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Kyoto University
Search for Dark Matter Axions with Rydberg Atoms in a Resonant Cavity

Izumi Ogawa, Shin Nakamura, Takahiro Takimoto, Masaru Tada and Seishi Matsuki

Based on quantum electronic techniques, novel methods to search for dark matter axions have been proposed. The experimental systems are being used and/or developed to detect axions in the mass range between 5 to 12 $\mu$eV.

**Keywords:** Dark matter in the Universe/ Cosmic axions/ Quantum electronics/ Rydberg atoms/ Axion-photon-atom interactions in a resonant cavity

It is now well established that there exists the dark matter in the Universe which exceeds 10 to 100 times more the normal visible baryonic-matter like light-emitting stars. However no definite evidence for the constituent particles of the dark matter has yet been found so far. One of the mostly attractive candidates of the non-baryonic dark matter particles is the axion which is a hypothetical pseudo-scalar particle proposed to solve the so-called strong CP problem in the QCD theory of strong interactions. The mass of the axion is constrained from astrophysical and cosmological arguments and the window still open is from 1 $\mu$eV to 1 meV. Due to the extremely weak interactions of axions with the ordinary matter, it is inevitably difficult to detect axions, although a few tries have been reported.

We have proposed a number of novel sensitive methods to search for dark matter particles with quantum electronic methods [1-4]: The most sensitive method (CARRACK: Cosmic Axion Research with Rydberg Atoms in a resonant Cavity in Kyoto) to detect axions among them is to firstly convert the axion into a microwave photon in a resonant cavity via the Primakoff effect in a strong magnetic field [1,3]. The converted photons are then detected by Rydberg atoms passed through the cavity. The cavity is cooled down to 10 mK so that the background due to thermal blackbody radiations from the wall of the cavity is appreciably suppressed. Since the Rydberg atom is expected to have inherently no noise, this scheme is much more sensitive compared to conventional amplifier-heterodyne method.

Schematic diagram of the experimental system with the method is shown in Fig. 1. The axions are converted to microwave photons in the conversion cavity which is in a magnetic field of 7 T. These photons thus produced are transferred to the detection cavity and absorbed by Rydberg atoms. The external magnetic field at the detection cavity is less than 0.9 kG due to the cancellation coils set between the main magnet and the cavity. The inside of the detection cavity made of Nb is kept to be free from magnetic field due to the Meissner effect in

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**NUCLEAR SCIENCE RESEARCH FACILITY —Beams and Fundamental Reaction—**

*Scope of research*

Particle beams, accelerators and their applications are studied. Structure and reactions of fundamental substances are investigated through the interactions between beams and materials such as nuclear scattering. Tunable lasers are also applied to investigate the structure of unstable nuclei far from stability and to search for as yet unknown cosmological dark-matter particles in the Universe.

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atomic beam oven
atomic beam slit
lasers

Figure 2. Schematic experimental diagram to search for dark matter axions by directly detecting axions with Rydberg atoms. Due to the axion-electron coupling, the axions are directly absorbed by Rydberg atoms, inducing the transition from the lower to the upper fine-structure states.

~ecryostat
laser is varied together with the resonance frequency of the cavity to scan the mass of the axion.

To confirm the excitation of Rydberg atoms with this laser system, a prototype cavity and an atomic beam apparatus were constructed. The cavity can be cooled down to 0.5 K with a liquid 3He cryostat system. The Rydberg states with the principal quantum number (n) of around 40 were successfully excited with the diode laser system and detected with the filed ionization method out of the cavity, thus indicating satisfying performance of the laser-Rydberg system. This experimental system is now being used to search for cosmic axions by directly detecting axions with Rydberg atoms [1,6]: Due to the axion-electron coupling, the axions are directly absorbed by Rydberg atoms, inducing the transition from the lower to the upper fine-structure states. The cavity is tuned out of the resonance to suppress the excitation of the upper state with photons. With this scheme, the upper limit of the coupling strength of the axion-electron interaction is obtained, giving more severe constraint than the previous laboratory experiments. The mass of the axions now searching for is around 5 µeV.

After finishing the search experiment with the direct detection method mentioned above, the whole experimental parts of CARRACK system are to be assembled. The first run of search with this system is scheduled in the middle of the next year, 1995.

References