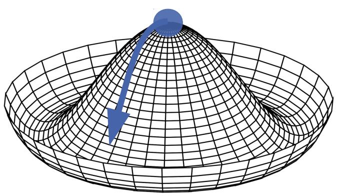
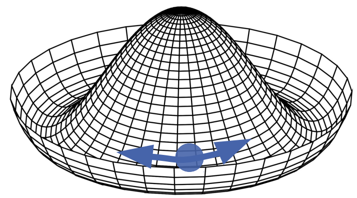
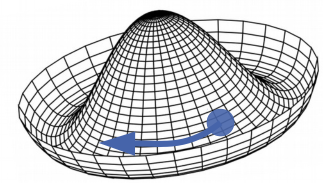
Axion Minicluster Power Spectrum and Mass Function

Andreas Pargner, Thomas Schwetz

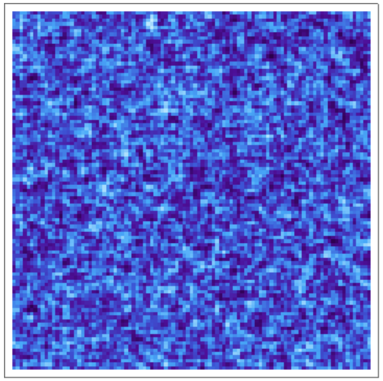
based on: JCAP 1712 (2017), no. 12 038, [1708.04466]

Theoretical Astroparticle Physics, Institute for Nuclear Physics (IKP)

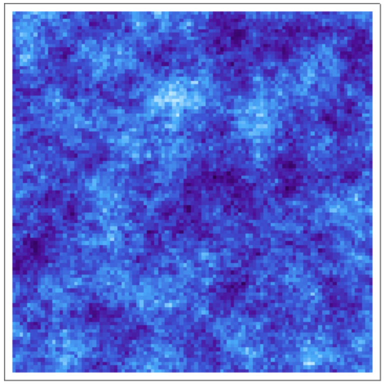
Non-Thermal Production Mechanism: Vacuum Realignment in the post-inflation Scenario

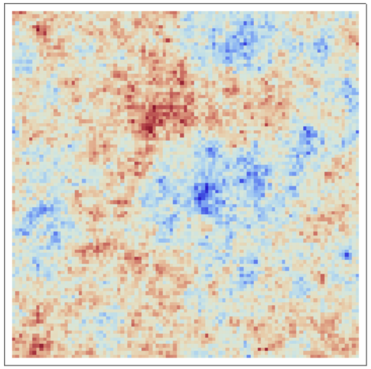
$T = T_{\mathrm{PQ}} \quad m_a = 0$ | $T_{\mathrm{QCD}} < T < T_{\mathrm{PQ}} \quad m_a = 0$ | $T \simeq T_{\mathrm{QCD}} \quad m_a \neq 0$



Random initial conditions lead to white noise field.



Field homogenizes up to Hubble horizon.

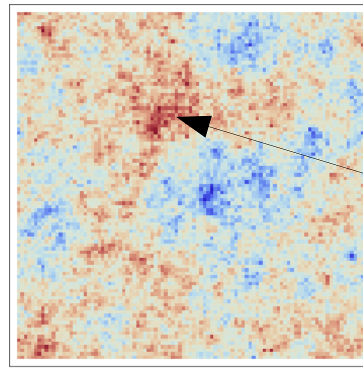


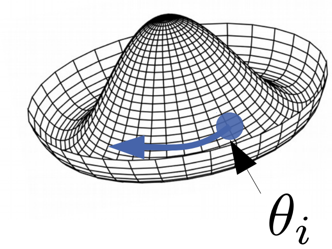
Oscillation commence. Inhomogeneous energy density.

