Multimessenger Astronomy Beyond the Standard Model and Quantum Sensing (Q-EYES 2025)

Report of Contributions

Contribution ID: **1** Type: **not specified**

Quantum sensor networks as exotic field telescopes for multi-messenger astronomy

Tuesday, 9 December 2025 10:00 (30 minutes)

Multi-messenger astronomy, the coordinated observation of different classes of signals originating from the same astrophysical event, provides a wealth of information about astrophysical processes. The focus of multi-messenger astronomy has been the search for conventional signals from known fundamental forces and standard model particles, like gravitational waves. In addition to these known effects, quantum sensor networks could be used to search for astrophysical signals predicted by beyond-standard-model theories. Of particular interest are exotic low-mass fields (ELFs) that can be emitted by cataclismic astrophysical events. I will review our original proposal [Nature Astronomy 5, 150 (2021)] for multi-messenger astronomy in the exotic physics modality and discuss theoretical progress. I will also present results of our search for ELFs temporally correlated with GW170817 merger, where we use the global network of GPS satellite atomic clocks as a distributed detector. We analyze clock data from the GPS constellation in windows bracketing the LIGO–Virgo trigger, constructing correlated observables that are sensitive to propagating disturbances with velocities near the speed of light.

Presenter: DEREVIANKO, Andrei (U. Nevada)

Session Classification: Plenary Session

Contribution ID: **2** Type: **not specified**

Multimessenger Astronomy Beyond the Standard Model: New Window from Quantum Sensors

Tuesday, 9 December 2025 10:30 (30 minutes)

Ultralight bosonic (ULB) fields with mass $m_\phi \ll 1$~eV often arise in theories beyond the Standard Model (SM). If such fields exist, violent astrophysical events that result in emission of gravitational wave, photon, or neutrino signals could also produce bursts of high-density relativistic ULB fields. Detection of such ULB fields in terrestrial or space-based laboratories correlated with other signals from transient astrophysical events opens a novel avenue for multimessenger astronomy. We show that quantum sensors are particularly well-suited to observe emitted scalar and pseudoscalar axion-like ULB fields coupled to SM. We demonstrate that multimessenger astronomy with ULB fields is possible even when accounting for matter screening effects. There are many opportunities to grow in this new field, and I will also discuss future directions.

Presenter: ARAKAWA, Jason (U. Delaware)

Session Classification: Plenary Session

Contribution ID: **3** Type: **not specified**

Observing Dark Matter Decays to Gravitons via Graviton-Photon Conversion

Tuesday, 9 December 2025 11:00 (30 minutes)

Since dark matter is only known to have gravitational interactions, it may plausibly decay to gravitons on cosmological timescales. Although such a scenario can be easily realized, there are currently no known limits on this possibility based on indirect detection searches. We find that the gravitons produced in dark matter decays can convert to photons in large-scale magnetic fields along the line of sight to an observer. These conversions primarily occur within cosmological filaments which occupy a large (order unity) volume fraction and contain ~10–100 nG fields with ~ Mpc coherence lengths. Thus, dark matter decays to gravitons predict an irreducible population of extragalactic photons, which we constrain using the extragalactic gamma-ray background measured by the Fermi-LAT telescope. Using this conservative method, we place the first limits on the dark matter lifetime in the 0.1GeV–108 GeV mass range, assuming only decays to gravitons. We also make projections for the Advanced Particle-astrophysics Telescope, which can improve sensitivity to this DM decay channel by an order of magnitude beyond those we set using Fermi-LAT data.

Presenter: KRNJAIC, Gordan (U. Chicago)

Session Classification: Plenary Session

Contribution ID: **4** Type: **not specified**

High frequency gravitational waves from reheating

Tuesday, 9 December 2025 13:00 (30 minutes)

I will review some recent developments on the production of high frequency gravitational waves during the reheating stage.

Presenter: NAKAYAMA, Kazunori (Tohoku U.)

