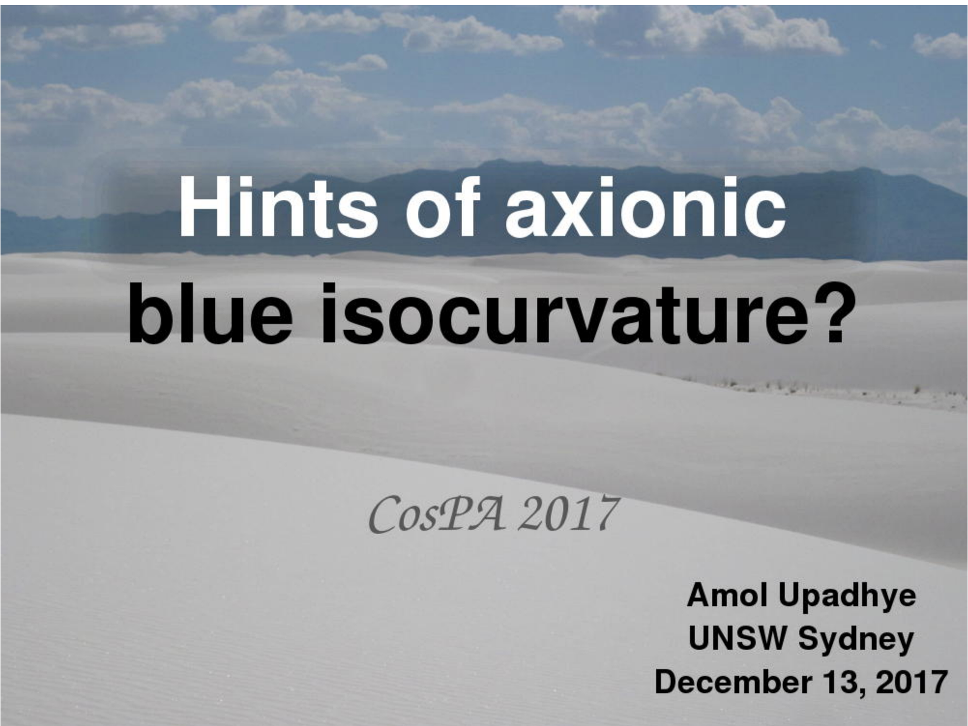


Hints of axionic blue isocurvature?

CosPA 2017

Amol Upadhye
UNSW Sydney
December 13, 2017

Outline

- Motivation: Inflation as a high-energy backlight illuminating new physics (fields and particles)

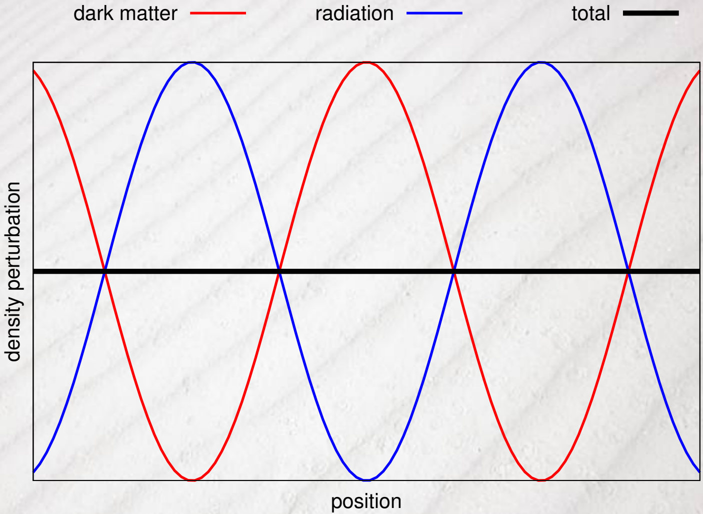
- Blue isocurvature: What and how

- A simple SUSY axionic model for blue isocurvature
    - Homogeneous field evolution
    - Perturbations and power spectra

- Constraints from CMB and large-scale structure data

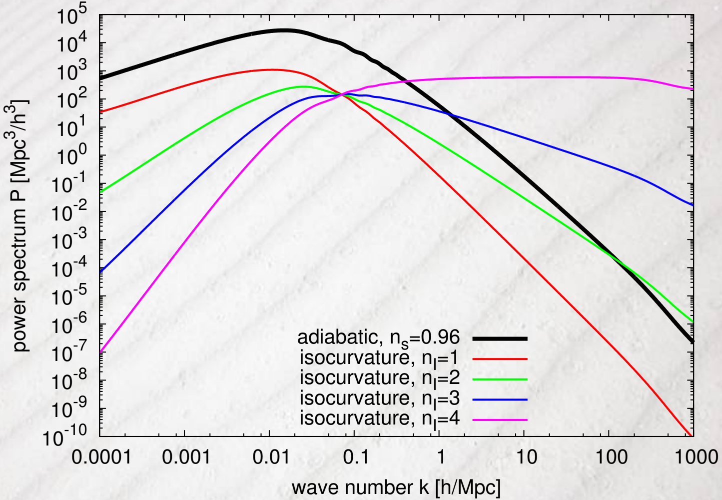
Chung, AU, PRD **95***:023503(2017)[1610.04284]*
Chung, AU, 1711.06736

