discussing symmetry breaking in a quasi-1D attractive BEC. Suppose that an attractive BEC is confined in a quasi-1D torus. On a mean-field level, the properties of the system can be described by the Gross-Pitaevskii (GP) equation

$$\left(-\frac{\partial^2}{\partial\theta^2} - \pi\gamma|\Psi_0|^2\right)\Psi_0 = E\Psi_0, \tag{22.1.1}$$

where $\Psi_0(\theta)$ is the ground-state wave function and γ is the dimensionless strength of interaction. When dimensionless strength of interaction γ is smaller than 1, the ground-state density is uniform. However, when it exceeds 1, the translational symmetry is spontaneously broken and a bright soliton is formed. Thus the mean-field theory predicts a second-order quantum phase transition at $\gamma = 1$.

We have numerically obtained the Bogoliubov spectrum and many-body spectrum. In the Bogoliubov spectrum, the zero-energy mode emerges in the soliton regime, this being the Goldstone mode associated with the breaking of translational symmetry. The many-body spectrum in the uniform BEC regime is similar to that of the Bogoliubov spectrum. However, a dramatic change in the landscape of the energy spectrum occurs in the bright soliton regime. In particular, a quasi-degenerate spectrum appears above the ground state in the bright soliton regime. This quasi-degeneracy is a signature of the breaking of the translational symmetry that generates a bright soliton. It is remarkable that many-body physics can automatically generate such a symmetry-breaking-inducing quasi-degenerate spectrum which is absent at the mean-field level.

22.2 Spinor BEC: chiral symmetry breaking

A long-standing question with magnetism is how the spontaneous magnetization of a ferromagnet can occur in an isolated system in which the total spin angular momentum is conserved. One possible solution is that all spins align in the same direction and that the system is in a quantum-mechanical superposition state over all directions. We propose here a different scenario, in that the system develops local magnetic domains of various types that depend on the nature of the interaction, conservation laws, and the geometry of the trapping potential.

Suppose that all atoms are prepared again in the $m = 0$ state in a pancake-shaped trap. In the low density region, the Bogoliubov modes with orbital angular momentum $\ell = \pm 1$ have imaginary parts, and they are therefore dynamically unstable and grow exponentially. When a ^{87}Rb BEC is prepared in this region, the $m = 0$ atoms are transfered into the $m = \pm 1$ states due to the dynamical instability, and they obtain the orbital angular momentum. The angular momentum conservation implies that the $m = 1$ and $m = -1$ components must have opposite sign of orbital angular momentum. There are two possibilities:

the $m = 1$ component can have either orbital angular momentum of $\ell = 1$ or $\ell = -1$; correspondingly, the $m = -1$ component can have either -1 or 1 orbital angular momentum. These two possibilities are degenerate, this degeneracy being a statement of the chiral symmetry. However, since a chirally symmetric state has higher energy than a chiral-symmetry-broken states, the chiral symmetry is dynamically broken and each spin component begins to rotate spontaneously.

Our predictions have recently been observed by the Berkeley group. They carried out experiments subject to the same initial conditions, i.e., all the atoms were initially prepared in the $m = 0$ state. As we predicted, the system remained unmagnetized during a certain latency period, before spontaneously developing magnetization. They also observed a polar-core vortex corresponding to our chiral-symmetry-broken state.

22.3 Dipolar BEC: Einstein–de Haas Effect and ground-state mass flow

The magnetic dipole-dipole interaction is a tensor force which causes spin-orbit coupling, and only the total, spin plus orbital, angular momentum is conserved. Therefore, the dipolar interaction transfers angular momentum between the spin and orbit, i.e., the Einstein–de Haas effect occurs. We have pointed out that the Einstein–de Haas effect occurs in the ^{52}Cr BEC and numerically shown the dynamics.

