Application Code	A2605
Reference Number	1221101202
Grant Number	

1221101202

National Natural Science Fund of China

Research Fund for International Scientists

Type: Research Fund for International Young Scientists

Applicant name	Takumi Kuwahara		
Nationality	日本	E-mail	kuwahara@pku.edu.cn
Project title	Study on Composite Dark Matter with Contact Interactions		
Grant period	01/01/2023-12/31/2023		
Host institution	Peking University		
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Postal Code	100871		

National Natural Science Foundation of China

General Information

Applicant information

Full Name	Takumi Kuwahara				
Gender	male	Date of birth	1989-05-06	Nationality	日本
Doctoral Degree Award Date		2017			
Current employer (if applicable)		Peking University			
Current academic title (if applicable)		Postdoctoral fellow			

Contact information

Tel.(Work)	15528430389	Tel.(Home)	
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Project information

Project title	Study on Composite Dark Matter with Contact Interactions
Application Code	A2605
Proposed stay at the host institution	From 01/01/2023 to 12/31/2023

Abstract

Abstract:

Dark matter (DM) is one of the greatest mysteries of our Universe. We know less about its particle nature even though cosmological observations have confirmed its existence. The idea of the dark sector has recently drawn attention as particle-physics models for the DM. The DM and associated particles (collectively named as the dark-sector particles) residing in the dark sector interact with each other, while the standard model (SM) particles have only feeble interactions with the dark-sector particles. The studies on the dark-sector models have intensively focused on simplified setups, where the dark sector consists of the DM and mediator particles (connecting the dark sector and the SM sector). However, it is plausible that the dark sector has a complicated structure as with the SM. In this project, I will focus on the dark-sector model with confining gauge dynamics, which lead to the dark sector composed of composite particles. There exist two DM candidates, dark baryon and dark pion, and the typical mass scale of the DM is similar to the masses of our hadrons (several hundred MeV to several GeV). These DM candidates have self-interaction, which is preferred by the small-scale structure of galactic halos. Accidental global symmetries (such as dark baryon number and residual symmetry after the chiral symmetry breaking) ensure the stability of the DM.

Meanwhile, there also exist associated dark particles, whose decay or transition processes leave the SM particles (such as electron-positron pair) via the mediator particles. These processes have characteristic signals that visible particles appear far from the production point of dark-sector particles due to the feeble connection between the dark sector and the SM sector. Ongoing and future terrestrial experiments have explored these signals by putting the detectors away from the collision point of experiments, called long-lived particle (LLP) searches. These future experiments will run on the time scale of the next decade, and it is timely to study the LLP searches on the dark-sector models. However, the theoretical studies of LLP searches have mainly focused on the dark-sector particle production via on-shell mediator particles (dark-sector particles are produced via the decay of mediator particles). My recent studies have focused on the dark-sector particle production via off-shell mediator particles, providing multiple visible signals with different decay lengths. These studies imply that various LLP searches are essential for a model distinction.

In this project, I will study the dark-sector model with contact interactions. This model is an alternative to the dark-sector models with mediator particles, where the SM matter fermions and the dark quarks have contact interaction. First, in this project, I will construct effective models of interactions among dark hadrons and SM particles in the presence of contact interactions at the quark level. I will also study the constraints on the effective interaction between the SM particles and the dark hadrons from cosmological observations, flavor physics, and CP-violating physics. This study will reveal the size of the contact interactions being consistent with observations and experiments. Next, I will apply the constructed effective models to the LLP searches for the dark hadrons in the cases with dark-baryon DM and dark-pion DM. This project will focus on a specific production via interactions originating from the contact interactions. However, by combining this project and existing studies, we will cover the standard production mechanism for the dark-sector particles at the LLP searches, particularly in composite DM models. Therefore, I am convinced that this project will helpful to the theoretical study on the dark-sector searches and the experimental study in near future.