Isocurvature



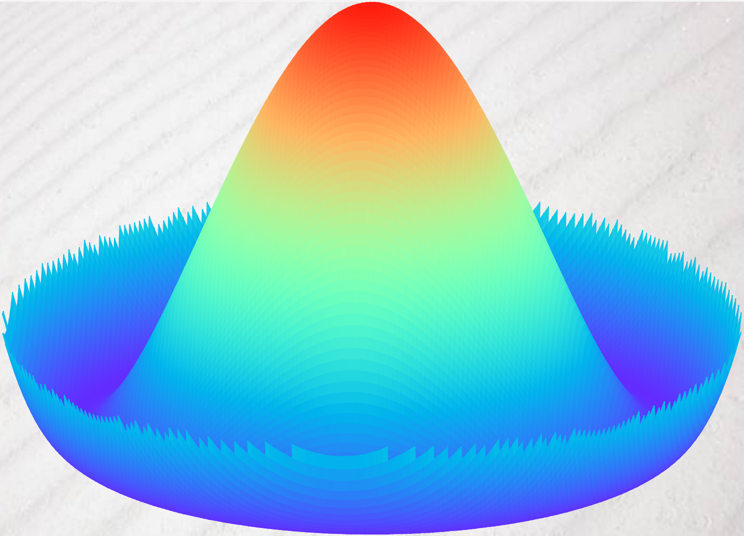
We expect isocurvature perturbations when additional (spectator) fields are non-negligible during inflation.

Isocurvature can't be blue at all scales



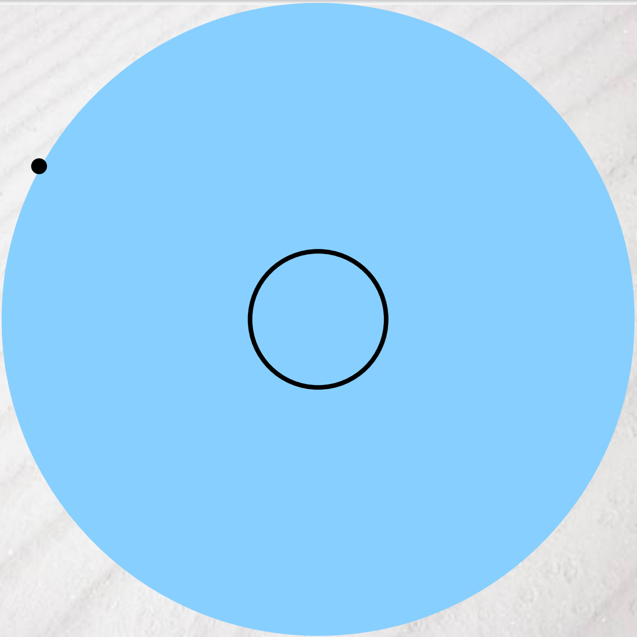
Isocurvature with a constant spectral index can't be bluer than $n_I = 2.4$. *Chung, PRD* **94***:043524(2016)[1509.05850]*

Blue spectrum from axionic field



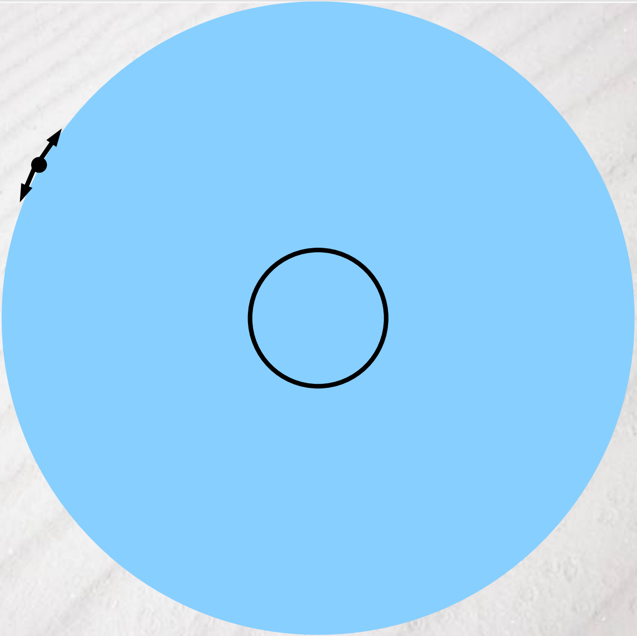
“Hat” potential $V(\Phi) = (\Phi^2 - F_a^2)^2$

