ADMX's Continuing Search for Dark Matter Axions

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Axions could solve the strong CP problem as well as be the source of dark matter. The ADMX experiment is currently searching for dark matter axions while testing SQUID amplifier technology to improve future searches. ADMX is currently sensitive to one broad class of axion-photon coupling models with masses near 3.5 μeV. The next phase of ADMX will be sensitive to pessimistically coupled models over a much wider range of masses. Additionally, ADMX can be used to look for other light new-physics particles.

1 Axions and Dark Matter

Axions are light pseudoscalar particles that are a result of the Peccei-Quinn solution to the strong CP problem [1],[2],[3]. Axions could be produced in such quantities in the early universe to account for dark matter [4]. The interaction between axions and photons through the Primakoff effect [5] provides a means for detecting axions.

The requirements of both solving the strong CP problem and constituting a large fraction of dark matter favor a narrow range of possible axion masses and couplings [6],[4],[7]. The Axion Dark Matter Experiment (ADMX) is searching for dark matter axions over the first decade of the 1 μeV to 1 meV favored mass region.

2 ADMX Design and Technology

ADMX is a axion cavity haloscope [8]; axions from the dark matter halo are stimulated to decay into photons by a strong magnetic field inside the experiment's microwave cavity. This excites electromagnetic modes inside the cavity which can be measured by an antenna. As the cavity is excited only when the total energy of the axion is equal to the cavity's resonant frequency, only a small range of axion masses may excite the cavity at any one time. Therefore the cavity's frequency must be tuned to allow a larger range of masses to be explored.

ADMX consists of a 22 liter cylindrical microwave cavity whose frequency is tuned by the position of two copper rods. The cavity sits inside a 7.6 Tesla magnet, and is kept at a temperature of 2 Kelvin by pumped liquid helium. An antenna in the top of the cavity leads to the amplifier electronics immediately above. Axion signals develop in the cavity, are amplified, and are carried out the top of the experiment, where they are mixed down and Fourier analyzed (Fig. 1). A more thorough description of the experiment can be found in [9].

The primary limiting factors to ADMX's axion photon coupling sensitivity are the system temperature and amplifier noise temperature. Previous incarnations of ADMX [10], were limited by the semiconductor amplifier noise, which had a minimum temperature of 2 K. The current

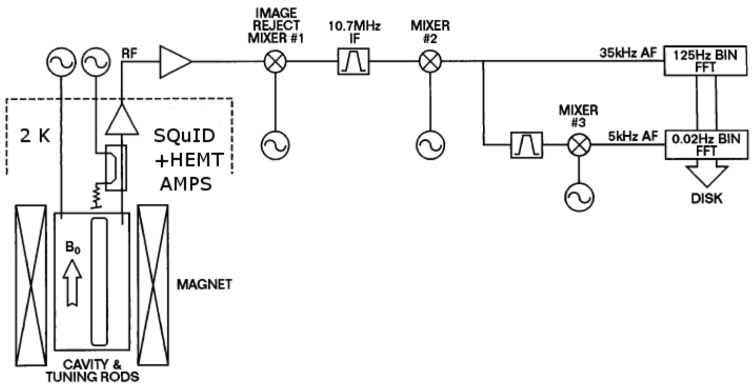

Figure 1: Schematic of ADMX receiver chain.

version of ADMX features a SQUID amplifier whose noise temperature can track physical temperature to as low as 100 mK [11]. The physical temperature of ADMX in this run, however, has not changed significantly from previous runs of the experiment, and so the axion-photon coupling sensitivity gain is slight; significant sensitivity gains will only come with improved cooling of the cavity. Given that SQUID amplifiers cannot function in magnetic fields, the main magnet's field must be canceled by a bucking coil, another addition to previous versions of ADMX. The primary technical challenge in this phase was to sufficiently cancel the field to insure proper SQUID functionality.

3 Preliminary Sensitivity and Phase 2

The 20 kHz wide raw power spectrum in the cavity is measured over 90 seconds, after which the rods are adjusted to change the cavity's resonant frequency. These spectra are corrected for the receiver transfer function and summed to give a power spectrum over a range of several MHz. Axion signals would appear in this power spectra as a narrow peak at a frequency corresponding to the axion mass with a width related to the velocity dispersion of dark matter axions near earth (Fig. 2).

If no signals are observed, an upper bound on axion-photon coupling over the covered mass range can be set. As of September 2009, the data taken by the 2009 run of ADMX is projected to be sensitive to axions models that couple stronger than the standard KSVZ (e/n=0) model as described in [12] for a standard virialized dark matter halo with local density of 0.45 GeV/cm^3[13]. Sensitivity is greater for unvirialized dark matter models with a smaller velocity distribution or relative velocity to the solar system (Fig. 3).