Axion Miniclusters

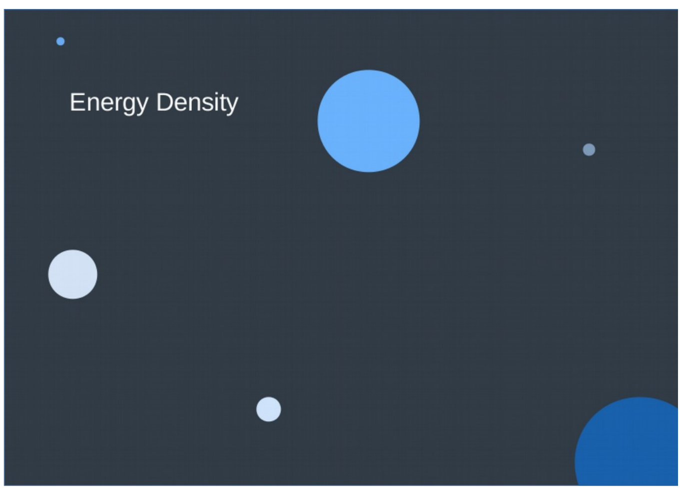
Inhomogeneous energy density:

- Large overdensities can decouple from Hubble expansion already in radiation dominated era
- Collapse into small and dense objects
- Axion Miniclusters





$$\rho_a(x) \sim m_a^2 f_{\mathrm{PQ}}^2 \theta_i^2(x)$$



Distribution in mass and size of Axion Miniclusters is of great importance for understanding

Influence of Axion Field on Cosmology and Direct Detecion Experiments.

Axion Field Evolution

Follow evolution of axion field and derive power spectrum of energy density

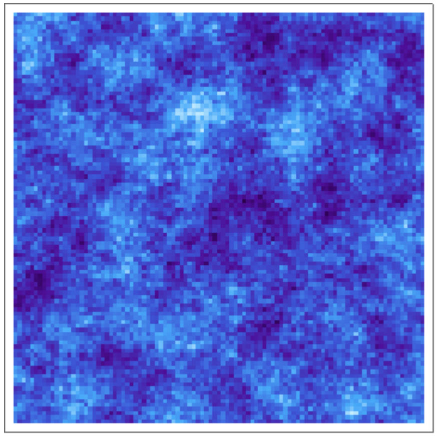
$$\ddot{\theta}_k + 3H\dot{\theta}_k + \frac{k^2}{a^2}\theta_k + m^2(T)\theta_k = 0$$

Problem of scales $T_{\rm PQ} \gg T_{\rm osc} \sim T_{\rm QCD}$

Use suitable initial “white noise” conditions and start evolving at $T_i \gtrsim T_{\rm osc}$

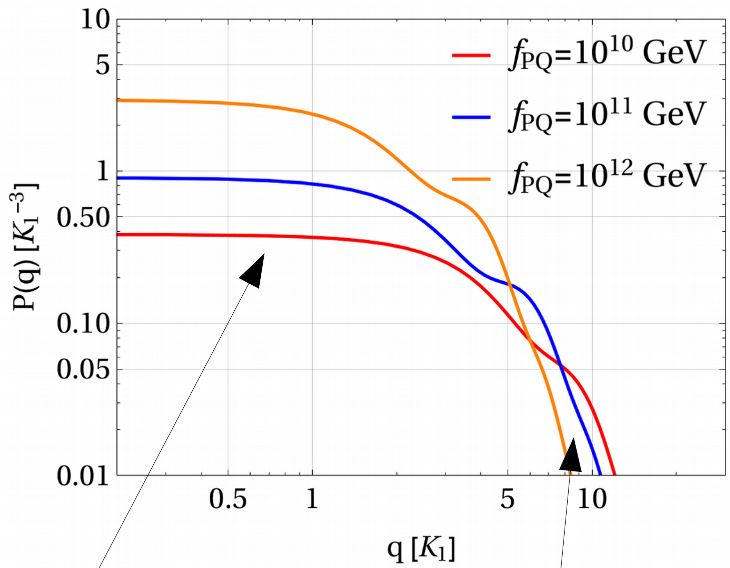
$$\langle \theta_k \theta_{k'} \rangle = (2\pi)^3 \delta(\vec{k} - \vec{k}') P_\theta(k) \quad P_\theta(k) = \frac{8\pi^4}{3\sqrt{\pi}K^3} \mathrm{e}^{-k^2/K^2}$$

