Understanding the impact of Bayesian inference on ultra-light axion limits

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**What are ultra-light axions?**

- **Axions** are theoretical elementary particles that are a well-motivated dark matter candidate
- **Ultra-light axions** (ULAs) have masses ranging from $10^{-33}$ to $10^{-20}$ eV
- Behave either like cold dark matter or dark energy depending on their mass
- Distribution of ULAs in parameter space is a 4-D distribution depending on axion, dark matter and dark energy densities $\Omega_a, \Omega_{DE}$ and $\Omega_c$ respectively, and axion mass $m_a$

**Objective:** to develop a robust method of sampling the full 4-D ULA distribution

- We use CMB data from the Planck telescope (below) to constrain axion distribution
- Prior studies only sampled “slices” of the distribution due to high cost of computing CMB power spectra
- However, new ML methods using axionEmu software make emulating CMB power spectra much faster!

**What does the ULA distribution look like?**

First design a 4-D test distribution with qualitatively similar shape to the previously estimated axion distribution

- Evaluate the performance of two different sampling algorithms, Markov chain Monte Carlo (MCMC) and Nested Sampling, on a test distribution
- Both methods were able to recover the test 4-D distribution

![Planck satellite](image1)

![Planck CMB map](image2)

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Demonstrating how the 2-D marginal distribution of ULAs in the $\Omega_a - \Omega_{DE}$ plane changes as axion mass increases

**How do we sample the true ULA distribution?**

- Sample the parameter space with MCMC, using the axionEmu neural networks (right) to emulate the CMB power spectrum for a given set of axion parameters
- Compare the axionEmu power spectrum to Planck data
- axionEmu neural networks (10 seconds per MCMC chain) can emulate CMB power spectra much faster than previous computational methods (30 hours!)
- Allows the full distribution to be sampled for the first time

- Preliminary results (left) showing contours for the 2-D marginal posteriors of the ULA distribution, at fixed axion mass of $10^{-25}$ eV
- **Next steps:** Sample over the full ULA distribution, letting axion mass vary as well

**Conclusions**

- Using MCMC and nested sampling, we recover a test ULA distribution in 4-D parameter space
- Apply sampling methods to derive constraints on true ULA distribution from Planck CMB data in conjunction with new axionEmu neural network