AXIONEMU: ACCELERATING THE SEARCH FOR AXION DARK MATTER IN COSMOLOGICAL DATA WITH NEURAL NETWORKS

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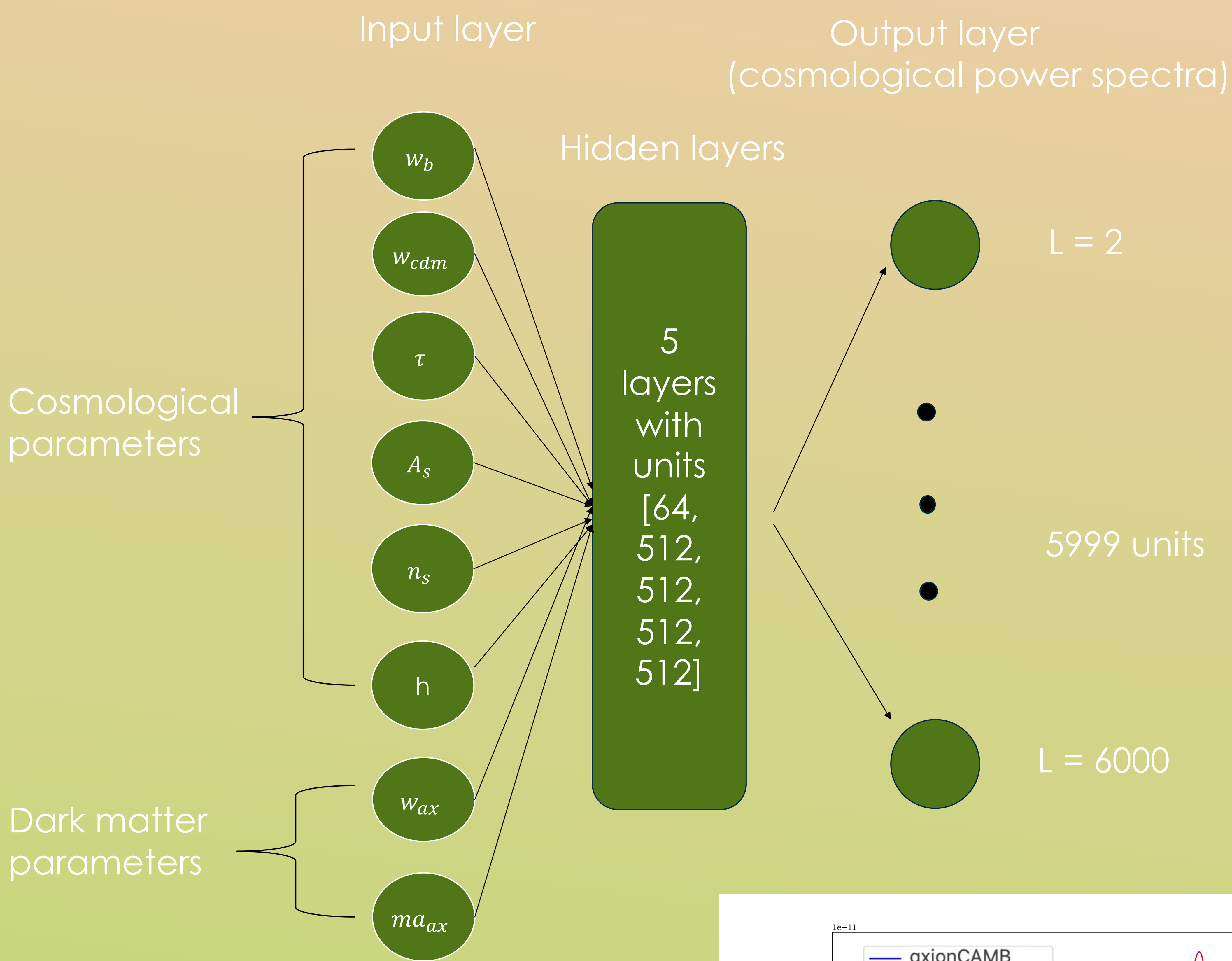
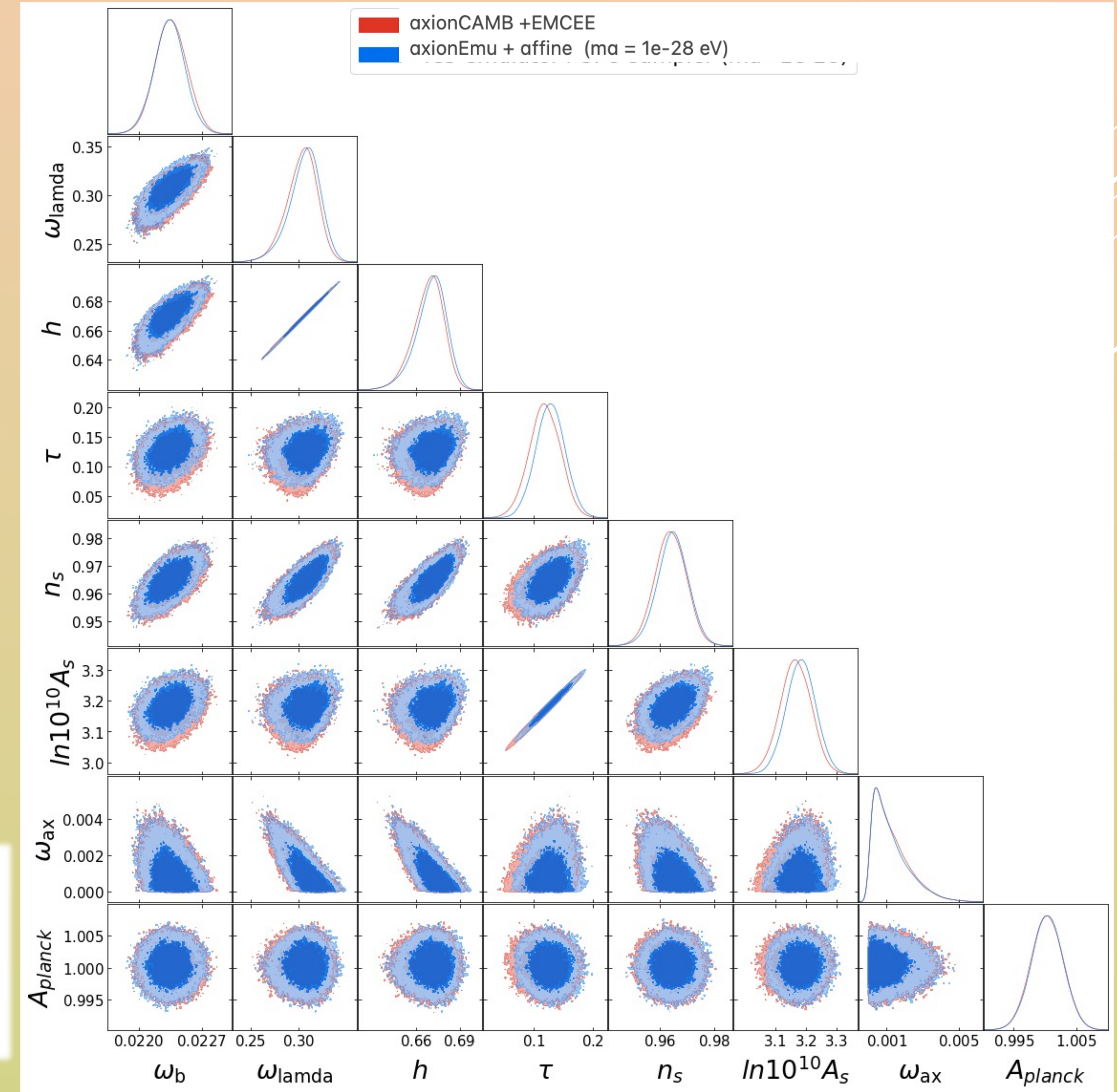


