History (April 2010–March 2011)

April
- Workshop “Recent advances in mathematics at IPMU II”
- Press Release “Shape of dark matter distribution”
- Mini-Workshop “Cosmic Dust”

May
- Shaw Prize to David Spergel
- Press Release “Discovery of the most distant cluster of galaxies”
- Press Release “An unusual supernova may be a missing link in stellar evolution”

June
- CL J2010: From Massive Galaxy Formation to Dark Energy
- Press Conference “Study of type Ia supernovae strengthens the case for the dark energy”

July
- Institut d’Astrophysique de Paris Medal (France) to Ken’ichi Nomoto
- IPMU Day of Extra-galactic Astrophysics Seminars: Chemical Evolution

August
- Workshop “Galaxy and cosmology with Thirty Meter Telescope (TMT)”
- Subaru Future Instrumentation Workshop
- Horiba International Conference COSMO/CosPA

September
- The 3rd Anniversary of IPMU, All Hands Meeting and Reception
- Inoue Science Prize to Toshiyuki Kobayashi
- The 4th Meeting of Origin of Matter and Evolution of Galaxies Institute “Supernova Explosions and Nuclear-synthesis”

October
- The 3rd Anniversary of IPMU, All Hands Meeting and Reception
- Focus Week “String Cosmology”
- Nishinomiya-Yukawa Memorial Prize to Eiichiro Komatsu
- Workshop “Evolution of massive galaxies and their AGNs with the SDSS-III/BOSS survey”
- Open Campus Day: Public lecture, mini-lecture and exhibits

November
- Yukawa-Kimura Prize to Tadashi Takayanagi
- Domenico Orlando and Susanne Reffert Selected for Highlights of Classical Quantum Gravity Journal
- PSJ Young Scientist Award to Fuminobu Takahashi
- Mini-Workshop “Neutrinos”
- Workshop “Population III Gamma-Ray Burst”

December
- Inoue Science Prize to Toshiyuki Kobayashi
- The 4th Meeting of Origin of Matter and Evolution of Galaxies Institute “Supernova Explosions and Nuclear-synthesis”
- Workshop “Science of Prime Focus Spectrograph (PFS)”

January
- Press Release “Sloan Digital Sky Survey III data release and IPMU contribution”
- IPMU as the first entity of Todai Institutes for Advanced Study (TODIAS)

February
- IPMU Workshop “Black Holes”
- Young Scientist Award in Theoretical Physics to Seong Chan Park
- Bruno Pontecorvo Prize to Yoichiro Suzuki and Serguey Petcov
- Workshop “Log Hodge Theory and Elliptic Flat Invariants”

March
- TODIAS Inauguration Lecture
- The 3.11 Earthquake: Interruptions and Comradeship
1 Mission

“Everything is made of atoms” had been the basic concept that had dominated our view of the universe for the past two centuries. The universe was made of atoms that obeyed quantum mechanics, and all gravity phenomena on Earth and in the solar system were well-described by Einstein’s general relativity.

But the 1998 discovery that “the universe is expanding with an accelerated speed” has changed our entire understanding. Many researchers now believe that mysterious dark energy must be distributed across the universe and the cause of this acceleration.

It has been known for some time that the galaxies must contain large amounts of invisible dark matter in order to hold their spiral shapes. But we do not know what they are.

An attempt to describe the early and still tiny universe faces another type of serious difficulty because quantum fluctuation becomes so enormous that theories of general relativity and quantum mechanics break down. Therefore, a necessity to combine quantum mechanics and general relativity, which has been a subject for fundamental understanding of elementary particles, also appears as we try to understand the beginning of the universe. Many researchers believe that superstring theory can solve this problem. But its whereabouts is still not known.

Our strategy to face these challenges is to bring the world top-level scientists in mathematics, physics and astronomy into one place. A close collaboration among those traditionally different research fields should induce a synergistic effect and develop into new ideas and new concepts.

It is essential to include mathematics in this approach. History teaches us that breakthrough in search for fundamental laws of nature was always built on the invention of new mathematics. Galileo, who lived at the dawn of cosmology in the 16th to 17th century, wrote that “The Universe is written in the language of mathematics.” More than ever before, we need a close collaboration of mathematicians with astronomers and physicists in order to answer big questions of the universe we face today.

We develop ultra-high resolution optical instruments, HyperSuprime Cam for collecting images and PrimeFocus Spectrograph for studying spectroscopy both with a large field of view, and attach to the Subaru telescope. Using “Gravitational Lensing Effect” we perform three-dimensional mapping of dark matter. Furthermore we explore the properties of dark energy by examining how the matter distribution varies with time.

We use three underground detectors: Super Kamiokande to search for “supernova relic neutrinos” (neutrinos that are produced by ancient supernova explosions and wander through the present universe); XMASS to directly search for dark matter that must be present in our Milky Way Galaxy; KamLAND to look for an important but yet to be discovered neutrino-less double beta decay.

We study phenomenology in particle physics to explore physics beyond the Standard Model. Data from collider experiments and astrophysical observations are closely examined for any clue of dark matter candidates, extra dimensions, and other exotic phenomena.

Investigation of dark matter and dark energy requires further development of theory and mathematics. Superstring theory, which attempts to unify GNGK-barubu.c.inderlateral relativity and quantum theory and is considered as a candidate for the ultimate unified theory of elementary particles, requires further investigation of geometrical properties of the theory. At IPMU, mathematicians and physicists work closely on this problem. String theory, if indeed the ultimate theory, should give consistent answers to a wide subject in physics. String theorists at IPMU initiate active collaboration with condensed matter physicists of other institutions in the area such as superconductivity. Systematic investigation to apply superstring theory to particle physics phenomena such as low energy baryon physics is also pursued at IPMU.

Teatime is held everyday at 3 o’clock at the Piazza Fujiwara, where lively discussion takes place among researchers of different disciplines. This large open space that occupies the center of the IPMU building from the 3rd floor and up was designed to attract scientists and have free and informal interactions. The word of Galileo “The Universe is written in the language of mathematics” is inscribed on the obelisk at the center of the space.
2 Introduction

The biggest news for us in FY 2010 came in January 2011. On 11th of January, the University of Tokyo established the Todai Institutes for Advanced Study (TODIAS), and approved IPMU as its first member-institute in this new and permanent organization.

The IPMU Director, Hitoshi Murayama said, “I deeply thank President Hamada for his bold vision, Director Okamura for his involvement in kick-starting IPMU, and everybody in the Todai community for making the TODIAS possible. This is a critical step for IPMU to become a permanent member of the Todai community. Indeed this provides IPMU a “citizenship” within Todai, and a wonderful opportunity to continue its research on the fundamental questions about the Universe. The IPMU members and I will do our best to fulfill the expectations in TODIAS, and ask for your continued support.”

IPMU was founded on October 1, 2007 by the World Premier International Research Center Initiative (WPI). The WPI funding has a term of 10 years, and mandates (1) world class research, (2) internationalization by adopting English as the official language and employing a large number of non-Japanese researchers, (3) scientific breakthroughs by fusion of disciplines, (4) new organizational structure unprecedented in Universities in Japan. This way, IPMU is required to achieve a high visibility to the worldwide scientific community.

"We are ushering in a time of great change. At this critical juncture, society expects universities and scholarship to play an important role in steering that change for the betterment of the world,” commented Junichi Hamada, the president of the University of Tokyo on this occasion, and went on saying, “As part of the measures to achieve these goals, we have established TODIAS as a university-wide organization. It will comprise research institutes that can function as a world-leading center of knowledge, aiming to enhance the University’s academic excellence as a whole and further advance our internationalization.”

“It is a tremendous honor and privilege that President Hamada has given me,” said Sadanori Okamura who was appointed to the founding director of TODIAS. He commented, “At the inaugural steering committee on Jan.11, 2011, the members were in consensus that IPMU was a suitable organization that met all the criteria. We have decided to designate IPMU as the first institute within TODIAS,” and concluded by saying “I am deeply committed to providing the best possible research environment for IPMU so that it can conduct research activities more quickly, flexibly and actively under stable management.”
Public lecture was held to celebrate the inauguration of the Todai Institutes for Advanced Study on March 9, 2011.

Inauguration of TODIAS was celebrated on March 9, 2011 at Yasuda Auditorium. Following speeches by the University of Tokyo President Junichi Hamada and the TODIAS Director Sadanori Okamura, public lecture was presented by the IPMU Director Hitoshi Murayama and a distinguished guest David Gross, the Director of Kavli Institute for Theoretical Physics of the University of California, Santa Barbara and the 2004 Nobel laureate in physics.

Starting from scratch, IPMU has been appointing researchers from around the world, setting its research agenda, and building up its infrastructure in a dizzying pace. In three years it has grown to a research institute of 67 full-time research staff (10 professors, 9 associate professors, 5 assistant professors, 43 postdoctoral fellows) and 38 administrative and support staff.

Total number of scientific staff including principal investigators, full time staff, joint appointments, students and long-term visitors (more than one month) reached 194 as compared with 165 one year ago. The JFY 2010 was another very productive one year for the IPMU scientists. We published 236 papers in refereed journals and produced 234 preprints, many of which are being submitted to refereed journals. We hosted 16 international conferences and held 186 seminars. We were visited by 862 scientists, of which 478 from abroad.

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3 Organization

The IPMU Director is appointed by the President of the University of Tokyo and reports directly to the President. The Director has a complete authority of making a wide range of decisions including proposing recruitment of the Principal Investigators to the President, and appointing other research staff and administrative staff. The Director is assisted by two Deputy Directors and Administrative Director. They hold the Executive Board (EB) regularly to ensure smooth operation of the Institute. The EB has direct access to the Office of the President for consultations on both scientific and administrative matters.

The Scientific advisory Committee (SAC) gives advice to the Director on hiring scientific staff and setting scientific strategies. As of March 2011, the members consist of two Deputy Directors and five among IPMU’s 18 Principal Investigators, all appointed by the Director.

Since IPMU has become a permanent member–institute of TODIAS in January 2011, the IPMU Director is now required to report the appointments of new principal investigators and faculty members to the TODIAS Director. Also, to clear the university’s formality in hiring faculty members, the IPMU decisions have to be endorsed by the IPMU’s Steering Committee consisting of the EB members plus two faculty members, Kyoji Saito and Tsutomu Yanagida.

The External Advisory Committee (EAC), appointed by the University President, reviews annually the scientific achievement and activities of the Institute and advises the President on scientific priorities and the research activities to keep the Institute stay on the course of their objectives.

The External Advisory Committee members (March 2011)

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hiroaki Alhara</td>
<td>U of Tokyo, high energy physics</td>
</tr>
<tr>
<td>Yoichiro Suzuki</td>
<td>U of Tokyo, ICRR, astroparticle physics</td>
</tr>
<tr>
<td>Toshitake Kohno</td>
<td>U of Tokyo, mathematics</td>
</tr>
<tr>
<td>Hiroi Ooguri</td>
<td>Caltech, particle theory</td>
</tr>
<tr>
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</tr>
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<td>David Spiegel</td>
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<td>IPMU, particle theory</td>
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The Scientific Advisory Committee members (March 2011)

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<tr>
<td>Tsutomu Yanagida</td>
<td>IPMU, particle theory</td>
</tr>
<tr>
<td>Nicolai Reshetkin</td>
<td>UC Berkeley, mathematics</td>
</tr>
<tr>
<td>Sadayoshi Kojima</td>
<td>Tokyo Tech, mathematics</td>
</tr>
<tr>
<td>Steve Weinberg</td>
<td>UC Santa Barbara, mathematics</td>
</tr>
<tr>
<td>Roberto Peccei</td>
<td>UCLA: Chair, particle theory</td>
</tr>
<tr>
<td>Steven Kahn</td>
<td>SLAC/Stanford U, astrophysics</td>
</tr>
<tr>
<td>John Ellis</td>
<td>CERN, particle theory</td>
</tr>
<tr>
<td>Makoto Gorokami</td>
<td>U of Tokyo, quantum optics</td>
</tr>
<tr>
<td>Young-Kee Kim</td>
<td>Fermilab/U of Chicago, high energy physics</td>
</tr>
<tr>
<td>Yoichiro Suzuki</td>
<td>U of Tokyo, ICRR, astroparticle physics</td>
</tr>
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IPMU has rather unique approach in organizing the research objectives, where the world’s leading scientists in their research fields are appointed as the Principal Investigators. There are 18 of them at the moment and they are affiliated to IPMU and other departments in the Host Institution (U of Tokyo) as well as other institutions. The Principal Investigators have a large autonomy in the research they conduct. They can make proposals to the Director to hire research staff at IPMU to help their research. The Director’s approval on the proposed appointments will reflect the scientific vision and priorities set by the Director, who may consult the SAC as needed.

IPMU has close relations with similar research institutions in the world for encouraging research and educational exchanges. We have signed either agreements or memorandum of understanding with those institutions.

The administrative staff is an integral part of the Institute. Providing the best possible environment to the researchers at IPMU is important for the IPMU’s mission. This part is headed by the Administrative Director. His function also enables the Director to spend more time to consider the Institute at large and focus on the direction of the research.

Collaborating Institutions

- National Astronomical Observatory of Japan (NAOJ)
- Yukawa Institute for Theoretical Physics, Kyoto University
- Department of Physics, Tohoku University
- Research Center for Neutrino Science, Tohoku University
- Department of Physics, University of California Berkeley
- Department of Astrophysical Sciences, Princeton University
- Institut des Hautes Études Scientifiques (IHES)
- High Energy Accelerator Research Organization (KEK)

Collaborating Institutions (domestic)

- Kashiwa Campus of the National Astronomical Observatory
- Kamioka Satellite of High Energy Accelerator Research Organization
- Berkeley Satellite

Collaborating Branches within the Host Institution (University of Tokyo)

- Department of Physics
- Institute for Cosmic Ray Research
- Graduate School of Mathematical Sciences
- Department of Astronomy

Collaboration takes place with many institutions.

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Foreign Institutions having exchange program with IPMU
University of California Berkeley, Physics Department
University of Chicago, Department of Astronomy and Astrophysics
Institute for Advanced Study, School of Natural Sciences
Johns Hopkins University, Department of Physics and Astronomy
New Mexico State University, Astronomy Department
Princeton University, Department of Astrophysical Sciences
University of Washington, Astronomy Department
Washington State University, Department of Mathematics
Stanford University, Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)
Technical University of Munich, Physics Department
Ludwig Maximilian University of Munich, Physics Department
Max Planck Institute, Astronomy and Astrophysics
Max Planck Institute, Extra-terrestrial Physics
Max Planck Institute, Physics Department
European Southern Observatory (ESO)
National Taiwan University, Research Center for Cosmology and Particle Astrophysics

Staff

Director
Hitoshi Murayama, particle theory, cosmology

Deputy Directors
Hitoshi Aihara, high energy physics, astrophysics
Yoichiro Suzuki, astroparticle physics, neutrino physics

Principal Investigators
Hitoshi Aihara, high energy physics, astrophysics
Alexey Bondal, mathematics
Masataka Fukugita, astrophysics
Kunio Inoue, neutrino physics
Takaaki Kajita, neutrino physics
Stavros Katsanevas, astroparticle physics
Yoichiro Suzuki, astroparticle physics
Tsutomu Yanagida, particle theory

Faculty Members
Paul Frampton (till May 2010), particle theory
Simeon Hellerman, string theory
Kentaro Hori, string theory
Hitoshi Karoji, astronomy
Saotachi Kondo, mathematics
Keiichi Maeda, particle theory
Kai Martens, astrophysics
Andrei Mikhailov (till June 2010), string theory
Shigeki Matsumoto, cosmology
Todor Milanov, mathematics
Shunji Mukohyama, cosmology
Hitoshi Murayama, particle theory, cosmology
Ken’ichi Nomoto, astronomy
Kyoji Saito, mathematics
Henry Sobel, astroparticle physics
David Spargue, astrophysics
Nasuki Sugiyama, cosmology
Yoichiro Suzuki, astroparticle physics
Tsutomu Yanagida, particle theory

Postdoctoral Fellows
Cosimo Bambi, cosmology
Tatsugata Basak (till August 2010), mathematics
Alex Bene (till August 2010), mathematics
Melina Bresten, astronomy
Scott Carnahan, mathematics
Chuan-Ren Chen, particle theory
Wen Sang Cho, particle theory
Rafael Da Silva De Souza, cosmology
Damien Easson (till December 2010), cosmology
Jason Evans, particle theory
Brian Feldstein, particle theory
Gaston Folatelli, astrophysics
Sergey Galkin, mathematics
Alexander Greiner, mathematics
Ahmet Emir Gumrukcuoglu, cosmology
Minxin Huang, string theory
Emille Ishida, cosmology
Keisuke Izumi, cosmology
Ishio Kayo, (JSPS Fellow) astrophysics
Johanna Knapp, string theory
Alexandre Kozlov, neutrino physics
Daniel Kretl (till September, 2010), string theory
Tsz Yan Lam, astrophysics
Guillaume Lambard (till September 2010), astroparticle physics
Wei Li, string theory
Yen-Ting Lin (till September 2010), astrophysics
Jing Liu, astroparticle physics
Soumyo Mandal, particle theory
Takahiro Nishimichi, astrophysics
Atsushi Nishizawa, astronomy
Takaya Nozawa, astronomy
Yutaka Ookouchi, particle theory
Domenico Orlando, string theory
Seong Chan Park, particle theory
Michael Pichot, mathematics
Susanne Reffert, string theory
Tomoki Saito, astronomy
Kenneth Shackleton, mathematics
Cornelius Schmidt-Colinet, string theory
Kazuhiro Shimizu, (JSPS Grant-in-Aid), astrophysics
Jing Shu, particle theory
Yogesh Srivastava (till July 2010), string theory
Charles Steinhardt, astronomy
Matthew Sudano, particle theory

Tsutomu Yanagida, particle theory
Naoki Yasuda, astronomy
Naoki Yoshida, astrophysics
Taiji Taniguchi, string theory

Staff
Hajime Taka, astrophysics
Masaoi Tanaka, astronomy
Masayuki Tanaka, astronomy
Jiayu Tang, cosmology
Masahito Yamazaki (til August 2010), string theory
Marcos Vides (JSPS Fellow) (til November 2010), astrophysics
Mireco Voinagui, mathematics
Kai Wang, particle theory

