KMI ACTIVITY IN DIVISION OF THEORETICAL STUDIES

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KOBAYASHI-MASKAWA INSTITUTE FOR THE ORIGIN OF PARTICLES AND THE UNIVERSE

NAGOYA UNIVERSITY

ON DIVISION OF THEORETICAL STUDIES IN KMI

基礎理論研究部門は、これまでの名古屋大学における基礎理論研究の輝かしい伝統を踏まえ、名古屋大学独自のアプローチで基礎理論研究のこの第2の革命期をリードしていくことを目指します。標準理論を超える理論の探求や標準理論のゲージダイナミクスの解明を行う素粒子論部、ダークマターやダークエネルギーなど宇宙と素粒子の融合研究を行う宇宙論部、ゲージ理論・弦理論対応を中心に数理構造研究を進める弦理論・数理構造部の各部門に加え、専用高速計算機を駆使した数値シミュレーションによってゲージ場理論や宇宙進化を解明する理論計算物理室が密接に協力し、さらには現象解析研究部門との連携を行うことで、新たな時代の基礎理論を開拓していきます。

At Nagoya University the foundation of ingenious research of theoretical physics was built by Prof. Shoichi Sakata and his colleagues, and various great achievements, led to the revolution of the fundamental physics that occurred in the 1970s, had been produced one after another. Among these are the Two-Meson Hypothesis which introduces μ lepton, Sakata model, which gave the foundation of the quark model, and Maki-Nakagawa-Sakata theory predicting the neutrino oscillations. These achievements culminated in the Kobayashi-Maskawa theory and further in the Standard Model of particle physics based on the gauge quantum field theory. After the Standard Model went through stringent tests of high-energy accelerator experiments, Prof. Kobayashi and Prof. Maskawa were awarded the 2008 Nobel Prize.

The standard model, which had been tested successfully through a wide variety of experiments and observations, recently became to show its flaws where the phenomena not explained with the simple standard model have been found. They are dark energy, dark matter, whose existence was established in recent precision astrophysical observations, and the neutrino oscillations found in the underground experiments. The long-waited experiments in the large hadron collider (LHC), now under operation, are expected to produce in a few years the key results to solve the question of the origin of mass of the elementary particles. It is no exaggeration to say that now the study of the fundamental theory of particles and the universe are entering the second revolutionary era after the first that produced the standard model in 1970th.

At the Division of Theoretical Studies in KMI, based on the brilliant tradition of research in the fundamental physics at Nagoya University, we aim to lead the fundamental theoretical physics with our original approach again in the period of this second revolution. The center consists of three divisions; The Theoretical Particle Physics Group studies the theory of elementary particle and explores the physics beyond the standard model. The Cosmology and Theoretical Astrophysics Group researches particle physics and cosmology to solve the problems such as the dark matter and dark energy. The String Theory and Mathematics Group investigates mathematical structures mainly for the gauge/gravity correspondence. In addition to the three divisions, Computational Theoretical Physics Laboratory carries out numerical simulation utilizing the high performance computers equipped in this institute to elucidate the evolution of the universe and the gauge dynamics of the quantum field theory. Working closely with all of these divisions and laboratory, and also in corporation with the Division of Experimental Studies, we will explore the fundamental theoretical physics in the new era.

GREAT HISTORY ON PARTICLE PHYSICS IN NAGOYA

- Two-Meson hypothesis (introducing μ lepton)
- Sakata Model (foundation of quark model)
- Maki-Nakagawa-Sakata theory (predicting neutrino oscillations)
- Kobayashi-Maskawa matrix (one of heart in Standard Model)