Keywords: Particle Physics ;Dark Matter ;Composite Particle ;Effective field theory ;Long-lived Particle

Budget

Reference Number:1221101202 PI:Takumi Kuwahara Unit:10,000 Yuan

No.	Items	Amount
1	一、Direct costs	20.0000
2	1、Equipment Expenses	3.8000
3	Purchase of Equipment	3.8000
4	2、Experimental and Operating Expenses	9.0000
5	3、Allowance	7.2000
6	二、Funds from other sources	0.0000
7	三、Total	20.0000

Budget Justification

（请按照《国家自然科学基金项目计划书预算表编制说明》等的有关要求，按照政策相符性、目标相关性和经济合理性原则，实事求是编制项目预算。填报时，直接费用应按设备费、业务费、劳务费三个类别填报，每个类别结合科研任务按支出用途进行说明。对单价≥50 万元的设备费及自筹资金进行必要说明。）

(Please prepare the project budget in accordance with relevant requirements of the "Instruction of Budget Table Preparation of the Research Plan of NSFC-Awarded Project" following the principle of "policy compliance, relevant goals and economic rationality. When filling in the plan, the direct costs should be divided into three categories including equipment expenses, experimental and operating costs, and allowance, with explanations for each category specifying the purposes of expenditure in accordance with scientific research tasks. Explanations should be made for a single purchase of equipment totaling 500,000 yuan or above and for self-financing funds.）

I apply for the budget with 200,000 RMB. I assume China and other countries will relax COVID-19 restrictions on travel in 2023. The followings are the detail:

Equipment expenses 38,000 RMB:

computing instruments (for analytical computations and numerical simulations) 20,000 RMB, software tools (annual license for calculation tools) 10,000 RMB

supplies cost 8,000 RMB: Two HDDs for data storage (2,500RMB per piece) and peripheral devices (such as connector and display) for computing instruments (3,000RMB).

Experimental and Operating expenses 90,000 RMB:

travel/conference/international cooperation 73,000 RMB

(1) I will attend two domestic conferences and three internal conferences (Japan, EU, and US). It will cost 5,000RMB for domestic conference including transportation, sojourn expenses, and conference fee. It will cost 20,000RMB for international conferences (EU and US). It will cost 5,000RMB for international conferences (Japan).
2*5,000+2*20,000 + 5,000 = 55,000 RMB
(2) I will invite international collaborator from Europe (or I will visit the collaborator's group). It will cost 15,000 RMB for flight and sojourn expenses.
(3) The remaining 3,000 RMB will be used for city transportation for discussion with collaborator in Beijing and for giving seminars at Universities in Beijing.

publication 15,000 RMB

I will write three papers in this project. The publication costs depend on the publishers, and average is about 5,000 RMB.

subscription for online tools for collaborating work 2,000 RMB

Allowance 72,000 RMB:

visiting researchers 36,000 RMB: I will invite three visiting researchers (one from domestic and two from abroad) as consultants to Peking University. It can be 1,500~2,400 RMB/person*day, hence it will cost 15,000 RMB (abroad) and 6,000 RMB (domestic) for a person, including transportation and sojourn for a seminar.
I will involve a student in one of this project, I will pay for the student 3,000 RMB per month, hence 36,000 RMB (one year) in total.

Research Proposal

Please detail your research proposal following the outlines printed in bold. Please do not delete or change the headings and the text in brackets. The proposal should be no more than 18 pages.

1.Project summary

(1)Project context(including research significance, research overview and prospect in China and abroad, and importance of the proposed study. A list of references should be provided.)

Introduction for this project

The Standard Model (SM) for particle physics has been well-established for about half a century. Quarks and leptons are the fundamental particles that constitute matter in the SM. The essential difference between them is that only quarks carry color charges which cause strong interaction. Analogous to the strong interaction not mediated among leptons, there would exist particles that do not have any charges of the SM, which is called the sequestered sector. The idea of the sequestered sector has been considered in various contexts (e.g., supersymmetry breaking in the hidden sector and its mediation). For about a decade, the dark sector where the dark matter (DM) resides has gotten received attention as new candidates of models beyond the SM (BSM) (e.g., see Ref. [1]). The dark sector has its own gauge dynamics, and the DM and/or its associated dark particles carry charges of dark gauge dynamics, while the SM particles do not.

There are several ongoing and future experiments/observations for the DM particle searches in terrestrial experiments and astrophysical observations. It is suggested that the DM would have a feeble interaction with the SM particles in light of the null detection of the DM particles at the collider experiments and the direct/indirect detection experiments. In particular, the DM direct-detection experiments (such as XENON and LUX), which measure the scattering between the DM and the SM nuclei, have put strong constraints on the scattering cross-section. The conventional weakly interacting massive particle (WIMP) scenario is now confronted with the direct-detection constraints. Its scattering process is related to the WIMP annihilation process that determines its abundance today. On the other hand, the dark-sector models would have the DM number changing processes (such as annihilation) within the dark sector independent of the scattering process with the SM particles. Therefore, I am focusing on the dark sector DM models that have been less explored than the conventional WIMP models.