The dipole-dipole interaction is also expected to yield ground-state spin texture in a ferromagnetic BEC, as in the case of the domain structure in a solid-state ferromagnet. The unique feature of the spinor dipolar BEC which is absent from a solid-state ferromagnet is the spin-gauge symmetry which relates the spin texture to a mass current. The fundamental query is whether or not a spinor dipolar BEC can exhibit a spontaneous mass current in the ground state. we have numerically explored the ground state of the spinor dipolar BEC and found that the ground state has nonzero orbital angular momentum in a certain parameter region.

23 Makishima Group & Nakazawa Group

Research Subjects: High Energy Astrophysics using Scientific Satellites, X-Ray Probing of the Universe, Development of Cosmic X-Ray/γ-Ray Instruments

Member: Kazuo Makishima, Kazuhiro Nakazawa

We study cosmic and solar high-energy phenomena in the X-ray and γ-ray frequencies, mainly using scientific satellites launched by the Japan Aerospace Exploration Agency.

The *Suzaku* satellite: In collaboration with several domestic and US groups, we have developed the Hard X-ray Detector (HXD) working in the 10–600 keV range. It was put onboard the cosmic X-ray satellite *Suzaku*, which was launched successfully into orbit on 2005 July 10.

Physics of Compact Objects: Mass accretion onto compact objects provides our favorite research subject. Observations of X-ray pulsars with the *Suzaku* HXD have yielded accurate measurements of the spectral features arising from electron cyclotron resonance in the extremely strong magnetic fields [5]. Utilizing ~ 0.3 keV to ~ 500 keV *Suzaku* spectra of several black-hole binaries (including the prototypical Cygnus X-1), we are investigating into the physics of hot corona around accreting black holes. We have strengthened the intermediate-mass black hole scenario for Ultra-Luminous X-ray sources (ULXs) in nearby galaxies. The *Suzaku* data on the type 2 Seyfert galaxy NGC 4945 has revealed that its obscring materials cannot have a thick torous geometry [7], in contrast to the currently popular view.

Plasma Heating and Particle Acceleration: Our studies reveal that the vast inter-stellar and inter-galactic space is a site of ubiquitous plasma heating and particle acceleration. Examples include; colliding stellar winds; globular clusters moving through the Galactic halo gas [3], and galaxy groups [2]. *Suzaku* observations have demonstrated that the interstellar space near the Galactic center is filled with hot thermal X-ray emission, as well as non-thermal hard X-ray signals [6]. Using *Suzaku*,we are placing tight upper limits on non-thermal emission from clusters of galaxies. In addition, unusually hot thermal emission was unexpectedly detected from a few merging clusters of galaxies.

Particle Acceleration in Thunderclouds and Solar Flares: From winter thunder clouds in a coastal area of the Sea of Japan, we have successfully detected two events of intense gamma-ray emission [1]. On both occasions, the emission lasted for about 1 minutes, and the gamma-ray spectrum extended up to 10 MeV. This means that electrons are accelerated in thunder clouds, either continuously or sporadically. Such electro-static particle acceleration may be relevant to the generation of energetic particles in solar flares [4]. There is a hint of *Suzaku* detection of neutrons from a solar flare on 2006 December 5.

Future Instrumentation: Together with many domestic and foreign groups, we are planning a cosmic X-ray/gamma-ray mission called *NeXT* (New Exploration X-ray Telescope). Scheduled for launch in 2013, it will serve as a successor to *Suzaku*, and will carry out hard X-ray imaging observations as well as high-resolution X-ray spectroscopy. Aiming at instrumentation for *NeXT*, we are developing double-sided Silicon strip detectors, large-volume BGO scintillators, and an onboard network using SpaceWire protocol.