2008 Nobel Prize for Kobayashi and Maskawa

CURRENT CHALLENGES

While Standard Model has been highly successful, …

- Dark energy and dark matter
- Neutrino oscillations,…

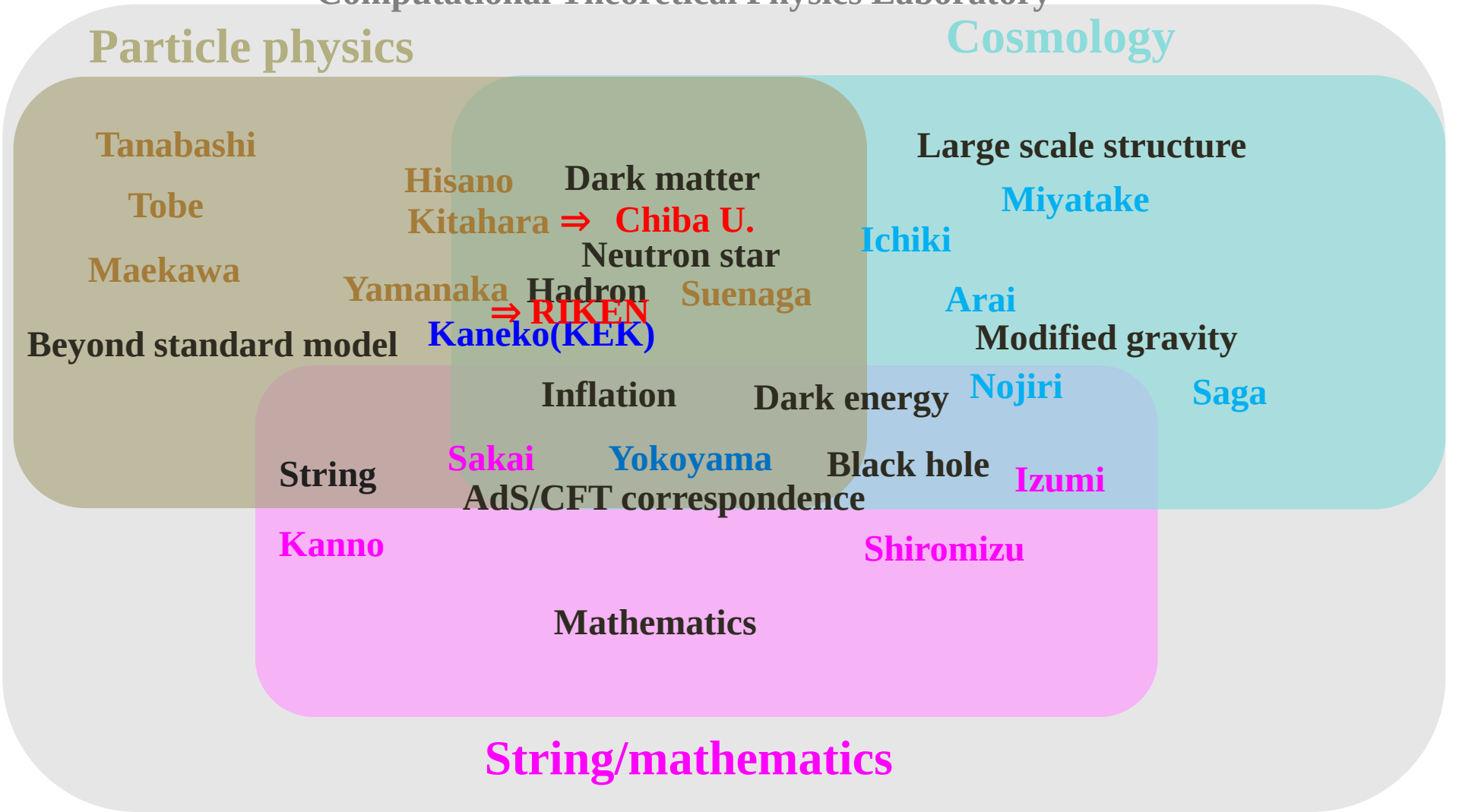
Beyond Standard Model

Dark Universe

Organization

ORGANIZATION IN FY2023

Computational Theoretical Physics Laboratory



COMPUTATIONAL THEORETICAL PHYSICS LABORATORY

organised by Tanabashi, Ichiki, Nonaka

Parallel computers

GPU machines