Many of the dark-sector models that have been recently focused on are simplified as particle physics models. These particle contents are assumed to be minimal, and masses and interactions are optimized for experiments or for explaining reported discrepancies of physical observables between the measured value and the SM prediction. These are convenient as benchmark models for experimental searches. However, these models do not explain why the dark-sector particles have specific masses and interactions. The lack of explanation has motivated me to focus on the dark sector with strong gauge dynamics. As with the SM strong force, the strong gauge dynamics in the dark sector lead to the confinement at the low-energy, and then the dark hadrons play a role of dark-sector particles. The masses and interactions of dark hadrons are predominantly determined by the strong dynamics analogous to the SM hadrons. The dark hadrons would have the masses similar to the SM hadrons when the ultraviolet origin of the dark strong dynamics is similar to that of the SM strong dynamics (such as grand unification or string theory). Global symmetries arise in the low-energy scale (as with the baryon number in the SM), and hence the accidental symmetries ensure the stability of dark hadrons. Analogous to the SM hadrons, it is expected that the dark hadrons would have the sizable self-scattering cross section, which is recently expected as a solution of the small-scale crisis of the galactic halos (see Ref. [2] for dark hadrons).

Dark hadrons are categorized into two groups: dark baryons and dark mesons. When the dark baryons are the DM, the DM abundance would be determined by the asymmetry as with the baryonic-matter abundance in the Universe, which is named as composite asymmetric dark matter (ADM) scenario. The symmetric component of the dark baryon relics is strongly depleted by emitting dark pion. Hence, dark pions predominantly carry the entropy in the dark sector unless the entropy is somehow released into the SM sector. My recent work has focused on the composite ADM with dark photon [3], where the dark photon releases the entropy in the dark sector to the SM sector. I have proposed an ultraviolet completion that naturally provides essential ingredients and the origin of fine-tuned parameters in the composite ADM with dark photon in the context of grand unification [4]. The proposed model has a mirror structure of gauge dynamics between the SM sector and the dark sector at the very high-energy scale, and then the similar structure between the two sectors remains even at the low-energy scale. Another possibility is that dark pions, the lightest dark mesons, are the DM. Suppose baryogenesis in the SM sector does not affect the number asymmetry of the dark baryons. In that case, the abundance of dark baryons is expected to be too small to explain the DM abundance since dark baryons efficiently annihilate into lighter particles such as dark pions. Thus, the dark pion is the DM candidate. Depending on the dark pion mass, the abundance of dark pions would be determined by different mechanisms [5]:

- Strongly interacting massive particle (SIMP) mechanism [6]
- Semi-annihilation mechanism with spin-1 resonances (so-called vector mesons) [5]
- Conventional annihilation mechanism (WIMP mechanism)

Due to the feeble interactions with the SM, it is often challenging to directly explore the dark sector at terrestrial experiments. However, thanks to the feeble interactions, the dark-sector particles tend to be long-lived. It is promising to investigate the dark-sector particles at the long-lived particle (LLP) searches, the fixed-target experiments and collider experiments, and at cosmological observations. The LLP searches at the terrestrial experiments are mostly parasitic experiments, which put a new detector to the original collider experiments. Therefore, their construction timeline is short compared to constructing a new facility for new collider experiments. One of the LLP searches at the collider experiment is FASER experiment, which is located in the forward direction at the ATLAS experiment at Large Hadron Collider (LHC). This experiment has been already accepted, and will take data during LHC-run3 (from 2022). As for the LLP searches at the fixed-target experiments, DarkQuest is a program of the search for dark-sector particles at the existing SeaQuest spectrometer experiment at Fermilab, which is originally planned to explore the antiquark structure of nucleons. The DarkQuest experiment will run on the timescale of 2023-2024. The studies on the LLP searches for the dark-sector particles are timely, and it is important to prepare the theoretical predictions for the experimental results.

