（別紙様式２）

フォトンサイエンス国際卓越大学院プログラム（XPS）

光科学特別実習　報告書

氏　　名	村井　開
所属部局	理学研究科　　物理学専攻
研究機関・企業名	マックス・プランク天体物理学研究所
日程	西暦　2021 年　2 月　17 日　～　西暦　2021 年　2 月　17 日

As the XPS special training in photon science, I participated in the Axion Day Workshop (homepage: https://indico.ph.tum.de/event/6985/) held online by the researchers in the Munich area on February 17th, 2022. At first, I planned to visit Max Planck Institute for Astrophysics in Munich, Germany. But, due to the spread of COVID-19, I abandoned the plan and, instead, decided to participate in this workshop. This workshop is focused on the axion physics and included 12 talks.

In this workshop, I made a 10-minute oral presentation titled “SU(N)-natural inflation”. This presentation is based on the collaboration with Tomohiro Fujita in WIAS, Waseda University, Kyohei Mukaida in KEK, and Hiromasa Nakatsuka in ICRR, University of Tokyo. The slide of this talk is uploaded to the workshop homepage.

Cosmological inflation describes the early stage of the Universe successfully by solving the horizon/flatness problems and providing the seeds of anisotropies observed in the cosmic microwave background (CMB). After inflation, the hot Universe should be generated, which requires a coupling between inflaton and other sectors. Nevertheless, the flatness of the inflaton potential should be protected from radiative corrections to have a sufficient duration of inflation. Axion-like particle is an attractive candidate for the inflaton as its (approximate) shift symmetry controls the flatness. In addition, its derivative couplings can induce rich phenomena, including the amplification of the gauge fields.

In particular, the model where the inflaton couples to SU(2) gauge fields through the Chern-Simons term, dubbed *chromo-natural inflation*, has attracted much attention. In the presence of inflaton velocity, the gauge fields have a homogeneous and isotropic attractor solution suitable to explain the current homogeneous and isotropic Universe. Also, the backreaction from the gauge fields enables the slow-roll inflation with a sub-Planckian axion decay constant. Such background gauge fields induce linear couplings between the metric and gauge field tensor perturbations, and the chiral gravitational waves are significantly produced. Although the original chromo-natural inflation is excluded from the CMB observations due to the overproduction of gravitational waves, this conflict can be evaded by introducing additional fields.

The SU(2) gauge group is the simplest example for the gauge fields to have a homogeneous and isotropic attractor solution. In general, we can extend the chromo-natural inflation model to an SU(N) gauge group with $N > 2$. We refer to this extension as “*SU(N)-natural inflation*”. The previous discussion on the SU(N) case was often limited to the simplest choice of SU(2) subgroup, and it was considered that the SU(N) case simply leads to the chromo-natural inflation (e.g., see [6]). Alternatively, some studies consider N/2 copies of SU(2) subgroups in SU(N) and discuss the production of gravitational waves. However, as we show in this letter, most of homogeneous and isotropic attractor solutions in the SU(N)-natural inflation have been unexplored.

In this work, we provided a general procedure for finding homogeneous and isotropic attractor solutions in the SU(N)-natural inflation under three reasonable assumptions. We found new solutions whose amplitudes of the gauge fields are larger than that in the chromo-natural inflation. In addition, the effective potential implies that the solution with the biggest amplitude is the most stable solution for SU(N) with $N > 2$. We also see that each solution corresponds to a non-equivalent embedding of SU(2) subgroup in the SU(N) group, implying different spontaneous symmetry breaking patterns of SU(N) under a chemical potential of the Chern-Simons number from a non-

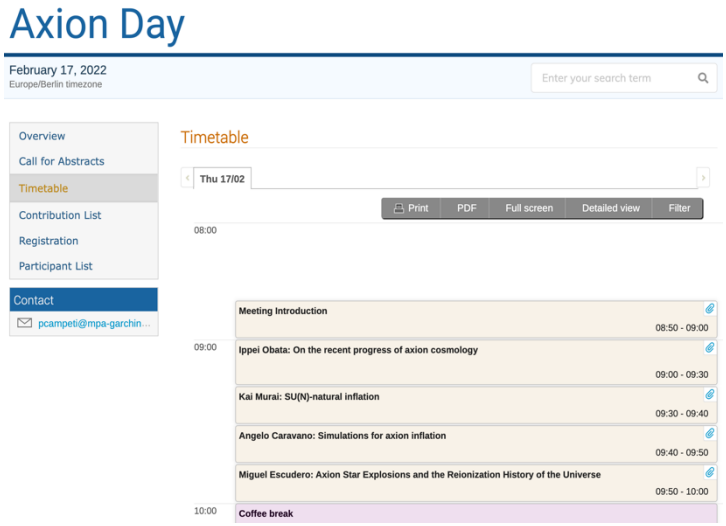

Figure: Homepage of the Axion Day workshop

vanishing inflaton velocity. Finally, we performed numerical simulations of the gauge field dynamics and confirm that the analytically found solutions are attractor and complete for N = 3, 4.

However, the effects of the different background solutions on the metric and gauge field perturbations are not investigated there and we are now studying the perturbations in the SU(N)-natural inflation. Since the background solution has a similar configuration to in the CNI model, we can expect that the SU(N)-natural inflation also show the enhancement of the gauge field perturbations and the generation of the gravitational waves as in the CNI model. The dynamics of the perturbations in the SU(N)-natural inflation is important in that it determine the validity of this model as an inflationary model or a model predicting observable gravitational waves. The results on the perturbations in the SU(N)-natural inflation is now in preparation for publication and then I omit the detailed explanation of the result here.

The workshop includes the coffee break time, when the participants can freely talk with each other using a virtual meeting application, gather town. At the end of the workshop, the participants discussed the several topics about the axion physics including the future prospects and possible detections. This workshop was my first experience of a talk in a meeting held by an oversea institution, and this was a precious opportunity to test my English and presentation skill. Finally, I would like to thank Ippei Obata for bringing this workshop to my attention.