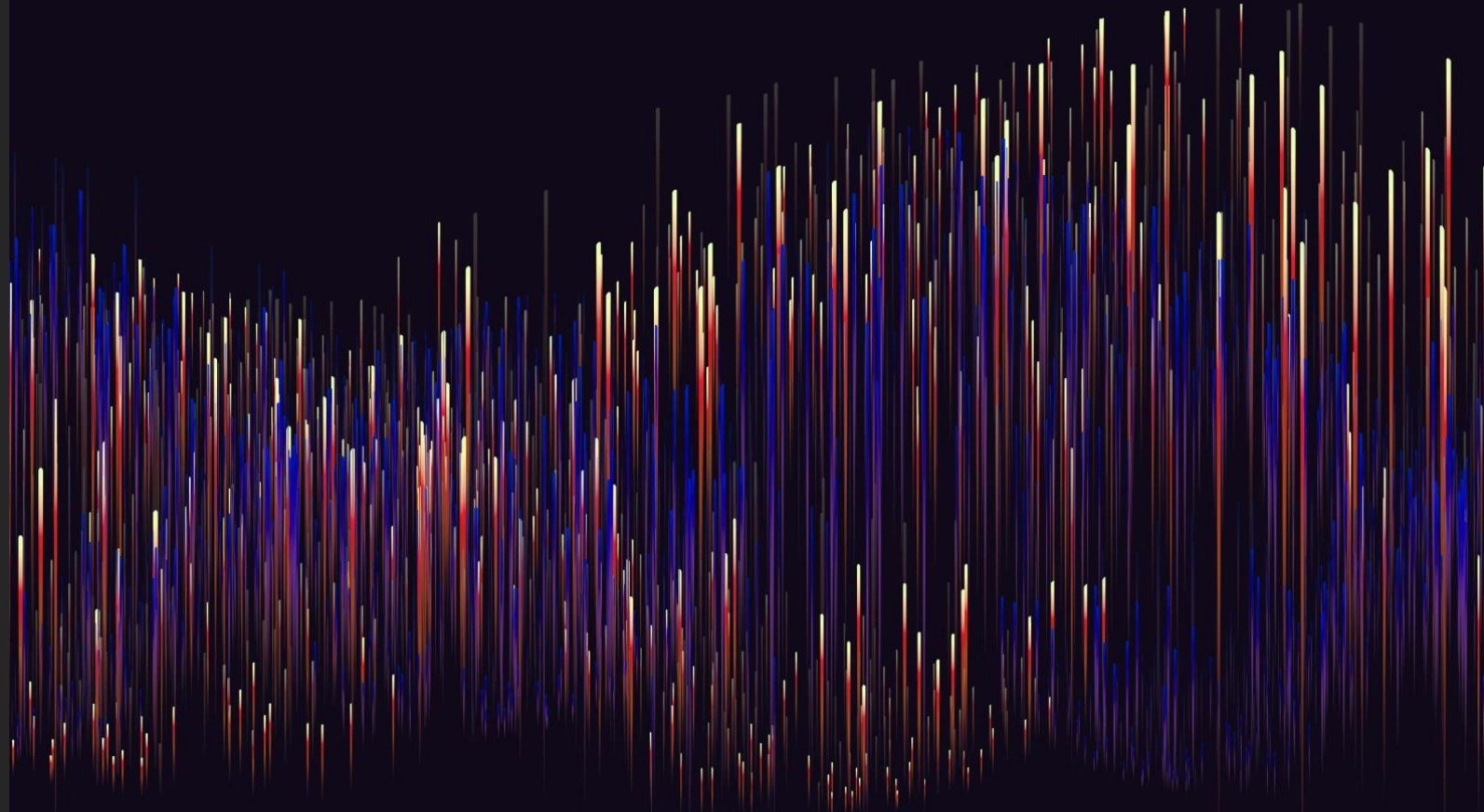

DOMAIN WALLS AND THE COMPANION AXION MODEL

PAVADOL YAMSIRI

IN COLLABORATION WITH CIARAN O'HARE

SYNDEY CPPC MEETING





BACKGROUND: AXIONS

- A theoretical elementary particle, first introduced as the solution to the strong CP problem by Peccei and Quinn in 1977¹.
- Interesting as a cold dark matter candidate:
 - Non-zero mass
 - Weak couplings to other SM particles
- Yet to be observed.