Blue spectrum from axionic field



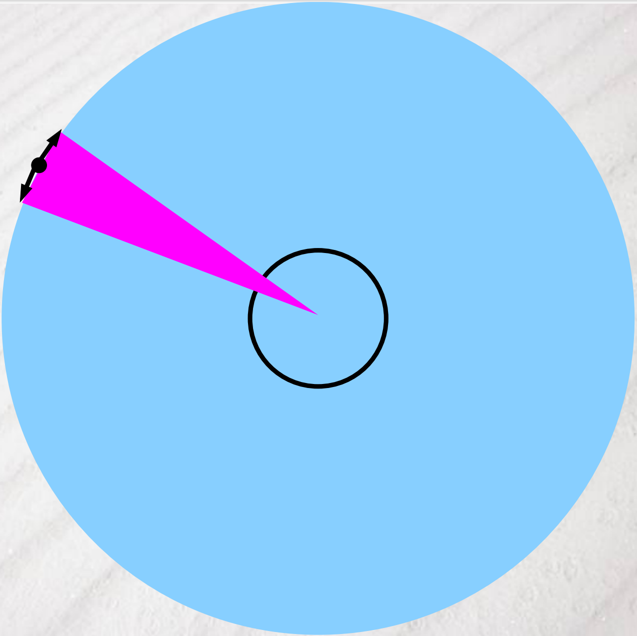
$\left(\text{out-of-equilibrium axion mass term } \frac{\Box f_{\rm PQ}}{f_{\rm PQ}} a^2 \sim H^2 a^2\right)$

Blue spectrum from axionic field



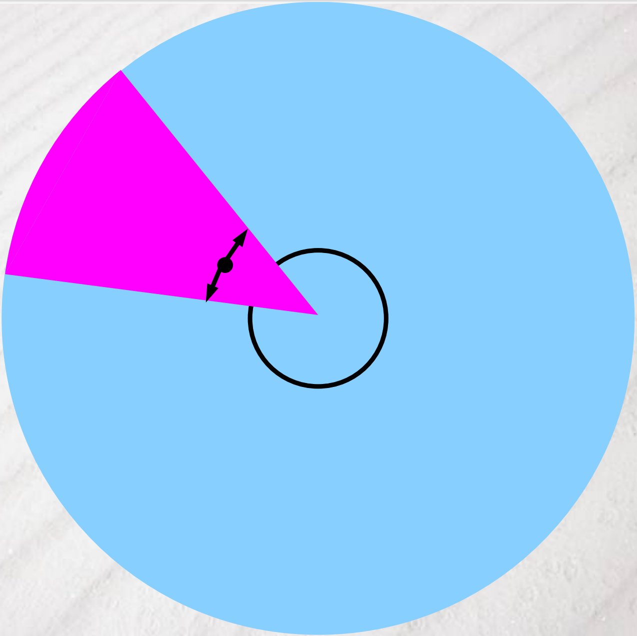
$\left(\text{out-of-equilibrium axion mass term } \frac{\Box f_{\mathrm{PQ}}}{f_{\mathrm{PQ}}} a^2 \sim H^2 a^2\right)$

Blue spectrum from axionic field



(out-of-equilibrium axion mass term $\frac{\Box f_{\mathrm{PQ}}}{f_{\mathrm{PQ}}} a^2 \sim H^2 a^2$)

Blue spectrum from axionic field



$\left(\text{out-of-equilibrium axion mass term } \frac{\Box f_{\mathrm{PQ}}}{f_{\mathrm{PQ}}} a^2 \sim H^2 a^2\right)$

Supersymmetric axion model

Superpotential $W = h(\Phi_+\Phi_- - F_a^2)\Phi_0$ for chiral superfields with charges $+1$, -1, and 0 under $U(1)$ Peccei-Quinn symmetry

Flat direction: $\Phi_0 = 0$, $\Phi_+\Phi_- = F_a^2$. Potential along the flat direction, including $\sim H$ mass corrections (from Kähler potential):

$$V = h^2\left|\Phi_+\Phi_- - F_a^2\right|^2 + c_+H^2\left|\Phi_+\right|^2 + c_-H^2\left|\Phi_-\right|^2$$

- "roll speed" $\gamma = \frac{3}{2}\left(1 - \sqrt{1 - \frac{4}{9}c_+}\right)$ with $\Phi_+ \propto \exp(-\gamma H t)$;
- spectral index $n_I = 1 + 2\gamma = 4 - 3\sqrt{1 - \frac{4}{9}c_+}$
- blue e-folds: $\eta_* = \gamma^{-1}\log\left(\frac{\Phi_{+,\mathrm{in}}}{F_a}\frac{c_+^{1/4}}{c_-^{1/4}}\right)$
- $\left.\frac{k_*}{a_0}\right|_{n_I=4} \lesssim 10\ \mathrm{Mpc}^{-1} e^{-(N_e-50)}\left(\frac{\Phi_{+,\mathrm{in}}}{0.3M_{\mathrm{Pl}}}\right)^{\frac{2}{3}}\left(\frac{T_{\mathrm{rh}}}{0.1H_{\mathrm{in}}}\right)^{\frac{1}{3}}\left(\frac{H_{\mathrm{in}}}{0.001F_a}\right)^{\frac{2}{3}}$