Graduate Students
Kouta Usui, particle theory
Gen Chiaki, astrophysics
Tomohiro Fujita, particle theory
Keisuke Harigaya, particle theory
Ayuki Kamada, particle theory
Yasunori Kamiyama, astronomy
William Klemm, particle theory
Sogo Mineo, high energy physics
Hironao Miyakata, high energy physics
Takahiro Moriya, astronomy
Kimihiko Nakajima, astronomy
Ryoichi Nishio, particle theory
Ryoosuke Sato, particle theory
Masato Shitsuki, astrophysics
Kohsaku Tobinaga, particle theory
Tomonori Uga, particle theory
Wen Yin, particle theory
Kanaye Yonekura, particle theory
Xu-Feng Wang, particle theory
Satoshi Shirai, particle theory

Joint Appointments
Ken Abe (Tokyo ICRR), astroparticle physics
Mina Amanagh (UC Berkeley), string theory
Raphael Bousso (UC Berkeley), cosmology
Patrick Decowski (NIKHEF), high energy physics
Mamoru Dori (U Tokyo), astronomy
Yuri Efremenko (U Tennessee), neutrino physics
Tobu Eguchi (Kyoto YITP), field theory
Motots Enoo (U Tokyo), string theory
Sanshiro Enomoto (U Washington), neutrino physics
Andrea Ferrari (S.N.S. Pisa), astronomy
Stuart Freedman (LBNL), neutrino physics
Brian Fujikawa (LBNL), neutrino physics
Masaki Fukushima (Tokyo ICRR), astroparticle physics
Kouu Hagiwara (KEK), particle theory
Lawrence Hall (UC Berkeley), particle theory
Koichi Hamaguchi (U Tokyo), particle theory
Yoshinori Hayato (Tokyo ICRR), neutrino physics
Masahiro Hayashi (Tokyo ICRR), neutrino physics
Masashi Hazumi (KEK), astrophysics
Yoshinari Hayato (Tokyo ICRR), neutrino physics
Koichi Hamaguchi (U Tokyo), particle theory
Lawrence Hall (UC Berkeley), particle theory
Pet Horava (UC Berkeley), string theory
Glenn Horton-Smith (U Kansas), neutrino physics
Shinobu Hosono (U Tokyo), mathematical physics
Ken’ichi Izawa (Kyoto YITP), particle theory
Masaki Kadota (Kyoto U), mathematics
Akihisa Katou (U Tokyo), mathematical physics
Masahiro Kawasaki (Tokyo ICRR), cosmology
Edward Kearns (Boston U), neutrino physics
Chika Kobayashi (Australia), astronomy
Tosihiko Kobayashi (U Tokyo), mathematical physics
Masayuki Koga (Tohoku U), neutrino physics
Eiichiro Komatsu (U Texas), cosmology
Yasuke Koshio (Tokyo ICRR), neutrino physics
Takahiro Kubota (Osaka U), string theory
Alexander Kusenko (UCLA), particle theory, astrophysics
Marco Limongi (INAF Rome), astronomy
Shigetaka Moriyama (Tokyo ICRR), neutrino physics
Takeo Moroi (U Tokyo), particle theory
Kengo Nakamura (Tohoku U), neutrino physics
Tsunoshi Nakaya (Kyoto U), high energy physics
Yasunori Nomura (UC Berkeley), particle theory
Masami Ouchi (Tokyo ICRR), astronomy
Serguei Petkov (ISSS), particle theory
Andreas Pierpaoli (U Alabama), neutrino physics
Yoshitaka Sato (U Tokyo), mathematics
Kate Scholberg (Duke U), neutrino physics
Hiroyuki Sekiya (Kyoto ICRR), neutrino physics
Masato Shiozawa (Tokyo ICRR), neutrino physics
Fedor Smirnov (Paris 6), mathematics
Michael Smy (UC Irvine), neutrino physics
James Stone (Boston U), high energy physics
Yasuo Tanaka (Tokyo ICRR), neutrino physics
Atsushi Tanaka (Rokko RESCEU), astrophysics
Nozomi Tominga (Konan U), astrophysics
Edwin Turner (Princeton U), astrophysics
Alexander Voronov (Duke U), neutrino physics
Masato Ouchi (Tokyo ICRR), particle theory
Yasuo Takeuchi (Tokyo ICRR), neutrino physics
Takeo Moroi (U Tokyo), particle theory

Long-term Visitors (more than 1 month)
C. S. Kim (Yonsei U), particle theory
Alexey Bondal (U Aberdeen), mathematics
Sanjoy Biswas (Harish-Chandra Inst), particle theory
Eiichiro Komatsu (U Texas), cosmology
Devendra Kumar Sahai (IAP), astronomy
Serguei Petrov (ISSS), particle theory
Luc Dessart (JWAPP), astrophysics
Massimo Marrani (NYU), cosmology
James Kenneth Sully (UCS), mathematics
Tatsuya Oshita (U Tokyo), particle theory
Yuki Tanabe (U Tokyo), particle theory
Ken-Ichi Yokoyama (Tokyo RESCEU), astrophysics
Ken’ichi Yoshikawa (Tokyo ICRR), mathematics

Financing
Yasuhito Kato, Tomoko Yamanaka

SuMIRe Project
Hideaki Mamyama, Chihiro Inami

International Relations
Midori Ozawa, Kenichi Nakamura, Rie Ujita (Symposium), Hiromi Kuboshima, Masami Nishikawa (Japanese instructor),

Public Relations
Fusae Miyazoe

Secretarial Support
Yasuo Enomoto (Director’s office), Tomoko Shiga, Rika Yamada, Kote Kawajiri

Library
Kayoko Kubota

Computing and Website
Hidetaka Tanaka (Project Assistant Professor), Aya Tsutsumi

Documentation
Kazuo Abe

Kamioka Satellite Office
Hiroshi Kanda, Sumiko Higashi, Motoichi Kanazawa, Yoko Shimizu

Purchasing
Noriko Abe, Hiroki Iyazawa, Yoshiya Ootaka, Satoru Usui

IPMU research staff (October 2010)

IPMU
Annual Report 2010
Alternative Gravity Theories

Einstein’s theory of relativity unifies a 3-dimensional space and a 1-dimensional time as a spacetime and describes gravity as a fabric of curved spacetime. This picture has been very successful in explaining and predicting many gravitational phenomena. Experimentally, however, we do not know how gravity behaves at distances shorter than 0.01 mm. At shorter distances, gravity may behave completely differently from what we expect. For example there may be hidden dimensions at short distances. In fact, many theories, including superstring theories and M-theory, require the existence of such extra dimensions. Extra dimensions may exist everywhere in our universe, but they are somehow hidden from us. One possibility recently investigated very actively is called the brane-world scenario. In this scenario our universe is supposed to be a 3-dimensional surface, called brane, floating in higher-dimensional space. Although we cannot see extra-dimensions directly, we may hope to detect some indirect evidence of extra-dimensions in high-energy experiments or cosmological observations.

Gravity at very long distances (for example, billions of light-years) may also be as weird as at short distances. Precision observational data recently revealed that the expansion of our universe is accelerating. If Einstein’s theory is correct, this requires that more than 70% of our universe is filled with invisible, negative pressure, energy. This energy is named dark energy, but we do not know what it really is. This situation reminds us of the story in the 19th century: when the perihelion shift of Mercury was discovered, some people hypothesized the existence of an invisible planet called Vulcan, a so-to-speak dark planet, to explain the anomalous behavior of Mercury. However, as we all know, the dark planet was not real and the correct explanation was to change gravity, from Newton’s theory to Einstein’s. With this in mind, we wonder if we can change Einstein’s theory at long distances to address the mystery of dark energy.

Alternative Gravity Theories Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosimo Bambi</td>
<td>General Relativity is our current and successful theory of gravity, but it has been tested essentially only in the perturbative and weak field limit. The challenge is to figure out if its predictions are still reliable in other contexts, such as the description of the universe or black hole physics.</td>
</tr>
<tr>
<td>Damien Easson</td>
<td>Alternatives to dark energy to explain the acceleration of the Universe. Constraining gravitational models using observational and theoretical considerations.</td>
</tr>
<tr>
<td>Shinji Mukohyama</td>
<td>Brane world scenarios and the Higgs phase of gravity.</td>
</tr>
<tr>
<td>Seong Chan Park</td>
<td>Study of various approaches.</td>
</tr>
<tr>
<td>Naota Sugiyama</td>
<td>Testing alternative gravity theories using observational data.</td>
</tr>
<tr>
<td>Atsushi Tanaka</td>
<td>Modeling and testing structure formation scenario in modified theories of gravity from large-scale structure data.</td>
</tr>
<tr>
<td>Jun’ichi Yokoyama</td>
<td>Model building and constraints on dark energy.</td>
</tr>
</tbody>
</table>

Collider Phenomenology Group

IPMU collider phenomenology group members pursue a broad range of research in testing physics of the standard model and beyond standard model at the colliders, especially the CERN Large Hadron Collider (LHC). With the LHC turn-on in 2009, we have great opportunities in exploring physics at the TeV scale. This machine enable us to systematically investigate electroweak symmetry breaking, to probe new physics like low energy supersymmetry, extra dimensions or other unexpected exotics. Researchers in the group are working on the theoretical tools to investigate these exciting physics. We also seek the connection between collider physics and dark matter/cosmic ray physics.
Cosmology and Statistics

The size of data set in cosmological observations is huge. For example, the Sloan Digital Sky Survey-III (SDSS-III) creates a color image of more than a trillion pixels. That is so big and detailed that one would need 500,000 high-definition TVs to view it at its full resolution. This trend will continue at even faster rates as larger telescopes become available in near future. For handling these massive data set and extracting maximum amount of information, we must keep developing more and more sophisticated statistical methods. Relevant issues that are actively pursued are selecting models, methods of estimating parameters, Bayes’ theorem and other statistical techniques.

In the study of gravitational lensing which is actively carried out at IPMU, as an example, we try to extract tiny distortion of the observed image of a galaxy from its true shape. We do so by modeling the galaxy shape in a mathematically rigorous manner and convolving the sampling effects and noise in the observation. This type of data analysis requires close collaboration between cosmologists and statisticians.

Dark Matter Experiment

We know that about 23% of the total energy and matter of the Universe is dark matter, but we do not know what that is made of. The aim of the dark matter search experiment, XMASS, is to directly observe interactions of the cold dark matter in the large detector placed underground and to reveal the character of dark matter—its interactions, mass and so on.

We use 1 ton liquid Xenon detector cooled down at the temperature of -100 degree Celsius and measure the scintillation light emanated from the interaction of the dark matter in the detector. The experimental sensitivity is roughly two orders of magnitude better than the currently available best limit.

Excavation of the cavity for housing the detector and construction of the 10-meter-high and 800-ton-weight cylindrical water tank for shielding gamma rays and neutrons from nearby rocks were completed in 2008. Assembling of major detector-components was completed in 2009. Most part of 2010 was devoted for final tuning of the detector and data handling system. We are very close to start the data taking.

Detectors Developments

We know what that is made of. The aim of the dark matter search experiment, XMASS, is to directly observe interactions of the cold dark matter in the large detector placed underground and to reveal the character of dark matter—its interactions, mass and so on.

We use 1 ton liquid Xenon detector cooled down at the temperature of -100 degree Celsius and measure the scintillation light emanated from the interaction of the dark matter in the detector. The experimental sensitivity is roughly two orders of magnitude better than the currently available best limit.

Excavation of the cavity for housing the detector and construction of the 10-meter-high and 800-ton-weight cylindrical water tank for shielding gamma rays and neutrons from nearby rocks were completed in 2008. Assembling of major detector-components was completed in 2009. Most part of 2010 was devoted for final tuning of the detector and data handling system. We are very close to start the data taking.

Active detector development provides the means to extend the reach of current and future experiments—and very possibly new technology that may well find its way back into your living room or workshop. It is a vital ingredient in our quest to understand the Universe. The projects below are as diverse as the problems encountered and the individuals working on them.

Dark Matter Experiment Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karsten Heeger</td>
<td>Direct dark matter searches in low-energy experiments.</td>
</tr>
<tr>
<td>Jing Liu</td>
<td>Direct Dark Matter search using the XMASII detector.</td>
</tr>
<tr>
<td>Shigetaka Moriyama</td>
<td>Direct detection of Dark Matter.</td>
</tr>
<tr>
<td>Masayuki Nakahata</td>
<td>Purification of Xenon for low background experiments.</td>
</tr>
<tr>
<td>Yoshio Suzuki</td>
<td>Discovery of Dark Matter.</td>
</tr>
<tr>
<td>Yasuo Takeuchi</td>
<td>Dark Matter search at XMASS.</td>
</tr>
</tbody>
</table>

Detector Developments

Experimental physics and observational astronomy rely on cutting-edge technologies to build detectors that push the frontier of knowledge with the data they deliver. Data is the lifeblood of science, as the scientific method demands that every insight be tested against the hard evidence of experimental data. The art of experimentation is to provide both reliable and pertinent data to test the theories that the disciplined use of knowledge and imagination conjure from the massive body of scientific data already accumulated.

Active detector development provides the means to extend the reach of current and future experiments—and very possibly new technology that may well find its way back into your living room or workshop. It is a vital ingredient in our quest to understand the Universe. The projects below are as diverse as the problems encountered and the individuals working on them.

Detector Development Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karsten Heeger</td>
<td>Liquids scintillator, water Cherenkov, and bolometric detectors. Ultralow background detectors and techniques.</td>
</tr>
<tr>
<td>Kunio Inoue</td>
<td>Neutrino oscillation, neutrino geophysics, neutrino astrophysics, neutrinoless double beta decay, and directional measurement of anti-neutrinos.</td>
</tr>
<tr>
<td>Kai Martens</td>
<td>Continuous removal of radon from liquid xenon.</td>
</tr>
<tr>
<td>Yasuo Takeuchi</td>
<td>Development of high sensitivity radon detectors in air, in water, and in xenon. Development of impurity measurement systems in xenon.</td>
</tr>
<tr>
<td>Mark Vagins</td>
<td>Improving the neutrino response of water Cherenkov detectors.</td>
</tr>
</tbody>
</table>
Inflation and Early Universe

The Universe is expanding; the further away a galaxy is, the faster it is moving, which is known as Hubble’s law. This observational fact implies that, if we go back in time, the Universe was small, dense and extremely hot. The evolution of the early universe is described by the Friedmann-Lemaitre-Robertson-Walker (FLRW) universe, a homogeneous and isotropic solution of the Einstein equations of the general relativity, and the standard big bang theory is based on the FLRW universe. The Hubble’s law, the big bang nucleosynthesis (BBN), the cosmic microwave background (CMB) radiation provide key support for the standard big bang theory. Those three observations still remain important probes of the early Universe.

Despite its great success, the big bang theory is plagued with serious theoretical issues such as the horizon problem, the flatness problem, and the monopole problem. Those problems are beautifully solved by introducing an inflationary expansion at the very early stage of the Universe. What is more important about inflation is that quantum fluctuations of a scalar field driving the inflation (called an inflation) generate tiny density perturbations, which can account for the seed of the structures such as galaxies and clusters of galaxies seen in the current Universe. The properties of the density perturbations depend on the inflation models, which can be probed by studying tiny inhomogeneities in the CMB temperature anisotropy.

The recent progress in observational techniques has enabled us to study the evolution of the early universe with unprecedented precision, and our understanding of the Universe has significantly increased. Nevertheless, it is not fully known how the inflation occurred, how the universe was reheated after inflation, how the dark matter as well as the baryon asymmetry were created, whether there is large non-Gaussianity in the density perturbations or not, and so on. We would like to tackle those questions in order to reveal how the universe evolved from the inflationary epoch into what it looks like at present.

Inflation and Early Universe Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosimo Bambi</td>
<td>General Relativity is our current and successful theory of gravity, but it has been tested essentially only in the perturbative and weak field limit. The challenge is to figure out if its predictions are still reliable in other contexts, such as the description of the universe or black hole physics.</td>
</tr>
<tr>
<td>Damien Easson</td>
<td>Building concrete models of inflation from string theory. Observable predictions of nonstandard inflationary theories.</td>
</tr>
<tr>
<td>Motoi Endo</td>
<td>Supersymmetric models, including collider phenomenology and particle cosmology.</td>
</tr>
<tr>
<td>Emir Gumrukcuoglu</td>
<td>Models of inflation that give rise to new signatures, such as non-Gaussianity and/or broken statistical isotropy. The effect of supersymmetric flat directions on the time scale of thermalization. Gravitational waves from cosmological sources, in particular, from the preheating of flat directions.</td>
</tr>
<tr>
<td>Koichi Hamaguchi</td>
<td>BSM, in particular, SUSY models, their LHC phenomenology and application to cosmology (baryogenesis, BBN constraints, dark matter and its signatures).</td>
</tr>
<tr>
<td>Minxin Huang</td>
<td>Non-Gaussianities in the Cosmic Microwave Background from inflation models.</td>
</tr>
<tr>
<td>Ken’ichi Izawa</td>
<td>Gauge/gravity-mediated supersymmetry breaking, supersymmetric inflation, unified models.</td>
</tr>
<tr>
<td>Takashi Kobayashi</td>
<td>Cosmology of the early universe through string theory.</td>
</tr>
<tr>
<td>Alexander Kusenko</td>
<td>Dark matter, baryogenesis, phase transitions.</td>
</tr>
<tr>
<td>Shinji Mukohyama</td>
<td>Inflation and brane cosmology.</td>
</tr>
<tr>
<td>Hitoshi Murayama</td>
<td>Leptogenesis. Models of inflation.</td>
</tr>
<tr>
<td>Seong Chan Park</td>
<td>Two different types of inflation models, the orbifold GUT inflation and the theory with $f(\varphi)R$ term, so-called the nonminimal coupling term. The $(\varphi)$ reheating of the inflation theory with the nonminimal coupling term.</td>
</tr>
<tr>
<td>Serguey Petcov</td>
<td>Leptogenesis. Low energy leptonic CP violation and leptogenesis.</td>
</tr>
<tr>
<td>Naoshi Sugiyama</td>
<td>Setting constraints on the inflation models and early universe phenomena such as big bang nucleosynthesis by using observational data.</td>
</tr>
<tr>
<td>Atsushi Tanaka</td>
<td>Probing the early epoch of the Universe through direct and indirect measurements of the stochastic background of gravitational waves via laser interferometers or observations of CMB anisotropies.</td>
</tr>
<tr>
<td>Tsutomu Yanagida</td>
<td>Finding theories beyond the standard model. Theories for strongly interacting gauge mediation and possible explanations on the anomalies observed in PAMELA experiments of cosmic rays.</td>
</tr>
</tbody>
</table>
Mathematics

In the 17th century, Newton found differential and integral calculus, giving a language and method to describe the law of dynamics in nature. This is a good example of mathematics providing the scientific community, and sometimes society in general, with a common language and method to describe phenomena in their study. This in turn helps to establish a mathematician's original concepts. Particularly in recent years the interaction between mathematics and physics has been in full flow.

