The Axion Dark-Matter eXperiment: Results and plans

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The axion affects issues of the origin of CP symmetry in the strong interactions and the composition of the dark matter of the universe; current constraints limit its mass to 1 μeV–10 meV, with the low end of this range (1–10 μeV) especially significant for dark-matter axions. Axions may be detected by their coupling to photons in a resonant cavity in a strong magnetic field. The Axion Dark-Matter eXperiment (ADMX) recently completed Phase I of an upgrade to its detector, incorporating SQUID electronics in the receiver front end and conducting a year-long data run. Phase II of the upgrade will install a high-capacity dilution refrigerator to cool the SQUID and cavity to $\sim$100 mK.

1 Introduction

The discovery of the axion, or placing unambiguous limits on its existence, would have profound implications for two of the most important problems in contemporary physics: (i) the origin of parity (P) and the product of charge conjugation with parity (CP) symmetry in the strong interactions and (ii) the composition of the dark matter of the universe. The Axion Dark-Matter eXperiment (ADMX) searches for axions in the dark-matter halo of our galaxy. Many observations imply the existence of large halos of non-luminous matter in galaxies. The composition of this dark matter is a mystery whose solution is one of the most exciting challenges in science today. It seems probable that much of the dark matter is non-baryonic; the leading candidates are finite-mass neutrinos, weakly interacting massive particles, and axions. Only the latter two candidates could be cold dark matter, preferred in most scenarios. Between these two, the axion is special in the sense that a laboratory experiment can be carried out with current technology that can detect or rule out axions at the expected level of abundance.

ADMX detects axions by their stimulated conversion into microwave photons in a high Q cavity permeated by a large magnetic field. [1] This detector [2, 3] consists of a large superconducting magnet containing one or more microwave cavities. Axions in the high-field region will be stimulated to decay into microwave photons (which have a frequency equal to the rest mass of the axions) when the resonant frequency of the cavity equals the mass of the axion.

The cavity frequency is slowly tuned to search for this resonant conversion. Over the past few years, the detector has scanned the 1.9–3.5 μeV axion mass range; its sensitivity is such that the detector could find a signal, given the constraints on dark matter density set by astrophysical and cosmological considerations. [4–9, 11]

ADMX was recently upgraded to incorporate superconducting quantum interference device (SQUID) amplifiers into the front end of the receiver. This upgrade is based on a remarkable breakthrough in making SQUIDs operate as high-gain, low-noise amplifiers into the GHz range [14] with measured SQUID noise temperatures of $T_N = 70$ mK. This noise, which is close to the quantum limit and which compares very well to the $T_N = 1.5$ K of the earlier HEMT amplifiers, requires the cavity and amplifier be cooled to 100 mK. The collaboration planned and proposed a conservative, two-step approach to this upgrade. First (as Phase I), the experiment was retrofitted to operate with SQUID amplifiers, but at the same physical temperature of $T \sim 1.5$ K. In this case the system background temperature is dominated by the physical temperature. The Phase I construction and commissioning ended in 2008 and was followed by a science run with the SQUID amplifiers prior to moving from LLNL to UW. Axion search results using the SQUID have been published [11], as well as results from searches for axion-like particles [12, 13].

Phase II will add a high-circulation-rate dilution refrigerator to the detector, reducing the physical temperature to $T \sim 100$ mK. The system noise temperature after Phase II is expected to be $T_s \sim 200$ mK. The upgrade will improve system noise performance to an extent that ADMX will be sensitive to—or be able to rule out—axions as a component of the halo of our galaxy with *all* plausible coupling strengths in the lowest decade of the allowed mass range, ($\sim$1–10 μeV).

2 ADMX Phase 1

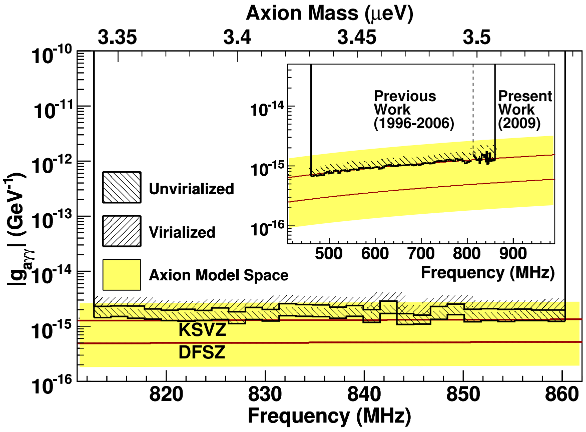

Figure 1: Axion couplings and masses excluded at the 90% confidence level by the experiment. The main figure shows the results from the Phase I upgrade and the inset the limits from all data by ADMX.

Figure 1 shows the axion couplings and masses excluded at the 90% confidence level by

ADMX. [4–9, 11] The plot shows the axion-to-photon coupling $g_{a\gamma\gamma}$ as a function of the axion mass $m_a = hf/c^2$ and photon frequency f. ADMX is 100 times more sensitive than earlier microwave cavity experiments, [15,16] and is the first to exclude realistic axion couplings: KSVZ axions of mass between 1.9 and 3.5 μeV. If a significant fraction of halo axions are distributed in a few narrow peaks, weaker axion two-photon couplings are excluded. [8–10]

3 ADMX Phase 2

Work is already underway on ADMX Phase II, which will have numerous improvements over the previous version. Foremost of the improvements is the addition of a dilution refrigerator, lowering the system (physical plus amplifier) noise temperature to 200 mK and allowing a scan rate 100 times that of ADMX Phase I. Also notable is the addition of a second, higher freqency, data taking channel. Dark matter axions incident on the ADMX cavity can excite the TM_{010} mode, which was used in previous experiments, but also can excite the TM_{020} mode. The coupling to the TM_{020} mode is weaker than that of the TM_{010}, but the frequency (and hence the detectable axion mass) is nearly twice that of the TM_{010} mode, doubling the axion mass range that can be covered in a single sweep. The expected sensitivity for both modes with the dilution refrigerator installed after one year of running is shown in Figure 2. This covers nearly the entire first decade of the favored axion mass range even for pessimistic axion-photon couplings.

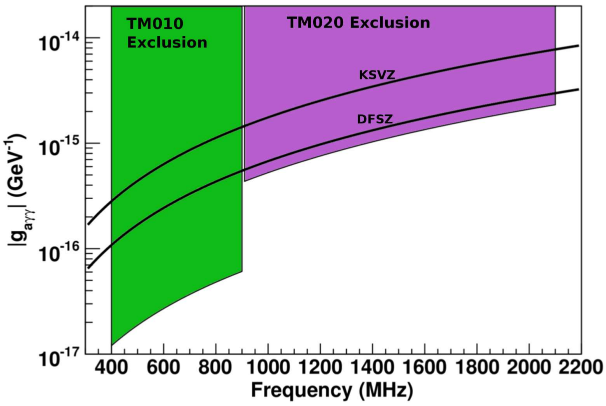

Figure 2: Target exclusion region for TM_{010} and TM_{020} modes of ADMX Phase 2 with dilution refrigerator installed after one year of running.

4 Conclusions

The QCD axion is a compelling dark matter candidate, and ADMX has proven it has the sensitivity necessary to find or exclude dark matter axions. The combination of SQUID technology established in Phase 1 and a dilution refrigerator upgrade in Phase 2 will allow ADMX to explore a significant fraction of allowed dark matter axion masses and couplings in the near future. With future work on high frequency cavities and amplifiers, it is likely ADMX will be able to cover the entire plausible range of masses and couplings and definitively answer the question of whether or not dark matter is made of axions.

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