Introduction

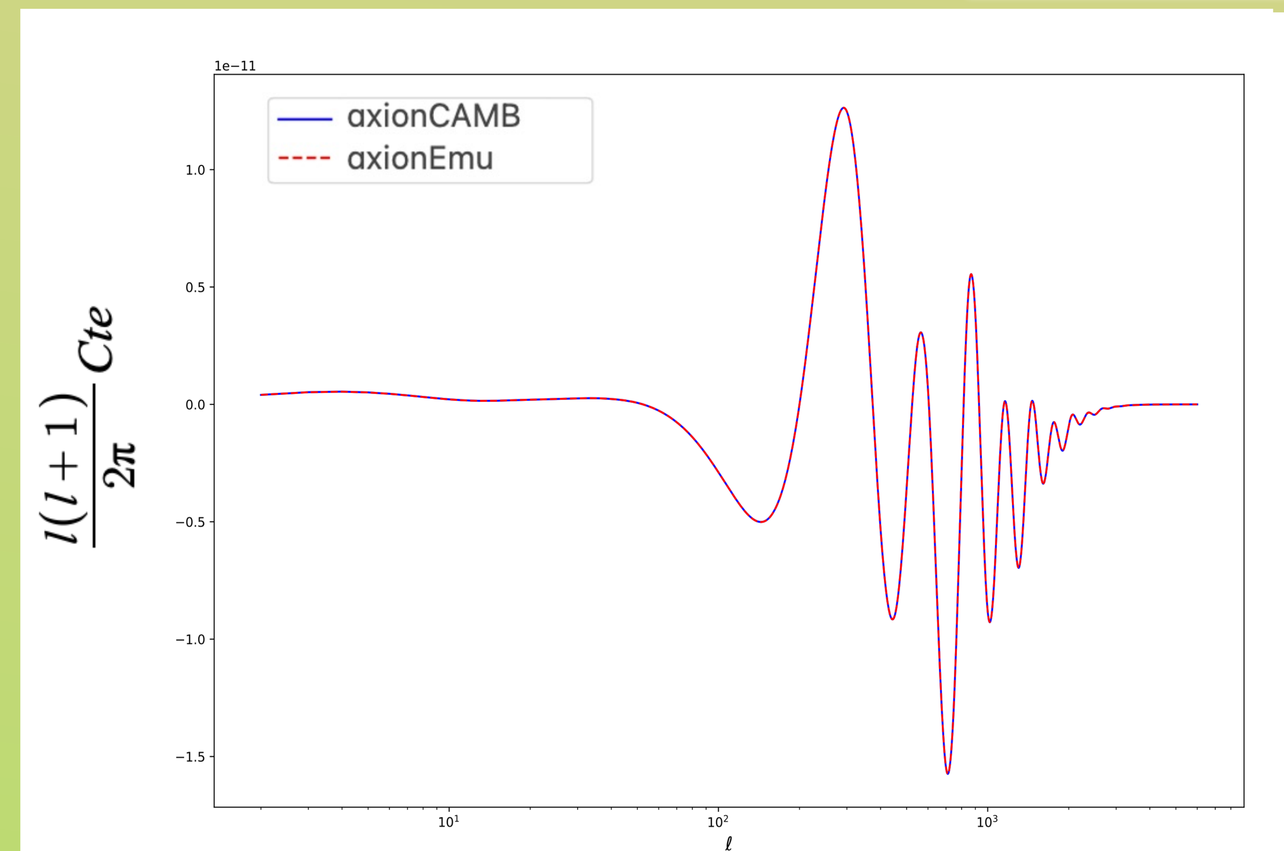
What are effects of different dark matter models on the Universe? **The Cosmic Microwave Background (CMB)** preserves a picture of the Universe as it was about 380 000 years after the Big Bang and can reveal the initial conditions for the evolution of the Universe. Axions with masses less than 10^{-23} eV are well-motivated source of dark matter in the Universe (Laguë et al., 2022). **The values of masses and energy densities of axions would affect the theoretical calculation of cosmic microwave background (CMB) power spectra** (Hlozek, Grin, Marsh and Ferreira, 2015). The current Einstein-Boltzmann solver—axionCAMB--can calculate CMB power spectra but it takes more than 10 hours to finish a survey involving Bayesian inference such as Planck's 2018 analysis, so **a faster emulator is needed for accelerating the search for axion dark matter in cosmological data. Our solution is training a set of neural networks that can replace the axionCAMB in next-generation surveys.**