Gauge theory, quantum field theory, general relativity, superstring theory and the theory of integrable systems in physics have provided major influences in the development of mathematics such as algebraic geometry, differential geometry, topology, representation theory, algebraic analysis and number theory. A large scale development has been newly emerging.

This close collaboration between mathematics and physics is particularly important for advancing the study of the concept of space and universe that have been developed by scientists such as Kepler, Newton, Gauss, Riemann, Maxwell, Einstein and many others.

For the past twenty years, methods of quantum field theory have had a major influence on mathematics. Since quantum field theory treats the differential and integral calculus of an infinite number of degrees of freedom, the rigorous development of quantum field theory in mathematics has yet to be established. Nevertheless, in these twenty years, a lot of concepts arising from quantum field theory such as quantum groups have had a major influence on modern mathematics and physics.

Mathematicians at IPMU are working to develop modern mathematics by closely working with physicists. The following are the fields of mathematics studied at IPMU. We divided the fields into geometry and algebra.

Geometry:

Geometric objects we study in mathematics include several kinds of spaces, such as topological spaces, differentiable manifolds, symplectic manifolds, complex manifolds and algebraic varieties. Recently these various branches of geometries are deeply connected and influence each other. For instance, mirror symmetry is a conjectural duality between symplectic manifolds and algebraic varieties, which was found by the duality between different types of string theories. One of the research focus of our geometry group is to invent and investigate the mathematical notions which describe the mirror symmetry, and give some applications to the geometric problems we are interested in.

In the theory of mirror symmetry, a Calabi-Yau 3-fold plays an important role. A Calabi-Yau 3-fold is a complex manifold of real dimension 6 with a Ricci flat metric. In string theory, the spacetime is expected to be 10-dimensional, and the extra 6-dimensional space is expected to take the form of a Calabi-Yau 3-fold. On a Calabi-Yau 3-fold, we can define the quantum invariant counting Riemann surfaces on it, called Gromov-Witten (GW) invariant. One of the ways to describe the mirror symmetry is to establish the relationship between GW-invariants and the period map on the mirror manifold. In our group, S. Galkin studies GW-invariant, K. Saito studies the period map, and they develop these theories.

Another way to describe the mirror symmetry is to use the homological algebra proposed by M. Kontsevich. It is stated as an equivalence of triangulated categories between derived category of coherent sheaves and derived Fukaya category on the mirror manifold. In our group, A. Bondal develops the theory of triangulated categories, and describes the structure of several triangulated categories, e.g. to show the existence of the exceptional collections. The development of this theory is relevant in understanding the mirror symmetry.

On a Calabi-Yau 3-fold, we can define another quantum invariant, called Donaldson-Thomas (DT) invariant. It counts D-branes in terms of string theory, and is expected to be equivalent to the GW-invariant. (GW/DT correspondence). The DT-theory depends on a choice of a stability condition on the derived category, and the set of stability conditions form a complex manifold, which is expected to be a stringy Kahler moduli space. Understanding DT-invariants and the structure of the space of stability conditions is important in connection with string theory, and Y. Toda studies these theories. Also the theory of quantum invariants of low dimensional manifolds has begun with the study of quantum theory such as integrable systems, soliton equations and the conformal field theory. These quantum invariants turn out to have a deep connection with GW-theory, and T. Kohno studies these invariants.

Algebra:

Algebra is a collection of branches of mathematics, which studies the system of numbers such as integers and polynomials. Some examples of the branches are set theory, group theory, (commutative) ring theory, algebraic number theory, category theory, algebraic geometry, combinatorics and representation theory. Of course, each branch may not be fully contained in algebra, and may lie in between geometry.

Algebra studied at IPMU includes homological algebra and category theory. Homological algebra began as a study of homology groups of topological spaces. K-theory is an example of cohomology theories. Recall that in connection with string theory, an interesting and basic example is that an element of a K-group of a certain topological space has a physical interpretation. This enables us to use the powerful machinery of homological algebra to the study of string theory.

Nowadays, a basic algebraic invariant associated with a geometric object is a triangulated category. For example, this appears from an algebraic variety as the derived category of coherent sheaves. The notion of triangulated category is so abstract that they appear everywhere in mathematics. We know that some non-commutative geometry is better described in this language. Recent research is focused on finding a more complicated structure than that of a triangulated category. Differential graded categories and model categories are examples of objects that are equipped with more structure than a triangulated category. We seek to reveal the algebraic structure common to various phenomena (which may or may not look unrelated) occurring in mathematics and physics.

Another basic example of an algebraic structure is a group or a group action. A group describes the symmetry of things. Groups are everywhere in mathematics from Galois groups in number theory to mapping class groups in topology. Study of groups, or representation theory, will then lead to the explanation of the phenomena caused by the symmetry. Let us give a list of those groups (or algebras) our researchers are interested in, just to give an idea on how diverse we are. The groups (or algebras) that appear are vertex operator algebras, Lie groups (algebras), braid groups, Galois groups, and mapping class groups. We refer to the table below of group members for more information on how each deals with the group in his research.

We certainly hope to go the other direction. An example question would be if the product structure in K-theory has an interpretation. We can ask if it has a physical interpretation. The “distance” of algebra from physics, compared with geometry, is greater, in the sense that many of the problems in physics are first stated using (quantum) field theory. While geometry is used to describe the universe rather directly as if taking a picture, algebra tends to seek for the exact laws behind the phenomena.
## Mathematics Group (Geometry)

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomoyuki Abe</td>
<td>Arithmetic geometry by using the p-adic analysis especially arithmetic D-modules, and its application to the Langlands program for function field in the p-adic setting.</td>
</tr>
<tr>
<td>Scott Carnahan</td>
<td>Moduli problems, logarithmic geometry, formal geometry, geometric representation theory.</td>
</tr>
<tr>
<td>Kwoleui Chan</td>
<td>Mirror symmetry for Calabi-Yau and toric manifolds, the SYZ conjecture and its applications to mirror symmetry, open Gromov-Witten theory.</td>
</tr>
<tr>
<td>Serguei Galquin</td>
<td>Fano varieties, their classification, degenerations, Gromov-Witten invariants, mirror dual Landau-Ginzburg models.</td>
</tr>
<tr>
<td>Alexander Getmanenko</td>
<td>Complex analytic methods for differential equations, with an application towards Witten Morse theory and the Fukaya category.</td>
</tr>
<tr>
<td>Kentaro Hori</td>
<td>Mirror symmetry as a bridge between symplectic geometry and complex geometry, real algebraic geometry, homological algebra, and their application to string theory.</td>
</tr>
<tr>
<td>Shinobu Hosono</td>
<td>Mirror symmetry of Calabi-Yau manifolds, and its applications to Gromov-Witten theory.</td>
</tr>
<tr>
<td>Toshiyuki Kobayashi</td>
<td>Discontinuous groups for homogeneous manifolds preserving indefinite-Riemannian structure, rigidity and deformation of discontinuous groups, and spectrum on locally indefinite-Riemannian symmetric spaces. Synthetic and systematic study of multiplicity-free representations by the original idea of &quot;visible actions&quot; on complex manifolds.</td>
</tr>
<tr>
<td>Toshiro Kohno</td>
<td>Construction of topological invariants for braids, knots and 3-dimensional manifold based on quantum groups and conformal field theory. Algebraic structures of the homology of the loop spaces of configuration spaces.</td>
</tr>
<tr>
<td>Todor Milanov</td>
<td>Gromov-Witten theory, singularity theory, and representations of infinite-dimensional Lie algebras.</td>
</tr>
<tr>
<td>Hiroi Ooguri</td>
<td>Application of new mathematical techniques emerging at the interface of string theory and geometry to solve mysteries of quantum gravity.</td>
</tr>
<tr>
<td>Susanne Reffert</td>
<td>Calabi-Yau geometries in the framework of string compactifications.</td>
</tr>
<tr>
<td>Kyoji Saito</td>
<td>Construction of primitive forms and associated period maps by use of infinite dimensional Lie algebras (e.g. elliptic algebras and cuspidal algebras) and their representation theory. Partition functions of Ising models on (non-commutative) discrete groups and monoids.</td>
</tr>
<tr>
<td>Yoshihisa Saito</td>
<td>Representation theory of infinite dimensional Lie algebras and quantum groups, especially in geometric approach to these subjects. Study of the area around these subjects, for example, integrable systems, combinatorics, finite dimensional algebras, algebraic groups, Hecke algebras and D-modules.</td>
</tr>
<tr>
<td>Kenneth Shackleton</td>
<td>Geometric group theory, hyperbolic and relatively hyperbolic groups. Low-dimensional topology, Teichmüller theory and mapping class groups. Curve complexes, pants complexes.</td>
</tr>
<tr>
<td>Akihiro Tsujiyha</td>
<td>Conformal field theory on representation theory of infinite dimensional algebraic groups and the theory of D-modules.</td>
</tr>
</tbody>
</table>

## Mathematics Group (Algebra)

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scott Carnahan</td>
<td>Vertex algebras, infinite dimensional Lie algebras, automorphic forms, moonshine.</td>
</tr>
<tr>
<td>Serguei Galquin</td>
<td>Arithmetic of Landau-Ginzburg models, cluster categories, derived categories.</td>
</tr>
<tr>
<td>Satoshi Kondo</td>
<td>Arithmetic geometry. Use of tools from algebraic geometry to study problems in number theory.</td>
</tr>
<tr>
<td>Kyoji Saito</td>
<td>Construction of primitive forms and associated period maps by use of infinite dimensional Lie algebras (e.g. elliptic algebras and cuspidal algebras) and their representation theory. Partition functions of Ising models on (non-commutative) discrete groups and monoids.</td>
</tr>
<tr>
<td>Hiroi Ooguri</td>
<td>Conformal field theories in diverse dimensions that are relevant to dynamics of strings and branes in superstring theory. Application of conformal field theory techniques to study the landscape of string vacua.</td>
</tr>
<tr>
<td>Domenico Orlando</td>
<td>Spin chains (XXZ model and related two-dimensional lattices) in connection to dimer models and topological strings.</td>
</tr>
<tr>
<td>Susanne Reffert</td>
<td>(Quantum) dimer models. (Quantum) crystal melting and spin chains.</td>
</tr>
<tr>
<td>Yoshihisa Saito</td>
<td>Representation theory of infinite dimensional Lie algebras and quantum groups, especially in geometric approach to these subjects. Study of the area around these subjects, for example, integrable systems, combinatorics, finite dimensional algebras, algebraic groups, Hecke algebras and D-modules.</td>
</tr>
<tr>
<td>Kenneth Shackleton</td>
<td>Geometric group theory, hyperbolic and relatively hyperbolic groups. Low-dimensional topology, Teichmüller theory and mapping class groups. Curve complexes, pants complexes.</td>
</tr>
<tr>
<td>Akihiro Tsujiyha</td>
<td>Conformal field theory on representation theory of infinite dimensional algebraic groups and the theory of D-modules.</td>
</tr>
<tr>
<td>Simon Wood</td>
<td>Understanding the representation theory of vertex operator algebras in the context of conformal field theory.</td>
</tr>
</tbody>
</table>
Models beyond the Standard Model

Up to now, we have seen that a quantum field theory with quarks, leptons and vector bosons for three different forces describes reasonably well all the experimental data available so far. Among the vector bosons, however, those corresponding to the weak force (which is responsible for the β-decay of nucleons) are known to have masses. There are three such vector bosons, and they are called \( W^+ \), \( W^- \) and \( Z \) bosons, or weak bosons, as a whole. From the consistency of quantum field theories, it is known that something must be behind the nonzero masses of these vector bosons. It has not been confirmed experimentally yet how these masses are generated.

What is called the Standard Model provides a simple theoretical idea how the weak bosons acquire masses. According to the Standard Model, the masses originate from condensation of quanta of a new scalar boson, called Higgs boson. The Higgs boson is the last missing piece of the Standard Model, and will be discovered in experiments in near future, if the weak bosons have masses through the mechanism predicted by the Standard Model.

Is that the end of the story? Maybe ..., but maybe not. Let us think about the following questions.

- **The Higgs boson is the only scalar field in the Standard Model; all other dynamical degrees of freedom in the Standard Model are either fermions or vector fields. Why does the Standard Model have one scalar field, and just one? Why does its condensation develop?**

- **The Newton constant \( G \approx 6.7 \times 10^{-11} \text{m}^3 \text{kg}^{-1} \text{s}^{-2} \) corresponds to an energy scale \( 1/\sqrt{G \hbar c^3} \approx 10^{-10} \text{GeV} \). Why is there a huge hierarchy of order \( 10^{12} \) between this energy scale and the weak boson masses of order \( 10^2 \) GeV, and how can the weak boson masses remain so small under quantum corrections?**

In order to solve these questions theoretically, various models beyond the Standard Model have been constructed so far, and we still continue to do so in quest of a better solution to these problems. Once we have concrete models, we can examine whether such models are really consistent with all the available experimental data, predict what kind of signals can be expected in future experiments, and even propose experiments to confirm such models.

The origin of the masses of the weak bosons is not the only puzzle of the Standard Model. It is known that huge fraction of the universe consists of dark matter and dark energy. It is very unlikely that dark matter is actually the ordinary matter particles in the Standard Model.

This is where we find another motivation to extend the Standard Model. Our universe may have become so large because of an inflationary process in the early universe, and quantum fluctuations of a scalar field may become the fluctuations of density in the early universe, which eventually become galaxies and clusters of galaxies. So, here is another motivation to introduce a new degree of freedom and extend the Standard Model. Such cosmological issues as inflation, primordial density perturbations and dark matter motivate extensions of the Standard Model, and models in quantum field theories are the appropriate framework in order to work on these issues.

Recent reports of excess in high-energy cosmic ray fluxes, deviation from the Standard-Model prediction of the anomalous magnetic moment of muon, and some other reports of deviations from the Standard Model predictions may also be indications of some physics beyond the Standard Model. We therefore seek for theoretical models that account for these phenomena.
Models Beyond the Standard Model Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chuan-Ren Chan</td>
<td>Collider phenomenology of the Standard Model and models beyond the Standard Model, including SUSY and Little Higgs models. Interplay between the LHC phenomenology and cosmology.</td>
</tr>
<tr>
<td>Won Sang Cho</td>
<td>Supersymmetry/Extra Dimension models, and their collider and dark matter phenomenology.</td>
</tr>
<tr>
<td>Damien Easson</td>
<td>Physics beyond the Standard Model to explain the origin of the dark components of the Universe.</td>
</tr>
<tr>
<td>Motoi Endo</td>
<td>Supersymmetric models including collider phenomenology and particle cosmology.</td>
</tr>
<tr>
<td>Brian Feldstein</td>
<td>Lately my work has focussed primarily on properties of dark matter, and possible signatures in direct detection or other types of experiments. I am also interested in cosmology, weak scale physics, etc.</td>
</tr>
<tr>
<td>Kohichi Hamaguchi</td>
<td>SUSY models and their LHC phenomenology and application to cosmology (baryogenesis, BBN constraints, dark matter and its signatures).</td>
</tr>
<tr>
<td>Junji Hisano</td>
<td>Supersymmetric models. Search for clues in accelerator and non-accelerator physics. Construction of realistic models at TeV and at GUT scales.</td>
</tr>
<tr>
<td>William Kleinm</td>
<td>Signatures from various beyond the standard models. Distinguishing from one another at a collider. Determination of spins of new particles.</td>
</tr>
<tr>
<td>Sourav Mandal</td>
<td>Models beyond the Standard Model, and their signatures in astrophysics, cosmic rays and colliders.</td>
</tr>
<tr>
<td>Shigeki Matsumoto</td>
<td>New Physics models at the TeV scale (SUSY, Little Higgs, Extradimensions, Gauge-Higgs Unification).</td>
</tr>
<tr>
<td>Hitoshi Murayama</td>
<td>Supersymmetry breaking models and phenomenology.</td>
</tr>
<tr>
<td>Hiroshi Oguri</td>
<td>General constraints on low energy effective theories that arise from superstring theory or any other consistent theory of quantum gravity. Supersymmetry breaking mechanisms in gauge theories and superstring theory.</td>
</tr>
<tr>
<td>Yudaka Oikouchi</td>
<td>Model building with supersymmetric gauge theories. Application of gauge/gravity duality to problems in particle physics.</td>
</tr>
<tr>
<td>Seong Chan Park</td>
<td>Various ideas of the BSM: warped extra dimension, model of EWSB in the context of Gauge-Higgs unification, orbifold GUT, little Higgs etc.</td>
</tr>
<tr>
<td>Sergeyev Patkov</td>
<td>Models of neutrino masses and mixing. Phenomenology of lepton flavour violation.</td>
</tr>
<tr>
<td>Jing Shu</td>
<td>Warped extra dimension models. Strongly coupled theory.</td>
</tr>
<tr>
<td>Matt Sudano</td>
<td>Dynamical supersymmetry breaking and its mediation.</td>
</tr>
<tr>
<td>Fumihiko Takahashi</td>
<td>Supersymmetry. Link between supersymmetric models and cosmology, such as SUSY breaking, dark matter, and SUSY inflation models.</td>
</tr>
<tr>
<td>Koshu Kobayashi</td>
<td>LHC Phenomenology of supersymmetry and extra dimensions.</td>
</tr>
<tr>
<td>Kai Wang</td>
<td>Model building of BSM physics, in particular SUSY models as well as neutrino models. Their collider tests at the CERN LHC.</td>
</tr>
<tr>
<td>Taizan Watari</td>
<td>Model building and phenomenology beyond the Standard Model in general. SUSY breaking and mediation, flavor pattern, GUT, inflation, Peccei-Quinn axion, quintessence, landscapes.</td>
</tr>
<tr>
<td>Tsutomu Yanagida</td>
<td>PAMELA and ATIC data searching for a convincing model that explains the observed anomalies.</td>
</tr>
</tbody>
</table>

Neutrino Physics

What are the building blocks of nature? Most people have heard of electrons, which are indeed (as far as we can tell) fundamental particles, as well as protons and neutrons, which are themselves composite objects composed of much smaller fundamental particles called quarks. But there are much more unusual fundamental particles, too, and perhaps the most mysterious of these are the neutrinos.