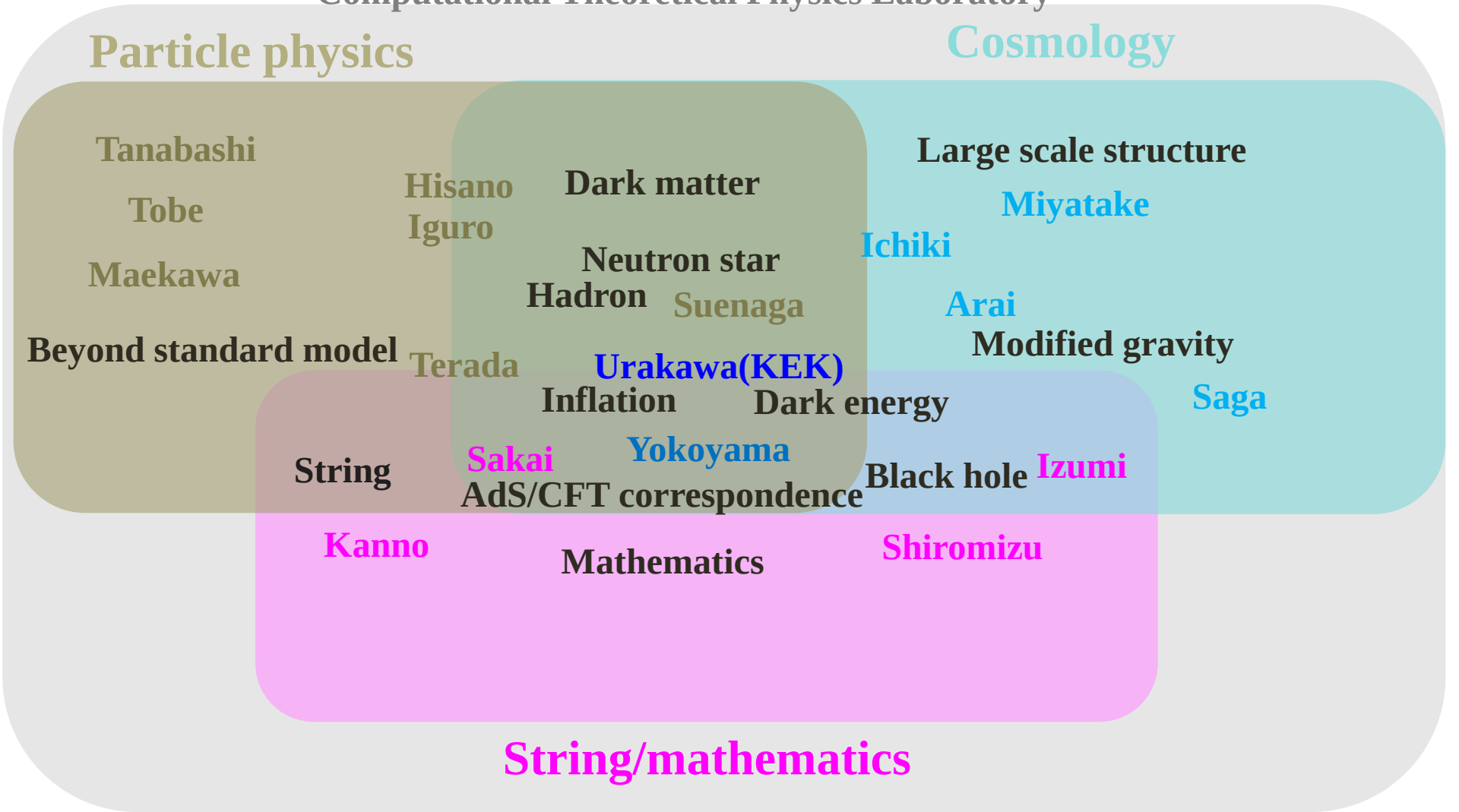
Hydrodynamic simulation for QGP

Cold and Dense QCD

Cosmological Simulation

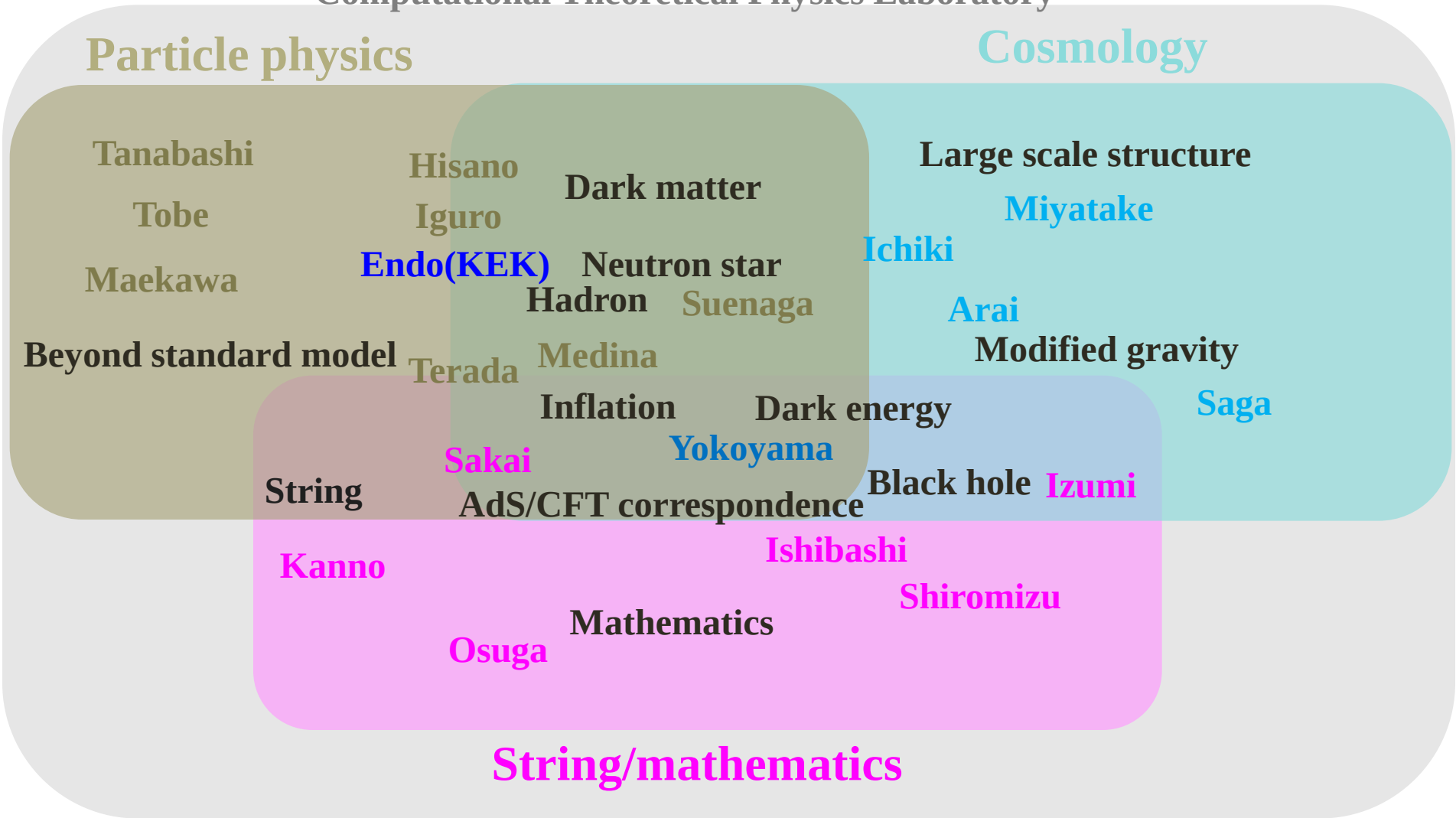
ORGANIZATION IN FY2024

Computational Theoretical Physics Laboratory



ORGANIZATION IN FY2025

Computational Theoretical Physics Laboratory



Summary of Achievements

FY2023 & 2024

FY2023

~ 80 published papers

Workshops@Nagoya

Nagoya Workshop on Exotic Hadrons, Nagoya, 14-17 Nov. 2023

32nd Workshop on General Relatively and Gravitation in Japan, Nagoya, 27 Nov.-1 Dec. 2023

41st Heavy Ion Cafe & 38th Heavy Ion Pub joint workshop, Nagoya, 4th Nov. 2023

1st workshop on General Relativity and Geometry, Nagoya, 8-9 Feb. 2024

Nagoya-Melbourne joint research workshop on cosmology, Nagoya, 19-21 Feb. 2024

Presentations

International 35 + domestic 27

FY2024

~ 60 published papers

Workshops@Nagoya

2nd workshop on dynamics of primordial black hole formation, Nagoya, 7-10 Oct. 2024

