Axion Isocurvature Perturbations in Low-Scale Models of Hybrid Inflation.

MAX-PLANCK-GESELLSCHAFT
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Kai Schmitz

Currently: Max-Planck-Institut für Kernphysik, Heidelberg, Germany

9/2018 – 8/2019: University of Padua, Padua, Italy

9/2019 – 8/2021: Marie Curie fellow at CERN, Geneva, Switzerland

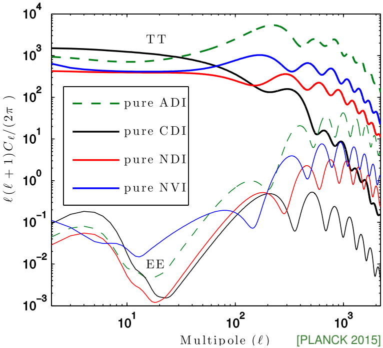
kai.schmitz@mpi-hd.mpg.de

Based on ARXIV:1806.06056 [HEP-PH].

In collaboration with **Tsutomu Yanagida** (Kavli IPMU, Kashiwa, Japan).

14th Patras Workshop on Axions, WIMPs and WISPs
Deutsches Elektronen-Synchrotron | Hamburg, Germany | June 21, 2018

Axion isocurvature perturbations



Suppose the $U(1)$ Peccei-Quinn symmetry is already spontaneously broken during inflation. Then:

- Axion quantum fluctuations during inflation:

$$\delta a = f_a \, \delta\theta \simeq \frac{H_{\rm inf}}{2\pi}$$

- *CDM density isocurvature* (CDI) perturbations:

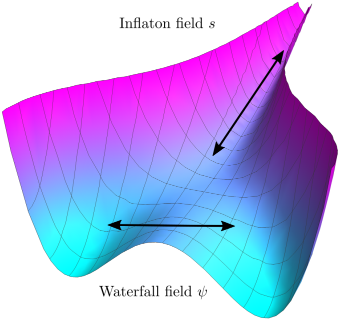
$$\delta\Omega_{\rm DM}^a \simeq \frac{\partial \Omega_{\rm DM}^a}{\partial\theta}\,\delta\theta$$

PLANCK bound on the amplitude of the isocurvature power spectrum: $\mathcal{P} = \left|\delta \ln \Omega_{\rm DM}\right|^2 \lesssim 8.7\times10^{-11}$

- Upper bound on the inflationary Hubble rate $H_{\rm inf}$ in dependence of the axion decay constant f_a:

$$\boxed{H_{\rm inf} \lesssim 1.3\times10^{9}\,{\rm GeV}\left(\frac{f_a}{10^{16}\,{\rm GeV}}\right)^{0.42}}$$

Supersymmetric hybrid inflation

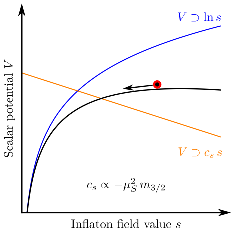


Our work: We show that the CDM isocurvature constraint on the inflationary Hubble rate $H_{\rm inf}$ can be easily satisfied in low-scale models of supersymmetric hybrid inflation.

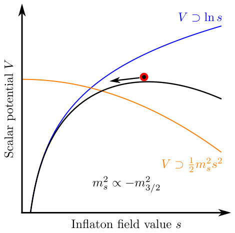
- Well-motivated models that connect cosmology and particle physics.
- Inflation ends in a symmetry-breaking phase transition $\rightarrow$ GUT phase transition.

Flat potential thanks to soft supersymmetry breaking

F-term hybrid inflation (FHI)



D-term hybrid inflation (DHI)



Our approach: Take into account spontaneous SUSY breaking!

- Use soft terms in the SUGRA potential (controlled by $m_{3/2}$) to reduce the gradient of the scalar potential:

$$\varepsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1$$

- Adjust the mass scale of the tree-level potential to fit A_s:

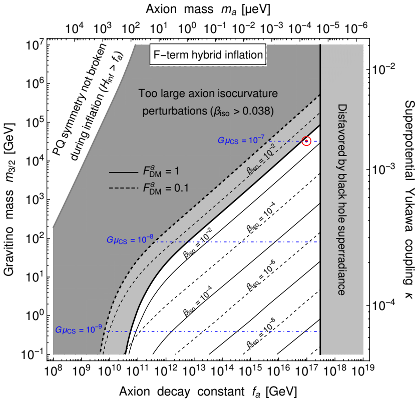
$$A_s = \frac{1}{24\,\pi^2}\,\frac{V_0}{\varepsilon} \simeq 2.2 \times 10^{-9}$$