Kasuya and Kawasaki, PRD **80***:023516(2009)[0904.3800]*

Chung and Yoo, PRD **91***:083530(2015)[1501.05618]*

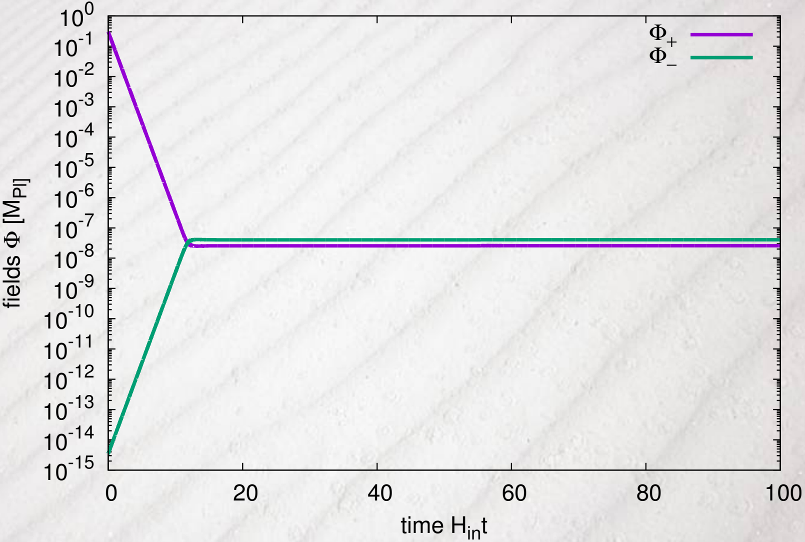
Chung, AU, PRD **95***:023503(2017)[1610.04284]*

Power spectrum from analytic arguments

Kasuya and Kawasaki, PRD **80***:023516(2009)[0904.3800]*,

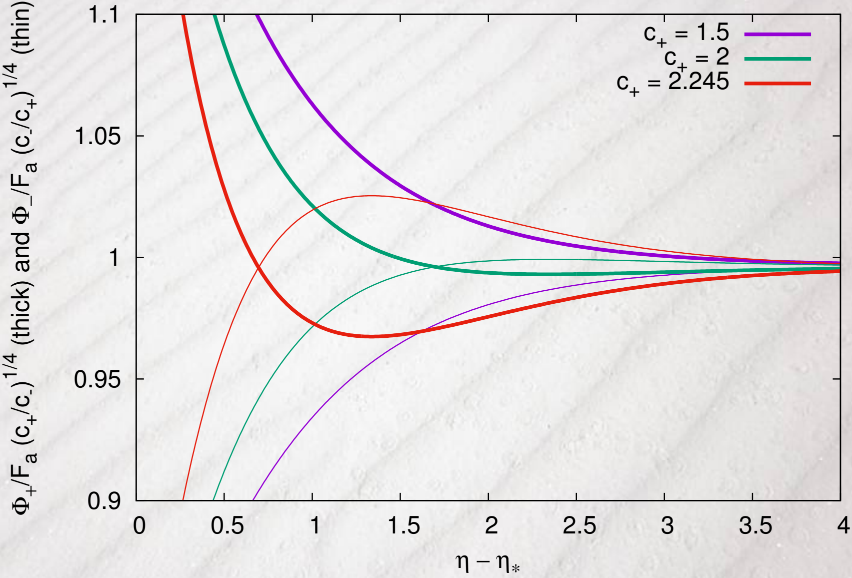
Chung and Yoo, PRD **91***:083530(2015)[1501.05618]*

