

## Searching for the fundamental nature of dark matter in the cosmic large-scale structure

The fundamental nature of dark matter so far eludes direct detection experiments, but it has left its imprint in the large-scale structure (LSS) of the Universe. Extracting this information requires accurate modelling of structure formation and careful handling of astrophysical uncertainties. I will present new bounds using the LSS on two compelling dark matter scenarios that are otherwise beyond the reach of direct detection. Ultralight axion dark matter, particles with very low mass and astrophysically-sized wavelengths, is produced in high-energy models like string theory ("axiverse"). I will rule out axions that are proposed to resolve the so-called cold dark matter "small-scale crisis" ( $m \sim 10^{-22}$  eV) using the Lyman-alpha forest ( $m > 2 \times 10^{-20}$  eV at 95% c.l.), but demonstrate how a mixed axion dark matter model (as produced in the string axiverse) could resolve the  $S_8$  tension ( $m \sim 10^{-25}$  eV) using Planck, ACT and SPT CMB data and BOSS galaxy multipoles. Further, I will set the strongest limits to-date on the dark matter - proton cross section for dark matter particles lighter than a proton ( $m < \text{GeV}$ ). The LSS model involves one-loop perturbation theory, a non-cold dark matter halo model and, to capture the smallest scales that drive improvements in bounds, a machine learning model called an "emulator", trained using hydrodynamical simulations and an active learning technique called Bayesian optimisation.

**Primary author:** ROGERS, Keir

**Presenter:** ROGERS, Keir

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