Session Classification: Plenary Session

Contribution ID: **5** Type: **not specified**

Principles and fundamental-physics applications of diamond quantum sensors

Tuesday, 9 December 2025 13:30 (30 minutes)

Diamond quantum sensors based on nitrogen-vacancy (NV) centers have attracted great attention owing to their high sensitivity, wide dynamic range, and high spatial resolution. Utilizing these outstanding properties, diamond quantum sensors have recently been proposed for applications in fundamental physics, including dark matter searches and investigations of quantum gravity. In this presentation, we will provide an overview of the operating principles of NV-based quantum sensors, recent advances in diamond materials, and their applications to studies of fundamental physics.

Presenter: MIZUOCHI, Norikazu (Kyoto U.)

Session Classification: Plenary Session

Contribution ID: **6** Type: **not specified**

Light dark-matter search with nitrogen-vacancy centres in diamond

Tuesday, 9 December 2025 14:00 (30 minutes)

Diamond is a host for various defects, notably the nitrogen-vacancy (NV) centre. This colour centre consists of a substitutional nitrogen and a neighbouring missing carbon atom, and it has electron spin. It is sensitive to various quantities, for example magnetic fields, and as such it finds use as a sensor in many applications, from biology to electronics. Moreover, quantum sensors are interesting for fundamental physics, since in the search for new physics, detecting tiny signals is essential. We investigate how the NV centre can be employed as quantum sensor for light dark-matter search. Furthermore, we look at how, compared to conventional sensing methods, there are benefits for dark matter search using the nuclear spin. Finally, we tackle some challenges by proposing a novel quantum sensing method with both spins. We hope to improve the retina of the quantum-sensing eye for multimessenger astronomy.

Presenter: HERBSCHLEB, David (Kyoto U.)

Session Classification: Plenary Session

Contribution ID: **7** Type: **not specified**

Multi-messenger astronomy with spin-based quantum sensors

Tuesday, 9 December 2025 15:00 (30 minutes)

Presenter: WICKENBROCK, Arne (JGU-Mainz)

Session Classification: Plenary Session

Contribution ID: **8** Type: **not specified**

Beyond Qubits: Multilevel Quantum Sensing for Dark Matter

Tuesday, 9 December 2025 15:30 (30 minutes)

Quantum sensing with qubits has advanced fundamental physics searches, but higher dimensional systems offer untapped potential. We present a universal qutrit framework that yields a sequence-independent fourfold increase in quantum Fisher information and a twofold gain in sensitivity. In ultralight dark matter searches, spin-1 NV-center qutrits can enhance the axion-electron coupling reach by an order of magnitude beyond qubits. This principle applies broadly to multilevel quantum systems including superconducting, neutral atom and trapped-ion qutrits, establishing higher dimensional sensing as a powerful tool for probing new physics.

Presenter: MA, Xiaolin (QUP, KEK)

Session Classification: Plenary Session

Contribution ID: **9** Type: **not specified**

Enabling new physics searches with high-precision atomic theory and open science

Tuesday, 9 December 2025 16:30 (15 minutes)

The search for new physics beyond the Standard Model using quantum sensors relies heavily on the synergy between experimental precision and accurate theoretical modeling. This talk outlines a comprehensive computational infrastructure designed to support these efforts, including complex atomic structure calculations with automated workflows and the consolidation of results into the Portal for High-Precision Atomic Data and Computation. By building a common language and shared toolset across AMO, particle physics and related fields, this infrastructure aims to lower the threshold for entry and maximize the scientific reach of precision experiments.

Presenter: CHEUNG, Charles (U. Delaware)

Session Classification: Contributed Talks

Contribution ID: **10** Type: **not specified**

Gravitational Wave Sources and Origin of Massive Binary Black Holes

Thursday, 11 December 2025 10:00 (30 minutes)

Since the first detection of gravitational waves from binary black hole mergers, a key question has been how such massive black holes—often exceeding 30 M⊠—are formed in the Universe. Recent results from GWTC-4 have even reported multiple black holes with masses beyond 100 M⊠, posing new challenges to our understanding of stellar evolution and compact-object formation. In this talk, I will review the possible astrophysical and cosmological origins of massive binary black holes, including isolated binary evolution channels, dynamical formation in dense stellar systems, remnants of Population III (first-generation) stars, and primordial black holes formed in the early Universe. Particular emphasis will be placed on the formation of black holes in low-metallicity environments and the role of binary interactions. I will also discuss how the rapid progress of gravitational-wave observations, combined with theoretical population-synthesis and stellar-evolution calculations, can help us unveil the origin and cosmic history of massive black-hole binaries.