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24 Takase Group

Research Subjects: High Temperature Plasma Physics Experiments, Spherical Tokamak, Nonlinear Physics, Collective Phenomena, Fluctuations and Transport, Advanced Plasma Diagnostics Development

Members: Yuichi Takase, Akira Ejiri

Thermonuclear fusion, the process that powers the sun and stars, is a promising candidate for generating abundant, safe, and clean power. In order to produce sufficient fusion reactions, isotopes of hydrogen, in the form of hot and dense plasma, must be confined for a long enough time. A magnetic configuration called the tokamak has reached the level where the International Thermonuclear Experimental Reactor (ITER) is being constructed to study the behavior of burning plasmas. However, improvement of the cost-effectiveness of the fusion reactor is still necessary. The spherical tokamak (ST) offers a promising approach to increasing the efficiency by raising the plasma beta (the ratio of plasma pressure to magnetic pressure). High beta plasma research using ST is a rapidly developing field worldwide, and is being carried out in our group using the TST-2 spherical tokamak. TST-2 is now located in a new experimental building in Kashiwa Campus. Our group is tackling the problem of creating and sustaining a high beta plasma using a variety of approaches.

Formation, heating and sustainment of the TST-2 spherical tokamak plasma

It is crucially important for ST to develop a scenario of plasma formation, heating and sustainment without the use of the central solenoid (CS). The physics of noninductive plasma initiation by RF power in the presence of a vertical magnetic field is being investigated on TST-2. Plasma is initiated and a small plasma current is formed by injection of microwave power at 2.45 GHz, which is resonant with electrons gyrating in a magnetic field of 0.0875 T. The plasma current ramp-up rate depends on the vertical field curvature and strength, gas pressure, microwave power, and electron cyclotron resonance position. Once the plasma current reaches a threshold level, closed flux surfaces are formed and the plasma current increases abruptly (current jump). Sustainment of the plasma current by radio-frequency power at 21 MHz was also demonstrated for the first time. Plasma heating by the high harmonic fast wave (HHFW) at 21 MHz is also being investigated. The electron temperature increases from 140 to 210 eV and the ion temperature increases from 50 to 100 eV in a typical discharge. A nonlinear process known as parametric decay was observed by both RF magnetic probes and microwave reflectometry. In addition to the well-know decay from HHFW to the ion Bernstein wave and the ion-cyclorton quasi-mode, a previously unknown decay into an intermediate frequency was discovered. A new diagnostic based on fast visible light detection is being developed to obtain further information on waves inside the plasma. The high beta plasma produced in ST is highly autonomous. Spontaneous deformation of the plasma by an instability and subsequent recovery are observed. This process involves nonlinear coupling of multiple modes leading to reconnection of magnetic field lines, and is called the internal reconnection event (IRE). A new analysis method is being developed to identify the mode structure. Analysis of the evolutions of the current density profile and the plasma pressure profile suggests that the instability is driven by the pressure gradient.

Formation of Ultra-High Beta Plasma by Plasma Merging

A new ST device, UTST, aiming at formation of ultra-high beta plasma by plasma merging is now in operation. Power aupply upgrades and installation of a neutral beam injector for plasma heating were carried out. In UTST, two ST plasmas are formed by induction from external coils. Strong ion heating due to magnetic reconnection is expected to form one ST plasma with very high beta (30–50%). Access to the second stability regime becomes much easier using this unique method. It is a challenge to maintain the plasma in such a state for long enough time (exceeding the energy confinement time) after reconnection is over. This is planned to be accomplished by innovative methods of heating and current drive using RF waves (such as the HHFW) and neutral beam injection.

Collaborations

Collaborative experiments are being carried out on the JT-60U tokamak at Japan Atomic Energy Agency (JAEA). Plasma current sustainment by the bootstrap current, driven spontaneously by the pressure gradient, was demonstrated using the newly developed constant surface flux control algorithm, which eliminates the possibility of inductive current drive. Collaborations with larger ST devices NSTX (USA) and MAST (UK), as well as a high magnetic field tokamak device Alcator C-Mod (USA) are also being carried out.