2nd workshop on General Relativity and Geometry, Nagoya, 18-19 Nov. 2024

Future of Artificial Intelligence for Science in Japan (FAIRS-Japan), Nagoya, 3-5 Dec. 2024

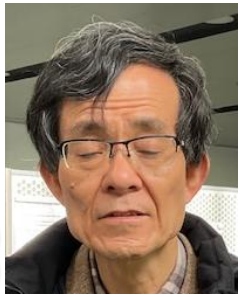
Presentations

International 41 + domestic 19

Awards

Junji Hisano 24th 素粒子メダル "Particle Medal" (18th Sept. 2024)

SENSE AND SENSIBILITY 2023


Harada


Hisano


Kaneko (KEK)

Highlights: Particle physics group

Neutron Stars & Hadron Physics (Harada)

Studied a_0 meson in neutron stars, octet baryons, hadron spectra, and singly heavy baryons.

QCD θ Parameter & CP Violation (Hisano, Kitahara)

Analyzed radiatively generated θ parameters, testing the Fock-Schwinger and Fujikawa methods.

Dark Matter & Astrophysical Constraints (Hisano)

Studied neutral vector particles, astrophysical bounds, and relic density in dark matter scenarios.

B Meson Decays & Lattice QCD (Kaneko)

Calculated $B \to \pi \ell \nu$ and $B \to D^* \ell \nu$ form factors to improve $|Vub|$ and $|Vcb|$ determinations.

Rare Top Quark Decays & New Physics (Kitahara)

Explored $t \to cZ$ decay, vector-like quark models, and implications for W mass shifts.

Di-Tau Excess & New Scalars (Kitahara)

Investigated a CMS di-tau excess, evaluating CP-even and CP-odd scalar interpretations.

Magnetic Monopoles & Fermion Scattering (Kitahara)

Proposed a 4D interpretation of fermion-monopole scattering and Fock space transitions.


Kitahara (Chiba U.)

SENSE AND SENSIBILITY 2023

Highlights: Particle physics group

Maekawa

Tanabashi

Fundamental Constants & Light Particles (Kitahara)

Developed a method to extract fundamental constants while considering light new physics.

Cosmic Strings & Gravitational Waves (Maekawa)

Investigated non-topological cosmic strings as sources of gravitational waves.

Heavy BSM Bosons & Particle Data Review (Tanabashi)

Reviewed searches for Z′, W′, leptoquarks, and compositeness in the 2024 Particle Data Book.

B Meson Anomalies & Leptoquarks (Tobe)

Studied $B \to D(*)lv$, $b \to svv$, and $b \to sl^+l^-$ anomalies with R_2 leptoquark models.

Electric Dipole Moments & CP Violation (Yamanaka)

Investigated EDMs in Xe atoms and two-loop R-parity violating supersymmetry effects.

Tobe

SENSE AND SENSIBILITY 2023

Highlights: String/Mathematics group

Kanno

Sakai

Painlevé VI & Conformal Block (Kanno)

Quantized a discrete Painlevé VI equation, linked to instanton partition functions.

Attractive Gravity Probe Surface (Shiromizu)

Developed AGPS and proved quasi-local mass positivity in cosmology.

Holographic QCD & Neutron Stars (Sakai)

Modeled high-density QCD, derived equation of state, and refined neutron star predictions.

Gravitational Effects in Asymptotically Flat Spacetime (Izumi)

Identified a force-like effect and improved conditions for null geodesic escape.

Izumi

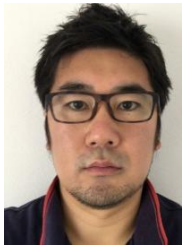
SENSE AND SENSIBILITY 2023


Nojiri


Ichiki


Miyatake


Nishizawa


Yokoyama


Kobayashi

Highlights: Cosmology group

Compact Stars & Modified Gravity (Nojiri)

F(R) gravity, entropy origins, inflation, dark energy, and gravitational wave speed constraints.

