学 位 論 文 要 約

題　目　Search for sub-eV axion-like particles via asymmetric stimulated resonant photon scattering in two-color coaxially focused laser beams

（２色の同軸集光レーザー下の非対称誘導共鳴光子散乱を介したサブ電子ボルトのアクシオン様粒子探索）

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Pseudo Nambu-Goldstone Boson (PNGB) can be generated when a global and continuous symmetry is spontaneously broken in general. Axion is the PNGB generated by breaking of the Peccei-Quinn symmetry introduced to solve the strong CP problem in Quantum chromodynamics. Axion has the coupling-mass relation from the calculation of the chiral perturbation theory. In contrast, axion-like particles (ALPs) don't require this relation. A model, ALP-*miracle*, simultaneously describes two major cosmological issues: inflation and dark matter. In particular, the predicted mass consistent with the observations of the cosmic microwave background is in the range of 0.01 ~ 1 eV.

We introduce the concept of a stimulated resonant photon collider (SRPC). For the creation of the resonance of an ALP, a laser beam in the coherent state (creation beam) is focused into the vacuum. In order to stimulate ALP decay into two photons, another laser beam (inducing beam) is coaxially focused at the same focal point. This stimulation process results in a signal photon with different wavelength from those of the creation and inducing beams. When two or more laser beams are incident to matter, photons with different wavelengths can be produced by the nonlinear optical process, four-wave mixing (FWM). FWM photons can have the same wavelength as that of signal photons and thus become the major background. Therefore, one of the biggest issues toward high sensitive searches is how to reject the FWM background photons. The atomic FWM background photons in the residual gas at the focal point are removable by decreasing the density of atoms, pressure, inside the vacuum chamber. On the other hand, the numbers of signal photons and atomic FWM background photons in the optical elements can be independent of pressure. Therefore, discrimination between signal photons and atomic FWM background photons via the optical elements is indispensable for the SRPC experiment.

The scattering rate in collisions between two photons with symmetric energies and symmetric incident angles was initially formulated in the past searches. However, in the focused and short-pulsed beams, the incident angles and the energies of photons must fluctuate due to the uncertainty principles in momentum and energy states. Therefore, the formulation for the SRPC has been generalized so that it includes asymmetric collisions within the coaxial focused beams. This formulation results in the prediction of signal emissions at cone angles beyond those determined by geometrical optics for the focused beams. This originates the fact that randomly selected two photons are asymmetric in general in terms of incident angles and incident energies. Also, since the emission angles of signal photons depend on the assumed ALP mass, the observation of

the emission angle distribution eventually determines the ALP mass.

Based on the asymmetric formulation, in this thesis, a search using a 2.5 mJ/40 fs Ti:Sapphire laser and a 1.5 mJ/9 ns Nd:YAG laser is presented. The pressure dependence of the number of observed photons was measured and the pressure-independent component was observed for the first time in this experimental setup below 1 Pa. FWM background photons via the optical elements are produced from the overlap of the two beams at the optical elements. On the other hand, signal photons are emitted to the area outside the beam cones. In order to identify possible sources of the pressure-independent component, the creation beam cross section dependence of the number of observed photons was measured. When the beam cross section of the creation laser was larger than that of the inducing laser, the number of observed photons showed the constant behavior. Therefore, the number of signal photons was found to be consistent with zero. The exclusion limits for ALP exchanges with mass m and coupling between the ALP and two photons, g/M, were obtained as the most sensitive coupling value $g/M = 1.14 \times 10^{-5}$ GeV^{-1} at $m = 0.18$ eV.