25 Tsubono Group

Research Subjects: Experimental Relativity, Gravitational Wave, Laser Interferometer

Member: Kimio TSUBONO and Masaki ANDO

The detection of gravitational waves is expected to open a new window into the universe and brings us a new type of information about catastrophic events such as supernovae or coalescing binary neutron stars; these information can not be obtained by other means such as optics, radio-waves or X-ray. Worldwide efforts are being continued in order to construct detectors with sufficient sensitivity to catch possible gravitational waves. Now the detection of the gravitational waves is one of the biggest challenges in the field of physics and astronomy.

TAMA300 is a 300-m baseline laser interferometric gravitational wave detector constructed in Mitaka. We started the operation of the detector in 1999. The achieved sensitivity, $h \sim 3 \times 10^{-21}/\sqrt{\mathrm{Hz}}$ at 700Hz to 1.5kHz, is sufficient to catch possible gravitational wave events in our galaxy. We can operate the detector for over 24 hours stably and continuously, and have accumulated over 3,000 hours data. We are now analyzing the obtained data searching for the gravitational waves from coalescing binaries, supernovae and pulsars. We are expecting to start the Japanese large-scale laser interferometer, LCGT, soon.

A space laser interferometer, DECIGO, was proposed through the study of the gravitational wave sources with cosmological origin. DECIGO could detect primordial gravitational waves from the early Universe at the inflation era. We have just stared the theoretical and technical investigation for the realization of the DECIGO space detector.

We summarize the subjects being studied in our group.

- Laser interferometric gravitational wave detectors
  - Current status of TAMA project

  - Systematic analysis of TAMA monitoring signal
  - Study of the next-generation laser interferometer, LCGT

- Space laser interferometer
  - Space laser interferometer, DECIGO
  - DECIGO pathfinder, DPF
  - Small size detector, SWIM
  - SWIM-signal processing
  - SWIM-control system
  - SWIM-balloon and airplane experiments

- Development of a gravitational wave detector using magnetic levitation
  - Gravitational wave detector using superconducting magnetic levitation
  - Experiments using permanent magnets

- Study of the precise measurements
  - Laser stabilization using optical fiber

- Study of the thermal noise
  - Study of the thermal noise in a space interferometer

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26 Sano Group

Research Subjects: Nonlinear Dynamics and Fluid Mechanics

Member: Masaki Sano and Yoshihiro Murayama

Our research group studies nonlinear dynamics and pattern forming phenomena in dissipative nonlinear systems. Oscillation, chaos, and turbulent behavior of fluid, solid, granular systems, chemical reactions and biological systems are investigated based on dynamical system's theory and laboratory experiments. Through these efforts we search for novel phenomena, and to develop new methods in understanding complex phenomena arising in the systems far from equilibrium. The followings are main subjects of our study.

1. Study of turbulence

(1) Search for the ultimate scaling regime in developed thermal turbulence

(2) Study of statistical properties and coherent structures in turbulence

(3) Turbulence - turbulence transition in electro hydrodynamic convection of liquid crystals

2. Nonlinear Dynamics and Chaos

(1) Pattern forming phenomena and their universalities in dissipative systems

(2) Spatio-temporal dynamics in spatially extended dissipative systems

3. Dynamical aspects of biological systems

(1) Single molecule level measurement of DNA collapsing, DNA-protein interaction, and gene expression

(2) Collective behavior of the activities in biological neural assemblies

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27 Yamamoto Group

Research Subjects: Submillimeter-wave and Terahertz Astronomy, Chemical Evolution of Interstellar Molecular Clouds, Star and Planet Formation, Development of Terahertz Detectors

Member: Satoshi Yamamoto and Tomoharu Oka

Molecular clouds are birthplaces of new stars and planetary systems, which are being studied extensively as an important target of astronomy and astrophysics. Although the main constituent of molecular clouds is a hydrogen molecule, various atoms and molecules also exist as minor components. The chemical composition of these minor species reflects formation and evolution of molecular clouds as well as star formation processes. It therefore tells us how a particular star has been formed. We are studying star formation processes from such a unique viewpoint.