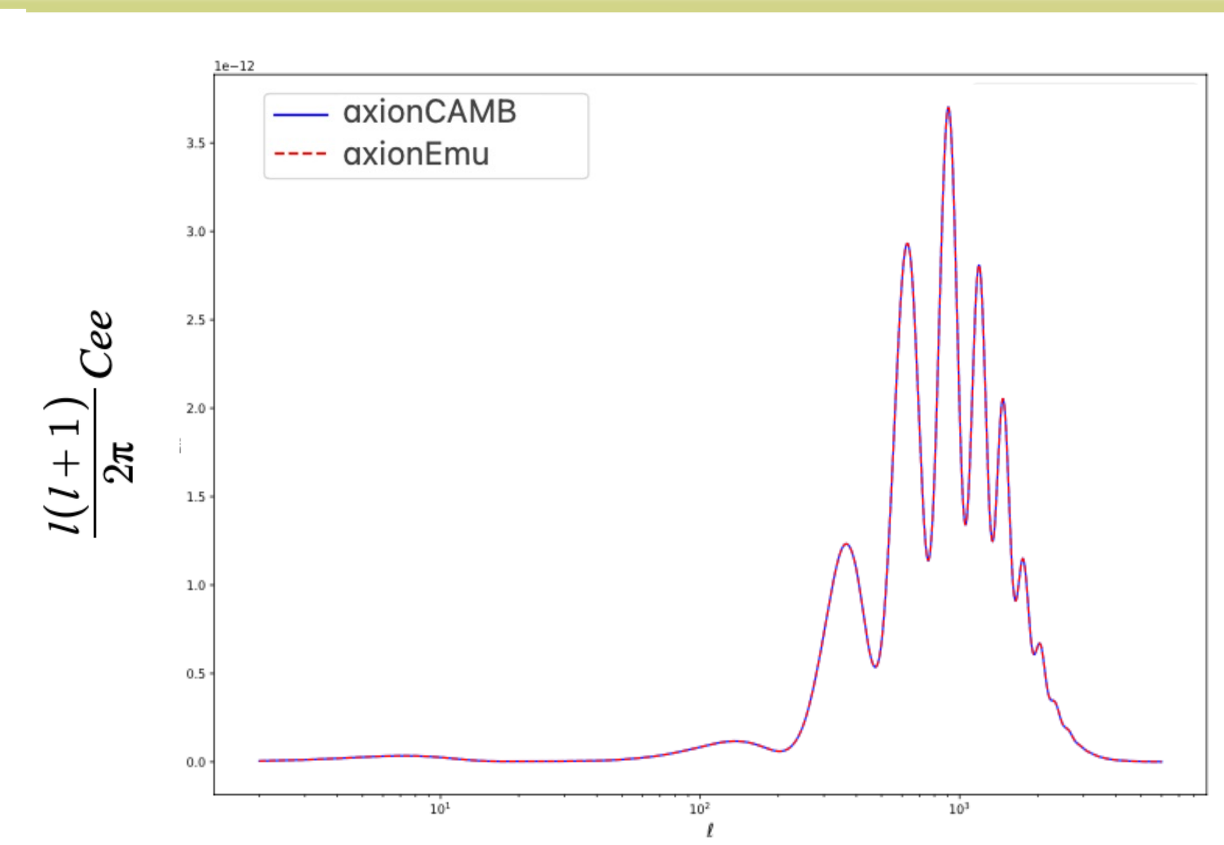
axionCAMB ~12 hours
axionEmu ~14 seconds!

