Snowmass2021 - Letter of Interest

Axion Dark Matter eXperiment's Alternative Discovery Channel: High Resolution Search

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
■ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Collaboration (optional): Axion Dark Matter eXperiment (ADMX)

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Abstract: The Axion Dark Matter eXperiment (ADMX) records high resolution time series data in tandem with the power spectra used in the main analysis. Searches conducted with the high resolution data provide ADMX with an additional, more sensitive, discovery channel for axions in dark matter flows that possess a small velocity dispersion. We discuss the details of the high resolution search. Prospects for future innovation include implementing near real-time triggers for the high resolution search, and the potential for cross-correlation analysis with the 2-4 GHz multi-cavity ADMX.

The high resolution search conducted by the Axion Dark Matter eXperiment (ADMX) provides an extremely sensitive discovery channel for dark matter axions [1–4], supplementing key limits from the mainline or medium resolution analysis [5]. The signals that these independent searches are sensitive to are illlustrated in Fig. 1.

The presence of fine structure, in addition to the main, isothermal halo signal is well motivated. Such fine structure will arise from any cold axion flow that has a small velocity dispersion. Sources can include late infall of cold dark matter onto the galactic halo, with specific predictions made in the Caustic Ring Model [6–9], and tidal tails from the disruption of satellite galaxies, such as Sagittarius A [10]. Cold flows are also seen in structure formation simulations with high enough resolution to capture this detail [11].

The power, P, developed in the microwave cavity of an axion haloscope [12] can be expressed as

$$P = 2.2\times10^{-23}\ \mathrm{W}\left(\frac{V}{136\ \mathrm{L}}\right)\left(\frac{B}{7.6\ \mathrm{T}}\right)^2\left(\frac{C}{0.4}\right) \times\left(\frac{g_\gamma}{0.36}\right)^2\left(\frac{\rho_a}{0.45\ \mathrm{GeV/cm^3}}\right)\left(\frac{f}{740\ \mathrm{MHz}}\right)\left(\frac{Q}{30000}\right) \quad (1)$$

where V is the volume of the microwave cavity, B is the strength of the magnetic field thoughout the cavity volume, C is the form factor for the TM_{010} mode of the cavity (the fundamental frequency is most sensitive for axion detection), g_γ is the axion photon coupling, f is the resonant frequency of the cavity, and Q is its quality factor. For Run 1b of ADMX, these factors are conveniently normalized to be of order one for the isothermal halo model and DFSZ axion [5].

However, if a flow in the vicinity of Earth contains a significant fraction of the local dark matter density, or is locally enhanced, as predicted in the Caustic Ring Model, a high power fine structure peak can be detected with large signal-to-noise ratio, provided the resolution of the search is of order the signal width. This is the strategy used by the high resolution search, and provides a powerful additional discovery channel for ADMX. For example, it is predicted that the Earth is located in a region of the halo with a local flow of density 2×10^{-23} g/cm^3, or $\sim$ 11 GeV/cm^3 [9], the "big flow". With all other factors in Eq. (2) still of order one, the power developed in the ADMX Run 1b cavity would be over 20 times that for the isothermal halo model.

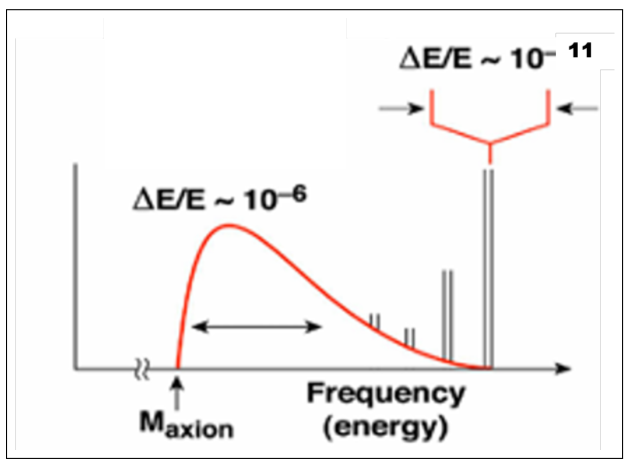

Figure 1: Cartoon of signals from axion dark matter as a function of frequency in an axion haloscope receiver. An isothermal halo model results in a Maxwell-Boltzmann distribution. Flows of cold dark matter axions with small velocity dispersion result in fine structure that appears in addition to the Maxwell-Boltzmann shaped signal.

While this local flow would contribute to enhancing the signal in the main ADMX analysis, the high resolution search strategy is to attempt to concentrate this power in a single frequency bin. The velocity dispersion of the flow gives a signal width, δf, of

$$\delta f = \frac{f v \delta v}{c^2}\ , \quad (2)$$

where f is the frequency corresponding to the axion mass, v is the flow velocity relative to the detector, and δv is the velocity dispersion. For the predicted big flow, the velocity is 520 km/s at the location of the Earth, relative to the local standard of rest[9]. While the velocity of the Sun relative to the local standard of rest, and the Earth's orbital motion and rotation need to be accounted for to obtain the relative velocity to the detector, we take 500 km/s as an approximation here. It has also been previously predicted that the velocity dispersion of this flow is less than 53 m/s[13]. With these numbers and the Run 1b normalized frequency of 740 MHz, such a flow would have a frequency width of approximately 0.2 Hz, and a search with this resolution would concentrate all the power in one or two frequency bins, giving a powerful discovery channel for dark matter axions.

Recent high resolution searches are performed in post-processing, i.e. the data is taken concurrently with the main ADMX search, and analyzed at a later date. This is not ideal, as if a strong candidate signal is detected, ADMX may have already begun taking data in a different run configuration, and making it arduous to re-examine such a candidate. In future improvements, we hope to develop a strategy where initial triggers above a threshold are automatically assessed for candidacy. The criteria of trigger persistence needs to include careful consideration of variability in power due to noise fluctuations and spectral leakage, and signal modulation due to the Earth's motion. Furthermore, the trigger level will need to be set at a higher power threshold than currently used in the post-processed search, which typically yields a few triggers per 100 s data set.

The future 2-4 GHz ADMX search, with a multi-cavity array, also offers an interesting opportunity to use cross-correlation between the data from each cavity to determine high resolution triggers. We expect this approach may increase the sensitivity of the high resolution search beyond what is currently possible.

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