The Standard Model of particle physics contains three generations of fundamental particles. In each of these generations, or families, there are two quarks and two much more massive particles called leptons. In the first family one such lepton is the electron, which carries an electric charge, and the other first-generation lepton is called the electron neutrino, which is electrically neutral. The second generation contains two more types of quarks, a charged lepton called the muon, and the muon neutrino, while the third family contains a final pair of quarks, a charged lepton called the tau, and a tau neutrino.

The three types of neutrinos, the electron neutrino, the muon neutrino, and the tau neutrino, are exceedingly challenging to study, because they hardly interact with matter at all. That means neutrino detectors need to be very big, very sensitive, or both. At IPMU we have teams of researchers working on some of the best and most famous neutrino detectors in the world.

The Super-Kamiokande [Super-K] detector is a 50,000 ton water tank buried deep under the Japanese Alps. By studying neutrinos generated by cosmic ray interactions in the Earth’s atmosphere, in 1998 Super-K made the stunning discovery that different types of neutrinos can spontaneously transform from one type to another, a process known as neutrino oscillation. This also implied that at least two of the three neutrinos have a small, but non-zero mass, something not predicted by the Standard Model. This was the first time since its inception that the Standard Model needed to be revised based on solid experimental data. In 2001 Super-K made a crucial contribution to the solution of the solar neutrino problem by indicating that solar neutrinos produced by the Boron-8 reaction in the Sun could change their flavor while in flight, and uniquely selected the large mixing angle solution to the problem. IPMU members are now working on GADZOOKS!, an initiative to enrich the ultrapure water inside Super-Kamiokande with the element gadolinium. This will greatly reduce backgrounds and, among many other physics benefits, should allow the first-ever detection of a constant stream of neutrinos from distant supernovas.

The KamLAND neutrino detector is located in the same ancient zinc mine as Super-Kamiokande, but instead of water it is filled with 1,000 tons of liquid scintillator. This makes it very sensitive, especially to low energy neutrinos from nuclear reactors and those generated by radioactive decays within the Earth itself. In 2002 KamLAND was the first experiment to observe disappearance of reactor neutrinos, which matched other experiments’ solar neutrino data in spectacular fashion. After lowering the energy threshold at which their data could be analyzed, in 2005 KamLAND was the first experiment to detect geoneutrinos, ushering in an entirely new way to study the Earth’s interior. Also in 2005, KamLAND saw evidence of spectral distortions in the reactor neutrino signal; clear proof of neutrino oscillations. IPMU members are currently working on modifying KamLAND to detect very low energy solar neutrinos produced by the Beryllium-7 reaction in the Sun, as well as transforming the KamLAND detector into a huge neutrinoless double beta decay experiment via the addition of Xenon-136 to the detector volume.

As we continue to understand the mysterious neutrinos, as well as the varied processes which produce them within the Earth, upon the Earth, above the Earth, within the Sun, and inside exploding stars, IPMU researchers are using these tiniest of particles to probe the most inaccessible places and farthest reaches of the universe itself.
Neutrino Physics Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karsten Heeger</td>
<td>Neutrino oscillation experiments with reactor neutrinos. Search for neutrinoless double beta decay.</td>
</tr>
<tr>
<td>Takaaki Kajita</td>
<td>Atmospheric neutrino. Long baseline experiments. Neutrino oscillations.</td>
</tr>
<tr>
<td>Alexander Kusenko</td>
<td>Supernova neutrinos, sterile neutrinos.</td>
</tr>
<tr>
<td>Kaizoh Matsusue</td>
<td>Super-Kamiokande experiment for detecting neutrinos from galactic supernova (type II) explosion.</td>
</tr>
<tr>
<td>Sourav Mandal</td>
<td>Models beyond the Standard Model, and their signatures in astrophysics, cosmic rays and colliders.</td>
</tr>
<tr>
<td>Hitoshi Murayama</td>
<td>Neutrino oscillation phenomenology. KamiLAND.</td>
</tr>
<tr>
<td>Masayuki Nakahata</td>
<td>Boron-8 solar neutrino measurement by Super-Kamiokande detector. Precise measurement of the energy spectrum for the confirmation of matter effect of the neutrino oscillation.</td>
</tr>
<tr>
<td>Serguey Petcov</td>
<td>All aspects of the physics of massive neutrinos, neutrino mixing and of neutrino oscillations. The problems of determining, i) the nature (Dirac or Majorana) of massive neutrinos, and ii) the type of spectrum (with normal or inverted ordering) the neutrino masses obey. Tests of the “non-standard” mechanisms of neutrinoless double beta decay. Leptonic (Dirac and/or Majorana) CP violation and its possible manifestations.</td>
</tr>
<tr>
<td>Yoichiro Suzuki</td>
<td>Experimental study on neutrino oscillations by using extraterrestrial neutrinos and also by using man-made neutrinos. Double beta decay experiments.</td>
</tr>
<tr>
<td>Yasuo Takeuchi</td>
<td>Low-energy neutrino observations in Super-Kamiokande.</td>
</tr>
<tr>
<td>Mark Vagins</td>
<td>Measurements of neutrinos and antineutrinos from supernovae, the sun, and nuclear power reactors. T2K experiment. GADZOOKS experiment.</td>
</tr>
</tbody>
</table>

Observational Cosmology

Understanding the nature and origin of large-scale structure in the Universe is one of most compelling issues in observational cosmology. The currently most conventional scenario is given by the cold dark matter (CDM) dominated model, where gravitational instability mainly driven by spatial inhomogeneities of CDM distribution amplifies the seed density perturbations to form the present-day hierarchical structures. Therefore revealing distribution and amount of CDM is crucial to understanding the formation of large-scale structure. In addition the presence of dark energy drives the accelerating cosmic expansion, and therefore affects the growth of structure formation. The dark matter distribution and the nature of dark energy can be explored from massive galaxy surveys.

We have been actively working both on the measurements using currently available telescope facilities and on the planning of future instruments. The two powerful investigative tools are the gravitational lensing effect and the baryon acoustic oscillation.

Gravitational lensing effect:
The path of light ray emitted by a distant galaxy is bent by gravitational force of intervening large-scale structure during the propagation, causing the image to be distorted—the so-called weak lensing shear. Conversely, measuring the coherent shear signals between galaxy images allows us to reconstruct the distribution of invisible dark matter. Moreover, since the weak lensing shear deals with the light propagation on cosmological distance scales, the lensing strengths depend on the cosmic expansion history that is sensitive to the nature of dark energy. Thus weak lensing based observables offer a powerful way for studying the nature of invisible components, dark matter and dark energy. We are carrying out observational and theoretical studies of weak lensing phenomena using our own Subaru data sets as well as simulations of large-scale structure.

Baryon acoustic oscillation:
To measure properties of dark energy, one needs to measure the expansion history of the universe precisely. Because light travels at a finite speed, one can measure the expansion rate of the past by looking far. Comparing the expansion rate at varying distances would reveal the expansion history. The expansion itself is relatively easy to measure. The light emitted by a distant galaxy is stretched by the expansion of space and becomes redder, which can be measured by any decent spectrograph.

To measure the expansion history, however, we also need to know how far back in time the light was emitted from the galaxy, or equivalently, how far away it is. Measuring precise distances in cosmological scales is very challenging. Clustering of baryonic matter at a certain characteristic scale that is imprinted by baryon acoustic oscillation (BAO), or propagation of acoustic waves, in the early universe serves as a “standard ruler” for cosmological observations. This technique requires to study millions of galaxies in a wide field of view, and map the spatial distribution of luminous galaxies to detect the characteristic scale.
Hyper Suprime Camera (HSC):
The HSC, currently under construction, is the project to replace the prime focus camera of Subaru Telescope (8.2 meter optical-infrared telescope at the summit of 4,200m-Mauna Kea, Hawaii), with a new camera that has wider field-of-view than the current one by a factor of 10. Fully utilizing the unique capabilities of HSC, its survey speed and excellent image quality, we are planning and designing a massive galaxy survey that covers an area of a few thousands square degrees and reaches to the depth to probe the Universe up to redshifts of a few. In fact these data sets will provide us an ideal data sets for exploring the nature of dark matter and dark energy via measurements of cosmological observables available from the data, weak lensing and galaxy clustering statistics. We, IPMU members, are actively involved in this HSC project, and working on the designing and planning of HSC galaxy survey and development of data analysis pipeline.

Sloan Digital Sky Survey III:
In January 2011, the SDSS-III collaboration released the largest digital color image of the sky ever made. The image has been put together over the last decade from millions of 2.8-megapixel images taken at the 2.5-meter telescope at the Apache Point Observatory in New Mexico, thus creating a color image of more than a trillion pixels. This new SDSS-III data release, along with the previous SDSS-I and SDSS-II data releases that it builds upon, gives astronomers the most comprehensive view of the night sky ever made. SDSS data have already been used to discover nearly half a billion astronomical objects, including asteroids, stars, galaxies and distant quasars.

IPMU has been a part of the SDSS-III and involved in the study of these rich images. But our focus has been to conduct a new survey to a deeper universe with the improved spectrograph. This survey, the Baryon Oscillation Spectroscopic Survey (BOSS), maps the spatial distribution of luminous galaxies and quasars to detect the characteristic scale imprinted by baryon acoustic oscillations in the early universe. Using the acoustic scale as a standard ruler, we can infer the angular diameter distance to the galaxy redshift. The BOSS has started to take data in 2009 and will continue until 2014. Its goal is to precisely measure how Dark Energy has changed over the recent history of the Universe.

Prime Focus Spectrograph (PFS):
The PFS project that mounts a next generation spectrograph on the Subaru telescope and is planned to start taking data taking later this decade was overwhelmingly endorsed at the Subaru Users meeting of January 2011. Using a wide angle view of Subaru telescope and the PFS, we can study several thousand galaxies at the same time and use the baryon acoustic oscillation technique.

In addition to BAO, there are a number of other measurements to constrain the properties of dark energy using this instrument. Furthermore, this type of spectrograph with a large field of view and a massive multi-object capability will be unique among the largest telescopes in the world, allowing for unprecedented studies of formation and evolution of galaxies, as well as the assembly history of our own Milky Way Galaxy.

The strength of this project comes from exploiting the data using HyperSuprimeCam (HSC), a 3-tonne digital camera with 900 million pixels, slated for the first light later this year. The combination of imaging using HSC and spectroscopy using PFS on Subaru is dubbed SuMIRe, Subaru Measurement of Images and Redshifts. The SuMIRe project is expected to repeat and exceed the tremendous success of Sloan Digital Sky Survey (SDSS), but with a much deeper view of the Universe back to the era that formed early stars and supermassive black holes.

Observational Cosmology Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rafael S. de Souza</td>
<td>Statistical analysis, PCA.</td>
</tr>
<tr>
<td>Emilie Ishida</td>
<td>Supernova cosmology - wide field surveys - Observational strategies.</td>
</tr>
<tr>
<td>Isshika Kayo</td>
<td>Extraction of cosmological information from the large-scale structure of the Universe, particularly using the actual data taken by the Sloan Digital Sky Survey and virtual data generated by N-body simulations. Construction of a homogeneous catalog of gravitationally lensed quasars to constrain the dark energy.</td>
</tr>
<tr>
<td>Tsz Yan Lam</td>
<td>Galaxy surveys to constrain cosmological models. Large-scale structure probes of primordial non-Gaussianity.</td>
</tr>
<tr>
<td>Yen-Ting Lin</td>
<td>Formation and evolution of galaxies. Roles of galactic mergers and feedback from supermassive black holes on the formation of giant galaxies. Data analysis of BOSS survey and radio surveys to elucidate the phenomenon of radio-loud active galactic nuclei. Evolutionary connections between galaxies at z=0 and z=1 using future HSC data.</td>
</tr>
<tr>
<td>Kazuki Maeda</td>
<td>Supernova cosmology, especially in the evaluation of applicability of Type Ia supernovae as cosmological distance indicators.</td>
</tr>
<tr>
<td>Takaya Nishizawa</td>
<td>Evolution of dust throughout the cosmic history. Evaluation of the impacts of dust on the observational cosmology using Type Ia supernovae as a standard candle.</td>
</tr>
<tr>
<td>Naoshi Sugiyama</td>
<td>Investigation of the Cosmic Microwave Background. Testing of dark energy models using observational data such as the baryon acoustic oscillation and gravitational lensing.</td>
</tr>
<tr>
<td>Masahiro Takada</td>
<td>Observational and theoretical studies of gravitational lensing caused by hierarchical structures of the universe. Nature of dark side of the universe, dark matter and dark energy, with the gravitational lensing observables. Future Subaru Weak Lensing Survey.</td>
</tr>
<tr>
<td>Masaomi Tanaka</td>
<td>Supernova cosmology. Observations and modelling of nearby Type Ia supernovae to understand the origin of their diverse properties.</td>
</tr>
<tr>
<td>Masayuki Tanaka</td>
<td>Observational studies of the formation and evolution of galaxies and large-scale structures using data from the Sloan Digital Sky Survey, Subaru telescope, and Very Large Telescope.</td>
</tr>
<tr>
<td>Atsushi Iwata</td>
<td>Modeling dynamics and statistics of large-scale structure of the Universe, and testing various cosmological scenarios and/or hypothesis through direct comparison between theory and observations. A pursuit of the prospects for future observations such as HSC and BOSS to constrain dark energy, massive neutrinos, primordial non-Gaussianity as well as to test theory of gravity.</td>
</tr>
<tr>
<td>Jun'ichi Yokoyama</td>
<td>Analysis of CMB anisotropy.</td>
</tr>
<tr>
<td>Naoki Yoshida</td>
<td>Large galaxy surveys and weak lensing observations. Computer simulations to generate a large number of mock catalogues for future observational programs.</td>
</tr>
</tbody>
</table>
Particle Astrophysics

High-energy phenomena naturally occurring in the universe provide a wealth of data and new valuable insights into particle physics and cosmology. IPMU researchers use the universe as a laboratory for testing new theories of dark matter and new physics beyond the Standard Model, and for understanding the basic properties of the universe. In the past year, several exciting developments in particle astrophysics were initiated by IPMU members.

Dark Matter

Its existence is supported by a substantial body of astrophysical evidence, but the identity of the dark matter particle (or particles) remains a mystery. Since one does not know the interactions of dark matter particles, besides their gravitational interactions, one must pursue a broad range of possibilities. IPMU researchers have studied several well-motivated possibilities, such as number-theory dark matter, gravitino in supersymmetric theories, axions, sterile neutrinos, asymmetric, decaying, and universally leptophilic dark matter.

Number-theory dark matter is an elegant and novel possibility proposed by Nakayama, Takahashi, and Yanagida. The stability of such dark-matter particles is due to a new symmetry, which is related to basic number theory and the Fermat theorem. (It is fitting that such a theory has emerged from an institute that has “physics and mathematics” ingrained in its name and in its mission.)

Matsumoto and collaborators have studied several dark matter candidates and their implications for cosmic-ray observations.

Kawasaki and collaborators have investigated cosmological aspects of inflation in supersymmetric axion models, as well as some general cosmological constraints on dark matter with velocity-dependent annihilation rates.

It is intriguing that the dark-matter particle can emerge from the neutrino sector in a natural and minimalistic fashion. Indeed, right-handed or sterile neutrinos are believed to exist at some scale, hence explaining the observed neutrino masses via the seesaw mechanism. If one of these additional fields appears to be light, as can happen in models with extra dimensions, the corresponding particle can account for cosmological dark matter. A simple model proposed by Kusenko, Takahashi, and Yanagida illustrates this possibility and motivates the search for sterile neutrinos. Loewenstein and Kusenko have began the first dedicated search for dark matter using three X-ray telescopes in space: Chandra, XMM-Newton, and Suzaku. The first published results include new limits on sterile dark matter, as well as a tantalizing feature in the Chandra data that may be the first hint of discovery. The search continues with scheduled new observations of dark-matter dominated dwarf spheroidal galaxies.

Ultra-high-energy cosmic rays

The UHECR presents a number of puzzles and scientific opportunities. Martens has spearheaded the experimental efforts at IPMU related to the Telescope Array experiment. On the theoretical side, Kusenko and collaborators have proposed that a non-negligible fraction of ultrahigh-energy nuclei in some energy range may come from past gamma-ray bursts and other unusual stellar explosions in our own Milky Way galaxy, thus explaining some recent data from Pierre Auger Observatory. While the protons leave the galaxy promptly, the nuclei get entangled in the web of galactic magnetic fields and bombard Earth over millions of years after the stellar explosion that produced them. This is first evidence of natural nuclear accelerators, such as gamma-ray bursts, in the past of our own galaxy.