I have recently discussed the LLP searches for dark hadrons at collider and fixed-target experiments: particularly in the composite ADM with dark photon [7] and in the SIMP model with dark vector mesons [8]. Compared to the LLPs in the simplified models, the dark-sector particles would have various lifetimes. Hence, it is essential to search for dark-sector particles with different decay lengths for the dark-sector model with confining dynamics. In particular, I have currently studied the searches for the LLPs produced via off-shell light dark photons. In composite ADM models, the production of the dark hadrons via off-shell dark photons is necessary since the dark photon is the lightest particle in the dark sector to release the entropy. The dark photon predominantly decays into the SM particles rather than the dark-sector particles in the case of production via off-shell dark photons. Meanwhile, the dark hadrons decay into lighter states, emitting dark photons, finally leaving the visible signals. The various signals are expected to be discovered at different experiments in the best case (see Figure 1): the dark photons at the prompt-decay searches or the displaced vertex searches and the dark hadrons at the LLP searches.

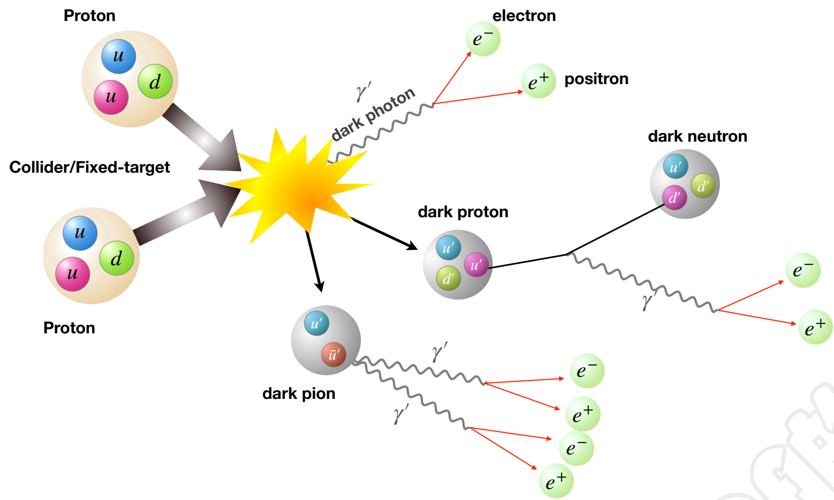

Figure 1. Various decay and transition processes in the dark-sector model with confining gauge dynamics. On-shell dark photon (denoted by γ') will decay into the SM particle (through mixing with the SM photon). Dark proton will convert into dark neutron with emitting dark photon (this process is caused by the symmetry breaking for dark photon). Dark pion decays into two dark photons via anomalous interaction (as with the neutral pion decay in the SM).

I have discussed the dark sector in the presence of light mediator particles (such as dark photons). The LLP searches have been intensively studied in the presence of mediator particles, particularly the case with the production via on-shell mediator particles. Light mediator particles play an important role in producing the LLPs, but these are not all. When the dark sector and the SM sector are connected via contact interactions (such as Fermi interactions) of quarks and dark quarks, the LLPs can be produced via the interactions. It is significant to include the dark hadrons produced via contact interactions for the comprehensive studies for the dark hadron searches at the LLP experiments. I expect that our work will help comprehend the structure of complicated dark-sector from the future and ongoing experiments, and that our work will give new insights into the dark-sector models.

Research significance

Recently, the dark-sector particle searches at LLP searches at terrestrial experiments have gotten attention. Many of the ongoing/future experiments for the LLP searches will run on the timescale of next decade. From theoretical point of view, it is an urgent task to clarify the theoretical predictions of the plausible particle-physics models. Most theoretical studies for the LLP searches have been focused on the case with the simple production of the dark-sector particles. My projects have covered two cases of production of the dark-sector particles (via on-shell/off-shell particles), particularly in the context of confining dark-sector models. In this study, I will cover an alternative production via contact interaction (see Figure 2). This study will give a complete set of methods for the standard production processes in the LLP searches.

Confining gauge dynamics for the dark sectors would give us a new insight from a theoretical point of view. Strong dynamics have been studied in various contexts, for example, in a chiral (massless quark) limit, in supersymmetric models, and so on. In this study, a composite particle is the DM candidate and is definitely a massive particle. I will apply and improve these methods and technologies to massive non-supersymmetric field theories for dark-sector particles. I expect that the knowledge from this study will deepen our understanding of strong dynamics.

References

The authors are listed in alphabetical order, common in the particle physics community. They have equal authorship.