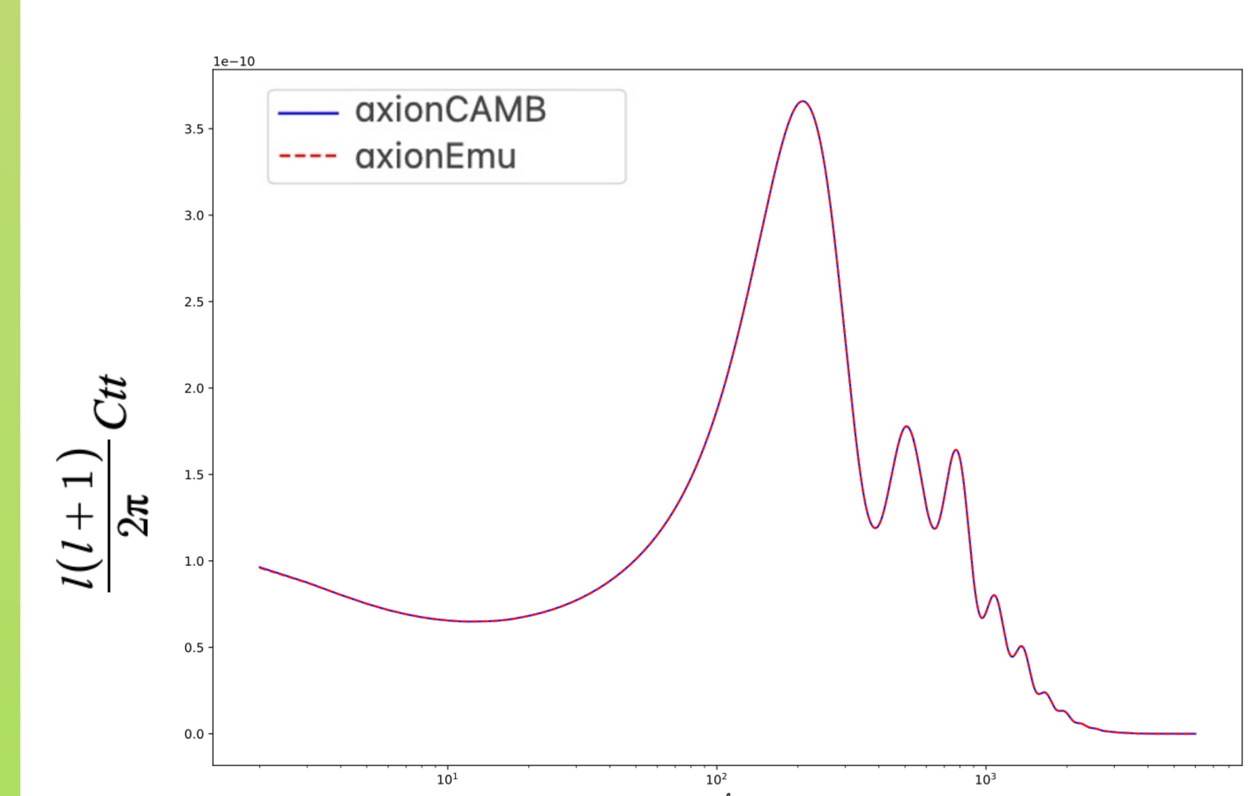


Methods

The models in axionEmu were trained using CosmoPower, a TensorFlow-based ML package (Spurio et al., 2022). For CMB power spectra emulators, the inputs of the neural networks in CosmoPower are the six LCDM parameters: physical baryon density, physical cold dark matter density, reionization optical depth, scale amplitude, scale spectral index, and Hubble constant. The outputs are CMB power spectra at multiples from 2 to 2508. We used a training set with ~0.4 millions power spectra for each probe from axionCAMB to train the deep neural networks. **The number of inputs is increased from six to eight (i.e., six LCDM parameters plus axion mass and axion energy density.), and we extended the outputs units from 2508 to 6000.**







Result & Next Step

Within the parameter space for axionEmu, the error of CMB power spectra is less than 10% of the Simons Observatory noise. (The Simons Observatory (SO) is a new cosmic microwave background experiment being built in Chile.) To further test out emulator, we performed **Planck's 2018 analysis**. (Planck is a project of the European Space Agency to measure the fluctuations of the CMB, and the likelihood is calculated based on Planck's 2018 measurements). The axionEmu and axionCAMB generate the same contours, but the analysis sourced axionEmu is in the order of 10^4 faster than the analysis sourced from axionCAMB, so it would be helpful in future research by accelerating the Bayesian inference. Depending on the value of masses, the axions' behaviours are either dark-matter-like or dark-energy-like. The axionEmu is valid in the range from $10^{-32}$to 10^{-23} eV with different upper limits for axion energy density. In the Planck likelihood case, the degeneracy between the energy density of axions and cold dark matters is strong as axion masses are greater than 10^{-26} eV; and the degeneracy between the energy density of axions and dark energy is strong as axion masses are less than 10^{-29} eV.
The next step can be performing a SO analysis using SO likelihood functions implemented in SOLikeT package to further test our emulator.

Reference

Hlozek, R., Grin, D., Marsh, D. and Ferreira, P., 2015. A search for ultralight axions using precision cosmological data. *Physical Review D*, 91(10).
Laguë, A., Bond, J., Hložek, R., Rogers, K., Marsh, D. and Grin, D., 2022. Constraining ultralight axions with galaxy surveys. *Journal of Cosmology and Astroparticle Physics*, 2022(01), p.049.
Spurio Mancini, A., Piras, D., Alsing, J., Joachimi, B. and Hobson, M., 2022. CosmoPower: emulating cosmological power spectra for accelerated Bayesian inference from next-generation surveys. *Monthly Notices of the Royal Astronomical Society*, 511(2), pp.1771-1788.
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