Presenter: KINUGAWA, Tomoya (Shinshu U.)

Session Classification: Plenary Session

Contribution ID: **11** Type: **not specified**

Searching for Astrophysical Signatures of ultralight dark matter in pulsars and lensing

Wednesday, 10 December 2025 10:00 (30 minutes)

Ultralight dark matter is an interesting dark matter candidate at the lowest mass end of the dark matter parameter space. One of the predictions of this model is that dark matter halos should have tightly packed O(1) density fluctuations which oscillate on the de Broglie time and length scales. For masses above ~10^18 eV these oscillations occur on observable timescales. In this talk we will discuss recent work describe the effect this would have on pulsar timing arrays (arxiv.org/pdf/2411.18051) and the stochastic lensing of stars (arxiv.org/pdf/2502.20697). The hope is that by characterizing the effect of ultralight dark matter on these observables the increasing sensitivity of new experiments will allow us to probe higher dark matter masses.

Presenter: EBERHARDT, Andrew (Kavli IPMU, U. Tokyo)

Session Classification: Plenary Session

Contribution ID: **12** Type: **not specified**

Space gravitational wave experiments

Wednesday, 10 December 2025 11:30 (30 minutes)

The detection of gravitational waves on ground has become a routine nowadays, providing various insight into astrophysics of compact objects and fundamental physics. While the ground-based detectors probe compact objects in the stellar mass range, the future space gravitational wave missions are expected to probe those with heavier masses. However, such a bright future would not be achieved without instrumentation activities because nobody has ever achieved the space gravitational wave detection to date. This talk aims to give an update on the research field and highlight some of the instrumentation activities, inviting discussion for possible synergies with other studies.

Presenter: IZUMI, Kiwamu (JAXA)

Session Classification: Plenary Session

Contribution ID: **13** Type: **not specified**

Laser interferometric searches for gravitational waves and ultralight dark matter

Wednesday, 10 December 2025 11:00 (30 minutes)

Since the first detection of gravitational waves a decade ago, more than 300 events have been reported. The Observing Run 4 (O4) concluded in November 2025, and LIGO, Virgo, and KAGRA have since begun upgrades aimed at further improving their sensitivities. These upgrades are expected to improve sky localization, which will aid multi-messenger observations. Moreover, laser interferometric gravitational-wave detectors offer excellent sensitivity to ultralight dark matter. In this talk, I will discuss the current status of gravitational wave observations as well as direct searches for axion and gauge boson dark matter using KAGRA.

Presenter: MICHIMURA, Yuta (U. Tokyo)

Session Classification: Plenary Session

Contribution ID: **14** Type: **not specified**

Super-Kamiokande Supernova monitoring: a trigger for multi-messanger analysis

Wednesday, 10 December 2025 13:30 (30 minutes)

Since SN1987A, we know that supernovae (SNs) produce burst of neutrinos which can be detected several minutes to hours before the electromagnetic burst. Detecting this neutrino burst would provide valuable information on the supernova explosion mechanism and allow to give an early warning of the imminent eletromagnetic burst arrival to the astronomer community. The Super-Kamiokande experiment, with its 50 ktons water Cerenkov detector, is one of the main neutrino detector able to provide this warning. In this presentation, we will present the last status and improvements of the Super-Kamiokande's supernova monitoring system, as well as our partnerships with telescopes to ensure the followup of our alerts.

Presenter: PRONOST, Guillaume (ICRR, U. Tokyo)

Session Classification: Plenary Session

Contribution ID: **15** Type: **not specified**

Multimessenger Searches for Dark Matter Powered Stars

Wednesday, 10 December 2025 14:00 (30 minutes)

Dark matter (DM) annihilation has been proposed as an alternate heat source to fusion in the first stars. These "dark stars" (DS) are modeled to become supermassive and survive for astronomically long timescales. At the end of their lives they are expected to collapse directly to black holes, seeding the supermassive black holes (SMBH) at the centers of modern galaxies. We study the diffuse background of both neutrinos and photons from a population of such objects which maps to the modern abundance of SMBHs while remaining consistent with JWST observations with can both motivate and constrain the DS population. Using Super-K, IceCube, and Fermi-LAT data, we place constraints on the microphysics of DM models powering these stars.