[1]. N. Arkani-Hamed, D. P. Finkbeiner, T. R. Slatyer and N. Weiner, Phys. Rev. D 79, 015014 (2009).
[2]. A. Kamada, H. J. Kim and T. Kuwahara, JHEP 12 (2020), 202.
[3]. M. Ibe, A. Kamada, S. Kobayashi and W. Nakano, JHEP 11, 203 (2018).
[4]. M. Ibe, A. Kamada, S. Kobayashi, T. Kuwahara and W. Nakano, JHEP 03, 173 (2019). M. Ibe, A. Kamada, S. Kobayashi, T. Kuwahara and W. Nakano, Phys. Rev. D 100, no.7, 075022 (2019).
[5]. A. Berlin, N. Blinov, S. Gori, P. Schuster and N. Toro, Phys. Rev. D 97, no.5, 055033 (2018).
[6]. Y. Hochberg, E. Kuflik, T. Volansky and J. G. Wacker, Phys. Rev. Lett. 113, 171301 (2014).
[7]. A. Kamada and T. Kuwahara, arXiv:2112.01202 [hep-ph], to appear in JHEP.
[8]. Q. H. Cao, T. Kuwahara and S. Yuan, in progress.
[9]. A. Kamada, S. Kobayashi and T. Kuwahara, in progress.

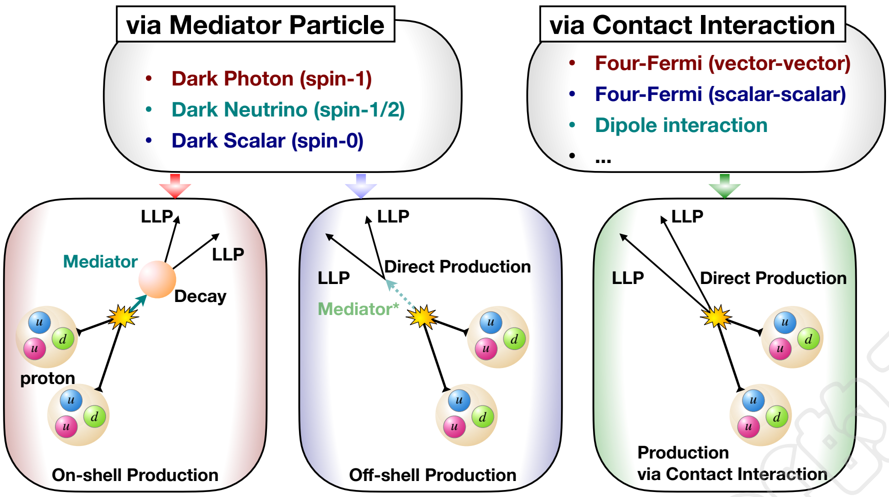

Figure 2. Schematic picture for production processes. Production via mediator particles is shown in the left panel (production via decay of on-shell mediator) and the middle panel (production via off-shell mediator), while direct production via contact interaction is shown in the right panel.

(2)Project description, objectives, and the key scientific problems to be solved.

As one of my long-term projects, I have studied the dark-sector models with confining gauge dynamics. In this project, I have recently studied the searches for the dark hadrons at the terrestrial experiments, in particular, LLP searches at the fixed-target experiments and the collider experiments. Towards an annual goal of this project, I will study the dark-sector model where the connection to the SM sector arises only from the contact interactions at the quark level. In this study, I will not explore the origin of contact interaction, but I expect this project will open a new avenue for model buildings for BSM. One of the critical issues is connecting the experimental results to the theoretical predictions of the models. It is not straightforward to connect the theoretical models with a confining sector to their observables due to the non-perturbative aspect of strong dynamics. Besides, it is also essential to confirm that the dark-sector models are consistent with cosmological observations, especially DM stability and entropy carried by dark-sector particles, in the presence of the contact interactions.

I will achieve this annual goal in two steps. First, I will construct an effective theory describing interactions between the dark hadrons and the SM particles. The different dark hadrons would be required depending on the phenomenological observables: more concretely, the different dark hadrons mean spin-0 dark pions, spin-1 resonances (rho meson-like dark mesons), and dark baryons. Hence, it must be important to change the effective theory for dark hadrons depending on the situation. Second, using the constructed effective theory, I will provide the experimental constraints on the model and the future sensitivities to the model. Dark hadrons would scatter with the SM nuclei when the dark quarks have contact interactions with the SM quarks. Hence, the DM direct detection may put an upper bound on the size of the contact interactions. Similar to the conventional dark-sector searches at the terrestrial experiments, I will focus on the long-lived particle searches. In addition, the contact interactions would induce the phenomenological impact on other observables related to the SM sector, such as flavor observables and CP-violation observables. It would be important to include radiative (quantum) corrections, more precisely renormalization group effects, since many of these observables are precisely measured. This project would involve the improvement of theoretical predictions by radiative corrections.