With the successful demonstration of the SQUID amplifier and bucking coil system in the present version of ADMX, the next version of ADMX can be prepared. In "Phase 2" of ADMX, the cavity and amplifier will be cooled K to 100 mK by a dilution refrigeration system. This will increase the speed at which masses can be covered by a factor of 100, allowing the entire promising 1 μeV to 10 μeV mass range to be covered for reasonable axion-photon couplings with only one year of operation, even if axions are a subdominant fraction of dark matter. Construction of phase 2 will begin shortly after the completion of the present run.

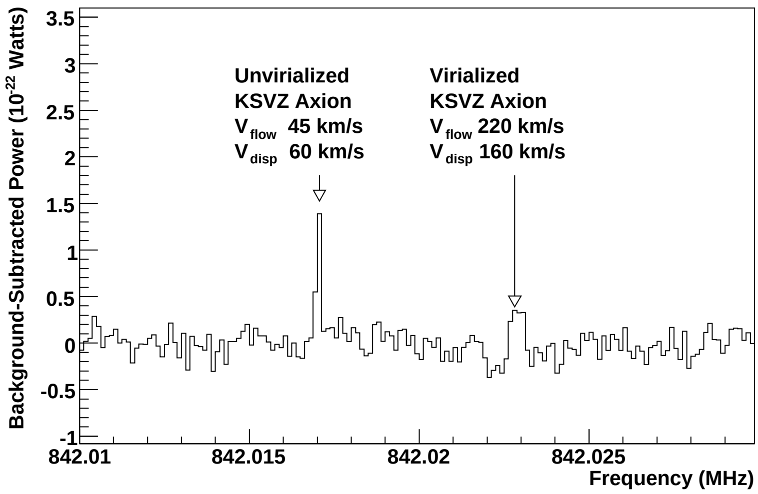

Figure 2: Two simulated axion signals imposed on a real power spectrum average.

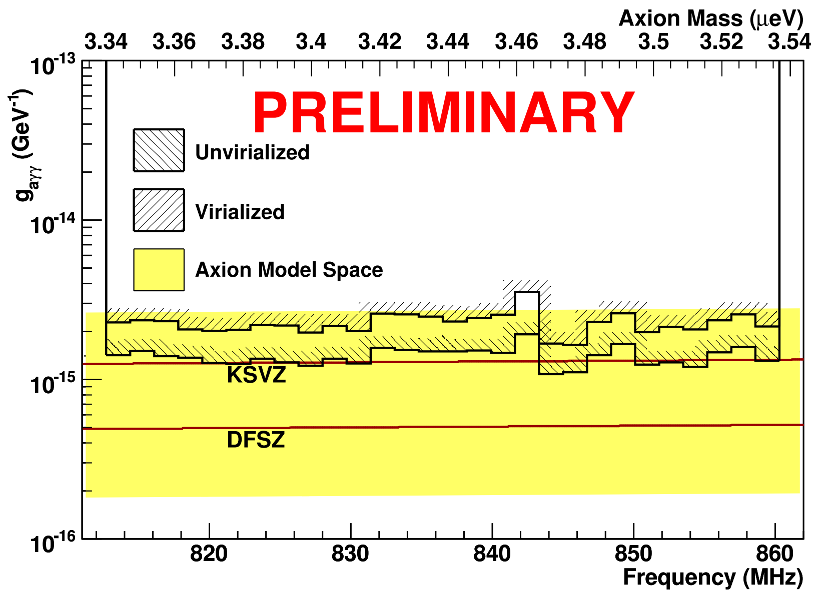

Figure 3: Preliminary ADMX sensitivity for the 2009 run.

4 Additional Searches

In addition to dark matter axions, ADMX has the potential to be sensitive to other light scalar and pseudoscalar particles. One example of these are chameleons, particles whose nonlinear self couplings lead to a density dependent mass and may be related to dark energy [14],[15], [16]. As low mass chameleons can be trapped inside the cavity, electromagnetic modes of the cavity can couple to chameleon modes. Once chameleon modes have been excited, their decay back into electromagnetic modes can be detected with the same system as is used to detect dark matter axions. With this method, ADMX should be highly sensitive to chameleon-photon coupling over a range of masses corresponding to the tuning range of the cavity. A chameleon search with ADMX is currently underway.

5 Conclusion

ADMX has demonstrated sensitivity to some promising axion dark matter models over a limited range of axion masses. Additionally, the current phase of ADMX has demonstrated the amplifier technology required to explore a range of potential dark matter axion masses and models. The upcoming Phase 2 of ADMX will utilize this technology combined with a lower temperature to have a good chance of seeing signs of axion dark matter if it exists. As well as being sensitive to dark matter axions, ADMX may also be sensitive to light new physics particles related to dark energy.

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