Numerical Simulation of the Cosmological Axion Field through the QCD Phase Transition

MB, Joshua Foster, Benjamin R. Safdi

to appear soon!

Malte Buschmann

University of Michigan

Motivation:

- Axion miniclusters are known to exist due to the collapse of large amplitude perturbations in the early Universe.
- These minicluster might cause microlensing events!

Therefore:

- Need to know the spectrum of perturbations

Problem:

- Many current papers rely on old simulations that were not able to resolve the region of interest
- Extrapolations are not very accurate

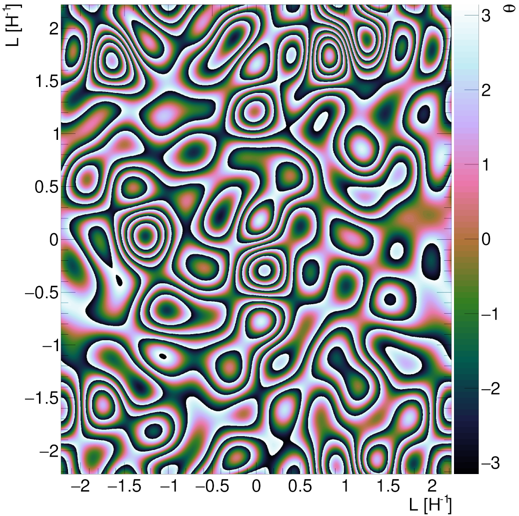
Lagrangian:

$$\mathcal{L} = \frac{1}{2}\left(\partial a\right)^2 - m_a^2(T) f_a^2 \left[1 - \cos\left(\frac{a}{f_a}\right)\right]$$

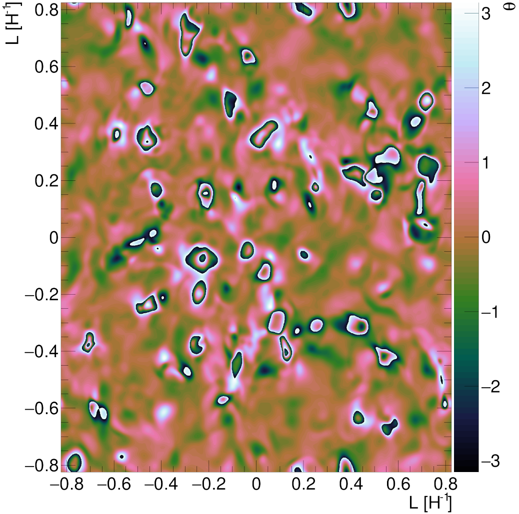
Equation of Motion for misalignment angle:

$$\theta'' + \frac{2}{\eta}\theta' - \nabla^2\theta + {\eta^*}^{6.68} \sin\theta = 0$$

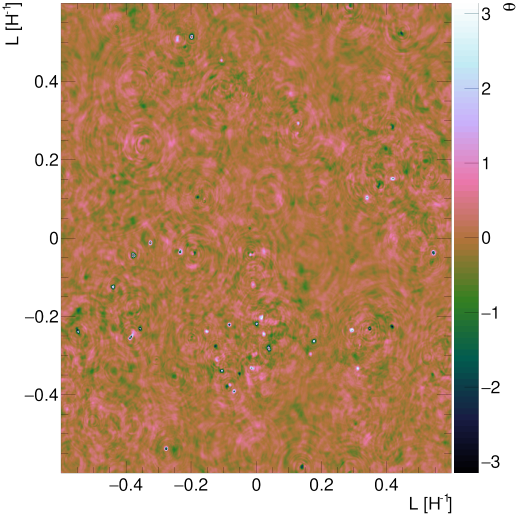
η: conformal time
$\eta^* = \eta$ for $\eta \leq \eta_s$
$\eta^* = \eta_s$ for $\eta > \eta_s$



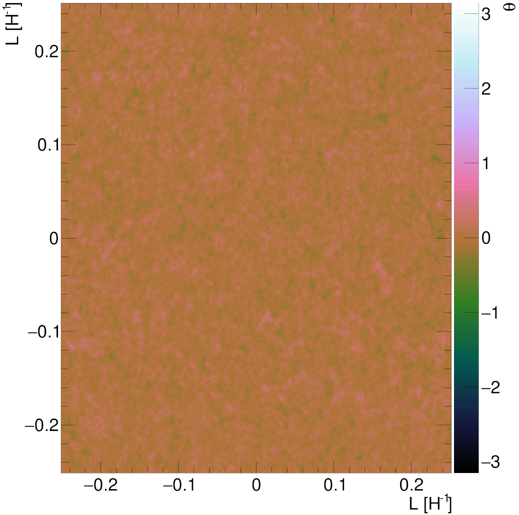
$\eta = 0.9$: At early times, the axion field θ follows a white noise distribution.



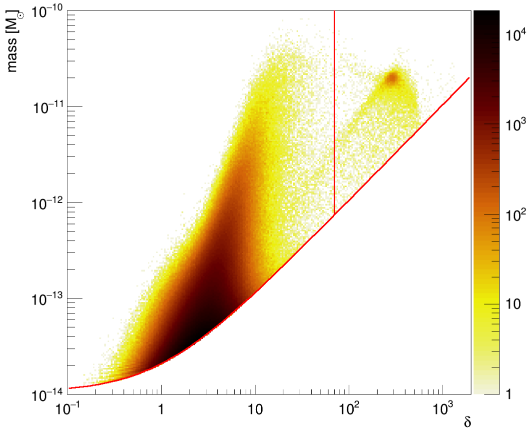
$\eta = 2.4$: Shortly after the QCD phase transition, around $\eta \approx 1.23$, closed domain walls start to form as the axion field starts to oscillate.



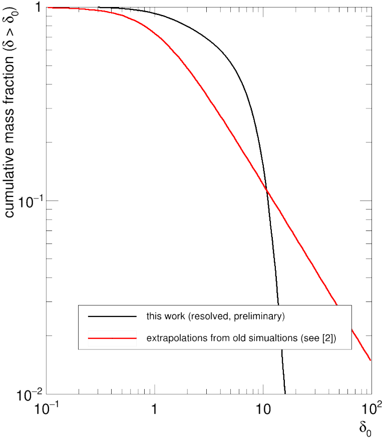
$\eta = 3.3$: Domain walls quickly decay and oscillons form out of large overdensities, often near the remnants of domain walls.



$\eta = 8.0$: Oscillons remain stable as long as the axion gains in mass, but fade away as soon as the axion mass growth is truncated. Yet, remnants in the form of large overdensities remain even at late times.



1. We can extract from our simulation the mass of a perturbation as a function of the overdensity parameter δ.
2. This spectrum defines the amount of axion miniclusters and their concentration parameter (i.e. compactness).



1. Overdensities → gravitational collapse to axion miniclusters → microlensing events?
2. Older simulation were not able to resolve important non-linear effects at later times!