Field evolution in homogeneous universe

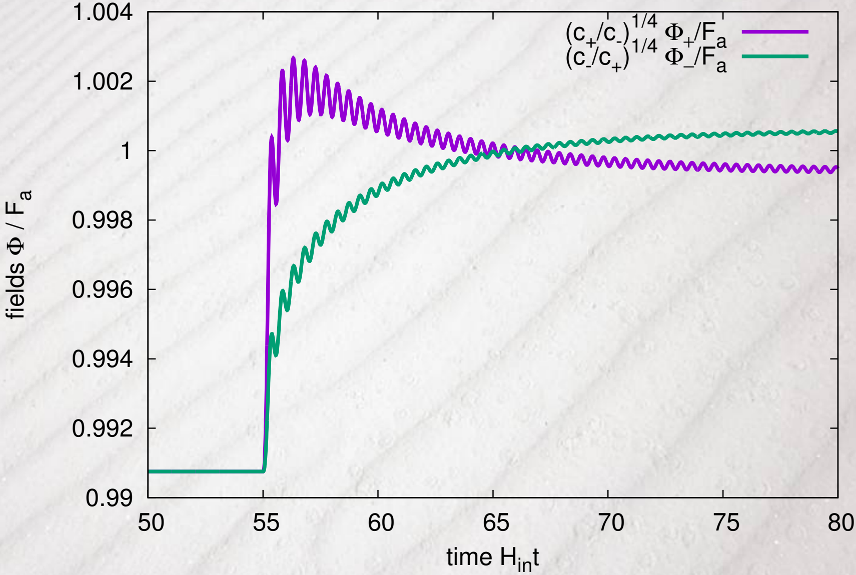


Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Blue-to-flat transition



End of inflation

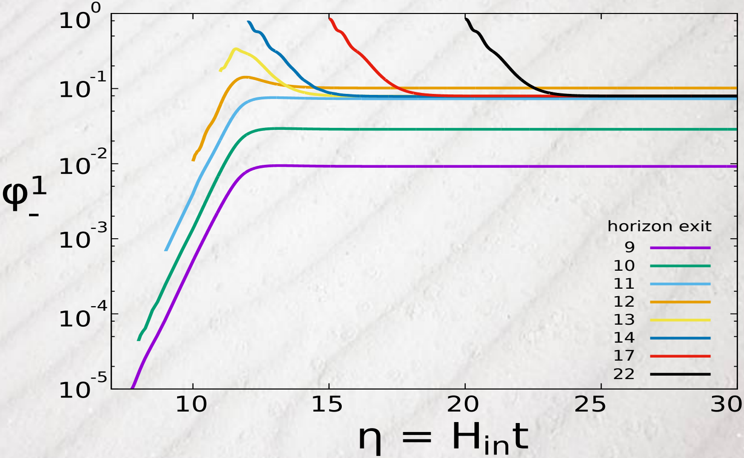


Evolution of linear perturbations

e.o.m.: $$\ddot{\varphi}^{\alpha}_{\pm} + 3H\dot{\varphi}^{\alpha}_{\pm} + \mu^2_{\pm}\varphi^{\alpha}_{\pm} + M^{\alpha\beta}_{\pm}\varphi^{\beta}_{\mp} = 0$$

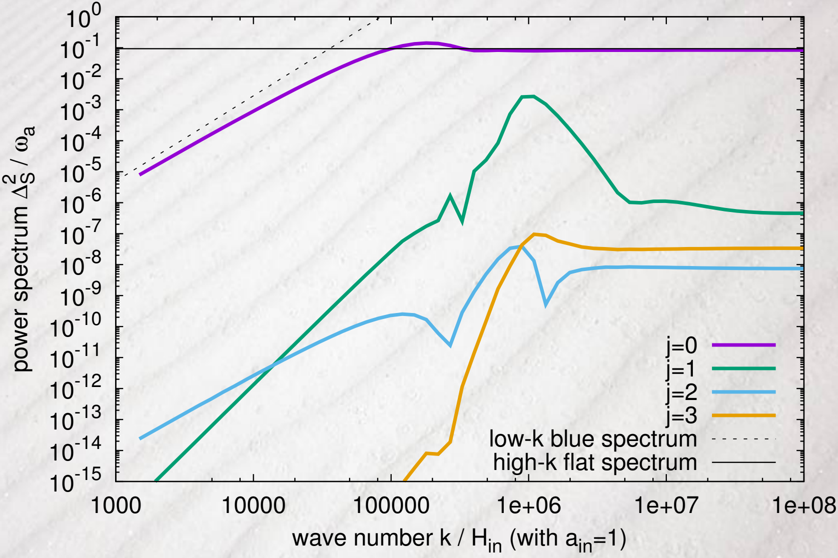
Perturbations: $\varphi^0_\pm = \mathrm{Re}(\Phi_\pm - \bar{\Phi}_\pm)$, $\varphi^1_\pm = \mathrm{Im}(\Phi_\pm - \bar{\Phi}_\pm)$

with $\mu^2_\pm = h^2|\bar{\Phi}_\mp|^2 + c_\pm H^2$, $\mathbf{M}_\pm = h^2\bar{\Phi}_+\bar{\Phi}_-\mathbf{Rot}(\mp 2\theta) + h^2(\bar{\Phi}_+\bar{\Phi}_- - F_a^2)\boldsymbol{\sigma_3}$