Very high energy gamma-rays

The VHEG from bright distant sources, such as supermassive black holes that accrete stellar matter and accelerate particles in gigantic jets, allow one to study both the most powerful objects in the universe and the properties of medium along the line of sight, such as the density of starlight photons and the intergalactic magnetic fields. Kusenko and collaborators have found a link between the observed gamma-ray signals from supermassive black holes and the cosmic rays produced in their jets. The surprising connection explains the observed spectra of the brightest gamma-ray sources in the universe, proves that cosmic rays are accelerated in active galactic nuclei, and sheds new light on cosmic backgrounds and magnetic fields. In particular, observational evidence points to the existence of universal magnetic fields of femtogauss (10^{-15} Gauss) strengths. Such fields may have astrophysical or primordial origin, and may permeate deep space since long before the stars and galaxies have formed.
### Particle Astrophysics Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosimo Bambi</td>
<td>General Relativity is our current and successful theory of gravity, but it has been tested essentially only in the perturbative and weak field limit. The challenge is to figure out if its predictions are still reliable in other contexts, such as the description of the universe or black hole physics.</td>
</tr>
<tr>
<td>Koichi Hamaguchi</td>
<td>Physics beyond the standard model, in particular SUSY models, their LHC phenomenology and application to cosmology (baryogenesis, BBN constraints, dark matter and its signatures).</td>
</tr>
<tr>
<td>Karsten Heeger</td>
<td>Solar neutrinos.</td>
</tr>
<tr>
<td>Junji Hisano</td>
<td>Theoretical studies for dark matter detection.</td>
</tr>
<tr>
<td>Alexander Kusenko</td>
<td>Ultrahigh-energy cosmic rays and very high energy gamma rays, dark matter, astrophysical neutrinos.</td>
</tr>
<tr>
<td>Sourav Mandal</td>
<td>Models beyond the Standard Model, and their signatures in astrophysics, cosmic rays and colliders.</td>
</tr>
<tr>
<td>Kai Martens</td>
<td>The Telescope Array experiment studies the highest energy cosmic rays that permeate the Universe with the aim to positively identify their origin. On the way to that lofty goal I want to use hybrid events to better understand the air showers themselves.</td>
</tr>
<tr>
<td>Hirotoshi Musayama</td>
<td></td>
</tr>
<tr>
<td>Mihoko Nojiri</td>
<td></td>
</tr>
<tr>
<td>Seong Chan Park</td>
<td>Dark matter is my primary concern. As a short term goal, I hope to explain the recently reported “anomalies” in astrophysical observations: The 511 keV line from the galactic center and the positron excess preliminarily reported by PAMELA. I am also interested in linking DM with inflation.</td>
</tr>
<tr>
<td>Jing Shu</td>
<td>Baryogenesis, electroweak phase transition, topological defects, and dark matter.</td>
</tr>
<tr>
<td>Naoshi Sugiyama</td>
<td>Acceleration of cosmic rays and its relevance for structures of the universe.</td>
</tr>
<tr>
<td>Fuminobu Takahashi</td>
<td>High-energy cosmic rays from dark matter.</td>
</tr>
<tr>
<td>Mark Vagins</td>
<td>My work involves probing the reactions within the sun via its neutrino emissions, as well as measuring the dynamics of supernovas via their neutrino spectra and time structure. Neutron detection in large water Cherenkov detectors would allow early warning, up to a week in advance, of the impending stellar collapse of a large, relatively nearby star like Betelgeuse, and it would enable the detection of very late-time black hole formation following supernova explosions anywhere within our galaxy.</td>
</tr>
</tbody>
</table>

### Proton Decay

The stability of the proton represents one of the greatest theoretical and experimental challenges in particle physics today. In most grand unified theories, particularly those with a TeV intermediate mass scale, the proton “wants” to decay. Experimentally, however, the proton seems determined to outlive us all. Beginning with the first large-scale searches in the 1980’s, one promising theory after another has floundered on the shoals of nucleon decay. To date, no hint of a nucleon decay signal has emerged.

In spite of this, the study of nucleon decay provides one of the few approaches to the problem of confronting grand unified theories with experimental data, and any progress toward this goal has unique value for the future development of physics. This program has already been a success. The simplest unification model, minimal SU(5), has been ruled out by the experimental results. Every subsequent grand unification theory will remain only a mathematical construct if further experimental information is not available.

The search for nucleon decay requires massive detectors. A search with a sensitivity of $10^{33}$ years, for example, requires a detector with approximately $10^{13}$ nucleons. Since there are $6 \times 10^{29}$ nucleons per ton of material, this implies detectors of multi-kiloton scale.

The “classical” proton decay mode, $p \rightarrow e^+ \nu$, can be efficiently detected with low background. At present, the best limit on this mode ($\tau/\beta > 5.1 \times 10^{33}$ yr, 90% CL) comes from a 206 kton-yr exposure of Super-Kamiokande. The detection efficiency of 45% is dominated by final-state $\pi^0$ absorption or charge-exchange in the nucleus, and the expected background is 2 events/Mton-yr.

Supersymmetric theories favor the mode $p \rightarrow \gamma K^+$, which is experimentally more difficult due to the unobservable neutrino. The present limit from Super-Kamiokande is the result of combining several channels, the most sensitive of which is $K^+ \rightarrow \mu^+ \nu$ accompanied by a de-excitation signature from the remnant $^{12}$N nucleus. Monte Carlo studies suggest that this mode should remain background free for the foreseeable future. The present combined limit is $\tau/\beta > 3.3 \times 10^{35}$ yr (90% CL).

Recent theoretical work suggests that if super-symmetric SO(10) provides the framework for grand-unification, the proton lifetime (into the favored $\gamma K^+$ decay mode) must lie within about one order of magnitude of present limits. Similarly, SO(10) theories suggest $\tau/\beta(\mu^0) > 10^{35}$ years—about a factor of ten beyond the present limit. Thus, continued progress in the search for nucleon decay inevitably requires larger detectors.

Moreover, the enormous mass and exposure required to improve significantly on existing limits (and the unknowable prospects for positive detection) underline the importance of any future experiment’s ability to address other important physics questions while waiting for the proton to decay. Proton decay experiments have made fundamental contributions to neutrino physics and particle astrophysics in the past, and any future experiment must be prepared to do the same.
### Proton Decay Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takaaki Kajita</td>
<td>Updated searches for proton decays.</td>
</tr>
<tr>
<td>Henry W. Sobel</td>
<td>Updated measurement of proton decay.</td>
</tr>
<tr>
<td>Yoichiro Suzuki</td>
<td>Future large water Cherenkov detectors and also future multipurpose detectors for dark matter, double beta decay and low energy solar neutrinos. Development of a new type of light sensor for such detectors.</td>
</tr>
<tr>
<td>Mark Vagins</td>
<td>Improving the proton decay measurement in water-based detectors via detection of free neutrons significantly suppressing atmospheric neutrino-induced proton decay backgrounds. Development of next-generation, megaton-scale experiments for proton decay.</td>
</tr>
</tbody>
</table>

In the past few hundred years, scientists have searched for fundamental laws of nature by exploring phenomena at shorter and shorter distances. Does this progression continue indefinitely? Surprisingly, there are reasons to think that the hierarchical structure of nature will terminate at $10^{-35}$ meter, the so-called Planck length. Let us perform a thought-experiment to explain why this might be the case. Physicists build particle colliders to probe short distances. The more energy we use to collide particles, the shorter distances we can explore. This has been the case so far. One may then ask: can we build a collider with energy so high that it can probe distances shorter than the Planck length? The answer is no. When we collide particles with such high energy, a black hole will form and its event horizon will conceal the entire interaction area. Stated in another way, the measurement at this energy would perturb the geometry so much that the fabric of space and time would be torn apart. This would prevent physicists from ever seeing what is happening at distances shorter than the Planck length. This is a new kind of uncertainty principle. The Planck length is truly fundamental since it is the distance where the hierarchical structure of nature will terminate.

Space and time do not exist beyond the Planck scale, and they should emerge from a more fundamental structure. Superstring theory is a leading candidate for a mathematical framework to describe physics at the Planck scale since it contains all the ingredients necessary to unify general relativity and quantum mechanics and to deduce the Standard Model of particle physics. Superstring theory has helped us solve various mysteries of quantum gravity such as the information paradox of black holes posed by Stephen Hawking. The theory has given us insights into early universe cosmology and models beyond the Standard Model of particle physics. It provides powerful tools to study many difficult problems in theoretical physics—often involving strongly interacting systems—such as QCD (theory of quark interactions), quantum liquid and quantum phase transitions. It has also inspired many important developments in mathematics. All of these aspects of string theory are vigorously investigated at IPMU.
### String Theory Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitsutoshi Fujita</td>
<td>Gauge/gravity correspondence, flavor branes, and condensed matter physics.</td>
</tr>
<tr>
<td>Simeon Hellerman</td>
<td>String theory and its connections to quantum gravity, cosmology, condensed matter, particle physics and mathematics. Development of tools to understand and apply string theory in generic environments.</td>
</tr>
<tr>
<td>Minxin Huang</td>
<td>Aspects of the AdS/CFT correspondence such as pp-waves, and giant gravitons. Topological string theory.</td>
</tr>
<tr>
<td>Kentaro Hori</td>
<td>4d N=1 string compactifications in various frameworks, especially, worldsheet approaches to Type II orientifolds with D-branes and fluxes, M-theory on G_2 holonomy manifolds, worldsheet approaches to heterotic strings. Topological strings as well as supersymmetric gauge theories in various dimensions.</td>
</tr>
<tr>
<td>Shinobu Hosono</td>
<td>Mirror symmetry of Calabi-Yau manifolds and its applications to Gromov-Witten theory.</td>
</tr>
<tr>
<td>Toshiya Imoto</td>
<td>Holographic QCD.</td>
</tr>
<tr>
<td>Johanna Knapp</td>
<td>Mathematical structure of the compact dimensions, dualities, such as mirror symmetry, which relate different string compactifications.</td>
</tr>
<tr>
<td>Wei Li</td>
<td>Black holes. Gauge/Gravity correspondence. 3D quantum gravity.</td>
</tr>
<tr>
<td>Todor Milanov</td>
<td>Topological string theory and its applications in geometry.</td>
</tr>
<tr>
<td>Shinnji Mukohyama</td>
<td>String cosmology.</td>
</tr>
<tr>
<td>Hiroi Ooguri</td>
<td>Development of theoretical tools to apply string theory to questions relevant to high energy physics, astrophysics, and cosmology.</td>
</tr>
<tr>
<td>Yuluka Oskowski</td>
<td>4D supersymmetric gauge theories and its application to problems in particle physics, including their work via string theories such as a gauge/gravity duality.</td>
</tr>
<tr>
<td>Domenico Orlando</td>
<td>Exact CFT solutions. Topological strings. Effective descriptions for M-theory.</td>
</tr>
<tr>
<td>Susanne Reffert</td>
<td>String compactifications. Topological string theory.</td>
</tr>
<tr>
<td>Johannes Schmude</td>
<td>Aspects of gauge/string duality, especially flavor-branes.</td>
</tr>
<tr>
<td>Kenneth Shackleton</td>
<td>Connection between string theory and the completion of the Weil-Petersson metric on Teichmüller space.</td>
</tr>
<tr>
<td>Cornelius Schmidt-Colinet</td>
<td>Conformal field theory and its applications in string theory.</td>
</tr>
<tr>
<td>Shigeki Sugimoto</td>
<td>Conjectured duality between string theory and gauge theory, and its application to QCD and hadron physics.</td>
</tr>
<tr>
<td>Yuji Tachikawa</td>
<td>Study of supersymmetric field theories in various dimensions using the help of string theory; study of mathematical structures behind string theory.</td>
</tr>
<tr>
<td>Tadashi Takayanagi</td>
<td>String theory as quantum gravity especially from the viewpoint of holography such as AdS/CFT duality. Relation between the entanglement entropy and the gravitational entropy such as the black hole entropy.</td>
</tr>
<tr>
<td>Taizan Watari</td>
<td>String phenomenology. Inflation (in the past), GUT and F-theory compactification.</td>
</tr>
<tr>
<td>Simon Wood</td>
<td>Conformal field theory and understanding its implications in string theory.</td>
</tr>
</tbody>
</table>

Structure Formation

There are rich structures in the present-day universe, such as stars, galaxies, and large-scale structure. We study how these objects are formed using large computer simulations and sophisticated theoretical models.

The standard Big Bang model posits that the universe was nearly homogeneous and very hot when it was born. Tiny “ripples” in the distribution of matter were generated through a rapid expansion phase called inflation in the very early universe. These primeval density fluctuations grew by the action of gravity, eventually forming luminous objects such as galaxies.

The energy content of the universe and basic statistic that describe the condition of the early universe have been determined with great accuracy from recent observations of cosmic microwave background radiation, large-scale galaxy distribution and distant supernovae. Cosmology is now at a stage where theory can make solid predictions, whereas a broad class of observations can be directly used to verify them. Planned large astronomical surveys such as Sloan Digital Sky Survey III and Subaru HyperPrime Cam Survey will provide rich information on the nature of dark matter and dark energy. Accurate theoretical predictions are needed to make the full use of the observational data.

Our primary interests are in primordial star formation in the early universe, the formation and evolution of galaxies, and the formation of large-scale structure. Results from these studies will be used for making good plans and proposals for Subaru-HSC/PFS dark energy survey.
## Structure Formation Group

<table>
<thead>
<tr>
<th>Member</th>
<th>Main Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rafael S. de Souza</td>
<td>Primordial magnetic fields, first stars, dark matter halos, primordial gamma ray bursts,</td>
</tr>
<tr>
<td>Issha Kayo</td>
<td>Extraction of cosmological information from the large-scale structure of the Universe, particularly using the actual data taken by the Sloan Digital Sky Survey and virtual data generated by N-body simulations. Construction of a homogeneous catalog of gravitationally lensed quasars to constrain the dark energy.</td>
</tr>
<tr>
<td>Tsz Yan Lam</td>
<td>Distributions of dark matter halos and dark matter field. Environmental dependence of halo formation.</td>
</tr>
<tr>
<td>Yan-Ting Lin</td>
<td>Atacama Cosmology Telescope (ACT) project, a large cluster survey that detects clusters via the Sunyaev-Zeldovich effect (SZE). Analyses of the data from ACT, SDSS, and Subaru, to study the evolution of galaxies within clusters, as well as to use the statistical properties of clusters (such as clustering and abundance) to constrain cosmology.</td>
</tr>
<tr>
<td>Tomoki Saito</td>
<td>Observational studies of high-redshift galaxies using the data from Subaru Telescope, Very Large Telescope, and various telescopes ranging from radio to X-ray. Calibration studies for wide-field imaging surveys with the Hyper Suprime-Cam.</td>
</tr>
<tr>
<td>Ikkoh Shimizu</td>
<td>Theoretical models of high redshift galaxies.</td>
</tr>
<tr>
<td>John Silverman</td>
<td>Observational studies of active galactic nuclei and their host galaxies. The formation and evolution of supermassive black holes are being investigated in survey fields including COSMOS, Chandra Deep Field South and the Sloan Digital Sky Survey. For example, we are carrying out a near-infrared spectroscopic survey of AGNs and quasars with Subaru/FMOS to measure the distribution of black hole masses and determine whether the local black hole-host galaxy mass relation holds at high redshift. Additional studies include the role of galaxy mergers in triggering accretion onto supermassive black holes and the influence of larger scale structures such as galaxy groups and clusters.</td>
</tr>
<tr>
<td>Naoshi Sugiyama</td>
<td>Investigation of linear evolution of structure in the universe and effect of magnetic fields.</td>
</tr>
<tr>
<td>Masahiro Takada</td>
<td>Observational and theoretical studies of gravitational lensing caused by hierarchical structures of the universe. Nature of dark side of the universe, dark matter and dark energy, with the gravitational lensing observables. Future Subaru/Weak Lensing Survey.</td>
</tr>
<tr>
<td>Masayuki Tanaka</td>
<td>Observational studies of the formation and evolution of galaxies and large-scale structures using data from the Sloan Digital Sky Survey, Subaru telescope, and Very Large Telescope.</td>
</tr>
<tr>
<td>Atsushi Taruya</td>
<td>Modeling dynamics and statistics of large-scale structure of the Universe, and testing various cosmological scenarios and/or hypothesis through direct comparison between theory and observations. A pursuit of the prospects for future observations such as HSC and BOSS to constrain dark energy, massive neutrinos, primordial non-Gaussianity as well as to test theory of gravity.</td>
</tr>
<tr>
<td>Naoki Yoshida</td>
<td>Formation of stars, galaxies and the large-scale structure of the universe using supercomputer simulations.</td>
</tr>
</tbody>
</table>

### Supernova

Supernovae are explosions of stars at the end of their lives. Core-collapse supernovae (Type II, Ib, and Ic) are the outcome of the gravitational collapse of massive stars (i.e., more than ten times as massive as the Sun), followed by formation of a neutron star or a black hole, announced by a huge amount of neutrinos. Thermonuclear supernovae (Type Ia) are explosions driven by nuclear reactions within a white-dwarf star.

Supernovae provide natural laboratories for a range of physical processes, such as neutrino physics, some of which cannot be addressed by experiments on the Earth. Furthermore, they are the main contributors of heavy elements in the Universe; without them, baryons in the Universe would be only hydrogen, helium and some minor elements, although in reality the Universe is filled with about a hundred different sorts of elements. Their energy produced at the explosions is huge, and supernova explosions could play important roles even in formation and evolution of galaxies. Finally, importance of understanding their natures is highlighted by their use as cosmological distance indicators, leading to the discovery of the Dark Energy.