Since the temperature of molecular cloud is as low as 10 K, only way to observe its physical structure and chemical composition is to observe the radio wave emitted from atoms and molecules. In particular, there exist a number of atomic and molecular lines in the millimeter to terahertz region, and we are observing them with various radio telescopes such as Nobeyama 45 m telescope and IRAM 30 m telescope.

We have recently established a new chemistry occurring in the vicinity of a newly born star, which is called Warm Carbon Chain Chemistry (WCCC). We have found high abundances of various carbon-chain molecules in a lukewarm region near the protostar in L1527. This is very surprising, because carbon-chain molecules are known to exist in the early stages of cold starless cores. In WCCC, carbon-chain molecules are produced by gas phase reactions of CH_4 which is evaporated from ice mantles. Existence of WCCC clearly indicates a chemical variety of low-mass star forming regions, which would probably reflect a variety of star formation.

In parallel to such observational studies, we are developing a hot electron bolometer mixer (HEB mixer) for the future terahertz astronomy. We are fabricating the diffusion cooled HEB mixer using Nb and the phonon cooling HEB mixer using NbTiN in our laboratory. Our NbTiN mixer shows the noise temperature of 500 K at 800 GHz, which is well comparable to the results reported by other groups. We are also studying bath-temperature dependence of the noise temperature in order to explore the mixing mechanism of the HEB mixer.

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28 Sakai (Hirofumi) Group

Research Subjects: Experimental studies of quantum optics and atomic/molecular physics

Member: Hirofumi Sakai and Shinichirou Minemoto

Our research interests are as follows: (1) Manipulation of neutral molecules based on the interaction between a strong nonresonant laser field and induced dipole moments of the molecules. (2) Controlling quantum processes in atoms and molecules using shaped ultrafast laser fields. (3) High-intensity laser physics typified by high-order nonlinear processes (ex. multiphoton ionization and high-order harmonic generation). (4) Ultrafast phenomena in atoms and molecules in the attosecond time scale. A part of our recent research activities is as follows:

(1) Laser-field-free molecular orientation with combined electrostatic and shaped laser fields

A sample of aligned or oriented molecules is an ideal anisotropic quantum system to investigate many interesting phenomena such as multiphoton ionization and high-order harmonic generation. As for the molecular orientation, we have already succeeded in the proof-of-principle experiments of one- and three-dimensional orientation of molecules with combined electrostatic and intense, nonresonant laser fields. These experiments were performed in the adiabatic regime, where the pulse width of the laser field is rather long compared to the rotational period of the molecules. In this case, the degree of molecular orientation follows the temporal profile of the laser pulse and reaches the maximum at the peak of the laser pulse.

On the other hand, in precise spectroscopic measurements and experiments including the observation of photoelectrons, it is desirable to prepare a sample of oriented molecules in the laser-field-free condition.

Noting that molecules can be oriented with combined moderate electrostatic and intense, nonresonant laser fields in the adiabatic regime, we have proposed that we use a shaped pulse which has a long rising edge compared to the rotational period of the molecule and is rapidly turned off at the peak of the pulse. Such a rapidly-turned-off pulse can be shaped with the plasma shutter technique. Thereby, in the laser-field-free condition at the rotational period of the molecule, we can expect the same degree of orientation as that achieved adiabatically by the peak of the shaped pump pulse. In this academic year, we developed a technique to shape the pump pulse with 12-ns duration and 100-mJ-class energy so that it can be truncated with the falling time of ∼200 fs. With the shaped pump pulse, we have demonstrated nonadiabatic laser-field-free orientation of OCS molecules. In fact, the observed temporal evolutions of both degree of alignment and the degree of orientation have been confirmed to be in good agreement with theoretical expectations.