Presenter: SCHWEMBERGER, Thomas (QUP, KEK)

Session Classification: Plenary Session

Contribution ID: **16** Type: **not specified**

TBA

Presenter: KATORI, Teppei (King's College London)

Session Classification: Plenary Session

Contribution ID: **17** Type: **not specified**

Probing New Frontiers of Astroparticle and Astrophysics with Cryogenic Quantum Sensor

Thursday, 11 December 2025 15:30 (30 minutes)

The Universe, born from the Big Bang, which is revealed by cosmic microwave background (CMB) photons that escaped during the epoch of recombination, evolved through the "dark ages"until gravity drove the collapse of primordial gas into the first stars and galaxies. These early structures reionized the intergalactic medium and seeded the large-scale cosmic web observed today. Interactions among baryons, dark matter, and dark energy shaped the spatial fluctuations of CMB photons and the large-scale distribution of galaxies, forming the basis of the standard cosmological model derived from observations of both the early and late Universe.

However, disturbing discrepancies remain across multimessenger observations, including the Hubble and S_8 tensions, the local missing baryon problem, and the unexpectedly rapid formation of massive black holes revealed by JWST. The unresolved origin of the cosmic infrared background and its possible correlation with the cosmic X-ray background may hint at a hidden population of primordial black holes, known as one kind of dark matter candidates.

To uncover such hidden information and resolve the missing pieces of cosmic evolution, extremely sensitive detectors are required. Cryogenic quantum sensors represent a promising approach for future astrophysical missions. I will introduce the principles and applications of cryogenic quantum sensors in probing new frontiers of astrophysics and astroparticle, including investigations of potential particle candidates for dark matter such as sterile neutrinos and axion-like particles.

Presenter: ZHOU, Yu (NAOC)

Session Classification: Plenary Session

Contribution ID: **18** Type: **not specified**

Applications of TES X-ray microcalorimeters in Accelerator-based Experiments

Thursday, 11 December 2025 09:30 (30 minutes)

TES microcalorimeters offer excellent energy resolution over a wide energy bandwidth, with a reasonable collecting area enabled by multiplexing techniques. This detector technology has now matured to the point where it can be effectively applied at accelerator facilities. In particular, we have explored its use in charged-particle beamlines, such as kaon and muon beams. In this talk, I will introduce our project on precision X-ray spectroscopy of kaonic atoms for studies of the strong interaction and muonic atoms for bound-state QED tests in high electric fields, highlighting key technical challenges and recent results.

Presenter: HASHIMOTO, Tadashi (RIKEN)

Session Classification: Plenary Session

Contribution ID: **19** Type: **not specified**

Casimir force computation technique for emerging materials

Wednesday, 10 December 2025 09:30 (30 minutes)

The computation of Casimir forces between material bodies, in principle, requires frequency responses of the permittivities of the materials over a sufficiently wide range. However, particularly for many emerging materials such as Weyl semimetals, the permittivities in high frequencies are not yet known experimentally or accounted for in existing models. In this talk, a computation technique is presented to compute Casimir forces for materials that lack high frequency spectra of the permittivities.

Presenter: IIZUKA, Hideo (Toyota TCRDL / QUP, KEK)

Session Classification: Plenary Session

Contribution ID: **20** Type: **not specified**

Development of a trapped-ion nuclear clock for fundamental physics research

Wednesday, 10 December 2025 15:30 (30 minutes)

The nuclear transition between the nuclear ground state and the isomer of thorium-229 offers a unique opportunity for direct laser spectroscopy of the atomic nucleus. One key application is a high-accuracy nuclear clock based on the resonance frequency of this nuclear transition. Furthermore, the nuclear clock has been proposed as a highly sensitive probe for new physics, such as searching for a variation of the fine-structure constant. We are developing a trapped-ion nuclear clock utilizing triply charged thorium-229. These ions are obtained as recoil ions from the alpha-decay of uranium-233 and subsequently trapped. We will report our recent activities towards laser cooling of the trapped triply charged thorium ions.

