（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）

国外連携機関長期研修　報告書

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I had visited Madrid, which is the capital in Spain, for three weeks. Madrid has a comfortable climate (at least in September), people are friendly and Spanish foods taste great. Salamanca, where a hotel I stayed is, is a high-class residential area and is easy to live. There are many Spanish restaurants, and I often ate the paella. I went to several places in Madrid on the weekends. For example, Reina Sofia Museum, where “Guernica” drawn by Pablo Picasso is displayed, Plaza mayor, which is very big plaza at the central of Madrid and has many tourists, the bullfight, which is a traditional public entertainment in Spain and the royal palace, which anyone no longer lives, but a popular sightseeing spot. I also went to Santiago Bernabeu stadium, which is the home ground of Real Madrid. Unfortunately, I could not watch the match. I enjoyed sightseeing in Madrid.

During my stay in Madrid, I had studied particle physics in Instituto Fisica Teorica (IFT), UAM-CSIC, hosted by Dr. Luca Merlo. This visit to IFT was realized thanks to Dr. Ryusuke Jinno. IFT is located at a suburb of Madrid, which is about an hour from Madrid city by train. It has researchers who are working on many kinds of fields of physics, particle physics, cosmology, astrophysics, and so on. Each students’ room has ones working on several kinds of fields, not only one field. It is easy to interact with ones in different fields. Some people have lunch and a chat in a common room. I often had lunch in this room and communicated with researchers in IFT. I joined drinking parties by PhD students at a nearby cafeteria in the evening. The environment of IFT was comfortable to engage in my research. I will give details of my activities in IFT in the following.

i) Seminar on my works on direct search for supernova axions.
ii) Discussion on models that can realize the mass hierarchy of the standard model fermions.
iii) Discussion on tunneling action formalism.
iv) Journal clubs of particle phenomenology group and cosmology-astrophysics group.

I had a talk on my works in a seminar in IFT. The topic is direct search for supernova axions. Axions, which have been predicted particles theoretically, are well-motivated subjects of the physics beyond the standard model. Particle physicists have tried to find axions by some experiments, but they have not been found. My works give a novel proposal to search supernova axions. We showed that we may detect supernova axions with helioscopes and collider detectors, if a nearby supernova occurs.

I discussed the mass hierarchy of fermions in the standard model of particle physics with Dr. Luca Merlo. The standard model has two types of particles (fermions) that compose matters. They are called quarks and leptons. Quarks have six copies of particles, up quark, down quark, strange quark, charm quark, bottom quark and top quark. Leptons also have six copies of particles, electron, muon, tauon, electron neutrino, muon neutrino and tauon neutrino. Experiments have shown that the masses of the particles are quite different. For example, the mass of top quark, which is the heaviest quark, is ten to the power of eleven times of one of up quark, which is the lightest quark. The large difference of masses causes the hierarchy of some dimensionless parameters in the quantum field theory, which is the fundamental theory describes particle physics. The mechanism of the hierarchy has not been revealed. This is one of serious problems in particle physics. We discussed how to realize the hierarchy in the presence of axions. The discussion is in progress.

I discussed tunneling action formalism with Dr. Ryusuke Jinno. In quantum theory, a particle can tunnel to another vacuum even in the presence of a potential barrier with finite probability. Tunneling does not occur in classical theory, so this is a characteristic phenomenon of quantum theory. The probability is represented by difference of the value of the action between before and after transition. Some papers have proposed a nice formalism to calculate the tunneling probability in a limited condition. We have tried to apply to a specific model. We calculated the value of action in both ordinary method and tunneling action formalism. The work is in progress.

I participated in the journal clubs of particle phenomenology group and cosmology-astrophysics group. In the journal clubs, a member briefly introduces abstract of a paper published recently projecting it on the screen. If someone have questions, everyone thinks abouts them. I briefly discussed about three or four papers in each seminar.

Spain has different language, climate, foods and lifestyle from Japan. It was sometimes hard to communicate with local people because some of them could not speak English. All I experienced in Spain are new and exciting. I had discussions for collaboration with researchers in IFT. This was a nice trip.