Our understanding of the above issues is still far from satisfying, with various issues still under investigation. At IPMU, we cover most of the topics related to supernovae both in theory and observation/experiment. Evolution of stars toward supernovae, theory of explosions, attempt to detect these neutrinos at Kamioka, nucleosynthesis of elements up to iron and beyond, formation of dust grains, theory of optical emission from supernovae and evaluation of their use as cosmological distance indicators, and observations using the Subaru telescope including future large survey planning with the HSC. By unifying these attempts, we aim to comprehensively understand supernovae and their influences on the evolution of the Universe.
### Supernova Group

<table>
<thead>
<tr>
<th>Member</th>
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<tbody>
<tr>
<td>Melina Barstien</td>
<td>Hydrodynamical models of core-collapse supernovae with the aim to study the physical properties of the progenitor stars.</td>
</tr>
<tr>
<td>Emile Ishida</td>
<td>Type Ia supernova-Influence on galaxies dark matter profile-Signatures in baryonic environment.</td>
</tr>
<tr>
<td>Rafael B. de Souza</td>
<td>Influence of the supernovae explosions in the dark matter density profile, magnetization of the universe by first supernovae.</td>
</tr>
<tr>
<td>Gaston Polletti</td>
<td>Supernova observations, including searches and intensive photometric and spectroscopic follow up. The goal is to gain a deeper understanding of the physical processes involved in the explosion, and of the stellar evolution paths that lead to different types of supernovae.</td>
</tr>
<tr>
<td>Masaomi Tanaka</td>
<td>Observations of core-collapse and Type Ia supernovae especially with optical light-curves and hunting for high redshift supernovae using groud-based and space telescopes.</td>
</tr>
<tr>
<td>Y asuo Takeuchi</td>
<td>Real-time neutrino burst search in Super-Kamiokande.</td>
</tr>
<tr>
<td>Yoichiro Suzuki</td>
<td>Development of future multi-megaton detectors which can detect neutrino bursts from supernovae every year.</td>
</tr>
<tr>
<td>Kazunori Nakayama</td>
<td>The new gauge symmetry must be spontaneously broken at TeV scale, in order to account for the recent observation of dark radiation. (If it had a large mass, it would be more like dark matter, not dark radiation.) In the early Universe, the chiral fermion η will be in thermal equilibrium through the new gauge interactions with the standard model particles. If the new gauge symmetry is spontaneously broken at TeV scale, the chiral fermion decouples from plasma after the QCD phase transition, and therefore accounts for dark radiation if it still remains light.</td>
</tr>
<tr>
<td>Ken'ichi Nomoto</td>
<td>Type Ia supernova cosmology to provide precision constraints on cosmic acceleration and the equation of state of dark energy by clarifying the progenitors and explosion mechanism. Evolution and nucleosynthesis of first stars to study cosmic chemical evolution. Gamma-ray bursts and hypernovae to clarify the production mechanisms of huge explosion energy from black holes and neutron stars.</td>
</tr>
<tr>
<td>Henry W. Sobel</td>
<td>Super-Kamiokande and T2K for studying neutrino physics, supernova, and proton decay.</td>
</tr>
<tr>
<td>Yasuo Takeuchi</td>
<td>Real-time neutrino burst search in Super-Kamiokande.</td>
</tr>
<tr>
<td>Masao Tanaka</td>
<td>Observations of core-collapse and Type Ia supernovae especially with optical spectroscopy and spectro-polarimetry. Numerical simulations of radiative transfer.</td>
</tr>
<tr>
<td>Mark Vagins</td>
<td>Detection of the diffuse neutrino background produced by distant supernovae. Improvement of Super-Kamiokande experiment's response to the arrival of a burst of neutrinos from a supernova within our galaxy.</td>
</tr>
<tr>
<td>Naoki Yoshida</td>
<td>Theory of evolution of very massive stars and core-collapse supernovae. Supernova light-curves and hunting for high redshift supernovae using ground-based and space telescopes.</td>
</tr>
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### 6 Research Highlight

#### Shedding Light on Dark Radiation

One of the most important discoveries in cosmology is that the Universe is expanding. According to general relativity, the expansion rate is determined by the energy contained in the Universe. In fact, measuring the expansion rate has been one of the central issues, because it provides fundamental cosmic age and distance scales. For instance, a precise measurement of Type Ia supernovae revealed that the present Universe is filled with dark energy, which accelerates the cosmic expansion. It is even possible to infer the particle content of the Universe in the past, by measuring the primordial abundance of $^4$He, the cosmic microwave background (CMB) anisotropies, and large scale structure (LSS).

The primordial abundance of $^4$He was the key observational evidence for the big bang theory. The big bang nucleosynthesis (BBN) calculation agreed reasonably well with the observed $^4$He mass fraction $Y_p$ together with other light element abundances given in terms of a function of the baryon-to-photon ratio, $\eta$. In the post-WMAP era, $\eta$ was determined to a very high accuracy, which allowed the internal consistency check of the BBN calculation based on the standard big bang cosmology. Recently, Izotov and Thuan claimed an excess of $Y_p$ at the 2σ level which can be understood in terms of an extra light degrees of freedom, namely, dark radiation. The CMB and LSS data are also sensitive to the presence of such dark radiation after matter-radiation equality, and the recent analysis based on the CMB and LSS data shows a slight preference for dark radiation at the 2σ level. It is remarkable that, while the helium abundance, the CMB and LSS data are sensitive to the expansion rate of the Universe at vastly different times, all the data mildly favor dark radiation.

Suppose that there is indeed dark radiation. Question is then what it is made of. The dark radiation may be composed of unknown particles. Fuminotho Takahashi and Tsutomu Yanagida at IPMU, in collaboration with Kazunori Nakayama at KEK, tackled this timely and interesting issue and examined various theoretical possibilities from a cosmological, as well as from a particle physics point of view. Their main conclusion is that the most plausible candidate for dark radiation is a chiral fermion $\psi$ charged under a new gauge symmetry, under which the standard model fermions such as quarks and leptons are also charged. Here the new gauge symmetry to forbid a bare mass for the chiral fermion, and that is why it remains light and can be dark radiation. (If it had a large mass, it would be more like dark matter, not dark radiation.) In the early Universe, the chiral fermion $\psi$ will be in thermal equilibrium through the new gauge interactions with the standard model particles. If the new gauge symmetry is spontaneously broken at TeV scale, the chiral fermion decouples from plasma after the QCD phase transition, and therefore accounts for dark radiation if it still remains light.

They also discussed a possible candidate for such new gauge symmetry. The simplest one is a U(1) gauge symmetry, which must be free from the quantum anomaly. One of the anomaly-free $U(1)$ is $U(1)_{B-L}$, which naturally appears in the SO(10) GUT. Actually, however, the $U(1)_{B-L}$ symmetry should be spontaneously broken at a scale much higher than the weak scale, in order to explain tiny neutrino masses through the seesaw mechanism. In fact, an additional anomaly-free $U(1)$ often appears in the breaking pattern of a GUT gauge group with a higher rank. They showed that there is indeed a suitable candidate for the new $U(1)$ gauge symmetry as well as the light chiral fermion $\eta$ in an $E_6$-inspired GUT, which contains an additional $U(1)$, as $E_6 \rightarrow SO(10) \times U(1)$.

The new gauge symmetry must be spontaneously broken at TeV scale, in order to account for the recent observations. Interestingly, therefore, it is in principle possible to directly probe the dark radiation sector at the collider experiments such as LHC. This was a rather unexpected result. The dark radiation may turn out to be a crucial key to understand not only the evolution of the early Universe, but also the high-energy physics from TeV scale up to the GUT scale.

Flat Dark-Matter Distribution

A team of researchers from Japan, Taiwan, and the United Kingdom has provided the first direct and clear evidence for an extremely flattened shape of dark-matter distribution in massive clusters of galaxies, a finding that confirms a major prediction of the prevailing dark matter model. The researchers took advantage of the gravitational lensing effect to make detailed measurements of the spatial distributions of dark matter in 20 massive clusters of galaxies. A thorough examination of the shape of dark-matter distribution in the cosmos may open up a new way to explore the nature of this enigmatic matter.

The nature of dark matter is still unknown and is currently a central problem in modern astronomy and physics. Dark matter is dark in a couple of ways. It is undetectable to visible light and has escaped detection at all electromagnetic wavelengths. Because it is invisible, its existence has to be inferred from its gravitational effect on other celestial objects as well as from theoretical models. Indirect evidence has established its relative abundance in our universe—probably five times greater than visible matter—in addition to its significance for understanding galaxy formation. For example, a considerable amount of dark matter probably sustains the structure of galaxies, because the gravitational force of visible matter cannot bind its member stars. The scientific challenge is how to study the nature of dark matter. Astronomers seek ways to use their observations to solve this puzzle.

One approach to a solution is to make detailed measurements of the spatial distribution of dark matter and then compare the data to predictions drawn from theoretical models. Both aspects of this approach have their difficulties. How can the distribution of dark matter be measured? What are plausible assumptions to include in models of dark matter?

A team led by Masamune Oguri at the National Astronomical Observatory of Japan and Masahiro Takada at IPMU decided to use gravitational lensing to measure and analyze the distribution of dark matter. Gravitational lensing provides a unique opportunity to explore dark matter distributions by measuring the distances that light travels from distant to foreground objects. Einstein’s general theory of relativity predicts that light from a distant object will bend around a massive object in the foreground, e.g., a cluster of galaxies or a concentration of dark matter. By measuring the distortion pattern of many distant galaxies, it is possible to infer the mass(es) of the object(s) in the foreground. Since the technique does not rely on assumptions about the visibility of the matter bending the light, gravitational lensing can be a powerful probe of dark matter.

The team fine-tuned their research by observing 20 massive clusters of galaxies with the Subaru Telescope’s Prime Focus Camera (Suprime-Cam). Clusters of galaxies are ideal sites for studying the distribution of dark matter, because they contain thousands of galaxies and are known to accompany a large amount of dark matter. The superb light-collecting power and excellent image quality of the Subaru Telescope gave the researchers an extra advantage. By using Suprime-Cam at prime focus, they could capture objects in a particularly wide field-of-view.

Observations with Suprime-Cam yielded wide-field images of 20 massive clusters of galaxies (typically located at 3 billion light years from Earth), which the team then used to measure and analyze dark matter distributions (first figure). From their detailed analysis of gravitational lensing effects in the images, the team obtained clear evidence that the distribution of dark matter in the clusters has, on average, an extremely flattened shape rather than a simple spherical contour (second figure). The measured degree of the flattening is quite large, corresponding to 2:1 in terms of the ratio of major to minor axes of the ellipse. This finding represents the first direct and clear detection of flattening in the dark matter distribution with the use of gravitational lensing.

In addition to the promise of using gravitational lensing for exploring the nature of dark matter, this research contributes to the theoretical modeling of dark matter. Detailed comparisons of the team’s findings with theoretical model predictions show that the observed degree of the flattening is in excellent agreement with theoretical expectations.

Theoretical predictions depend on what kind of dark matter model is assumed. This research strongly supports the prevailing model, which begins with the assumption that dark matter consists of weakly interacting massive particles that are relics of the Big Bang. These particles are assumed to be “cold,” i.e., thermal motions of the particles are negligibly small. According to this scenario, clusters of galaxies are dynamically young objects that form through the merging of many small objects. This theory predicts that the dark matter distribution in clusters of galaxies would be non-spherical, reflecting a large-scale structure of dark matter filaments (i.e., ribbons of cold material). Since the team’s findings confirm a non-spherical distribution, they demonstrate the feasibility of exploring the nature of dark matter via flattening in the dark matter distribution.

Are “Standard Candles” Really Standard?

Type Ia supernovae have been playing a key role in cosmology and in the discovery of the Dark Energy, since they can be used to measure distances across the Universe. This relies on the well-developed relation between their brightness and the decline rates—brighter supernovae decline slower.

This single-parameter description of type Ia supernovae may well reflect the uniform nature of the progenitor system. Type Ia supernovae are explosions of a white dwarf consisting of carbon and oxygen. The explosion is triggered by sparks of thermonuclear flames ignited in the innermost part of the white dwarf, although how the explosion is initiated is still in debate. The explosion most likely takes place when the white dwarf reaches the so-called Chandrasekhar mass (about 1.4 times the Sun) through accreting materials from its binary companion or by merging with another white dwarf.

However, recent investigations have revealed that the true nature of type Ia supernovae is far more complicated. They indeed do not look like a uniform system in their spectral features: type Ia supernovae that look like twins concerning their luminosity evolution can demonstrate a quite different behavior in the speed with which their spectral features evolve (the so-called velocity gradient). This spectral evolution diversity was first noticed in the late 1980s, and quantified beyond the doubt in 2005.

The origin of this diversity has not been clarified, raising a couple of concerns: Are they really good standard candles? Are they indeed from a uniform progenitor system?

The research group led by Keiichi Maeda (also including Ken’ichi Nomoto and Masaomi Tanaka of IPMU) has reported that they have finally identified the origin of the diversity. They have found that the velocity gradient is closely related to another independent observed quantity, namely the wavelength shift of emission lines in late-time spectra of type Ia supernovae, taken about > 200 days after the explosion (first figure).

This late-time emission-line shift has a straightforward interpretation: the shift can arise only if the innermost part of supernovae is asymmetric and the degree of the shift depends on the direction from which a SN is observed. Now the origin of the spectral evolution diversity must be the same: it is merely a consequence of the random directions from which an SN is viewed.

This finding is not only about uncovering the origin of the spectral diversity. It can get rid of a concern about using type Ia supernovae for cosmology, since this viewing angle effect will average out if we collect many supernovae for cosmology. In addition, the idea of the uniform progenitor system is rescued. Finally, this is the first strong observational indication about how the thermonuclear flames are ignited in the explosion: the finding points to asymmetric, off-centre explosions, as opposed to what most people had believed so far.

Instantons and Two-dimensional Conformal Field Theories

Instantons, which were introduced in the 1970s, are elementary excitations of the four-dimensional gauge theory, localized in both spatial and temporal directions. They play important roles in the theoretical understanding of the dynamics of the quantum chromodynamics governing the “strong force”, one of the four basic forces of nature. Not only that, instantons turned out to be a rich source of mathematics. They obey a non-linear partial differential equation, which was found to be exactly solvable on a flat four-dimensional space by Atiyah, Drinfeld, Hitchin and Manin. Furthermore, instantons were shown by Donaldson to provide a host of new insights into the geometry of four-dimensional curved manifolds, revolutionizing the field.

Conformal field theory describes a physical system which is invariant under the change of the length scale. This typically happens when the system is at the critical point, that is, when the parameter is chosen very carefully so that its phase is about to change. A magnet exactly at the temperature when it loses its magnetization is an example of such a system. Conformal field theories in two dimensions are particularly interesting objects, because they have an infinite-dimensional symmetry. In the middle of 1980s, Belavin, Polyakov and Zamolodchikov showed that this infinite-dimensional symmetry allows us, in some cases, to completely determine the dynamics by the symmetry alone. Such systems can be experimentally realized, and the observed values were in agreement with the theoretical predictions.

Both instantons and two-dimensional conformal field theories are rigorous subjects in mathematical physics intensively studied in the last thirty years. People had observed that there are tantalizing similarities between these two types of objects, and finally in 2009, string theorists Alday, Gaiotto and Tachikawa found a concrete way to relate the quantity on one side to another quantity on the other side. The most basic instance of the relation is as follows: on the side of the instantons, one considers a statistical-mechanical ensemble of instantons, and compute its partition function; on the side of the two-dimensional conformal field theory, one studies a coherent state of the system, and take the norm of that coherent state. By a simple mapping of parameters, the partition function of the four-dimensional theory agrees with the norm of the coherent state.

Instantons are objects in four-dimensional spacetime, two-dimensional conformal field theories are obviously theories in two-dimensional spacetime. Therefore connecting them was a nontrivial manner, from a traditional point of view of mathematical physics, which usually dealt with phenomena in a definite number of spacetime dimensions, usually equal or less than four because our spacetime is four-dimensional. String theory was useful in the following manner. First, the consistency of string theory requires that the spacetime
is either ten or eleven-dimensional. This causes great trouble when string theory is thought of as providing a microscopic description of the real world, because our world is four-dimensional. However having a lot of dimensions comes in handy in this case. String theory has solitonic objects called M5-branes, which extend along six spacetime directions. The M5-branes, being six-dimensional, can be put on the product of a four-dimensional curved manifold and a two-dimensional curved manifold. Then, physical quantities associated to the M5-branes can be calculated either from the four-dimensional viewpoint, or from the two-dimensional viewpoint. The first route reduces to the calculation involving instantons, and the second route reduces to two-dimensional conformal field theory. Most simply put, the important relation is that $6=4+2$: the six-dimensional physics can encompass both two-dimensional and four-dimensional physics. String theorists Yuji Tachikawa and Min-xing Huang at IPMU have worked and written papers on this subject.

This relation can be thought of as an instance of general phenomena, where a calculation of a physical quantity in string theory reduces to two completely different-looking calculations. Mirror symmetry which relates symplectic geometry and complex geometry is another famous instance of this general phenomena. String theory is not at all rigorous from the point of view of contemporary mathematics. However, the relation extracted from string theory, such as mirror symmetry or this relation between instantons and two-dimensional conformal field theories, can be formulated completely rigorously, and becomes a conjecture to be proved by serious mathematicians.

In this particular example, the mathematically formulated version of this relation is that the equivariant cohomology group of the moduli space of instantons should have a natural action of the infinite-dimensional Virasoro algebra. There is in fact a subfield of mathematics called geometric representation theory, where infinite-dimensional algebras are constructed in terms of geometric structures, and this relation gave a lot of impetus to the experts in this field. Simplified versions of this statement has already been proved in 2010, and the full proof is said to be quite close.

This division of labor between string theorists and mathematicians can be compared to the division of labor between theoretical physicists and experimental physicists. Experimental physicists perform experiments, which theoretical physicists interpret and come up with a theory; then theoretical physicists give predictions and experimental physicists either confirm or disprove them by real data. Similarly, mathematicians provide theorems, which string theorists interpret in string theory; then string theorists give further conjectures in mathematics, which mathematicians prove by rigorous means.

Young Scientist Award of the Physical Society of Japan was awarded to Fuminobu Takahashi based on his three publications, “Gravitino overproduction in inflaton decay,” “The gravitino overproduction problem in inflationary universe” and “Inflaton Decay in Supergravity.”

Toshiyuki Kobayashi won the Inose Science Prize for his important contribution on analysis of symmetry of infinite dimensions. The citation said “His work is a beautiful harmony of all areas of basic concepts that constitute mathematics, namely algebra, geometry and analysis. His work has given great impacts on many areas of mathematics and has pioneered new areas of research.”

The Young Scientist Award in Theoretical Physics was awarded to Seong Chan Park based on his publication “Rotating black holes at future colliders: Greybody factors for brane fields,” which treated black holes in detail, for the first time, for building a particle physics model beyond-the-standard-model containing extra dimensions.