AXION MODELS

- The first axion model consists of a complex scalar field with the Lagrangian

- $$L = (\partial_\mu \phi)(\partial^\mu \phi^*) - \frac{\lambda}{4} (|\phi|^2 - \eta^2)^2 + 2K \cos(N \arg(\phi))$$

- Since then there other axion models have been proposed for a variety of reasons, forming a class of axion-like particles.

SIMULATING FIELDS (PRS TRICK)

- As axions are estimated to be very light, their occupancy numbers are high i.e. fields can be treated classically.
- The expansion of the universe shrinks features in the field, shortening the length of simulations.
- Using the PRS trick, named after Press, Ryden and Spergel (1989)², simulations can be run for longer.
- For a field ϕ , modify the equation of motion by adding a parameter α , equal to the number of spatial dimensions

- $$\frac{\partial^2 \phi}{\partial \tau^2} + \alpha \frac{\partial \ln a}{\partial \tau} \frac{\partial \phi}{\partial \tau} - \nabla^2 \phi = -\frac{\partial V}{\partial \phi}$$

- This can then be solved with a second order leapfrog numerical scheme.

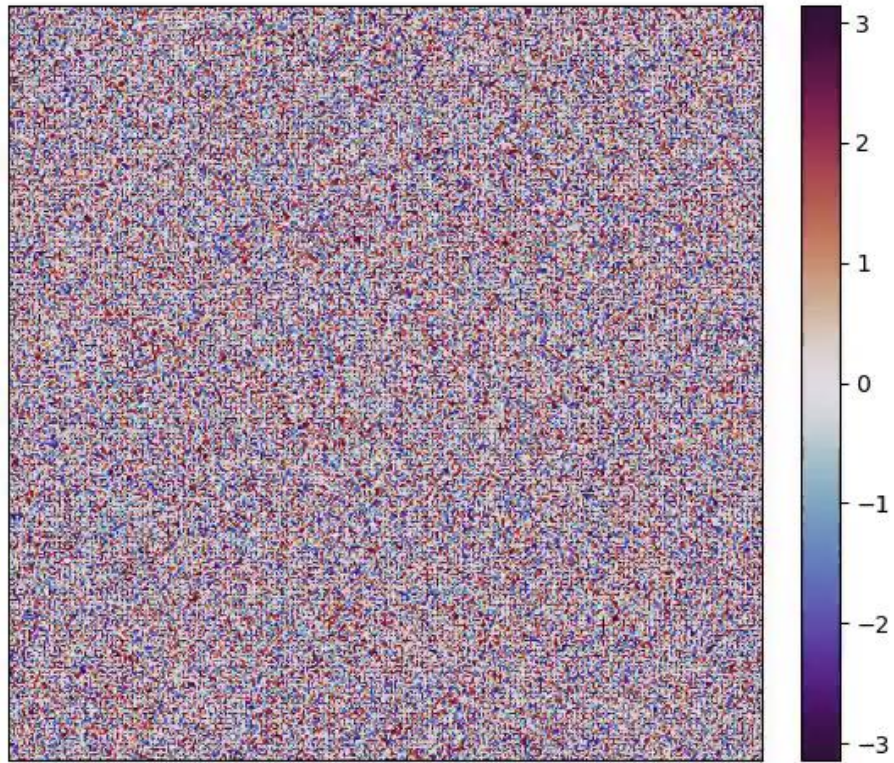


Figure 1a: Axion field simulation for $N = 1$

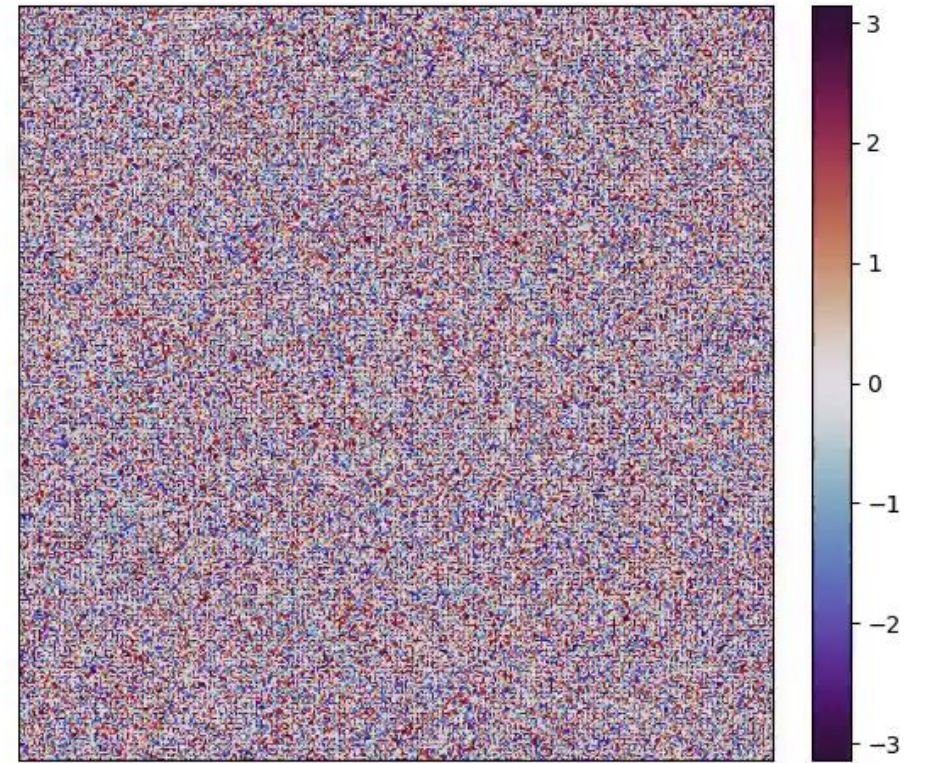


Figure 1b: Axion field simulation for $N = 4$

TOPOLOGICAL DEFECTS

- Topological defects occur during spontaneous symmetry breaking.
- Domain walls are a type of topological defect.
- The energy density of domain walls would dominate the energy of the Universe. This is not observed however.
- Other types of cosmological defects include:
 - Cosmic strings
 - Textures