Chung and Upadhye, PRD **95**:*023503(2017)[1610.04284]*

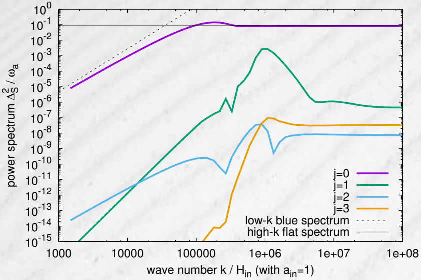
Power spectrum, $c_+ = 2.235$

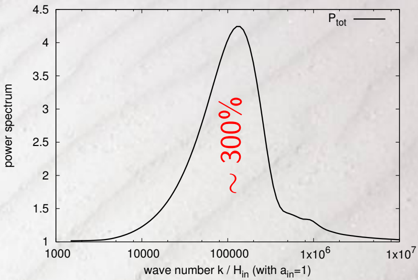


Chung and Upadhye, PRD ***95****:023503(2017)[1610.04284]*

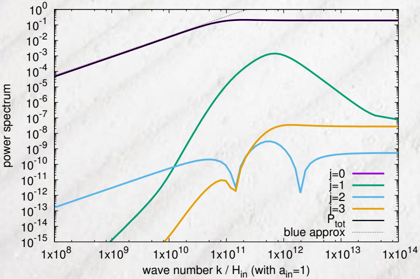
Bluer spectra get bigger bumps

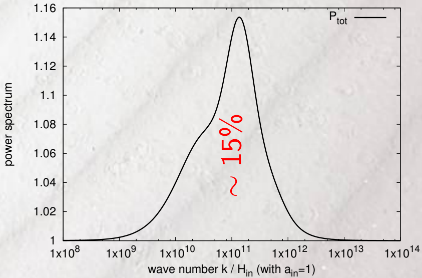
$c_+ = 2.235$





$c_+ = 1.5$

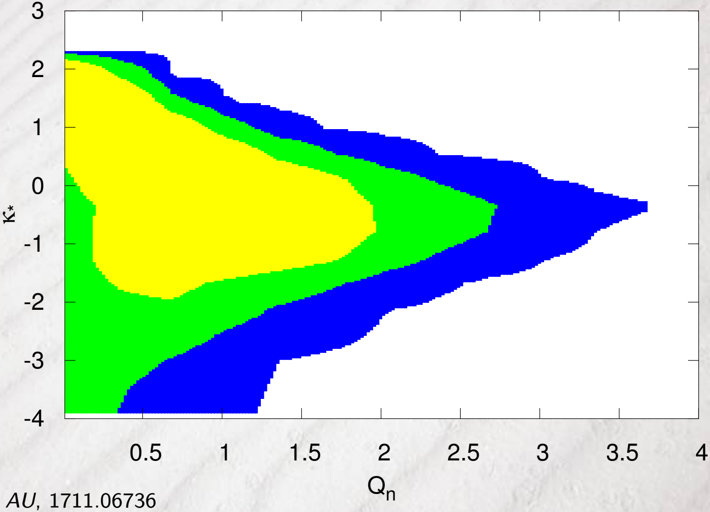




Chung and Upadhye, PRD **95***:023503(2017)[1610.04284]*

Constraints from Planck and BOSS data

$\kappa_\star = \ln(k_\star/k_0)$ and $Q_n = 10^{10} Q_{\rm flat}/(1+e^{n_I \kappa_\star})$ with $k_0 = 0.05/\mathrm{Mpc}$



Chung, *AU*, 1711.06736
Adam, et al., *A&A* **594***:A10(2016)*; *Aghanim*, et al., *A&A* **594***:A11(2016)*
Beutler, et al., *MNRAS* **443***:1065(2014)*; *Beutler*, et al., *MNRAS* **444***:3501(2014)*

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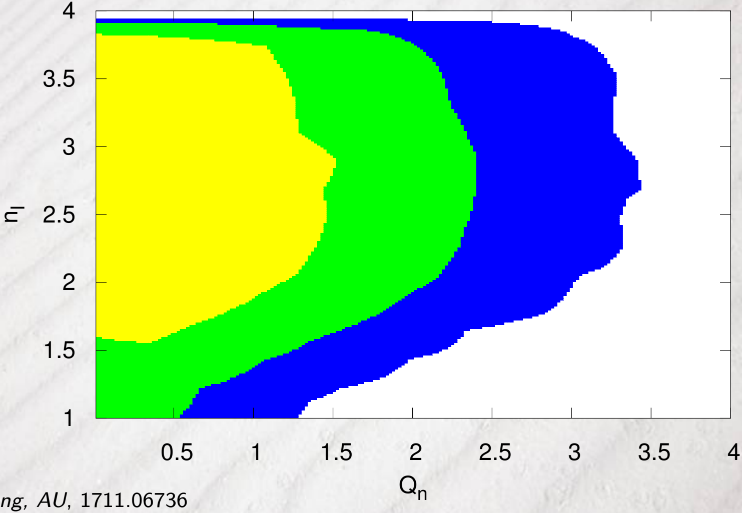

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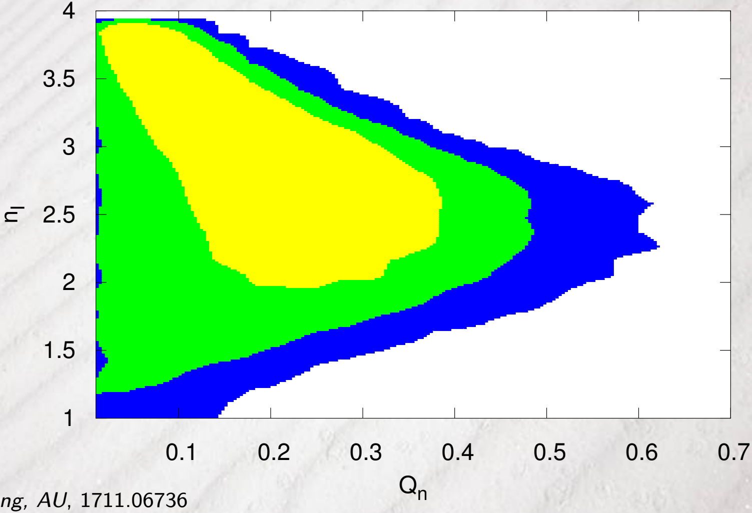

