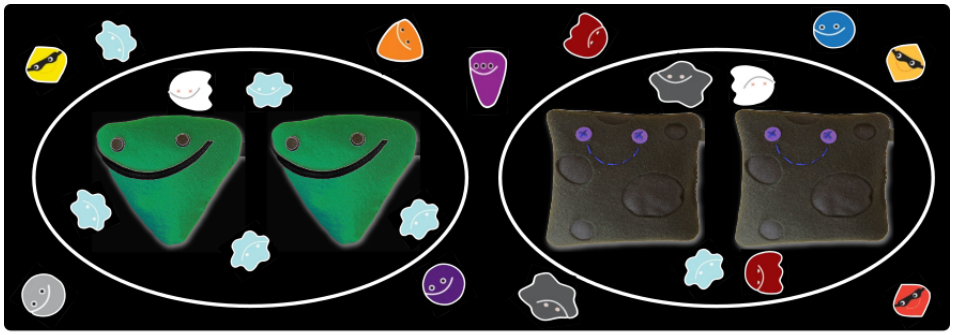
Quarkonia meet Dark Matter



Report of Contributions

https://indico.ipmu.jp/e/389

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

Electroweakly-interacting dark matter

Tuesday 15 June 2021 20:00 (40 minutes)

WIMPs are the candidate of dark matter in the universe. In this talk, I will talk about elecroweakly intearcting dartk matter. It is well-motivated in particle physics model beyond the standard model. The direct and indirect detection of dark matter and also dark matter sesarches at LHC now give severe constraints on the WIMP models while elecroweakly intearcting dartk matter is still free from them. It is considered that the dark matter may be tested in future experiments. For the purpose, we need to evaulate the prediction more morecisely, and it requires knowledge of thermal processes in the early universe.

Presenter: HISANO, Junji

Session Classification: Main program

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

Dark matter bound states

Tuesday 15 June 2021 20:40 (40 minutes)

The production of dark matter via thermal decoupling from the primordial plasma, and the direct, indirect and collider signals associated with this mechanism, have been the pillars of dark matter phenomenology in the past decades. In sharp contrast to the sub-TeV regime, the interactions of thermal-relic dark matter with multi-TeV or larger mass manifest as long-range. This is supported by unitarity arguments, and shown by explicit calculations in WIMP and other models. The long-range nature of the interactions gives rise to non-perturbative effects, with the most prominent being the existence of bound states. The formation and decay of unstable bound states in the early universe decrease the dark matter density, thereby changing its predicted mass and/or couplings. Stable and unstable bound state formation during CMB or inside galaxies gives rise to novel indirect detection signals.

Presenter: PETRAKI, Kallia

Session Classification: Main program

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

Pair annihilation and bound states in a thermal plasma

Tuesday 15 June 2021 21:40 (40 minutes)

After comparing the physical roles of thermal pair annihilation of non-relativistic particles in QCD and in cosmology, I discuss the tools that can be used for estimating this rate, either perturbatively or through lattice simulations. Subsequently it is illustrated how in strongly coupled systems, bound states may give a large contribution to the thermal pair annihilation rate, even if model details matter quite a bit here.

Presenter: LAINE, Mikko

Session Classification: Main program

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

Quarkonium in medium: a NR EFT approach to dissociation and ricombination

Tuesday 15 June 2021 22:20 (40 minutes)

I discuss quarkonium dissociation and evolution in a medium in the framework of non relativistic EFTs. In particular I compute the gluodissociation and inelastic parton scattering widths, and, by treating the quarkonium as an open quantum system, write and solve the corresponding Lindblad equation. Finally I compare the so obtained nuclear modification factor with LHC data.