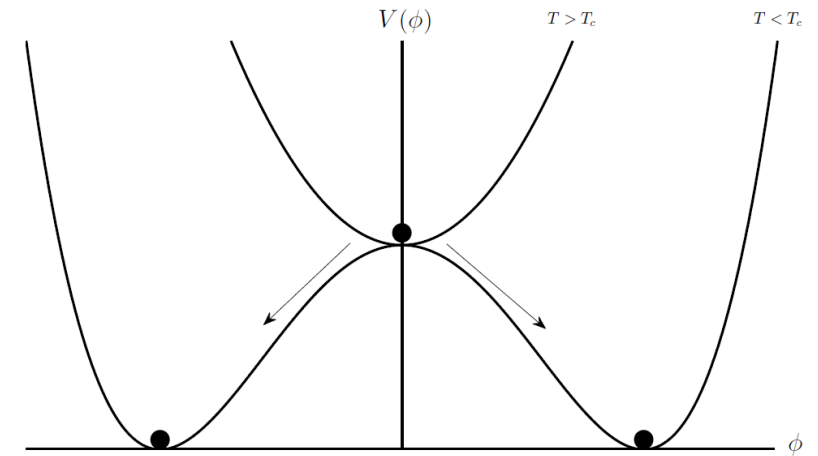


Figure 2: Spontaneous symmetry breaking of Z_2 symmetry³

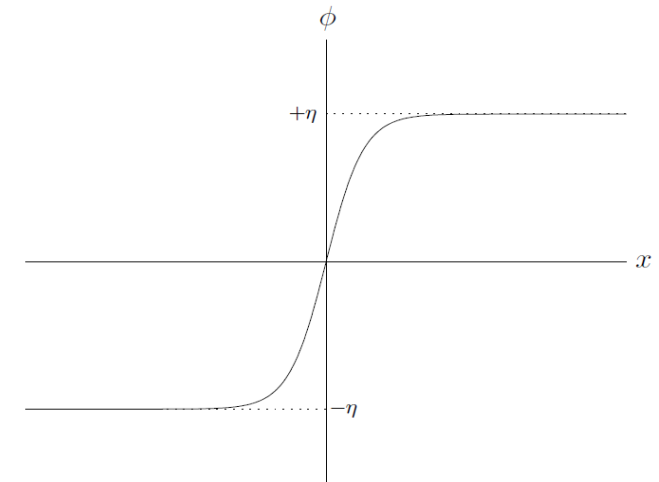


Figure 3: Kink solution of domain wall³

AXION POTENTIAL

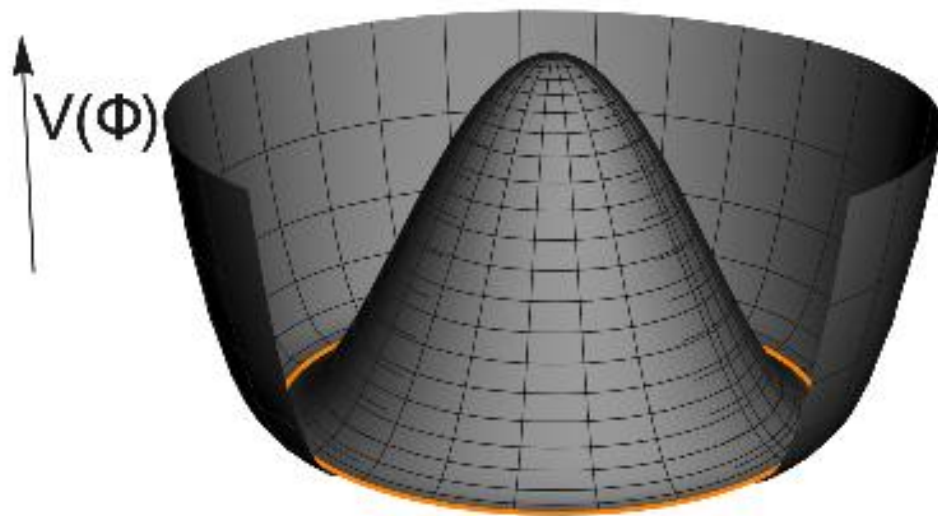


Figure 4: Peccei-Quinn potential before symmetry breaking

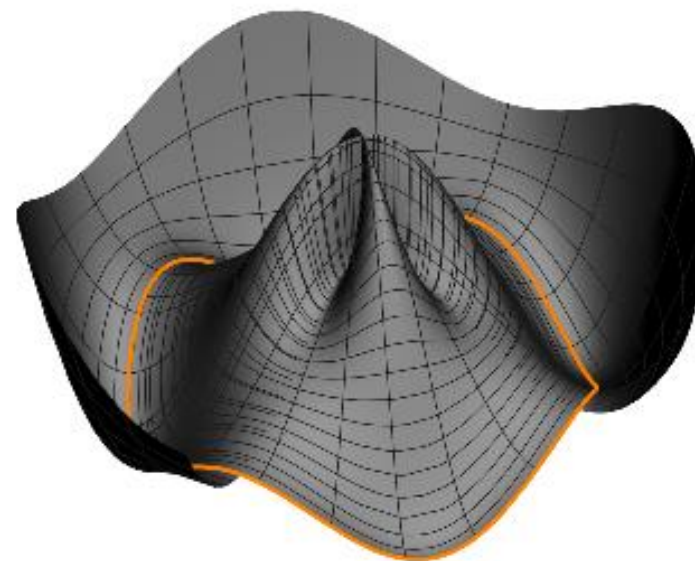


Figure 5: Symmetry broken potential for $N = 4$

COMPANION AXION MODEL

- The companion axion model is a new axion model introduced by Chen and Kobakhidze in 2021¹ in order to rescue the Peccei-Quinn axion from coloured gravitational instantons (an additional source of CP violation).
- The added potential
 - $V(\theta, \theta') = -2K \cos(N\theta + N'\theta') - 2\kappa K \cos(N_g\theta + N'_g\theta')$
- Introduces a second axion field.
- This second field is believed to help disperse domain walls².