Presenter: YAMAGUCHI, Atsushi (RIKEN)

Session Classification: Plenary Session

Contribution ID: **21** Type: **not specified**

Hunting Dark Matter at Kamioka Underground

Thursday, 11 December 2025 11:00 (30 minutes)

We are conducting a low-mass dark matter search at the Kamioka Underground Observatory, targeting dark matter in the sub-GeV mass regime. The experiment employs Transition Edge Sensor (TES)–based cryogenic detectors to measure tiny signals from particle interactions in a liquid helium target operated at ultra-low temperatures. Underground operation at 2700 m.w.e., together with dedicated gamma and neutron shielding, provides the low-background environment required for this search. This presentation will give an overview of the experimental concept and current status, with a focus on recent progress in background estimation, detector installation, and on-site preparation.

Presenter: BUI, Khai (QUP, KEK)

Session Classification: Plenary Session

Contribution ID: **22** Type: **not specified**

Neutrino Measurements and Neutrinoless Double-Beta Decay Search with KamLAND

Thursday, 11 December 2025 11:30 (30 minutes)

KamLAND is a kiloton-scale liquid-scintillator detector located in the Kamioka underground laboratory in Japan, originally designed to study reactor antineutrino oscillations. Over more than two decades of operation, KamLAND has evolved into a versatile facility for neutrino and rare-event physics. In this talk, I will give an overview of recent and ongoing results on astrophysical and geophysical neutrinos, as well as searches for neutrinoless double-beta decay.
On the astrophysical side, KamLAND has performed searches for electron antineutrinos from core-collapse supernovae and the diffuse supernova neutrino background, providing competitive constraints in the MeV energy range and complementary coverage to water-Cherenkov detectors. For geoneutrinos, KamLAND's long-term data set has enabled precision measurements of the radiogenic heat contribution from U- and Th-decay chains in the Earth's interior. I will also present the status and prospects of the KamLAND-Zen neutrinoless double-beta decay program, which has set world-leading limits on the 136Xe half-life and the corresponding effective Majorana neutrino mass. I will conclude with a brief outlook on future opportunities for neutrino and rare-event physics with KamLAND.

Presenter: ISHIDOSHIRO, Koji (Tohoku U.)

Session Classification: Plenary Session

Contribution ID: **23** Type: **not specified**

Use of entanglement of quantum sensors for detecting dark matter

Thursday, 11 December 2025 13:30 (30 minutes)

Recently, the use of quantum sensors for detecting dark matter has gained significant attention. In this talk, we explore how entanglement among quantum sensors can benefit the detection of dark matter signals. Roughly speaking, there could be three types of benefits: (i) improving the sensitivity of each sensor, (ii) reducing the measurement noise, and (iii) extracting the properties of dark matter from spatially separated sensors. I will discuss these benefits and present our recent theoretical work on utilizing entangled quantum sensors for dark matter detection.

Presenter: FUKUDA, Hajime (U. Tokyo)

Session Classification: Plenary Session

Contribution ID: **24** Type: **not specified**

Wave-like dark matter searches in DarQ experiment

Thursday, 11 December 2025 14:00 (30 minutes)

Presenter: CHEN, Shion (Kyoto U.)

Session Classification: Plenary Session

Contribution ID: **25** Type: **not specified**

Enhancing the Dynamic Range of Quantum Sensing via Quantum Circuit Learning

Wednesday, 10 December 2025 16:00 (30 minutes)

Quantum metrology is a promising application of quantum technologies, enabling the precise measurement of weak external fields at a local scale. In typical quantum sensing protocols, a qubit interacts with an external field, and the amplitude of the field is estimated by analyzing the expectation value of a measured observable. Sensitivity can, in principle, be enhanced by increasing the number of qubits within a fixed volume, thereby maintaining spatial resolution. However, at high qubit densities, inter-qubit interactions induce complex many-body dynamics, resulting in multiple oscillations in the expectation value of the observable even for small field amplitudes. This ambiguity reduces the dynamic range of the sensing protocol. We propose a method to overcome the limitation in quantum metrology by adopting a quantum circuit learning framework using a parameterized quantum circuit to approximate a target function by optimizing the circuit parameters. In our method, after the qubits interact with the external field, we apply a sequence of parameterized quantum gates and measure a suitable observable. By optimizing the gate parameters, the expectation value is trained to exhibit a monotonic response within a target range of field amplitudes, thereby eliminating multiple oscillations and enhancing the dynamic range. This method offers a strategy for improving quantum sensing performance in dense qubit systems.
reference: arXiv:2505.04958 (2025)

Presenter: MATSUZAKI, Yuichiro (Chuo U.)