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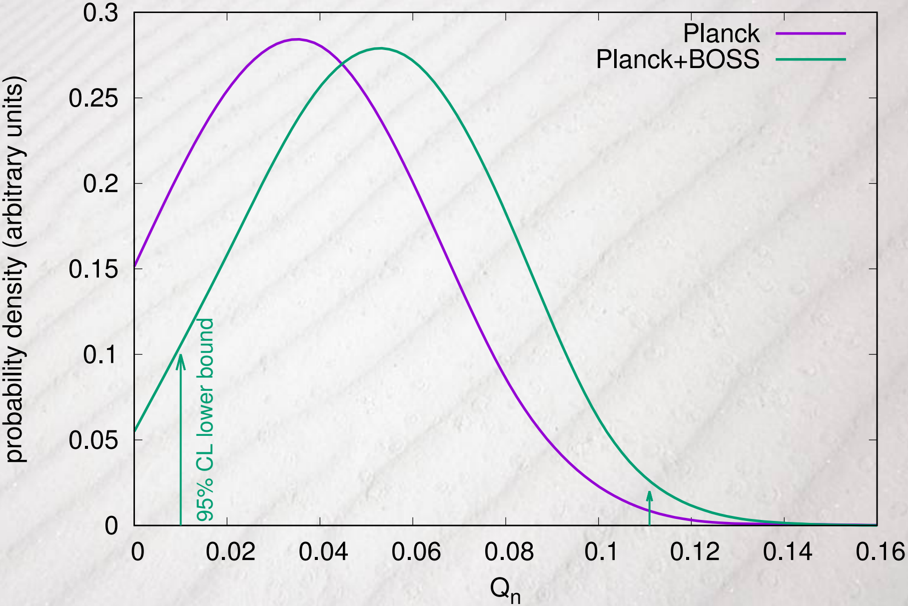
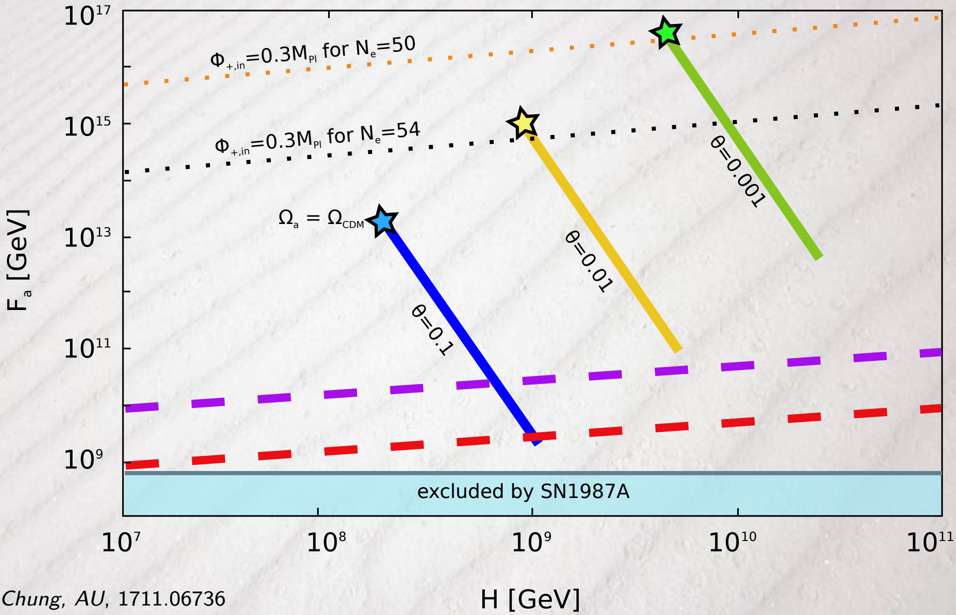
Beutler, et al., *MNRAS* **443***:1065(2014)*; *Beutler*, et al., *MNRAS* **444***:3501(2014)*

Constraints on the bluest models: $n_I = 3.9$, $k_\star = 0.5/\text{Mpc}$



Implications for phenomenology



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Conclusions

1. Cosmic inflation can serve as a backlight illuminating other physics at high energies.
2. A SUSY axion model with a time-variation in its mass gives rise to extremeley blue-tilted isocurvature spectra $n_I \lesssim 4$.
3. Power spectra for the bluest models have a bump at the transition scale which we have fit numerically. This cannot be pushed beyond $k_* \approx 10/\mathrm{Mpc}$ for the bluest tilts.
4. CMB and galaxy survey data allow a broad range of models and show $\approx 2\sigma$ hints for very blue-tilted isocurvature.
5. Best-fit models are consistent with axion angle $\theta_{\rm in} = 0.1$ and allow axions to make up all of the dark matter.