Presenter: VAIRO, Antonio

Session Classification: Main program

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

Non-equilibrium theory of non-relativistic pairs inside an environment

Wednesday 16 June 2021 20:00 (40 minutes)

We derive differential equations from path-integral based non-equilibrium quantum field theory, that cover the dynamics and spectrum of non-relativistic two-body fields for any environment. For concreteness of the two-body fields, we choose the full potential non-relativistic Quantum Electrodynamics Lagrangian in this work. After closing the correlation function hierarchy of these equations and performing consistency checks with previous literature under certain limits, we demonstrate the range of physics applications. This includes Cosmology such as Dark Matter in the primordial plasma, Quarkonia inside a quark gluon plasma, and other phenomena in Condensed or strongly Correlated Matter physics.

Presenter: BINDER, Tobias (Kavli IPMU)

Session Classification: Main program

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

Potential non-relativistic QCD and open quantum system description of the non-equilibrium evolution of quarkonium inside the medium

Wednesday 16 June 2021 20:40 (40 minutes)

Quarkonium suppression is one of the probes of the formation of a quark-gluon plasma in heavy-ion collisions. Three phenomena influence the evolution of quarkonium in a medium: screening, collisions with medium partons and recombination. A formalism in which all these mechanisms can be described consistently is that of open quantum system. In this talk, I will review how to combine the open quantum system framework with Effective Field Theories that exploit the non-relativistic nature of quarkonium. I will discuss how to obtain a Lindblad equation that describes the evolution of the reduced density matrix of quarkonium and how Lattice QCD data can help to constraint the parameters of this equation. Efficient numerical methods to solve this evolution for phenomenological purposes will also be discussed.

Presenter: ESCOBEDO ESPINOSA, Miguel Ángel

Session Classification: Main program

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

Quarkonium production in pp and heavy ion collisions

Wednesday 16 June 2021 21:40 (40 minutes)

I will review the Non-Relativistic Quantum Chromodynamics (NRQCD) factorization formalism for the calculation of quarkonia production and decays. I will discuss the current status of quarkonium production in pp collision, highlighting successes and pointing out outstanding problems. I will then discuss a theoretical approach to deriving transport equations for quarkonia in the quark-gluon plasma using open quantum systems and effective field theory.

Presenter: MEHEN, Tom

Session Classification: Main program

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

Nuclear modification of open heavy flavor and quarkonia production in heavy ion collisions

Wednesday 16 June 2021 22:20 (40 minutes)

High-energy nuclear collisions create a new state of hot and dense matter—the quark-gluon plasma (QGP), which then undergoes fast hydrodynamic-like expansion and eventually freezes out to hadrons. The presence of the QGP medium strongly modifies the production yield of quarkonia. Quarkonia, as bound states of heavy- and anti-heavy quark pairs under the strong force, are sensitive to the color screening effects of the QGP medium that induces quarkonia suppression. Furthermore, the dynamics of quarkonia are also intertwined with the transport of unbound heavy quarks, as they can be regenerated from a pair of unbound nearby quarks as the medium cools down. Combining the progress in potential non-relativistic QCD, open quantum system, and partonic transport theory, we developed a consistent theoretical and simulation framework to model the production and in-medium dynamics of heavy quark and quarkonia [1]. The expansion of the QGP medium is described by a well-calibrated 2+1D viscous hydrodynamic model. Quarkonia dissociation and regeneration are coupled to the evolution of unbound heavy quarks, including both elastic collisions and radiative energy loss. We discuss the impact of this coupled evolution on the QGP modifications to the ground and excited states of bottomonia.

Presenter: KE, Weiyao

Session Classification: Main program

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

Dark matter and coloured co-annihilators: from the relic density to experimental constraints

Thursday 17 June 2021 20:00 (30 minutes)

In order to compute accurately the relic energy density of dark matter particles featuring co-annihilating partners, it is important to address the annihilations of the latter if the mass splitting is small. Coloured co-annihilators participating QCD interactions offer a rich phenomenology, and their dynamics in the early universe resembles that of heavy quarks in a quark-gluon plasma. Making contact with modern EFTs, we recast the thermal annihilation cross sections in terms of expectation values of 4-particle operators in NREFTs, the determination of which requires thermal potentials derived within pNRQCD. Experimental constraints on the parameter space compatible with the observed energy density are also discussed.