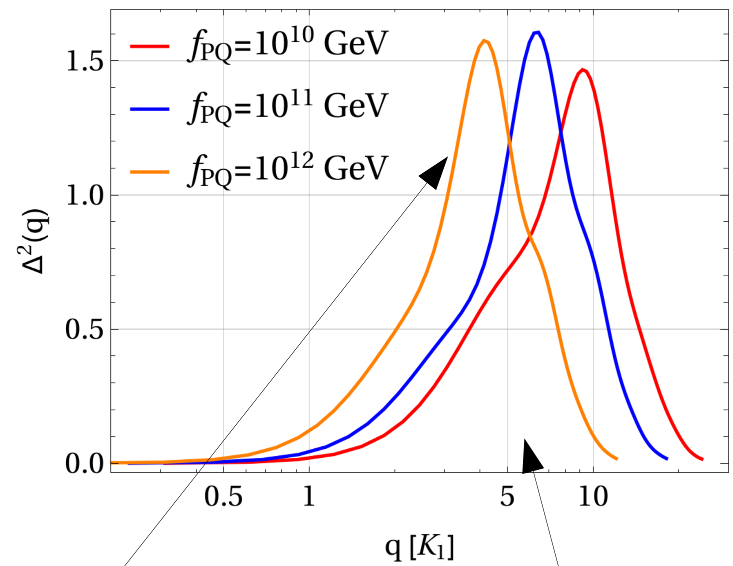
$K = a_i H_i$ is the cut-off wave number, field should be uncorrelated on larger scales



Axion Energy Density Power Spectrum

Karlsruhe Institute of Technology

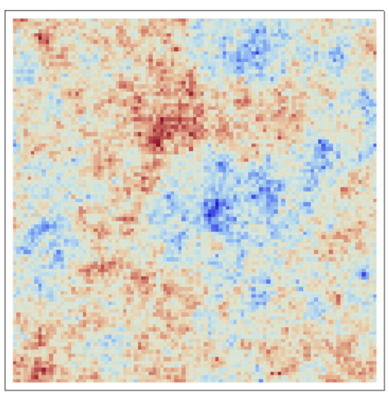




White noise on large scales.

Correlated on small scales.

Inhomogeneities are non-linear.

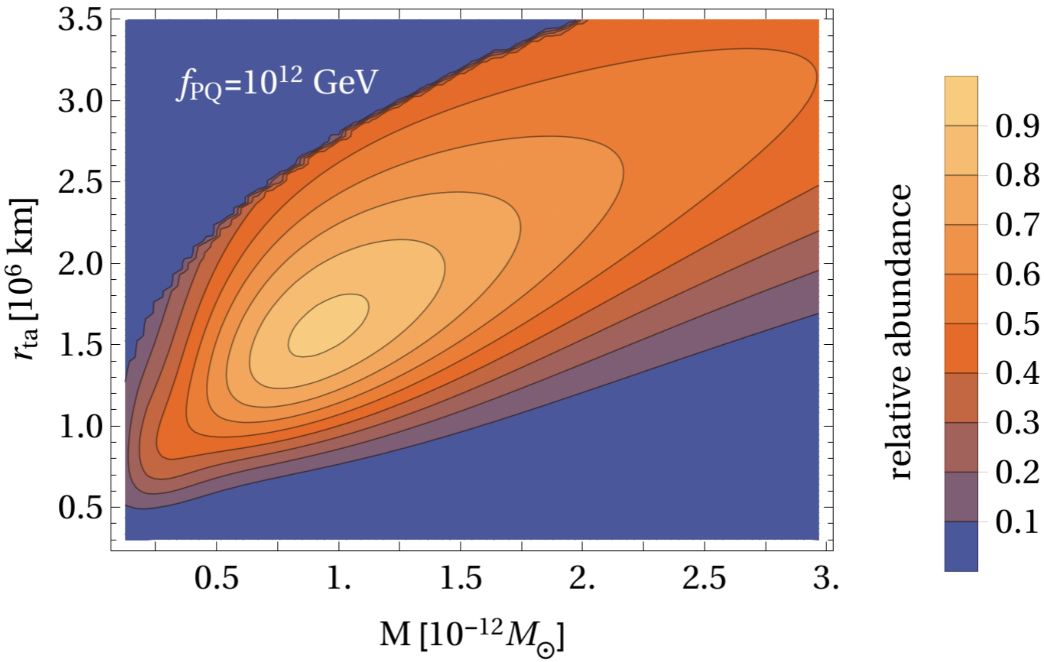


Characteristic size of inhomogeneities.