(3) Research approach and methodology, as well as feasibility analysis.

Research details

The dark-sector models have currently received attention as new candidates of BSMs after LHC run-1 and 2, as I mentioned before. It is very natural to consider the dark sector is complicated as the SM sector. I will focus on the dark sector with the confining gauge dynamics in this project: notably, there are only contact interactions between the quarks and the dark quarks.

At the first stage, I will study the effective theory describing interactions between the dark hadrons and the SM particles. It is not straightforward to construct the effective theory from the strong dynamics. Fortunately, since quantum chromodynamics (QCD) has been studied from the theoretical and experimental points of view for about half a century, we can utilize the understanding of QCD to construct the effective model of dark hadrons. The low-energy degrees of freedom would differ depending on the phenomena of interest. I plan to use the chiral Lagrangian construction for spin-0 dark mesons (e.g., dark pions) and Hidden-Local Symmetry construction for spin-1 dark resonances (e.g., dark rho mesons). Since these constructions rely only on symmetry arguments, many unknown parameters will not be required to be introduced. These constructions would lead to more plausible predictions for the phenomena. I will use the “naive dimensional analysis (NDA)” method for heavier resonances and baryons, if necessary, to determine interactions and masses. I need to explore a better way to construct the effective theory instead of NDA if the predictions are uncertain due to multiple parameters.

We should care about the DM candidate when we consider the dark-sector models. We have two options for DM in the dark-sector models with confining dynamics: dark-baryon DM and dark-pion DM. In the case of dark-baryon DM, the DM would be accidentally stable thanks to accidental global symmetry as with the SM proton, and its abundance is realized as the asymmetric DM scenario. Furthermore, I should restrict our system of the dark-baryon DM to specific ones since the properties of dark baryons strongly depend on gauge group: spin, stability, and so on. It is crucial to deplete enormous entropy in the dark sector, which arises from strong annihilation processes of dark baryons, as discussed before. At least, the lightest dark pions should decay into the SM sector via the contact interactions in order to achieve the significant suppression of dark-pion number in the Universe. One of the promising experiments to explore this model is the LLP searches. Once dark pions are produced via the interaction at the collider and fixed-target experiments, a dark pion leaves visible decay signals via the very same interactions.

Meanwhile, very different situations would arise when a dark pion is the DM. The decay process of the lightest dark pion originating from the contact interactions should be prohibited or extremely small to ensure the longevity of the DM. If other dark pions have the decay operators to the SM sector, these would also provide the visible decay signals. In this case, the DM abundance is affected by the contact interactions, and hence it is necessary to find the parameters realizing the correct DM relic abundance. When the DM abundance is realized via the SIMP mechanism, it is known that the pion self-interaction tends to be large. This implies that the dark pion masses would be close to the dark dynamical scale. Hence, the contributions from the (vector) resonances whose masses are close to the dynamical scale would not be negligible. In this case, the vector resonances can be long-lived due to the kinematics. The searches for the dark vector-resonances at the fixed-target experiments (particularly, DarkQuest) have been studied. I am currently studying the searches for the dark vector-resonances at the collider experiments, such as the FASER experiment. In this project, I will consider the case that the vector resonances are produced only via the contact interactions, and I will discuss the discovery potential at the fixed-target experiment (DarkQuest) and the collider experiment (FASER).

There are other interesting features of this project. The contact interactions between two sectors may have the flavor violation and the CP-violating phases in the SM sector. Hence, these give new contributions to the flavor and CP-violation observables. The precision measurements of these observables would put constraints on the contact interactions besides the DM direct detection and the LLP searches. These constraints get stronger when the light SM quarks or leptons are included in the interactions: especially the bounds from Kaon/pion physics and lepton-flavor universality violation. Last but not least, I will not treat the origin of the contact interactions in this project. But, after I clarify the structure of the contact interactions, I will also discuss their origin in the context of grand unification or some ultraviolet model buildings.