Yoichiro Suzuki won the Bruno Pontecorvo Prize for his outstanding contribution to the discovery of atmospheric and solar neutrino oscillations in the Super-Kamiokande experiment. The prize, awarded annually since 1995 by the Joint Institute for Nuclear Research (JINR) in Russia, recognizes significant achievements in elementary particle physics.

Serguey Petcov won the Bruno Pontecorvo Prize for his fundamental contribution to the investigation of neutrino propagation in matter, $\mu \rightarrow e + \gamma$, $\mu \rightarrow 3 \nu$ processes and Majorana properties of neutrinos.

8 Seminars

Masaomi Tanaka (IPMU)
Spectropolarimetric View of Supernova Explosions
Apr 01, 2010

Hiroyuki Fuji (Nagoya)
Volume Conjecture and Topological Recursion
Apr 06, 2010

Joshua Ruderman (Princeton)
Hiding the Higgs with Lepton Jets
Apr 08, 2010

Bertrand Toën (Montpellier)
Lecture 1: Generalities on dg-categories
Apr 13, 2010

Bertrand Toën (Montpellier)
Lecture 2: Moduli 1: moduli space of simple objects
Apr 14, 2010

Alexander Kusenko (UCLA)
A tale of two spectrums: from a gamma-ray puzzle to cosmic rays and dark matter
Apr 15, 2010

Bertrand Toën (Montpellier)
Lecture 3: Moduli 2: moduli of non simple objects and higher stacks
Apr 15, 2010

Boris Tsygan (Northwestern)
Oscillatory Modules and Applications to Symplectic Geometry
Apr 19, 2010

Semeny Shkolnik (Ben Gurion)
Looking for new particles at the LHC
Apr 26, 2010

Bruce Draine (Princeton)
New Views of Interstellar Dust
Apr 19, 2010

Masato Taki (YITP)
2D Conformal Symmetries, 4D Gauge Theories, & AGT Relations
Apr 20, 2010

Bruce Draine (Princeton)
Lecture 1 Observed Properties of Interstellar Dust
Apr 20, 2010

Bruce Draine (Princeton)
Lecture 2 Physics of Interstellar Dust (1)
Apr 21, 2010

Christoph Weniger (DESY)
Decaying dark matter, anisotropies, lines, and the Fermi LAT gamma-ray data
Apr 22, 2010

Bruce Draine (Princeton)
Lecture 3 Physics of Interstellar Dust (2)
Apr 22, 2010

Andrea Prudenziati (SISSA)
Taming open/closed string duality with a Lasers trick
Apr 23, 2010
Albrecht Klemm (Bonn)
Wall-crossing holomorphic anomaly and mock modularity of multiple M5-branes
Jan 11, 2011

Fuminobu Takahashi (IPMU)
Another dark component of the Universe
Jan 13, 2011

Andrea Ferrara (Scuola Normale Superiore, Pisa)
First Stars and their Local Relics
Jan 21, 2011

Oscar Varela (MPG)
Consistent truncations from wrapped branes, and a Lifshitz solution
Jan 24, 2011

Maria J Rodriguez (MPI)
New nonspherical black holes and charged black rings
Jan 24, 2011

Luis Ho (Carnegie Observatories)
Supermassive Black Holes in Nearby Galaxies: Insights into Accretion and Jet Physics
Jan 24, 2011

Dongsu Bak (Seoul Nat U)
Phase Transitions in the U(1) Charged Sector of ABJM Theory
Jan 25, 2011

Luis Ho (Carnegie Observatories)
Coevolution of Black Holes and Galaxies: Recent Developments
Jan 26, 2011

Dmitry Kaledin (Steklov)
Witt vectors as a polynomial functor
Jan 31, 2011

Kwokwai Chan (IPMU)
The SYZ picture of mirror symmetry
Feb 03, 2011

Kwokwai Chan (IPMU)
The SYZ picture of mirror symmetry
Feb 04, 2011

Yuki Tachikawa (IPMU)
6 = 4+2
Mar 01, 2011

Hajime Sugai (Kyoto)
Active galaxies observed with integral field spectroscopy
Mar 05, 2011

Takuya Okuda (Tokyo)
Exact results for ‘t Hooft loops in supersymmetric gauge theories
Mar 08, 2011

Shinobu Hosono (Tokyo)
Mirror symmetry and projective geometry of Ray congruences
Mar 10, 2011

Kentaro Hori (IPMU)
Motivation and Application of Recent Development in Supersymmetric Gauge Theories
Mar 10, 2011

Eibun Senaha (NCTS)
Electroweak baryogenesis in the MSSM revisited
Mar 31, 2011

Elena Sorokina (Sternberg Astronomical Inst)
Supernova Explosions inside Carbon-Oxygen Circumstellar Shells
Feb 10, 2011

Carsten Rott (Ohio State U)
Closing in on Dark Matter
Feb 15, 2011

Norikazu Yamada (RIKEN)
Search for Walking Technicolor theory using Lattice
Feb 17, 2011

Ed Turner (Princeton)
The Limits of Reductionism
Feb 18, 2011

Hiroshi Iritani (Kyoto)
Ruan’s conjecture and integral structures in quantum cohomology
Feb 21, 2011

Scott Dodelson (Fermilab/ U Chicago)
The Dark Sector vs. Modified Gravity
Feb 23, 2011

Yusei Koyama (Tokyo)
Panoramic mapping of star formation in and around distant clusters of galaxies
Feb 24, 2011

Michel Granger (U of Angers)
Linear free divisors and quivers
Feb 28, 2011

Yuji Tachikawa (IPMU)

Conferences
April 5–6
Workshop on Recent Advances in Mathematics at IPMU

April 28–29
Mini-Workshop on Cosmic Dust

June 28–July 2
CL2010: from Massive Galaxy Formation to Dark Energy

July 13
IDEAS (IPMU Day of Extragalactic Astrophysics Seminars) on Chemical Evolution

August 4–5
Workshop “Galaxy and Cosmology with Thirty Meter Telescope(TMT)”

September 9–10
Subaru Future Instrumentation Workshop

September 27–October 1
Horiba International Conference COSMO/CosPA 2010

October 4–8
Focus Week: String Cosmology

October 25–28
Workshop “Evolution of Massive Galaxies and Their AGNs with SDSS-III/BOSS Survey”

November 8–11
Mini Workshop on Neutrinos

November 15
Workshop on Population III Gamma-Ray Burst

December 1
The 4-th Meeting of OMEG Institute “Supernova Explosions and Nucleosynthesis”

December 9–10
PFS (Prime Focus Spectrograph) Science Workshop

February 7–8, 2011
Workshop on Geometry and Analysis of Discriminants

February 24
Workshop “Log Hodge Theory and Elliptic Flat Invariants”

February 21–25
IPMU Workshop on Black Holes

April 3–5
Workshop on Recent Advances in Mathematics at IPMU 2

April 28–29
Mini-Workshop on Cosmic Dust

June 28–July 2
CL2010: from Massive Galaxy Formation to Dark Energy

July 13
IDEAS (IPMU Day of Extragalactic Astrophysics Seminars) on Chemical Evolution

August 4–5
Workshop “Galaxy and Cosmology with Thirty Meter Telescope(TMT)”

September 9–10
Subaru Future Instrumentation Workshop

September 27–October 1
Horiba International Conference COSMO/CosPA 2010

October 4–8
Focus Week: String Cosmology

October 25–28
Workshop “Evolution of Massive Galaxies and Their AGNs with SDSS-III/BOSS Survey”

November 8–11
Mini Workshop on Neutrinos

November 15
Workshop on Population III Gamma-Ray Burst

December 1
The 4-th Meeting of OMEG Institute “Supernova Explosions and Nucleosynthesis”

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Workshop “Log Hodge Theory and Elliptic Flat Invariants”

February 21–25
IPMU Workshop on Black Holes
IPMU Programme on AdS Holography and the Quark-Gluon Plasma
(2010.08.02 - 06, Daejeon, Korea)
Shigeki Sagimoto
Holographic QCD
M. C因为她
Mesons as open strings in holographic QCD
Wakate Summer School
(2010.08.06 - 08.07, Kussharo, Japan)
Masahito Takehara
Mesons as open strings in holographic QCD
Lectures on Ads/CFT
(2010.08.07 - 20, Aspen, Colorado)
Ken’ichi Nomoto
Proponents theories
Seminar at Hiroshima University
(2010.08.10, Hiroshima, Japan)
Masahito Takehara
Subaru Weak Lensing Study of Galaxy Clusters
SLAC Summer Institute
(2010.08.12 - 13, SLAC)
Mark Vasai
Atmospheric Neutrinos
The 4th International Conference on Representation Theory
(2010.08.13, Xian, China)
Ken’ichi Nomoto
Highest weight representation of Elliptic Lie Algebras
International conference and summer school on LHC physics
(2010.08.16 - 08.25, Tsinghua University, China)
Jing Shu
New Physics from the 3rd generation?
Looking for New Physics in the 3rd Generation
ESI Conference on Ads Holography and the Quark-Gluon Plasmas
(2010.08.17, ESI, Geneva)
Shigeki Sagimoto
Mesons as open strings in holographic QCD
APCTP Focus Program Aspects of Holography and Gauge/string duality
(2010.08.17 - 18, APCTP, Pohang, Korea)
Tadashi Takayanagi
Emergent Holography on D-branes and Quantum Quench from Ads/CFT
Tadashi Takayanagi
Topological Insulators and Superconductors from String Theory
Topologyological Insulators and Superconductors from String Theory
(2010.08.18, NAM. Mitaka, Tokyo)
Hiroshi Murayama
Status of SuMIRe project
NAGA Symposium
(2010.08.19, NAM. Mitaka, Tokyo)
Hiroshi Murayama
Status of SuMIRe project
RUSY 2010
(2010.08.23 - 08.28, University of Bonn)
WonSong Cho
New Particle Mass Spectrometry at the LHC
Spectropolarimetry of Supernovae: Prospects for TMT
(2010.08.20 - 24, Lorentz Center, Leiden, Netherlands)
Ken’ichi Nomoto
Perspective Talk in Neutrino Physics
JPS Fall meeting
(2010.08.21 - 08.25, Kyusyu kogyo University, Japan)
Fumio Nozaki
Dark Matter from Split Sessas
Shigeki Sagimoto
Quark Confinement and Chiral Symmetry from String Theory
Na TheME: Neutrino Theory, Models, and Experimental Perspective
(2010.08.23, Geneva)
Hiroshi Murayama
Perspective Talk in Neutrino Physics
Workshop: Observational signatures of type Ia supernova progenitors
(2010.08.20 - 24, Lorentz Center, Leiden, Netherlands)
Ken’ichi Nomoto
Single degenerate progenitor models
Workshop on Topologies for Early LHC Searches
(2010.08.27 - 09.25, SLAC)
Michio K. Numori
Class of Models with Jets+MET, Kinematics, Branches and Interactions
International Conference Japan-Mexico on Topology and its Applications
(2010.09.27 - 10.10, Colima University, Mexico)
Toshio Kukline
Quantum representations of mapping class groups
Conference on Real Singularities
(2010.09.11 - 09.15, Salvador, Japan)
Chihara Hatake
Cosmological implications of gravity at a Lifshitz point
Fumio Nozaki
Higgs inflation with a running kinetic term
Chao Ren Chen
The variant axion models at the LHC
Emir Gumrukcuoglu
Signature from Anisotropic Inflation
Conference Talks
Workshop on Mirror Symmetry and Related Topics (2011.01.22 - 02.04, University of Miami, Florida) Sergey Galkin

Laurent phenomenon for Landau-Ginzburg potential
Sergey Galkin

G-Fano thresholds and Mathieu group

Seminar at University of Tokyo (2011.01.24, Hongo, Tokyo) Matthew Sudano

Non-Renormalization Theorems and O-term SUSY Breaking
Extra Dimension 2011 (2011.01.24 - 01.25, Osaka University) Shigeki Matsumoto

Indirect detections of dark matter using cosmic rays
Kosuke Toda

Discovery of minimal UED at the LHC

ADC Colloquium (2011.01.25, NAOJ, Mitaka, Tokyo) Daiki Koyan

Velocity Power Spectrum of the SDSS Galaxies: Spherical Harmonics Analysis
The 4th Symposium on Deciphering the Ancient Universe with Gamma-Ray Bursts (2011.02.07 - 09, Tokyo Tech) Ken'ichi Nomoto

The evolution and final fate of mass accreting Pop III stars
2011 Shanghai Asia-Pacific School and Workshop on Gravitiation (2011.02.10, Shanghai Normal University, China) Shintaro Mukohyama

Alternative Gravity Theories
KIAS Geometry Seminar (2011.02.11, 02.14, 02.21, KIAS, Korea) Sergey Galkin

Mirror symmetry for minuscule varieties
Sergey Galkin

Degenerations, mirrors and their mutations
Sergey Galkin

Mirrors for Fanos thresholds
Unresolved Problems in Astrophysics and Cosmology (2011.02.14, Velaquez, Spain) Hisao Miyamato

Neutrinos

Seminar at Cambridge University (2011.02.16, 02.17, DAMTP, Cambridge) Shigeki Matsumoto

Baryons as Solitons in Holographic QCD
Sergey Galkin

3-manifolds in Holographic QCD
Shing-Fu Shao

U Tokyo GCORE-physics research assistant retreat (2011.02.18, Izu-Nagaoka, Japan) Taizan Watari

String Theory Useful for Particle Physics
Himeji PDE conference (2011.02.19 - 02.20, Himeji, Japan) Akihiro Gomonaka

Resurgent analysis of the Witten Laplacian in one dimension
Workshop on Fano Varieties and External Laurent Polynomials (2011.02.22 - 02.23, Imperial College London) Sergey Galkin

1. Beyond Minkowski ansatz,
2. Cones and Unicorns; Tom, Jerry and Spike,
3. Special Cremoana group gauge-equivalence principle: Cremoana ansatz and towards “Einrich ansatz”
Columbia at Excellence Cluster (2011.02.21, Excellence Cluster, Garching) Masayuki Tanaka

A new method to identify AGNs and the nature of low-luminosity AGNs
Seminar at King’s College (2011.02.24, King’s College London) Sergey Galkin

Mirrors for minuscule varieties
Colloquium at University of Tokyo (2011.02.25, Tokyo, Japan) Todor Milanov

Integrable systems in GW theory

The evolution and explosion of mass-accreting Pop III stars
Integral systems, random matrices, algebraic geometry and geometric invariants

Sato-Kondo

Expressions of local L and factors in Hecke eigenvalues
Seminar at Carnegie Observatories (2011.03.01, Carnegie Observatories, Pasadena) Ken’ichi Nomoto

The Evolution of Pop III Stars and Extremely Metal-Poor Stars
Multi Messengers from Supernovae

Masayuki Tanaka

3D Geometry of Supernovae Revealed by Optical Spectropolarimetry
Semen at Kinki University (2011.03.04, Kinki University, Japan) Tadashi Takayanagi

Holographic Entanglement Entropy
Long Term Workshop Geometry and Analysis (2011.03.08, Ohio State University) Mark Vagnum

F-functions associated with cancellative monoids
DENST 2011 Subaru HSC meeting (2011.03.07, ASIAA, Taiwan) Masayuki Tanaka

Photo-z working group progress report
Center for Cosmology and Particle Physics Seminar (2011.03.08, Stockholm University) Mark Vagnum

GAZIQUIS! How to See Extragalactic Neutrinos by their Neutrinos
Colloquium at National Central University (2011.03.09, National Central University, Taiwan) Tai-Yan Lamm

Analytical modelings in large-scale structure
PHY 880 Guest Lecture (2011.03.09, Ohio State University) Mark Vagnum

Chasing Neutrinos Around the World: A Personal History
Special Seminar at ASIAA (2011.03.10, ASIAA, Taiwan) Tai-Yan Lamm

Analytical modelings in large-scale structure

Exponential Asymptotics and Virtual Turning Points
Colloquium at University of Tokyo (2011.03.10, University of Tokyo, Komaba, Tokyo) Sergey Galkin

Resurgent analysis of the Witten Laplacian in one dimension

PFS Technical Meeting (2011.03.01, Princeton) Hiroshi Morimoto

PFS Status
Electronic Symmetry Breaking

(2011.03.11 - 03.17, YITP, Kyoto University) Shigeki Matsumoto

Discussion: Composite Higgs models

Inflations in Complex Geometry
(2011.03.14 - 18, Moscow) Alexey Bondal

Coherent sheaves on minuscule varieties
Cosmological Perturbation and Cosmic Microwave Background

(2011.03.15, Kyoto) Ken’ichi Nomoto

Status of Horava-Lifshitz gravity
Rencontres de Morand (2011.03.20 - 2011.03.27, La Thuile, Aosta, Italy)

Cosmic Bambi

Compact objects with spin parameter > 1
Shigeki Matsumoto

Holographic Description of Hadrons from String Theory
Spring meeting of the German Physical Society (2011.03.21, Muenster, Germany)

Kai Martin

X Mass Experiment in Kamioka
Symposium on Future Applications of Germanium Detectors in Fundamental Research (2011.03.23 - 2011.03.29, Beijing) Jing Liu

Pulse shape simulation for segmented detectors

Branes and Bottom Ansatz in Supersymmetric Gauge Theories Workshop: Detectors in Fundamental Research (2011.03.21, Muenster, Germany)

Tsz Yan Lam

Analytical modelings in large-scale structure

JPS Annual Meeting

JPS Annual Meeting

Mark Vagnum

Status of Horava-Lifshitz gravity

JPS Annual Meeting

Analytical modelings in large-scale structure

Joint Seminar on Number Theory of Laboratoire J.-V. Poncelet and Sector 4.1 ITP-RAS (2011.03.28, Independent University of Moscow) Sergey Galkin

Fano and Mathieu

Seminar of the Department of Algebra

(2011.03.28, Steklov Mathematical Institute, Russia) Sergey Galkin

Mutation of potentials

IPSS Annual Meeting (2011.03.29, Nagoya, Japan)

Kohtaku Toda

Discovery of minimal UED at the LHC

Conference Talks
Visitors

(This list includes principal investigators and joint appointment staff.)