Presenter: BIONDINI, Simone

Session Classification: Main program

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

Chromoelectric field correlator for quarkonium transport and thermal dark matter relic abundance

Thursday 17 June 2021 20:30 (25 minutes)

Quantifying the transport properties of heavy particles traveling through thermal non-abelian plasmas is of paramount importance to interpret measurements on those particles conducted after the freezeout. One such example is quarkonium suppression in heavy-ion collisions (HIC). To explain the experimental data and extract physical quantities encoding the properties of the QGP, a solid theoretical understanding of how the properties of the QGP modify the quarkonium dissociation and formation rates within the thermal plasma is necessary. Analogously, heavy dark matter (DM) particle candidates in the early universe may also have undergone processes of bound-state formation and dissociation in co-annihilation scenarios. A precise calculation of the relevant transition rates is crucial to constrain the parameters associated with those DM particles from measurements of the present-day DM abundance. In this work, by using the real-time formalism of thermal field theory, we perform the first complete NLO calculation of the gauge-invariant chromoelectric correlator that determines the transition rate between a bound singlet state and an adjoint representation unbound state in potential Non-Relativistic Effective Field Theory (pNREFT) inside a thermal SU(N_c) non-abelian plasma. The connection from quantum fields to semiclassical transport rates is elucidated through an open quantum system description of the heavy quark/DM pair system interacting with the thermal plasma environment. We explicitly verify, up to NLO, that the resulting rates are infrared and collinear safe, as well as manifestly gauge-invariant in R_\xi gauge. We find that if the temperature is of the same order as the binding energy, which is a crucial temperature regime to determine the abundance of these heavy particles after the freezeout, the NLO rates are significantly enhanced compared to the LO ones. This observation highlights the need to have a solid quantitative grasp on the role of transitions between bound or unbound quarkonia/DM states in order to understand the final quarkonium yields in HIC and the present-day DM abundance in terms of the underlying theory that govern their dynamics.

Presenter: SCHEIHING HITSCHFELD, Bruno

Session Classification: Main program

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

Electroweak WIMP annihilation, resummed beyond LO with non-relativistic dark matter EFT and SCET

Thursday 17 June 2021 21:10 (40 minutes)

This talk approaches electroweak WIMP annihilation from the perspective of the EFT for quarkonium annhilation. After discussing the similarities and differences, I cover next-to-leading order corrections to the potential between static sources with SU(2) x U(1) charge after electroweak symmetry breaking and their impact on the computation of the Sommerfeld-corrected dark matter relic density. Precise calculations of annhilation into an exclusive or semi-inclusive final state with electroweak charges requires in addition the summation of large electroweak Sudakov logarithms. The cosmic ray spectrum of high-energy photons with near maximal energy from dark matter annihilation is resummed at NLL' accuracy with SCET methods and combined with the NLO Sommerfeld effect.

Presenter: BENEKE, Martin

Session Classification: Main program

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

Bound-state effects in EW and colored co-annihilation and unitarity bound

Thursday 17 June 2021 21:50 (30 minutes)

Dark matter freezeout can be severely affected by non-perturbative effects, such as bound state formation. This is particularly relevant in the regime where the dark matter mass exceeds the mass of the force mediator. Concrete examples are: heavy dark matter, that interacts with the electroweak force, and dark matter that freezes out in a co-annihilation process with a color-charged partner particle. At large dark matter masses the existence of new annihilation channels via bound-state formation also affects the theoretical unitarity bound on the dark matter mass, and cross section. Furthermore, bound-state formation effects in dark matter systems lead to new late time signatures, that will significantly improve the sensitivity of upcoming gamma-ray and neutrino telescopes.