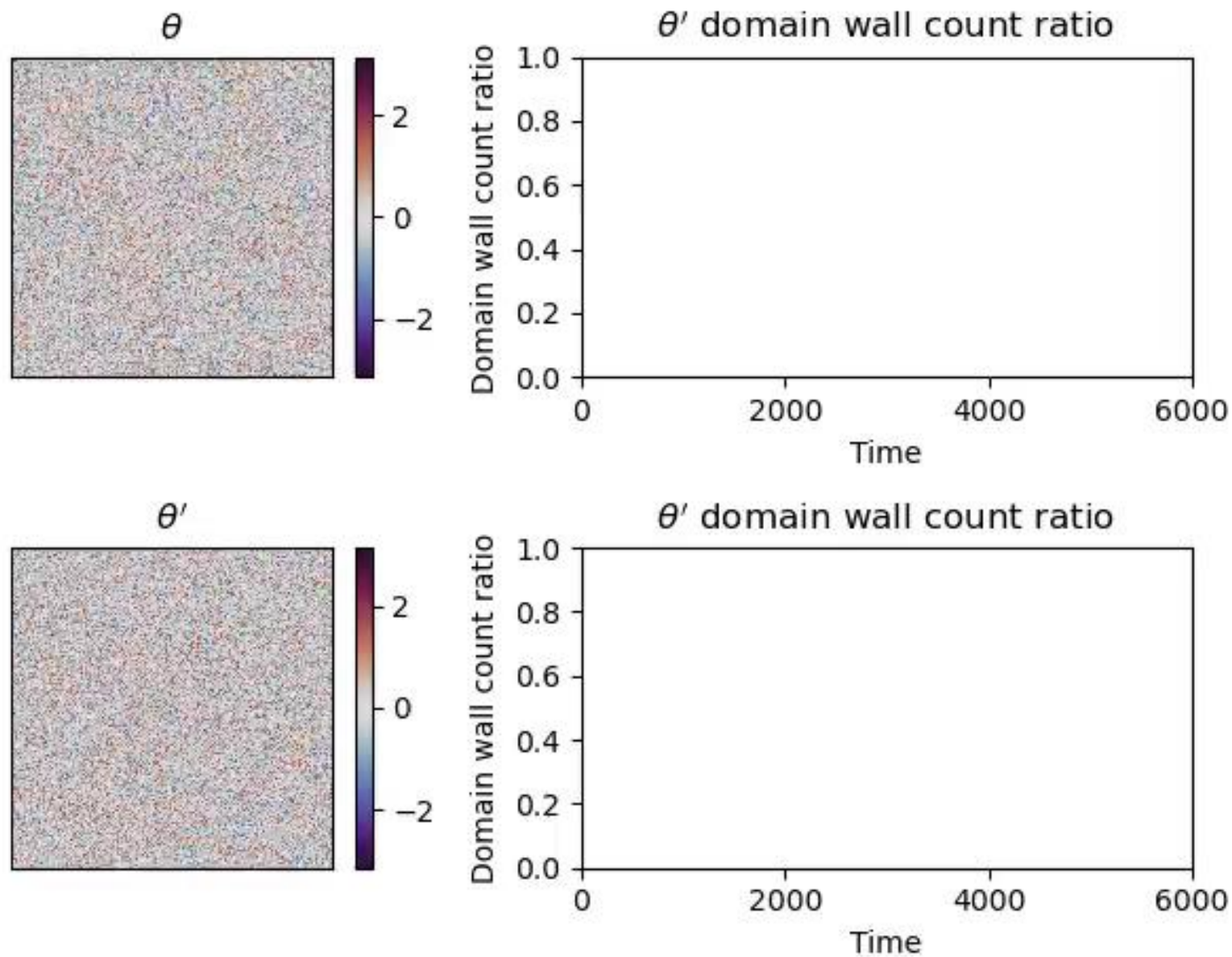