(2) Efficient generation of high-order sum and difference frequencies in the xuv region by combining a longer-wavelength field

In our earlier study, high-order sum and difference frequencies in the xuv region were found to be efficiently generated by combining a weak longer-wavelength field with an intense Ti:sapphire laser field centered at 800 nm. In this academic year, we employed a 60-fs 1300-nm laser field delivered from an optical parametric amplifier as a combined field. The ultrashort duration of the 1300-nm pulse has made it possible to use the high intensity of 1×10^{14} W/cm^2 without significant ionization of the nonlinear medium. When the polarization of the 1300-nm pulse is parallel to that of the 800-nm pulse, sum and difference frequencies including at least 11 1300-nm photons were observed. Our observations were successfully reproduced by our theoretical model, which was developed based on the 2-color Lewenstein model so that a field with arbitrary polarization and nonperturbative intensity can be combined.

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29 Nose Group

Research Subjects:Molecular Mechanism of Neural Network Formati

Member:Akinao Nose, Hiroshi Kohsaka and Etsuko Takasu

What is the physical basis of formation of the brain? The aim of our laboratory is to elucidate the molecular mechanism of neural development and function by using, as a model, the simple nervous system of the fruitfly, Drosophila. We focus on the synapses between motor neurons and their target muscles, and study the molecular mechanisms of how specific synaptic partners recognize each other and form synaptic connections. The following research plans are in progress.

1. Molecular mechanism of the neuromuscular target recognition 1.1. Genome-wide search for target recognition molecules by microarray To systematically identify novel genes involved in neuromuscular target recognition, we performed microarray analysis. We compared the expression of genes in two neighboring muscles, 12 and 13, which are innervated by distinct motor neurons, and identified 200 genes that are differentially expressed. We conducted functional analyses of genes encoding transmembrane or secreted proteins and showed that Wnt4, a secreted protein of WNT family plays a major role in target specificity.

2. Molecular Mechanisms of Synaptogenesis 2.1 Live imaging of neuromuscular synaptogenesis Cell adhesion molecules (CAMs) have been proposed to mediate interactions between innervating axons and their targets. However, such interactions have never been directly observed in vivo. We studied the function and dynamics of Fasciclin2, a homophilic CAM expressed both pre- and postsynaptically during the formation of neuromuscular synapses in Drosophila. By live-imaging of functional Fas2-GFP, we show that postsynaptic Fas2 accumulates at the synaptic contact site soon after the arrival of the nerve. The accumulation of postsynaptic Fas2 was dependent on its extracellular domain and the presence of axonal Fas2, consistent with recruitment by presynaptic Fas2. This notion was further supported by photobleaching experiments, which demonstrated presynaptic-Fas2-dependent reduction of postsynaptic Fas2 motility. In fas2 mutants, we found reduced postsynaptic accumulation of glutamate receptors and Dlg/PSD-95, a scaffolding protein known to bind Fas2. These results suggest that Fas2 mediates trans-synaptic adhesion that is necessary for the initiation of postsynaptic assembly.

2.2. Innervation and activity dependent changes in postsynaptic oxidative metabolism The level of mitochondrial energy metabolism is highly correlated with neuronal activity to ensure the balance of energy consumption and production. Yet it remains largely unknown whether this relationship holds in the postsynaptic cell during synaptogenesis when it receives increasing amount of inputs from the presynaptic neuron. We have studied the changes in postsynaptic oxidative metabolism by monitoring the redox of mitochondrial flavoproteins during neuromuscular synaptogenesis. Flavoproteins cycle between fluorescent and non-fluorescent states as they are oxidized and reduced in the respiratory chain. We found that the postsynaptic muscle cells spontaneously emit green autofluorescence transients originating in flavoproteins under blue light excitation. The fluorescence transient is dependent on external Ca2+ and correlates with an increase in intracellular Ca2+ concentration. Notably, the rate of transients in muscle cells increases during synapse formation presumably through a contact with motoneuronal axon. The rate is also influenced by the magnitude of synaptic inputs. Thus, our results indicate that presynaptic cells dynamically regulate the level of postsynaptic energy metabolism during the early stage of neuromuscular synapse formation.