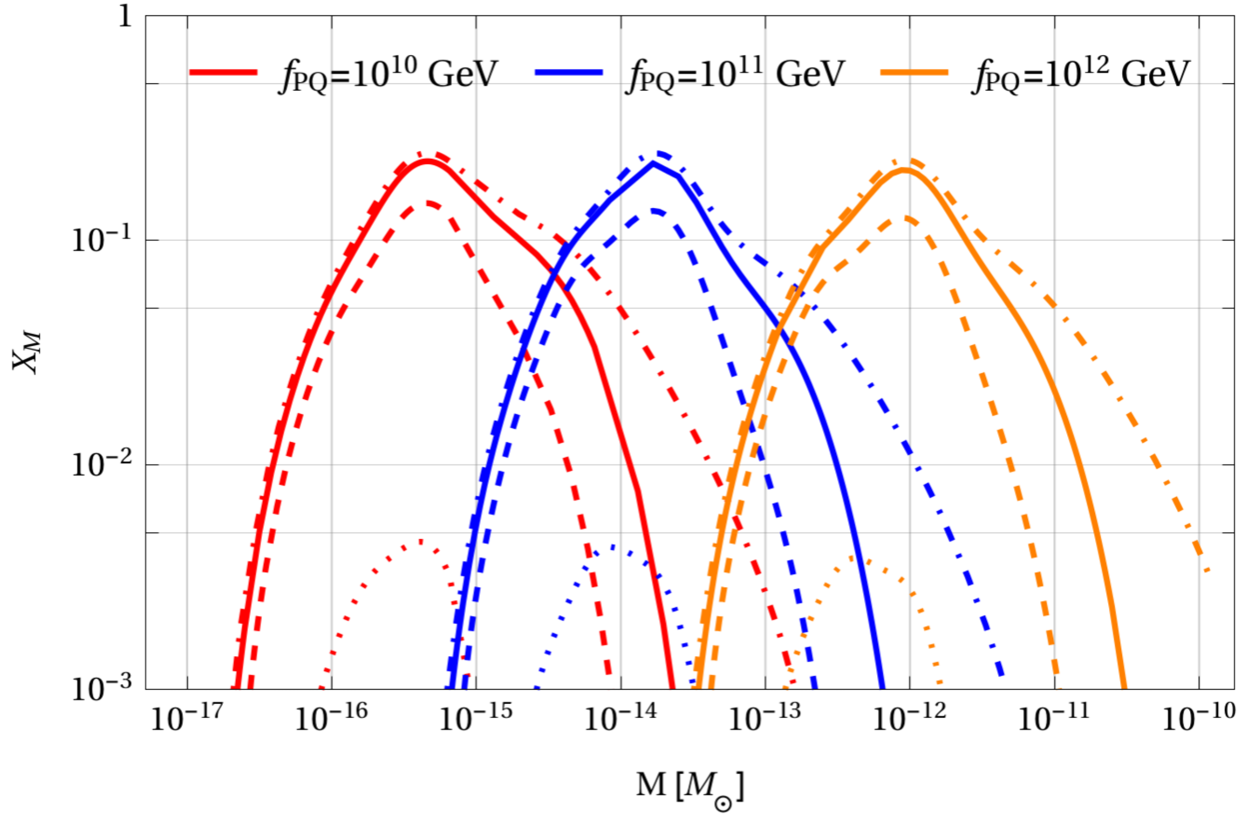
Depends on breaking scale and therefore time when oscillations commence.

Size and Mass of Axion Miniclusters

- Fluctuations are not small.
- Decoupling from Hubble Flow already in radiation dominated era
- Standard Methods not applicable.
- Consider collapse in an expanding background.
- Develop and use a modified Press-Schechter approach to determine distribution of MCs in mass and size.



Size and Mass of Axion Miniclusters



f_{PQ} [GeV]	M_{peak} [$M_\odot$]	M range [$M_\odot$]	r_{ta}^{peak} [km]	r_{ta} range [km]
10^{10}	4×10^{-16}	$[2\times10^{-17}, 1\times10^{-14}]$	4×10^{4}	$[2\times10^{4}, 2\times10^{5}]$
10^{11}	2×10^{-14}	$[5\times10^{-16}, 3\times10^{-13}]$	2×10^{5}	$[4\times10^{4}, 7\times10^{5}]$
10^{12}	8×10^{-13}	$[6\times10^{-14}, 2\times10^{-11}]$	2×10^{6}	$[7\times10^{5}, 7\times10^{6}]$

Fate of Miniclusters: How are the MCs today?