Chung, AU, PRD **95***:023503(2017)[1610.04284]*
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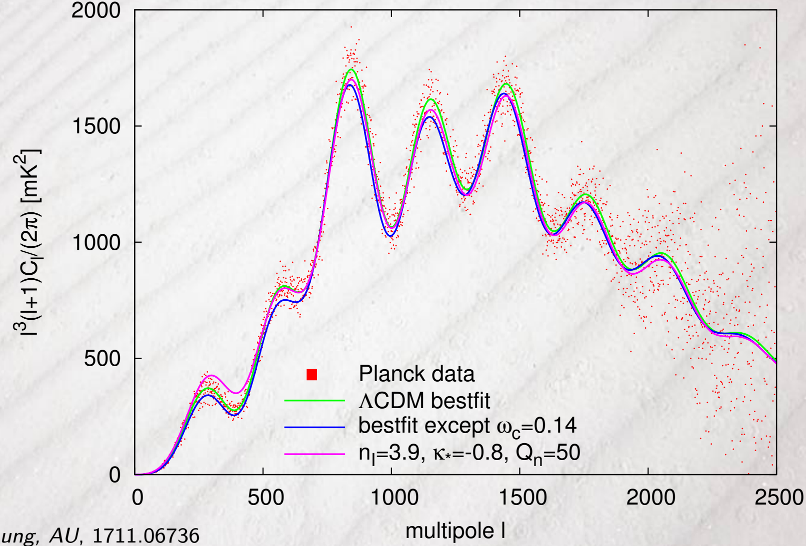
Extra slides

Could isocurvature explain high-ℓ vs. low-ℓ shift?

2.5σ discrepancy between $\Omega_c h^2$ values determined using $\ell < 1000$ and $\ell \geq 1000$ data (*Addison*, et al., *Ap. J.* **818**:*132(2016)[1511.00055]*)



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Planck + BOSS parameter constraints

	KK+b_5, PB	KK+ω_ν+b_5, PB	KK, PB	NB, PB
n_s	$0.9653^{+0.0041}_{-0.0042}{}^{+0.0081}_{-0.0086}$	$0.9668^{+0.0048}_{-0.0047}{}^{+0.0095}_{-0.01}$	$0.965^{+0.0042}_{-0.0045}{}^{+0.0085}_{-0.0084}$	$0.9651^{+0.0041}_{-0.0043}{}^{+0.0086}_{-0.0086}$
σ_8	$0.821^{+0.018}_{-0.017}{}^{+0.034}_{-0.035}$	$0.809^{+0.021}_{-0.015}{}^{+0.036}_{-0.036}$	$0.818^{+0.018}_{-0.018}{}^{+0.034}_{-0.034}$	$0.819^{+0.018}_{-0.018}{}^{+0.033}_{-0.037}$
h	$0.6768^{+0.0052}_{-0.0045}{}^{+0.0093}_{-0.0098}$	$0.6717^{+0.0069}_{-0.0057}{}^{+0.012}_{-0.013}$	$0.6764^{+0.0048}_{-0.005}{}^{+0.0099}_{-0.0098}$	$0.6762^{+0.005}_{-0.005}{}^{+0.01}_{-0.01}$
ω_{c}	$0.1188^{+0.001}_{-0.0011}{}^{+0.0021}_{-0.002}$	$0.1183^{+0.0011}_{-0.0014}{}^{+0.0029}_{-0.0025}$	$0.1189^{+0.0011}_{-0.0011}{}^{+0.0021}_{-0.0022}$	$0.119^{+0.0011}_{-0.0012}{}^{+0.0022}_{-0.0022}$
ω_{b}	$0.02226^{+0.00013}_{-0.00014}{}^{+0.00028}_{-0.00028}$	$0.0223^{+0.00015}_{-0.00016}{}^{+0.0003}_{-0.0003}$	$0.02227^{+0.00014}_{-0.00014}{}^{+0.00029}_{-0.00028}$	$0.02225^{+0.00013}_{-0.00015}{}^{+0.00028}_{-0.00028}$
ω_ν		$0.0014^{+0.0005}_{-0.0011}{}^{+0.0016}_{-0.0014}$		
τ	$0.071^{+0.024}_{-0.02}{}^{+0.043}_{-0.045}$	$0.082^{+0.032}_{-0.027}{}^{+0.049}_{-0.058}$	$0.067^{+0.025}_{-0.022}{}^{+0.043}_{-0.051}$	$0.067^{+0.025}_{-0.024}{}^{+0.044}_{-0.047}$
Q_n	$1.0^{+0.3}_{-1.0}{}^{+1.3}_{-1.0}$	$1.1^{+0.3}_{-1.0}{}^{+1.5}_{-1.1}$	$0.96^{+0.32}_{-0.93}{}^{+1.3}_{-0.96}$	$1.1^{+0.3}_{-1.0}{}^{+1.4}_{-1.1}$
n_I	$2.72^{+1.2}_{-0.69}{}^{+1.2}_{-1.2}$	$2.78^{+1.1}_{-0.59}{}^{+1.2}_{-1.2}$	$2.76^{+1.1}_{-0.59}{}^{+1.2}_{-1.2}$	$2.65^{+0.75}_{-0.7}{}^{+1.2}_{-1.2}$
$\kappa_\star$	$-0.37^{+1.5}_{-0.98}{}^{+2.6}_{-2.7}$	$-0.21^{+1.3}_{-1.1}{}^{+2.5}_{-2.5}$	$-0.21^{+1.5}_{-1.1}{}^{+2.5}_{-2.4}$	$-0.31^{+1.5}_{-1.2}{}^{+2.6}_{-2.4}$

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