Justification

I have continued to study particle physics models with dark sectors. I have discussed the experimental/observational signature in the context of the confining dark sector:

- The long-lived particle searches at the collider and the fixed-target experiments [7,8]
- Cosmic-ray signals [2]
- The self-interaction of DM motivated by the small-scale structure of galactic halos [2,9]

One of the essential building blocks for this study is the long-lived particle searches. I have recently derived approximate (semi-analytic) formulae for the existing constraints and the future sensitivities of the long-lived particle searches [7] and have improved the numerical codes for the searches, including the off-shell production [8]. I will utilize and improve these methods for searching for long-lived particles with contact interactions. I have also studied the strong dynamics in the dark sector in the literature: SIMP [9], SIMP with vector resonances [8], and baryon effective theory with linear sigma model [7]. In the context of the model-building, I have proposed an ultraviolet model for the composite asymmetric dark-matter model with a dark photon portal. In this study, I have addressed two unknown ingredients for the composite ADM, tiny kinetic mixing between dark photon and visible photon and portal interaction sharing the matter asymmetry and the DM asymmetry.

(4)Originality and innovative aspects of the proposed study.

This project contains the following new ideas.

(1). I will construct the dark-sector models with the contact interaction. These models are alternatives to the models with light mediator particles, which have not been explored yet.

(2). This study will cover possible production mechanisms for dark hadrons by combining these new models and the conventional studies.

(3). Compared to the conventional dark-sector models with mediator particles, since the dark particles directly couple to the SM particles only through the contact interactions, the dark particles would induce non-trivial phenomenology. In particular, the contact interactions may induce new contributions to flavor or CP-violation observables. The future precision measurements for the observables will find some experimental deviation from the SM predictions.

(5) Annual research plan and expected results.

I plan to carry out the proposed project by following the steps below:

1. Construct the effective theories deduced from the confining dark sector with the contact interactions to the SM particles, and classify the effective theories based on gauge and flavor symmetries in the dark sector.
2. Provide experimental bounds on the contact interactions from flavor and CP-violation observables, and interpret these bounds in terms of the effective theories for dark hadrons. (optional) improve the theoretical prediction by including radiative corrections.
3. Applying the effective theories to the case of dark baryon DM.
4. Applying the effective theories to the case of dark meson DM.

I will make the first paper for steps 1-2 as the generic constraints on the effective theories with the confining gauge dynamics. Then, I will write two papers for the latter steps as the applications for the concrete models (composite asymmetric dark model for dark baryon and SIMP scenario). I have to revise the thermal history of these models in the presence of contact interactions, and hence I will write two papers separately.

2.Other issues that should be specified

(1) Have you applied for other NSFC programs this year? (If so, please list the programs and project titles and explain the differences and connections between those projects and this proposal.)

No.

(2) Are you currently undertaking any research projects related to this proposed study? (If so, please list the title and grant number of the research projects, your role in the projects, source of funding, starting and ending dates, and connection with this proposal.)

No.

(3)Have you (as PI or as participant) submitted applications to NSFC from more than one host institution in the same year? (if so, please list the program, title, and host institution of the applications you submitted (as PI or as participant), and explain why you submitted the applications from different host institutions.)

No.

(4)Do you have any on-going NSFC grants applied through other host institutions? (if so, please list the grant number, program and title, host institution, starting and ending dates of the on-going grants, and explain why you applied through different institutions.)

No.

(5)Are there any career break in your education or work experience? (if so, please explain the reason.)

I have a career break between September 2020 and August 2021. I could not enter China due to COVID-19, and thus I could not start the work at Peking University from

September 2020. During the period, I have stayed in Japan and visited Nagoya University.

Takumi Kuwahara Resume

北京大学， 物理学院， 助理研究员

Education:

(1) 2014-04 至 2017-03, Nagoya University, Physics, 博士

(2) 2012-04 至 2014-03, Nagoya University, Physics, 硕士

(3) 2008-04 至 2012-03, Tokyo University of Science, Physics, 学士

Postdoctoral work experience:

(1) 2021-09 至 今, 在站, Peking University

(2) 2017-09 至 2020-08, institute for basic science

(3) 2017-04 至 2017-08, University of Tokyo

Research and work experience (Except Postdoctoral work experience) :

(1) 2021-09 至 今, Peking University, School of Physics, 助理研究员

Other identity documents that have been used:

无

NSFC projects the applicant has undertaken either as PI or participant in the last 5 years:

无

Other research projects the applicant has undertaken either as PI or participant in the last 5 years (Except NSFC projects) :

无

Representative research achievements and academic awards:

一、Representative publications:

(1) Ayuki Kamada; Hee Jung Kim; **Takumi Kuwahara** ; Maximally self-interacting dark matter: models and predictions, *Journal of High Energy Physics*, 2020, 12(202) (期刊论文)

(2) Masahiro Ibe; Ayuki Kamada; Shin Kobayashi; **Takumi Kuwahara**; Wakutaka Nakano ; Baryon-dark matter coincidence in mirrored unification, *Physical Review D*, 2019, 100(7) (期刊论文)

(3) Jason L.Evans; Kenji Kadota; **Takumi Kuwahara** ; Revisiting flavor and CP violation in supersymmetric SU(5) with right-handed neutrinos, *Physical Review D*, 2018, 98(7) (期刊论文)

(4) Junji Hisano; **Takumi Kuwahara**; Yuji Omura ; Threshold corrections to baryon number violating operators in supersymmetric SU(5) GUTs, *Nuclear Physics B*, 2015, 898: 1-29 (期刊论文)

(5) Junji Hisano; **Takumi Kuwahara**; Natsumi nagata ; Decoupling Can Revive Minimal Supersymmetric SU(5), *Journal of High Energy Physics*, 2013, 2013(38) (期刊论文)

二、Representative research achievements and academic awards:

无

Attachment

No.	File name	Note	Attachment type
1	Contract		Agreement
2	Certificate of Employment		Agreement
3	publication (1)-1		Representative papers （no more than five）
4	publication (1)-2		Representative papers （no more than five）
5	publication (1)-3		Representative papers （no more than five）
6	publication (2)		Representative papers （no more than five）
7	publication (3)		Representative papers （no more than five）
8	publication (4)		Representative papers （no more than five）
9	publication (5)	Published version is not open access and is not available from Peking University.	Representative papers （no more than five）

Title:	Study on Composite Dark Matter with Contact Interactions
Program/Type:	Research Fund for International Scientists/Research Fund for International Young Scientists
Application Code:	A2605.标准模型精确检验与新物理

Letter of Commitment for Research Integrity of Applicants for National Natural Science Fund Projects

I hereby solemnly promise that, in accordance with the requirements of the NSFC Guide to Program and other relevant regulations, the proposal and documents submitted are authentic and effective and there is no violation of scientific research integrity. In the whole process of application, review and implementation of NSFC projects, I will strictly abide by ethics and professional standards, and scientific morality, as well as stick to review rules of NSFC and other provisions. I will avoid any misconduct that may affect the fairness of the review of NSFC projects.

I am aware that if any of the foregoing statements made by me are willfully violated, I am subject to punishment according to regulations of the National Natural Science Foundation of China and laws of China.

Signature:

Date:

Title:	Study on Composite Dark Matter with Contact Interactions
Program/Type:	Research Fund for International Scientists/Research Fund for International Young Scientists
Application Code:	A2605.标准模型精确检验与新物理

国家自然科学基金项目申请单位科研诚信承诺书

本单位承诺：按照国家自然科学基金项目指南等国家自然科学基金委员会相关文件的要求，已对本单位申请人的申请条件、科研道德及申请人所提交申请材料的真实性、完整性和合规性进行审核。

我们将按照相关规定履行科学基金项目申请、评审、管理、监督、保障等职责，严格遵守国家自然科学基金委员会关于项目评审、资助管理等工作规则和要求，杜绝可能影响科学基金项目评审公正性的行为，恪守科研伦理，加强科研诚信建设，共同营造科学基金项目资助及实施的良好环境。

如违背承诺，本单位自愿接受国家自然科学基金委员会和相关部门做出的处理决定。

Letter of Commitment for Research Integrity of Host Institution for National Natural Science Fund Projects

This is to certify that we’ve conducted check on the applicant’s eligibility and research ethics, as well as the authenticity, completeness and compliance of the documents submitted by the applicant in accordance with the National Natural Science Foundation of China (NSFC) Guide to Program and relevant regulations.

We will fulfil the responsibilities related to the application, review, management, supervision and support of NSFC projects in accordance with NSFC regulations. We will strictly abide by the NSFC regulations on project review and funding management, and avoid any activities that may affect the fairness of review. We will strictly uphold research ethics and foster scientific integrity, so as to contributing to a sound environment for project funding and implementation.

In case of breach of commitment, we will accept the penalty decision made by the National Natural Science Foundation of China and relevant departments.

依托单位公章:
Stamp of the host institution
日期:　　　年　　月　　日