Session Classification: Plenary Session

Contribution ID: **26** Type: **not specified**

SRF cavity searches for New Physics

Thursday, 11 December 2025 15:00 (30 minutes)

Presenter: SHU, Jing (Peking U.)

Session Classification: Plenary Session

Contribution ID: **27** Type: **not specified**

Spacetime symmetry tests with neutrinos

Wednesday, 10 December 2025 14:30 (30 minutes)

Lorentz symmetry, a foundational principle in both the Standard Model of particle physics and general relativity, is challenged by certain quantum gravity models that predict possible violation. Detecting these tiny Lorentz symmetry violation, or Lorentz violation, has become a global scientific interest, with interference experiments and other precise systems offering the sensitivity needed for such tests. Neutrino oscillations, which act as natural interferometers, provide an ideal framework for investigating Lorentz violation.

In this talk, I will begin by introducing Lorentz violation and the theoretical framework to look for Lorentz violation, known as the Standard Model Extension (SME). Then I will discuss Lorentz violating neutrino oscillations that might explain existing data anomalies and conclude with prospects for one of the most precise Lorentz symmetry tests using astrophysical high-energy neutrinos at neutrino telescopes.

Presenter: KATORI, Teppei (King's College London)

Session Classification: Plenary Session

Contribution ID: **28** Type: **not specified**

Distributed quantum sensing for ultralight dark matter

Tuesday, 9 December 2025 16:45 (15 minutes)

Presenter: XU, Bin (KIAS)

Session Classification: Contributed Talks

Contribution ID: **29** Type: **not specified**

Strongly Coupled Qubit-Cavity System Simulations for Broadband Dark Matter Search

This presentation discusses strategies to broaden the tuning range of such a cavity tuning system. This improvement is crucial for expanding the mass search range for dark matter. We report on the progress of a cavity haloscope with galvanically contacted transmon qubits. This approach is designed to achieve a strong qubit-cavity coupling regime, which is expected to enable a GHz-scale frequency tuning range.

Presenter: NAKAZANO, Kan (ICEPP, U. Tokyo)

Session Classification: Contributed Talks

Contribution ID: **30** Type: **not specified**

Group Photo

Wednesday, 10 December 2025 12:00 (10 minutes)

Contribution ID: **31** Type: **not specified**

QUP Director's Introduction

Tuesday, 9 December 2025 09:30 (25 minutes)

Presenter: TOSHIYUKI, Azuma

Session Classification: QUP Director's Opening Remarks and Welcome

Contribution ID: **32** Type: **not specified**

Opening Remarks

Tuesday, 9 December 2025 09:55 (5 minutes)

Presenter: TAKHISTOV, Volodymyr (QUP, KEK)

Session Classification: QUP Director's Opening Remarks and Welcome

Contribution ID: **33** Type: **not specified**

Closing Remarks

Thursday, 11 December 2025 16:00 (10 minutes)

Presenter: TAKHISTOV, Volodymyr (QUP, KEK)

Session Classification: Closing Remarks

Contribution ID: **34** Type: **not specified**

Charged Lepton Flavor Violation in IceCube

Tuesday, 9 December 2025 17:00 (15 minutes)

Lepton flavor violation in neutrinos aka neutrino-oscillation is a telltale signature of Beyond the Standard Model (BSM) physics. If a similar phenomenon is found in the charged leptons as well, that will further consolidate the existence of BSM physics. In this work, we look for signature of charged lepton flavor violation, muon to tau conversion, in the IceCube. Moreover, we set a constraint on the parameter space of Z', the BSM mediator of such charged lepton flavor violating interaction, from the analysis of the existing IceCube data. We compare our obtained constraint to that from collider experiments and find an allowed parameter space for charged lepton flavor violation to occur in IceCube.

Presenter: MAITRA, Writasree (U. Washington, St. Louis)

Session Classification: Contributed Talks