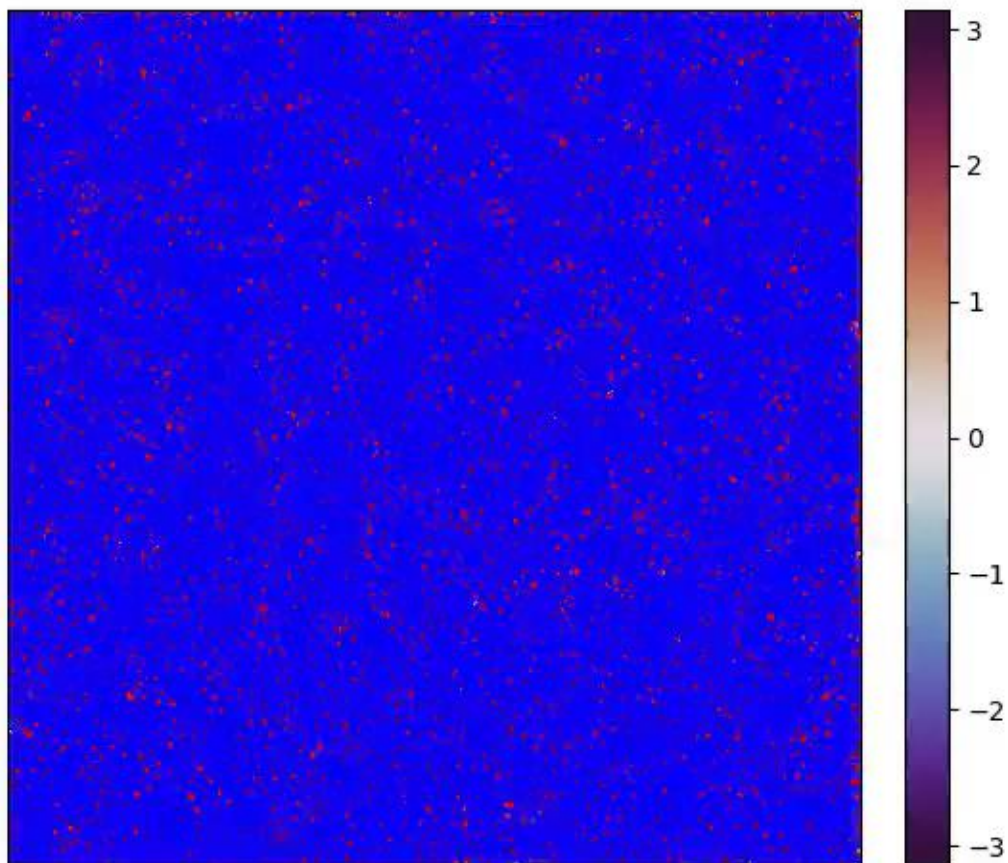