Further collapse into stable configuration?
How do these configuration look like?
Is the collapse violent?
Are Axion Stars formed inside the MCs?

$$i\partial_t \phi = -\frac{\Delta\phi}{2m} - g\left(\phi^*\phi\right)\phi + m\Phi_N\phi$$

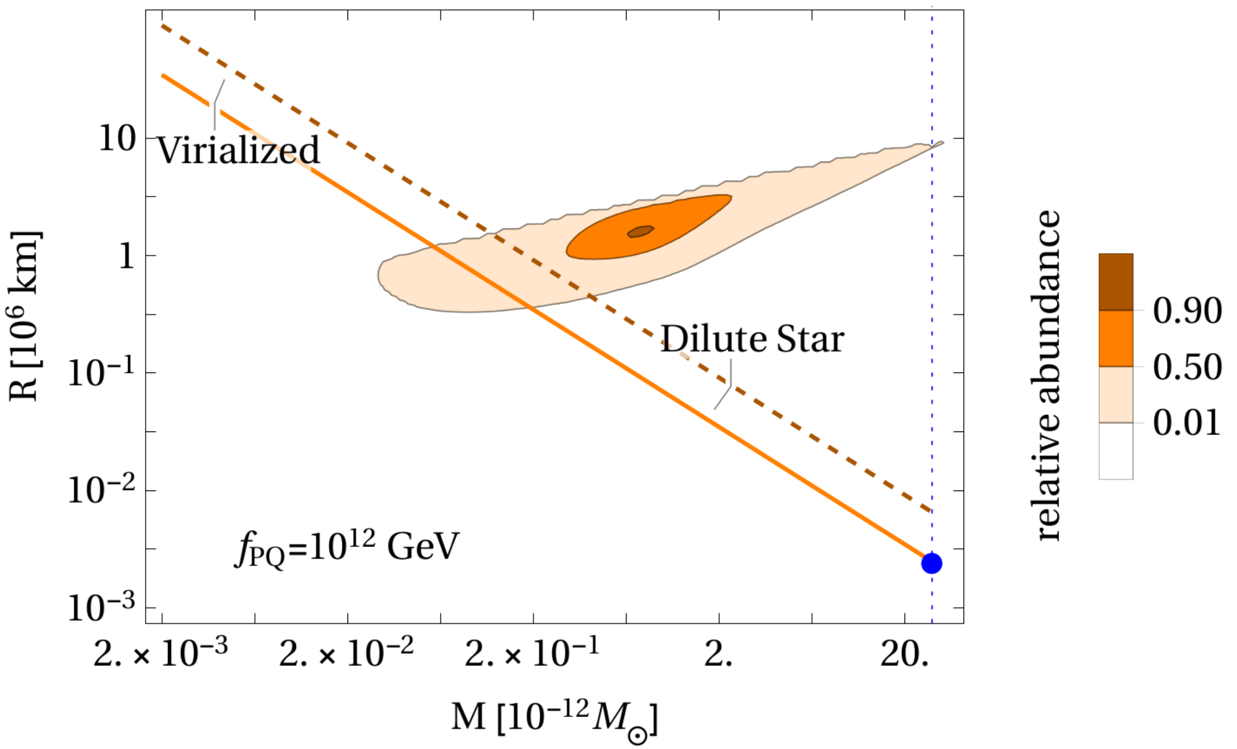
$$\Phi_N = 4\pi G m \phi^*\phi$$

How can we detect them?

Gravitational Lensing?

Interaction with Cosmic Rays?

Gamma Ray Bursts?



Fate of Miniclusters: How are the MCs today?

Further collapse into stable configuration?
How do these configuration look like?
Is the collapse violent?
Are Axion Stars formed inside the MCs?

$$i\partial_t \phi = -\frac{\Delta\phi}{2m} - g\left(\phi^*\phi\right)\phi + m\Phi_N\phi$$
$$\Phi_N = 4\pi G m \phi^* \phi$$

How can we detect them?

Gravitational Lensing?

Interaction with Cosmic Rays?

Gamma Ray Bursts?