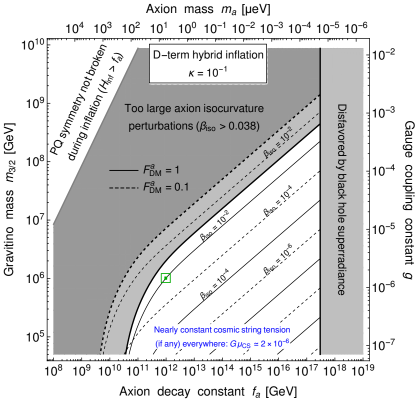
- A small energy scale corresponds to a small Hubble rate:

$$H_{\rm inf} = \sqrt{\frac{V_0}{3}}$$

$\varepsilon = \varepsilon\left(m_{3/2}\right) \;\Rightarrow\;$ Bound on $H_{\rm inf}$ translates into bound on $m_{3/2}$.

Constraints on parameter space





Upper bounds on $m_{3/2}$ (gravitino mass), κ (Yukawa coupling), g (gauge coupling):

- F-term hybrid inflation: $\kappa \lesssim \mathcal{O}\left(10^{-3}\right)$ and $m_{3/2} \lesssim \mathcal{O}\left(10^{5}\right)$ GeV.
- D-term hybrid inflation: κ or $g \lesssim \mathcal{O}\left(10^{-3}\right)$ and $m_{3/2} \lesssim \mathcal{O}\left(10^{9}\right)$ GeV.

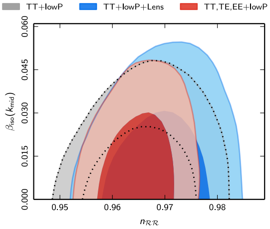
Conclusions

1. Theory: Nontrivial constraints on the mass scale of soft supersymmetry breaking.

2. Phenomenology: Testable parameter correlations between various axion and CMB observables.

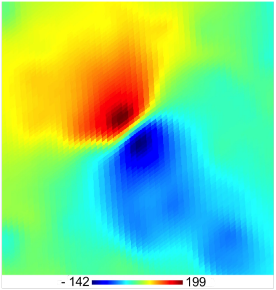
CDM isocurvature perturbations

[PLANCK 2015]



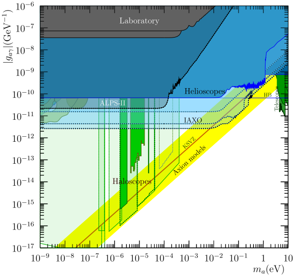
Cosmic strings

[PLANCK 2013]

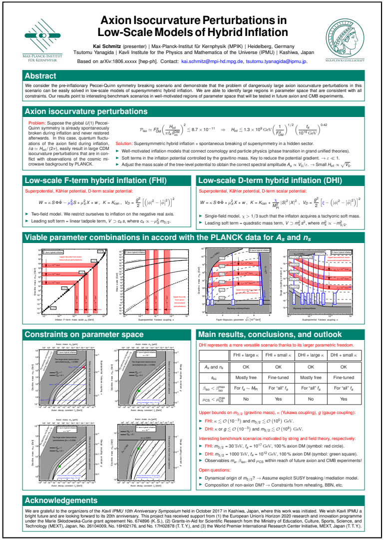


Axion dark matter

[Irastorza & Redondo 2018]



For more details, please come see my poster!



Axion Isocurvature Perturbations in Low-Scale Models of Hybrid Inflation

Kai Schmitz (presenter) | Max-Planck-Institut für Kernphysik (MPIK) | Heidelberg, Germany
Tsutomu Yanagida | Kavli Institute for the Physics and Mathematics of the Universe (IPMU) | Kashiwa, Japan
Based on arXiv:1806.xxxxx [hep-ph]. Contact: kai.schmitz@mpi-hd.mpg.de, tsutomu.tyanagida@ipmu.jp.

Abstract

We consider the pre-inflationary Peccei-Quinn symmetry breaking scenario and demonstrate that the problem of dangerously large axion isocurvature perturbations in this scenario can be easily solved in low-scale models of supersymmetric hybrid inflation. We are able to identify large regions in parameter space that are consistent with all constraints. Our results point to interesting benchmark scenarios in well-motivated regions of parameter space that will be tested in future axion and CMB experiments.

Axion isocurvature perturbations

Problem: Suppose the global $U(1)$ Peccei-Quinn symmetry is already spontaneously broken during inflation and never restored afterwards. In this case, quantum fluctuations of the axion field during inflation, $\delta a \simeq H_{\rm inf}/(2\pi)$, easily result in large CDM isocurvature perturbations that are in conflict with observations of the cosmic microwave background by PLANCK.

$$\mathcal{P}_{\rm iso} \simeq F_{\rm DM}^2 \left(\frac{H_{\rm inf}}{\pi f_a \theta_{\rm ini}^{\rm DM}}\right)^2 \lesssim 8.7 \times 10^{-11} \quad \Rightarrow \quad H_{\rm inf} \lesssim 1.3 \times 10^9\,{\rm GeV} \left(\frac{1}{F_{\rm DM}^2}\right)^{1/2} \left(\frac{f_a}{10^{16}\,{\rm GeV}}\right)^{0.42}$$

Solution: Supersymmetric hybrid inflation + spontaneous breaking of supersymmetry in a hidden sector.