Foreground Removal for CMB (Ichiki)

Improved method to extract inflationary gravitational waves from cosmic microwave background data.

Cosmic Shear & Large-Scale Structure (Miyatake)

Analyzed Subaru HSC data, confirming the S_8 tension with Planck results.

Photometric Redshift Measurement (Nishizawa)

Developed a machine-learning-based method to improve galaxy redshift estimation.


Sunayama

Primordial Black Holes & Gravitational Waves (Yokoyama)

Investigated PBH formation, non-Gaussianity, and stochastic GW signals detectable by LISA.

Axions, Inflation & Dark Matter (Kobayashi)

Explored the Peccei-Quinn field as a unified solution for inflation, the strong CP problem, and dark matter.

Optical Cluster Anisotropy & Lensing (Sunayama)

Modeled anisotropic galaxy clusters, developed methods to quantify lensing signal boosts.

SENSE AND SENSIBILITY 2024

Highlights: Particle physics group

Compact Stars & Hadron Physics (Harada)
Studied HESS J1731-347 as a neutron star, phase transitions, and exotic heavy hadrons.

Electron EDM & CP Violation (Hisano, Kitahara)
Calculated three-loop EDM contributions from new SU(2)L interactions.

New Physics & B Meson Decays (Iguro, Kitahara)
Explored leptoquarks, LFU violation, and high-energy B physics constraints.

Grand Unified Theories & Proton Decay (Maekawa)
Investigated fine-tuning issues and proton decay predictions in natural GUTs.

Beyond Standard Model Bosons (Tanabashi)
Reviewed searches for Z′, W′, and leptoquarks in Particle Data Book (2024).

Dark Energy & DESI Constraints (Terada)
Interpreted dark energy evolution via quintessence and axion potentials.

Primordial Black Holes & Dark Matter (Terada)
Analyzed the memory burden effect and gravitational wave signals of PBH dark matter.

Leptoquarks & B Physics Anomalies (Tobe)
Studied NP effects in $B \to D(*)\tau\nu$, $B \to K\nu\nu$, and $b \to s l^+ l^-$.

Exotic Hadrons & Superflavor Symmetry (Yamaguchi)
Modeled Tcc, Tbb, and Tccs tetraquarks and their possible experimental discovery.


Iguro


Terada


Yamaguchi

SENSE AND SENSIBILITY 2024

Highlights: String/Mathematics group

Non-Stationary Difference Equation & Quantum Groups (Kanno)

Proved equivalence to the quantum Knizhnik-Zamolodchikov equation, confirming previous conjectures.

Loosely Trapped Surfaces in Kerr Black Holes (Shiromizu)

Identified infinite LTS solutions and proved uniqueness of the maximum marginal LTS.

Holographic QCD & Neutron Stars (Sakai)

Refined high-density QCD models, predicting phase transitions and neutron star M-R relations consistent with observations.

ADM Mass & Surface Area Inequality (Izumi)

Derived an improved area-mass inequality, incorporating electromagnetic field effects and black hole extremality conditions.

SENSE AND SENSIBILITY 2024

Highlights: Cosmology group

Modified Gravity & Black Holes (Nojiri)

Einstein-Gauss-Bonnet gravity, mimetic gravity issues, F(R) gravity, and holographic cosmology.

Gas Stripping in Subhalos & 21cm Signal (Ichiki)

Simulated ram pressure stripping in subhalos, refining predictions for the 21cm forest signal.

Cluster Cosmology & Large-Scale Structure (Miyatake)

HSC cluster cosmology studies, mass calibration, and DESI collaboration for high-redshift surveys.

Photometric Redshifts & Machine Learning (Nishizawa)

Developed machine-learning-based redshift estimation, improving accuracy for deep imaging surveys.

Primordial Black Holes & Gravitational Waves (Yokoyama)

Studied PBH mergers, stochastic GW signals, and their detectability via LIGO/Virgo/KAGRA.

Magnetic Monopoles & Cosmic Structures (Kobayashi)

Investigated monopole acceleration and proposed a new early matter domination structure formation.

Subaru PFS & Cosmology Surveys (Sunayama)

Worked on target selection for Subaru PFS and contributed to cluster cosmology analyses.