Presenter: SMIRNOV, Juri

Session Classification: Main program

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

Higgs enhancement and bound state formation in coannhilation scenarios of dark matter

Thursday 17 June 2021 22:20 (30 minutes)

Given the growing constraints on WIMP dark matter, coannihilation scenarios gain more and more interest. However, in order to theoretically predict the relic density, different effects have to be taken into account. In colored coannihilation scenarios, the importance of long-range interactions mediated by gauge bosons, the so-called Sommerfeld effect, is by now well established. Due to its mass, the Higgs boson as mediator was usually neglected in this context. However, we demonstrate that the Sommerfeld effect via Higgs exchange can lead to similarly striking effects. In the same regime, also bound state formation via the emission of a gauge boson can become relevant, altering the prediction of the dark matter abundance by its subsequent decay. We demonstrate that the Higgs boson as long-range force mediator similarly alters the bound state formation process and hence impacts the relic density prediction sizeably such that it must be taken into account for determining the viable parameter space of these scenarios. We conclude by commenting on implications for experimental searches.

Presenter: HARZ, Julia

Session Classification: Main program

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

Thermal Squeezeout for Strongly Interacting Dark Matter

Friday 18 June 2021 20:00 (40 minutes)

I will discuss the potential importance of a dark hadronization phase transition in the early universe in setting the measured relic abundance, for a simple model of strongly interacting dark matter. Enhancement of the dark matter density within shrinking pockets of the deconfined phase leads to a dramatic reduction in the late-time dark matter abundance, allowing for much heavier dark matter than in the standard thermal freezeout scenario.

Presenter: SLATYER, Tracy

Session Classification: Main program

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

Monopole transitions via emission of a charged scalar and their importance for dark matter coupled to the Higgs

Friday 18 June 2021 20:40 (25 minutes)

Abstract: The capture of particle-antiparticle pairs or pairs of identical particles into bound states via emission of a neutral scalar is a quadrapole transition that becomes phenomenologically significant only at rather large couplings. However, if the scalar carries a conserved charge, then its emission alters the Hamiltonian of the interacting particles, resulting in monopole transitions that can be extremely rapid even for small couplings. In models where multi-TeV DM or its co-annihilating partners couple to the Higgs doublet, the capture into unstable bound states via emission of a Higgs doublet can change the predicted dark matter density by orders of magnitude.

Presenter: PETRAKI, Kallia

Session Classification: Main program

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

Bottomonium suppression in heavy ion collisions

Friday 18 June 2021 21:20 (40 minutes)

The strong suppression of bottomonia in ultra-relativistic heavy-ion collisions is a smoking gun for the production of a deconfined quark-gluon plasma (QGP). In this talk I will discuss recent work that aims to provide a more comprehensive and systematic understanding of bottomonium dynamics in the QGP. The new paradigm is based on an open quantum system approach applied in the framework of potential-based non-relativistic QCD (pNRQCD). We demonstrate that the computation of bottomonium suppression can be reduced to solving a Lindblad-type equation for the evolution of the b-bbar density matrix including both singlet and octet states and transitions between them. To solve the resulting Lindblad equation, we make use of a "quantum trajectories method"which can be deployed in a massively parallel manner. Our computation depends on two transport coefficients that have been evaluated independently using lattice QCD. I demonstrate that our final phenomenological predictions agree well with available data from LHC 5.02 TeV Pb-Pb collisions for both bottomonium suppression and anisotropic flow.

Presenter: STRICKLAND, Michael

Session Classification: Main program

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

Strongly interacting systems at finite T: results from the lattice

Friday 18 June 2021 22:00 (40 minutes)

The past decade has seen ample progress in the study of the dynamical properties of strongly interacting systems at finite temperature. Lattice QCD constitutes a key tool and promises first principles access to phenomenologically relevant phenomena, such as (charge-)transport and in-medium binding properties of heavy fermions. In this presentation I will review recent selected lattice QCD results on dynamical properties of strongly interacting systems at finite temperature.

Presenter: ROTHKOPF, Alexander

Session Classification: Main program

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

Excited dark states matter by Graham White

Tuesday 15 June 2021 23:20 (35 minutes)

In many dark matter models bound state transitions are fast. In a thermal bath, excited states contribute significantly to the effective annihilation cross section. Preliminary results indicate a dramatic change to the unitarity bound.