JFY2010

2010

Charlie Boll, UC Santa Barbara (USA), mathematics 03.24-06.18
Thomas O'Donnell, LBL (USA), neutrino-physics 3.27-6.45
Michael Ratz, Technical U Munich (Germany), particle theory 3.28-4.02
George Smoot, LBL (USA), astrophysics 4.02-4.04
Alexandros Usimich, Zurich (Switzerland), mathematics 4.03-4.25
Antonio Buarras, Technical U Munich (Germany), particle theory 4.04-4.48
Alexey Bondal, Abderdeen (UK), mathematics 4.04-4.17
Alexander Kusenko, UCLA (USA), particle theory 4.05-4.05
Josh Rulofman, Princeton (USA), particle theory 4.05-4.11
Daniel Storlshimer, Bourgogne (France), mathematics 4.05-4.06
Tomosuki Abe, Tokyo (Japan), mathematics 4.05-4.06
Ryo Oskawa, Tokyo Tech (Japan), mathematics 4.05-4.06
Masaki Harada, Tokyo IoA (Japan), mathematics 4.05-4.06
Yoichiro Akiyoshi, Tokyo (Japan), mathematics 4.06-4.06
Daniel Sternheimer, Bourgogne (France), mathematics 5.12
Nobuhiro Okabe, Osaka U (Japan), particle theory 5.11-5.11
Eiji Takahashi, Osaka U (Japan), particle theory 5.11-5.11
Ryosuke Kodera, Kyoto (Japan), mathematics 5.12
Masahiro Futaki, Tokyo (Japan), mathematics 5.24-5.24
Atsushi Nishizawa, Tohoku (Japan), astronomy 5.24-5.24
Jia-Wei Chien, Academia Sinica (Taiwan), astronomy 5.24-5.24
Akira Ishii, Kyoto (Japan), astronomy 5.24-5.24
Hisanori Furusawa, Tohoku (Japan), astronomy 6.23-6.25
Kenta Matsushita, Keio (Japan), high energy physics 6.23-6.25
Yusa Keyama, Tokyo (Japan), 6.23-6.26
Kenta Matsuoka, Elime (Japan), cosmology 6.23-6.25
Sugio Mine, Tokyo (Japan), astrophysics 6.23-6.25
Satoshi Miyazaki, NAOG (Japan), astronomy 6.23-6.25
Tomoki Morishima, NAOG (Japan), astronomy 6.23-6.25
Tohru Nagao, Elime (Japan), astronomy 6.23-6.25
Hiroaki Nishioka, Academia Sinica (Taiwan), astrophysics 6.23-6.25
Atsushi Nishizawa, Tokyo (Japan), astronomy 6.23-6.25
Masumune Osuga, NAOG (Japan), cosmology 6.23-6.25
Tomohiro Okumura, Tohoku (Japan), astronomy 6.23-6.25
Jun Okumura, Kyoto (Japan), astrophysics 6.23-6.25
Yuki Okura, NAOG (Japan), astronomy 6.23-6.25
Kazuhiro Shimakawara, Tohoku (Japan), astronomy 6.23-6.25
Ken-ichi Takada, Tokyo (Japan), astronomy 6.23-6.25
Ryuichi Takahashi, Hirokawa (Japan), astronomy 6.23-6.25
Mikito Tamura, Tohoku (Japan), astronomy 6.23-6.25
Atsushi Tsuruya, Tokyo (Japan), astrophysics 6.23-6.25
Tatsuyoshi Terai, Kobe (Japan), astronomy 6.23-6.25
Naoumi Tomimori, Konan U (Japan), astrophysics 6.23-6.25
Yuji Utaka, NCU (Taiwan), astronomy 6.23-6.25
Keichi Uemitsu, Academia Sinica (Taiwan), astrophysics 6.23-6.25
Yoonsuk Utsunomi, NAOG (Japan), astronomy 6.23-6.25
Pin-Wen Wang, NTNU (Taiwan), astronomy 6.23-6.25
Yoshitake Ueda, Kyoto (Japan), astrophysics 6.23-6.24
Chi-Hung Yuan, ASEAA (Taiwan), astrophysics 6.23-6.24
Kohki Konishi, Tokyo RIKR (Japan), astrophysics 6.23-6.25
Mei-Wei Li, JINS (China), cosmology 6.25-7.02
Toshikazu Kawaguchi, Tokai (Japan), astrophysics 6.25-6.25
August Eyrard, Michigan State (USA), astrophysics 6.26-7.02
Henk Hooftstra, Leiden (Netherlands), cosmology 6.26-7.02
Paul Martin, Ohio State (USA), astrophysics 6.26-7.02
Johan Richard, Durham (UK), cosmology 6.26-7.02
Anthony Gonzalez, Florida (USA), astrophysics 6.27-7.03
William Holzapfel, UC Berkeley (USA), astrophysics 6.27-7.02
Stefano Borsani, U Trieste (Italy), cosmology 6.27-7.01
James Bullock, UC Irvine (USA), cosmology 6.27-7.03
Daisuke Nagai, Yale (USA), cosmology 6.27-7.16
Gabriella De Luca, INFN-FATT Trieste (Italy), cosmology 6.27-7.04
Hans Bongirn, MPI (Germany), cosmology 6.27-7.03
Sudeep Das, IBL (USA), cosmology 6.27-7.07
12 Publications

JFY2007


4. The process nucleosynthesis in population III core-collapse supernovae.


29 Chasing the nonlinear evolution of matter power spectrum with a numerical resummation method: Solution of closure equations, 2009.


121. **ARKI INFRARED OBSERVATIONS OF IMPERSONATOR'S REMNANT G292.0+1.8: UNVEILING CIRCUMSTELLAR MEDIUM AND SUPERnova 1E 0102.2-7219.**

122. **B → τντ and new sources of CP violation in super asymmetry.**

123. **FIRST YEAR SLOAN DIGITAL SKY SURVEY-II PERNOW RESULTS: Hubble Diagram and Cosmological Parameters.**

124. **ANALYTIC SOLUTION FOR MATTER DENSITY PERTURBATIONS IN A CLASS OF VIABLE COSMOLOGICAL IRM MODELS.**

125. **FLAVOR effects on the electric dipole moments in supersymmetric theories: A beyond leading order analysis.**

126. **Accleration process onto super-spinning objects.**

127. **Crystal Melting and Toric Calabi-Yau Manifolds.**

128. **Cosmic ray spectra in Nambu-Goldstone dark matter models.**

129. **Like-sign dilepton signals in Higgsless models at the LHC.**

130. **Cosmic-Ray Electron and Positron Excesses from Hidden Gauging Dark Matter.**

131. **Superpotentials for superconformal Chern-Simons theories from representation theory.**

132. **Right-handed neutrinos in F-theory compactifications.**

133. **Holographic entanglement entropy: an overview.**

134. **EARLY PHASE OBSERVATIONS OF EXTREMELY LUMINOUS TYPE Ia SUPERnovae 2009nc.**

135. **THE ROLE OF TYPE Ia SUPERnovAE IN CHEMICAL EVOLUTION. I. LIFETIME OF TYPE Ia SUPERnovAE AND METALLICITY EFFECT.**

136. **Horava-Lifshitz holography.**

137. **Nonlinear evolution of baryon acoustic oscillations: Convergence Regime of N-body Simulations and Analytic Models.**

138. **Cosmic-Ray Electron and Positron Excesses from Hidden Gauging Dark Matter.**

139. **Superpotentials for superconformal Chern-Simons theories from representation theory.**

140. **Right-handed neutrinos in F-theory compactifications.**

141. **Holographic entanglement entropy: an overview.**

142. **EARLY PHASE OBSERVATIONS OF EXTREMELY LUMINOUS TYPE Ia SUPERnovae 2009nc.**

143. **THE ROLE OF TYPE Ia SUPERnovAE IN CHEMICAL EVOLUTION. I. LIFETIME OF TYPE Ia SUPERnovAE AND METALLICITY EFFECT.**

144. **Horava-Lifshitz holography.**

169. Reevaluation of Higgs-mediated n-o transition in the MSSM

170. Spin and chirality determination of superparticles with long-lived stau at the LHC


IPMU10-0001
Sergey Galitski
Toric degenerations in the mirror: Laurent phenomenon for Landau-Ginzburg potential

IPMU10-0002
Sophie Villani, Alexei Uminic
G-minimal varieties are quantum minimal

IPMU10-0003
Fumihito Takahashi
Linear Inflation from Running Kinetic Term in Supergravity

IPMU10-0011
Keisuke Nakai, Stefano Benetti, Maximilian Stanzinger, Friedrich K. Roeske, Guston Felleti, Jøsper Sollermann, Stefan Teuberbergen, Ken'ichi Nomoto, Georgios Leloudas, Mario Hamuy, Masamori Tanaka, Paolo A. Mazzalli, Nancy Elias-Rosa
An asymmetric expansion as the origin of the spectral evolution diversity in type Ia supernovae

IPMU10-0012
Yong-Joon Song, Cristiano G. Sabiu, Iosha Kayo, Robert C. Nichol
Measuring Coherent Motions in the Universe

IPMU10-0013
J. Hisano, K. Kohri, and N. Nagata
Gluon contribution to the dark matter direct detection

IPMU10-0014
Yun-Ting Lin, Yue Shen, Michael A. Strauss, Gordon Nichol
On the Populations of Radio Galaxies with Extended Morphology at z < 0.3

IPMU10-0015
Seoni Chan Puk, Joo Shu, Kai Wang, Tsutomu T. Yanagida
T'W: scale horizontal gauge symmetry and its implications in B Physics

IPMU10-0016
Roland de Putter, Masahiro Takada
Halo-Galaxy Lensing: A Full Sky Approach

IPMU10-0017
Satoko Konno, Shinji Mukohyama, T. Richards, Raphaël Lindfors
Local I. and epically factors in Hecke eigenvalues

IPMU10-0018
Daniel Klei and Johannes Walcher
Extended Holomorphy Anomaly in Gauge Theory

IPMU10-0019
Takahiro Ninomiya, Atsushi Taruya, Kazuya Koyama, Christian Sabia
Scale Dependence of Halo Reflectometry from Non-Gaussian Initial Conditions in Cosmological N-body Simulations

IPMU10-0020
Hirosi Ooguri, Chang-Soon Park
Mohrgraph and End-Point of Spatially Modified Phase Transition
arXiv:1006.5199 [hep-th]

IPMU10-0021
Kenji Hashimoto and Norim Yukoaki
Soft Lepogenesis and Gravitino Dark Matter in Gauge Mediation

IPMU10-0022
Re-capturing cosmic information

IPMU10-0023
N. Okabe et al. (including M. Takada)
LeCOSB: Calibrating Mass-Observable Scaling Relations for Cluster Cosmology with Sunyaev Weak Lensing Observations

IPMU10-0025
F. Meinhardt et al. (including Y.-T. Lin)
The Atacama Cosmology Telescope: Physical Properties and Purity of a Galaxy Cluster Sample Selected via the Sunyaev-Zel'dovich Effect

IPMU10-0026
Shinsei Ryu and Tadashi Takayanagi
Topological Insulators and Superconductors from String Theory
JHEP 1010, date of acceptance 2010.09.24

IPMU10-0027
Kazuo Nakayama, Fumimori Takahashi, Tsutomu T. Yanagida
Constraint on the gravitino mass in hybrid inflation

IPMU10-0028
Yukinobu Toda
Curveting invers from the cornold point arXiv:1007.0026 [hep-th]

IPMU10-0029
Thomas T. Dumitrescu, Zohar Komargodski, Matthew Nomoto
Global Symmetries and D-terms in Super-yect Field Theories
JHEP 1003, 071 (2010), date of acceptance 2010.01.29, arXiv:1001.0053 [hepp-th]

IPMU10-0030
W. S. Cho, W. Klemm, M. M. Nojiri
Mass Measurement in Bosed Dacay Systems at Hadron Colliders

IPMU10-0031
W. S. Cho, W. Klemm, S. Mandal, M. M. Nojiri
New Particle Mass Spectrometry at the LHC: Revealing Combinatorial Endpoints
JHEP 1004, 071 (2010), date of acceptance 2010.03.17, arXiv:1002.4644 [hepp-th]

IPMU10-0032
Cosmo Bamb
Violation of the Carter-Israel conjecture and its astrophysical implications

IPMU10-0033
Antonio Cabaza, Alexander Kusenko, Shigehiro Nagata
Role of plastic sources and magnetic fields in forming the observed energy-dependent composition of ultrahigh-energy cosmic rays

IPMU10-0034
Shuichiro Ando, Alexander Kusenko
Interactions of keV sterile neutrinos with matter

IPMU10-0036
Alexander Kusenko

IPMU10-0037
Motoe Endo, Keisuke Hamaguchi, Koutaki Nakai
Probing High Reheating Temperature Scenarios at the LHC with Long-Lived Staus

IPMU10-0038
Kazunori Nakayama and Fumimori Takahashi
Running Kinetic Inflation
JCAP 09, 01085 (2010), date of acceptance 2010.08.26, arXiv:1002.3262 [hep-th]

IPMU10-0039
Ichiro Nakada, Mathew Sudano, Tsutomu T. Yanagida
A C-flavor solution of the muon-antimuon problem of gauge mediation
JHEP 1006, 040 (2010)

IPMU10-0040
Masahiro Ibe, Yuri Shirman, Tsutomu T. Yanagida
Cascade supersymmetry breaking and low-scale gauge mediation
JHEP 1005, 074 (2010), date of acceptance 2010.05.13, arXiv:1002.4895 [hep-th]

IPMU10-0041
Masami Tanaka, Paolo A. Mazzali, Vally Stansbeh, Immanuel Maurer, Wolfgang E. Kerzendorf, Ken'ichi Nomoto
Abundance stratification in Type Ia supernovae - III. The normal SN 2003du

IPMU10-0042
Observations of the Optical Transient in NGC 300 with AKARI/IRC: Possibilities of Asymmetric Dust Formation

IPMU10-0043
I. Sakon, T. Kato and T. Yanagida
Gravitational Supersymmetry Breaking

IPMU10-0044
Rich Bolt, Alexis Finkernau, Masayuki Tanaka, et al.
The WiBAC Deep Infrared Cluster Survey I: Groups and Clusters at z < 0.11
14 Outreach and Public Communications

We continue to convey the importance and excitement of our research activities to the general public through public lectures and a variety of outreach programs. For the public lectures, we have established a tradition of having enough time for discussion after each lecture so that the audience can directly ask questions to the speaker. We organized fifteen public lectures in this period.

Attracting young people into science is an important part of our outreach programs. We organized, as a part of UT Science Faculty project, a special event for motivating the scientific mind of female junior high school and high school students. Optionally, their parents were also allowed to participate because we think the mindset of the parents plays an important role in this effort.

We published four more editions of IPMU NEWS in this period, covering a wide range of information including conferences and seminars, research highlights and newly arrived members. They also feature interesting topics in other research fields. We broadcasted six more “Ask a Scientist” video clips on the website, in which IPMU scientists explain technical terms to the general public in just one minute.

We actively participated in various events within our capacity for the promotion of science in general and IPMU’s activity. Good communication with the local community as well as within the institute helps quality of life, especially for those from abroad, which reflect to their research output. We have valuable support from “IPMU Volunteers.” Daily teatime is not just for science talks, but occasionally, for happy gatherings.

George Smoot of UC Berkeley, Nobel laureate of 2006, talks about Creation and History of the Universe with the help of Naoshi Sugiyama’s translation.

Shinji Mukohyama answers questions after the public lecture on the Universe Beyond the Four Dimensions.

Female students from junior high-school and senior high-school are trying to have good feel about the scale of the universe.

Public Lectures

- The creation and history of the universe
  George Smoot (2006 Nobel laureate in physics), April 3, Yayoi Hall.

- Miraculous string theory—towards the final theory of matter
  Shigeki Sugimoto, April 17, The 3rd Joint ICRR-IPMU Public Lecture.

- Relativity, elementary particles and cosmology
  Naoki Yoshida, June 26, Kawagoe High School.

- Mystery of dark energy that fills the universe
  Hiroshi Karoji, June 26, Nayoro, Hokkaido.

- Final theory of elementary particles
  Hirosi Ooguri, September 12, Science cafe in Nagoya.

- Galaxies living in the universe
  Naoki Yoshida, November 12, Science cafe in Kogakuin University.

- The universe beyond the four dimensions
  Shinji Mukohyama, November 14, The 4th ICRR-IPMU Public Lecture.

- Einstein’s dream—mystery of gravity and string theory—
  Shigeki Sugimoto, December 10, Science cafe in Kogakuin University.

- Birth of stars, galaxies and black holes
  Naoki Yoshida, January 22, Suwa-Seiryu High School, Nagano.

- Dark universe and luminous stars
  Naoki Yoshida, February 9, Roppongi Astronomy Club.

- What is the universe made of?
  Hitoshi Murayama, March 9, TODIAS Inauguration Public Lecture, Yasuda Hall.

- The frontiers of fundamental physics
  David Gross (2004 Nobel Laureate in physics), March 9, TODIAS Inauguration Public Lecture, Yasuda Hall.
IPMU joined other WPI centers at the Science Festa that took place in Kyoto. [June 2010]

Midori Ozawa of International Relations section presented “Dealing with Foreign Scientists” during the Open Campus Day. [October 2010]

Murayama hosted a tea-time for IPMU-volunteer members. [October 2010]

Marriage of Liqin and Minxin was celebrated during a daily tea-time with special home-made cakes. [December 2010]

Video Clips

- Hadrons and String Theory by Shigeki Sugimoto in April
- Super-massive Black Hole by John Silvermann in September
- Supersymmetry by Kai Wang in November
- Cosmology by Shinji Mukohyama in December
- Holographic Principle by Tadashi Takayanagi in January
- Baryon Acoustic Oscillation by Yen-Ting Lin in February

IPMU NEWS

IPMU NEWS hosted a round table discussion by foreign researchers on “Life in Japan, Life at IPMU.” [June 2010]

Members of Japanese class play a well-known Japanese fairy tale ‘Momotaro’ during the Open Campus Day. [October 2010]

Marriage of Liqin and Minxin was celebrated during a daily tea-time with special home-made cakes. [December 2010]