Fragmentation of the axion field in the early universe

Parametric resonance effects in novel models

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Axion fragmentation

In the axion has a large initial kinetic energy, then it travels many barriers before it stops.

This can arise from

- Axion receives a kick from explicit PQ breaking in the UV 1910.14152, 2004.00629, 2006.05687
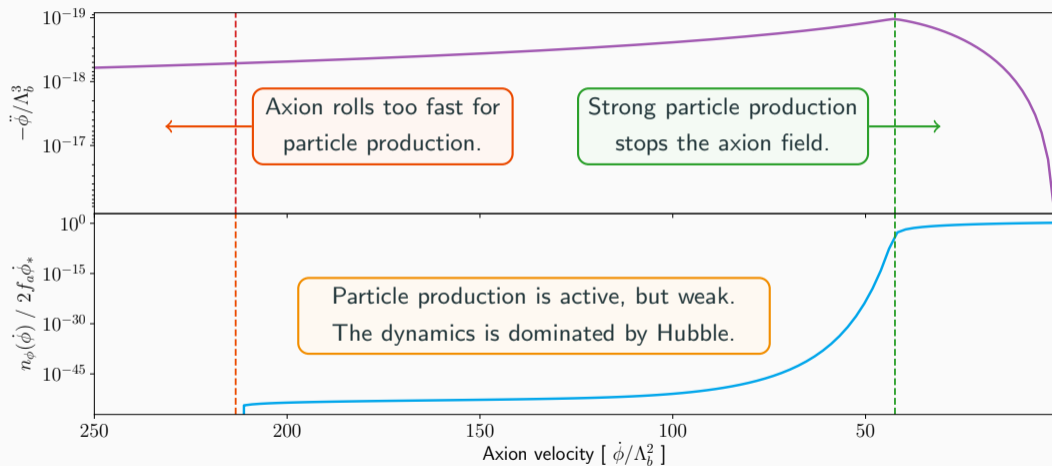- Trapped misalignment 2102.00012, 2102.01082

During the rolling, modes inside the instability band experiences exponential growth.
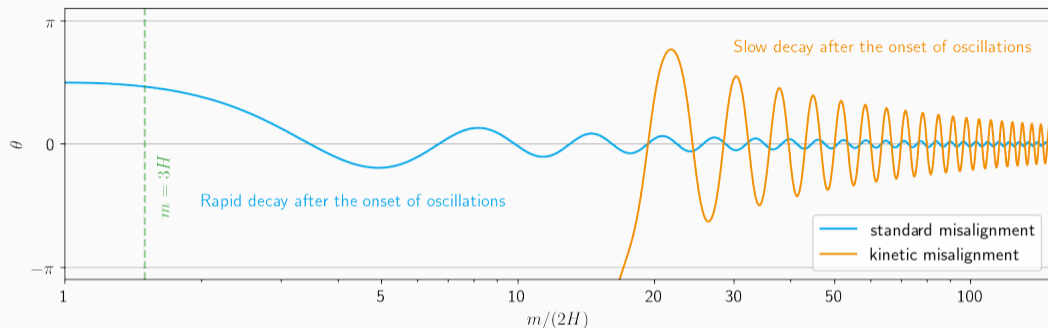
1911.08472, 1911.08473

$$\frac{\dot{\phi}^2(t)}{4f^2} - \frac{\Lambda_b^4}{2f^2} < \frac{k^2}{a^2(t)} < \frac{\dot{\phi}^2(t)}{4f^2} + \frac{\Lambda_b^4}{2f^2}$$
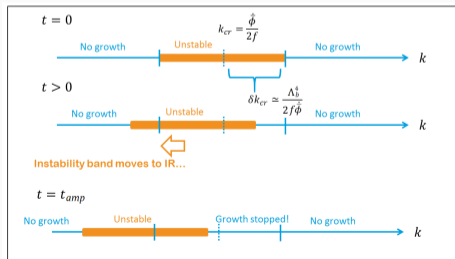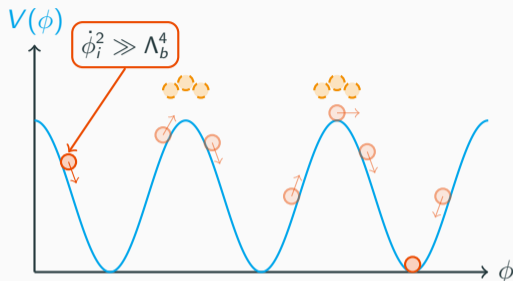
Axion fragmentation in a nutshell

Axion fragmentation after trapping

Even in the absence of fragmentation during rolling, the onset of oscillations are delayed which can lead to efficient fragmentation even after trapping:

$$\frac{n_{\text{fluct}}}{n_{\text{zero-mod}}} \sim \left(\frac{m(T_*)}{f} \right)^2 \int d\kappa \, \kappa^2 \exp \left\{ \frac{m(T_*)}{H(T_*)} \underbrace{\mathcal{B}(\kappa)}_{\sim \mathcal{O}(1)} \right\}, \quad \kappa = \frac{k/a_*}{m_*}.$$

Observational prospects (in progress)

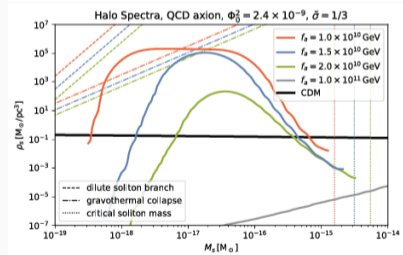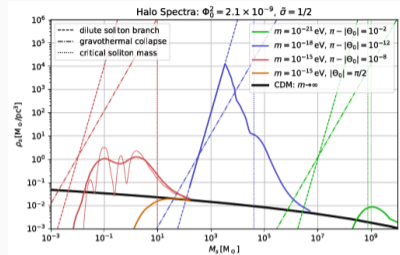After the fragmentation, the power spectrum of the axion fluctuations becomes $\mathcal{O}(1)$:

$$\mathcal{P}_\phi(k \sim m_* a_*) = \left. \frac{2\pi^2}{k^3} |\delta_\phi(k)|^2 \right|_{k \sim a_* m_*} \sim \mathcal{O}(1)$$

When these fluctuations reach to a critical density, they experience gravitational collapse:

$$\delta_c^2(z_{\text{col}}) \simeq \sigma_R^2(z_{\text{col}}) = \int d\ln k \, \mathcal{P}_\phi(k, z_{\text{col}}) |W(k, R)|^2$$

Large fluctuations do collapse earlier yielding much denser dark matter halos:

$$\rho_s \sim 200 \rho_\phi(z_{\text{col}}) \propto \rho_{\phi,0}(1 + z_{\text{col}})^3$$

Arvanitaki et al. 1909.11665

Conclusions

- In models where the axion field has a large initial kinetic energy, axion fluctuations play a prominent role, and can yield complete fragmentation.
- Under suitable conditions, the fragmentation can be effective before the axions gets trapped by the potential, so that the rolling is stopped by the backreaction of the fluctuations.
- Even if the fragmentation is not efficient prior to trapping, it can become efficient after since the large initial kinetic energy delays the onset of oscillations allowing the axion to probe non-quadratic parts of its potential.
- After the fragmentation, the power spectrum becomes $\mathcal{O}(1)$ which leads to much denser dark matter halos.
- All the discussion is applicable to the QCD axion, to a generic ALP model, and also to other kind of potentials such as monodromy (Ongoing project with Aleksandr Chatrchyan, Matthias Koschnitzke, Géraldine Servant)

    Stay tuned for our upcoming paper(s) for much more details!

Thank you for your attention!

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