Figure 6: Companion axion simulation for $N = 3, N' = 1, N_g = 1, N_g' = 1$

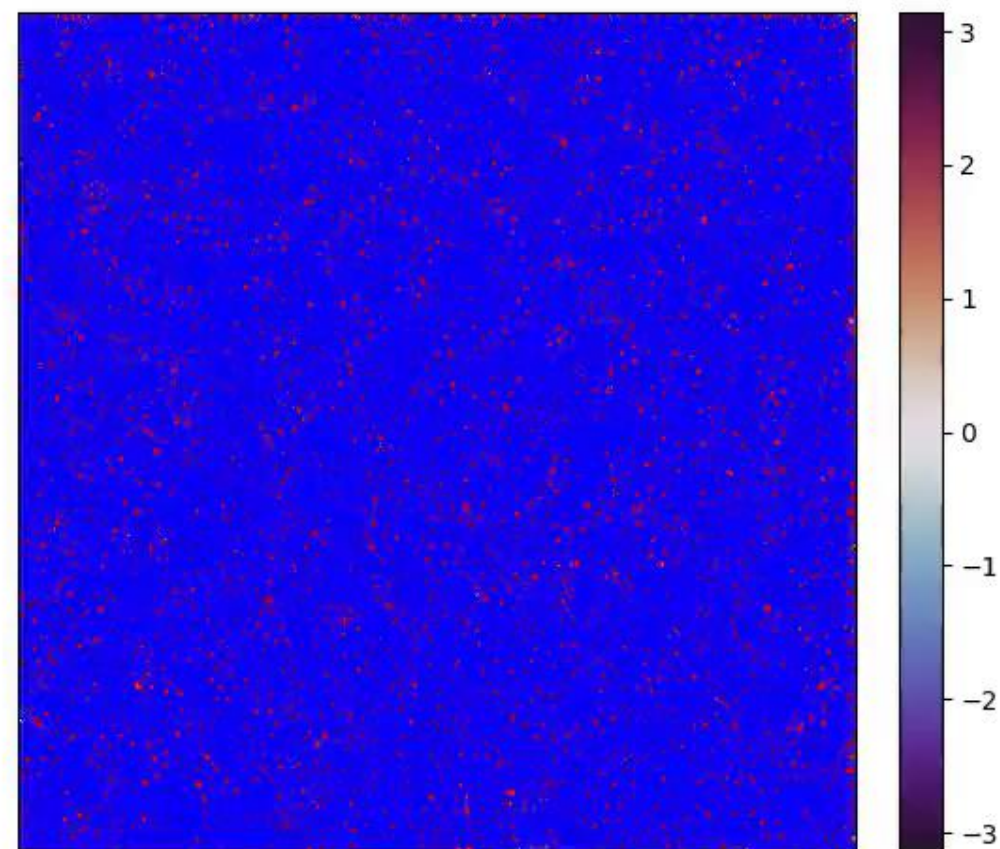
PLANS FOR THE FUTURE

- The companion axion model has many parameters to consider:
 - Color anomaly coefficients - N, N', N_g, N_g'
 - The K and κ coefficients and their temperature scaling
- Explore the phase space of parameters for domain wall dispersal.
- Currently, simulations are quite slow, ~20 mins per run, limiting the ability to do statistical analysis.
- Numerical artifacts can also occur for some parameter configurations.

APPENDIX: SINGLE AXION HIGHLIGHTING



$N=1$



$N=4$

APPENDIX: COMPANION AXION HIGHLIGHTING