Presenter: WHITE , Graham (Kavli IPMU)

Session Classification: Poster session (Gather town)

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

A model of electroweakly interacting non-abelian vector dark matter

Tuesday 15 June 2021 23:20 (35 minutes)

In this talk, we propose a new electroweakly interacting spin-1 dark matter (DM) model. We consider the non-Abelian extension of electroweak symmetry. Namely, we extend the $SU(2)_L$ group in the Standard Model (SM) into the direct products of three SU(2) groups. We also impose the exchange symmetry between two of these SU(2) groups to realize the spin-1 stable spectrum. In this setup, the DM pair efficiently annihilate into SM particles through the electroweak interaction. Therefore, we can obtain the DM energy density correctly via the freeze-out mechanism. We also find not only electroweak processes but also Higgs exchange processes give the relevant contribution to determine the DM energy density. We conclude a next-generation DM searches will be an excellent probe of this spin-1 DM.

Presenter: FUJIWARA, Motoko

Session Classification: Poster session (Gather town)

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

Indirect search for dark matter bound state formation

Tuesday 15 June 2021 23:20 (35 minutes)

Title: Indirect search for dark matter bound state formation Abstract: Indirect searches for dark matter (DM) have conventionally been applied to the products of DM annihilation or decay. If DM couples to light force carriers, however, it can be captured into bound states via dissipation of energy that may yield detectable signals. We extend the indirect searches to DM bound state formation and transitions between bound levels, and constrain the emission of unstable dark photons. Our results significantly refine the predicted signal flux that could be observed in experiments. As a concrete example, we use Fermi-LAT dwarf spheroidal observations to obtain constraints in terms of the dark photon mass and energy which we use to search for the formation of stable or unstable bound states.

Presenter: BALDES, Jason (Université Libre de Bruxelles)

Session Classification: Poster session (Gather town)

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

Bottomonium suppression in an open quantum system using the quantum trajectories method

Tuesday 15 June 2021 23:20 (35 minutes)

We solve the Lindblad equation describing the Brownian motion of a Coulombic heavy quark-antiquark pair in a strongly coupled quark-gluon plasma using the highly efficient Monte Carlo wave-function method. The Lindblad equation has been derived in the framework of pNRQCD and fully accounts for the quantum and non-Abelian nature of the system. The hydrodynamics of the plasma is realistically implemented through a 3+1D dissipative hydrodynamics code. We compute the bottomonium nuclear modification factor and compare with the most recent LHC data. The computation does not rely on any free parameter, as it depends on two transport coefficients that have been evaluated independently in lattice QCD. Our final results, which include late-time feed down of excited states, agree well with the available data from LHC 5.02 TeV PbPb collisions.

Presenter: VANDER GRIEND, Peter

Session Classification: Poster session (Gather town)

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

Search for new light vector boson using J/Ψ at BESIII and Belle II by Yongsoo Jho

Tuesday 15 June 2021 23:20 (35 minutes)

Presenter: JHO, Yongsoo

Session Classification: Poster session (Gather town)

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

Thermal Real Scalar Triplet Dark Matter by Yu Watanabe

Tuesday 15 June 2021 23:20 (35 minutes)

Real scalar triplet dark matter, which is known to be an attractive candidate for a thermal WIMP, is comprehensively studied paying particular attention to the Sommerfeldeffect on the dark matter annihilation caused by the weak interaction and the otherinteraction between the dark matter and the Higgs boson. We find a parameter region that includes the so-called 'WIMP-Miracle'one is still surviving, i.e. it respects all constraints imposed by dark matter searches at collider experiments, underground experiments (direct detection) and astrophysical observations (indirect detection). The region is also found to be efficiently searched for by various near future experiments.In particular, the XENONnT experiment will cover almost the entire parameter region.

Presenter: Mr WATANABE, Yu (UTokyo)

Session Classification: Poster session (Gather town)