- Well-motivated inflation models that connect cosmology and particle physics (phase transition in grand unified theories).
- Soft terms in the inflaton potential controlled by the gravitino mass. Key to reduce the potential gradient. $\rightarrow \varepsilon \ll 1$.
- Adjust the mass scale of the tree-level potential to obtain the correct spectral amplitude $A_s \propto V_0/\varepsilon$. $\rightarrow$ Small $H_{\rm inf} \propto \sqrt{V_0}$.

Low-scale F-term hybrid inflation (FHI)

Superpotential, Kähler potential, D-term scalar potential:

$$W = \kappa\, S\, \Phi\bar{\Phi} - \mu_S^2 S + \mu_X^2 X + w\,, \quad K = K_{\rm can}\,, \quad V_D = \frac{g^2}{2}\left[\left(|\phi|^2 - |\bar{\phi}|^2\right)\right]^2$$

- Two-field model. We restrict ourselves to inflation on the negative real axis.
- Leading soft term = linear tadpole term, $V \supset c_s\, s$, where $c_s \propto -\mu_S^2\, m_{3/2}$.

Low-scale D-term hybrid inflation (DHI)

Superpotential, Kähler potential, D-term scalar potential:

$$W = \kappa\, S\, \Phi\bar{\Phi} + \mu_X^2 X + w\,, \quad K = K_{\rm can} + \frac{\chi}{M_{\rm Pl}^2}|S|^2|X|^2\,, \quad V_D = \frac{g^2}{2}\left[\xi - \left(|\phi|^2 - |\bar{\phi}|^2\right)\right]^2$$

- Single-field model. $\chi > 1/3$ such that the inflaton acquires a tachyonic soft mass.
- Leading soft term = quadratic mass term, $V \supset m_s^2\, s^2$, where $m_s^2 \propto -m_{3/2}^2$.

Viable parameter combinations in accord with the PLANCK data for A_s and n_s

Constraints on parameter space

Main results, conclusions, and outlook

DHI represents a more versatile scenario thanks to its larger parametric freedom.

	FHI + large κ	FHI + small κ	DHI + large κ	DHI + small κ
A_s and n_s	OK	OK	OK	OK
$s_{\rm ini}$	Mostly free	Fine-tuned	Mostly free	Fine-tuned
$\beta_{\rm iso} < \beta_{\rm iso}^{\rm max}$	For $f_a \sim M_{\rm Pl}$	For "all" f_a	For "all" f_a	For "all" f_a
$\mu_{\rm CS} < \mu_{\rm CS}^{\rm max}$	No	Yes	No	Yes

Upper bounds on $m_{3/2}$ (gravitino mass), κ (Yukawa coupling), g (gauge coupling):

- FHI: $\kappa \lesssim \mathcal{O}(10^{-3})$ and $m_{3/2} \lesssim \mathcal{O}(10^5)$ GeV.
- DHI: κ or $g \lesssim \mathcal{O}(10^{-3})$ and $m_{3/2} \lesssim \mathcal{O}(10^9)$ GeV.

Interesting benchmark scenarios motivated by string and field theory, respectively:

- FHI: $m_{3/2} = 30$ TeV, $f_a = 10^{17}$ GeV, 100 % axion DM (symbol: red circle).
- DHI: $m_{3/2} = 1000$ TeV, $f_a = 10^{12}$ GeV, 100 % axion DM (symbol: green square).
- Observables m_a, $\beta_{\rm iso}$, and $\mu_{\rm CS}$ within reach of future axion and CMB experiments!

Open questions:

- Dynamical origin of $m_{3/2}$? $\rightarrow$ Assume explicit SUSY breaking / mediation model.
- Composition of non-axion DM? $\rightarrow$ Constraints from reheating, BBN, etc.

Acknowledgements

We are grateful to the organizers of the *Kavli IPMU 10th Anniversary Symposium* held in October 2017 in Kashiwa, Japan, where this work was initiated. We wish Kavli IPMU a bright future and are looking forward to its 20th anniversary. This project has received support from (1) the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 674896 (K. S.), (2) Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan, No. 26104009, No. 16H02176, and No. 17H02878 (T. T. Y.), and (3) the World Premier International Research Center Initiative, MEXT, Japan (T. T. Y.).

Thank you

very much

for your

attention!

... and see you for the drinks at the posters.