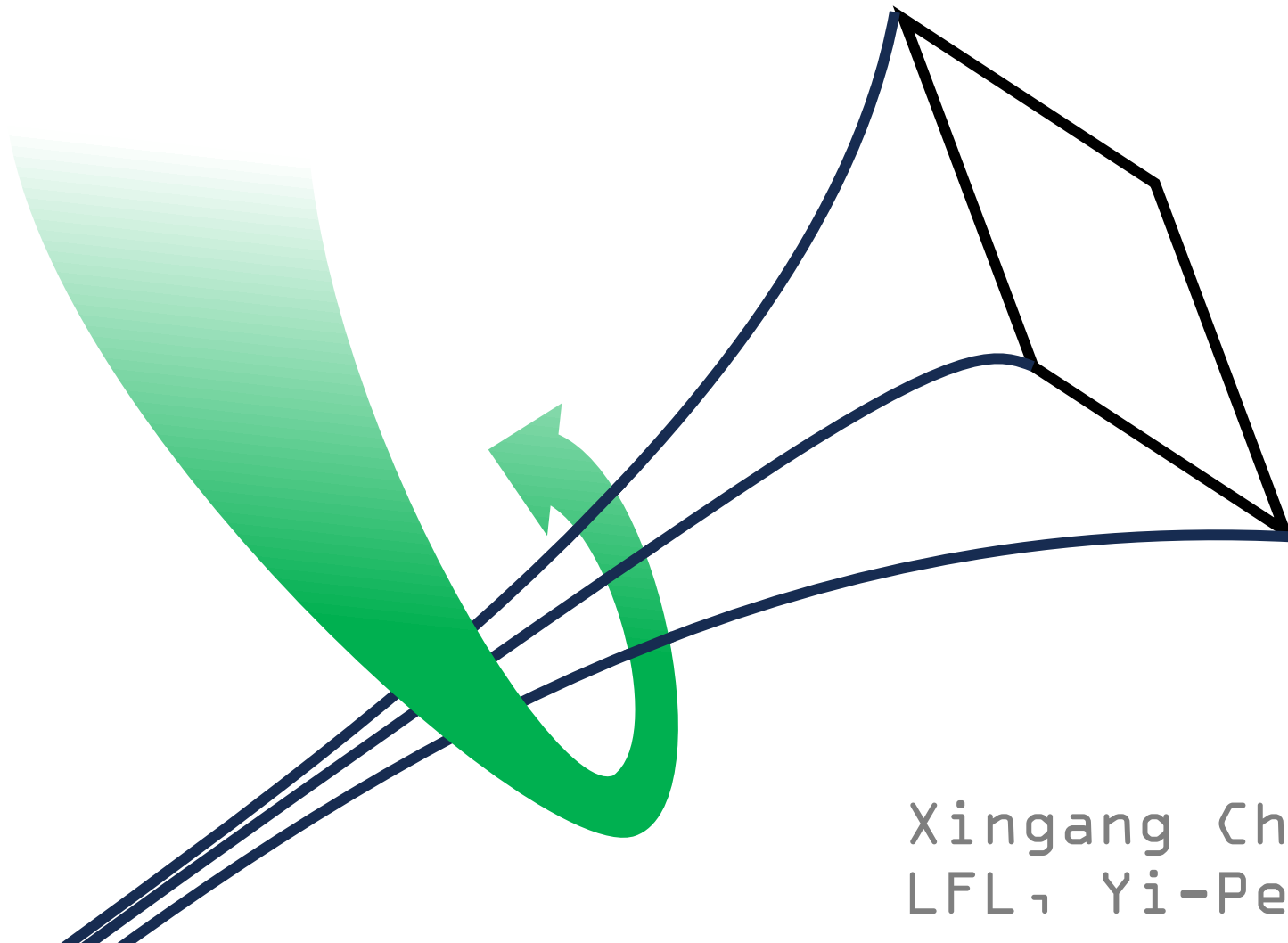
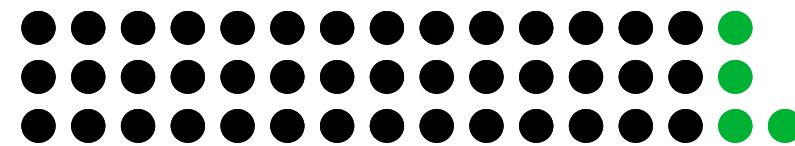


PRIMORDIAL FEATURES FROM BARYOGENESIS



Lingfeng Li
(李凌风)

Apr. 13, 2026

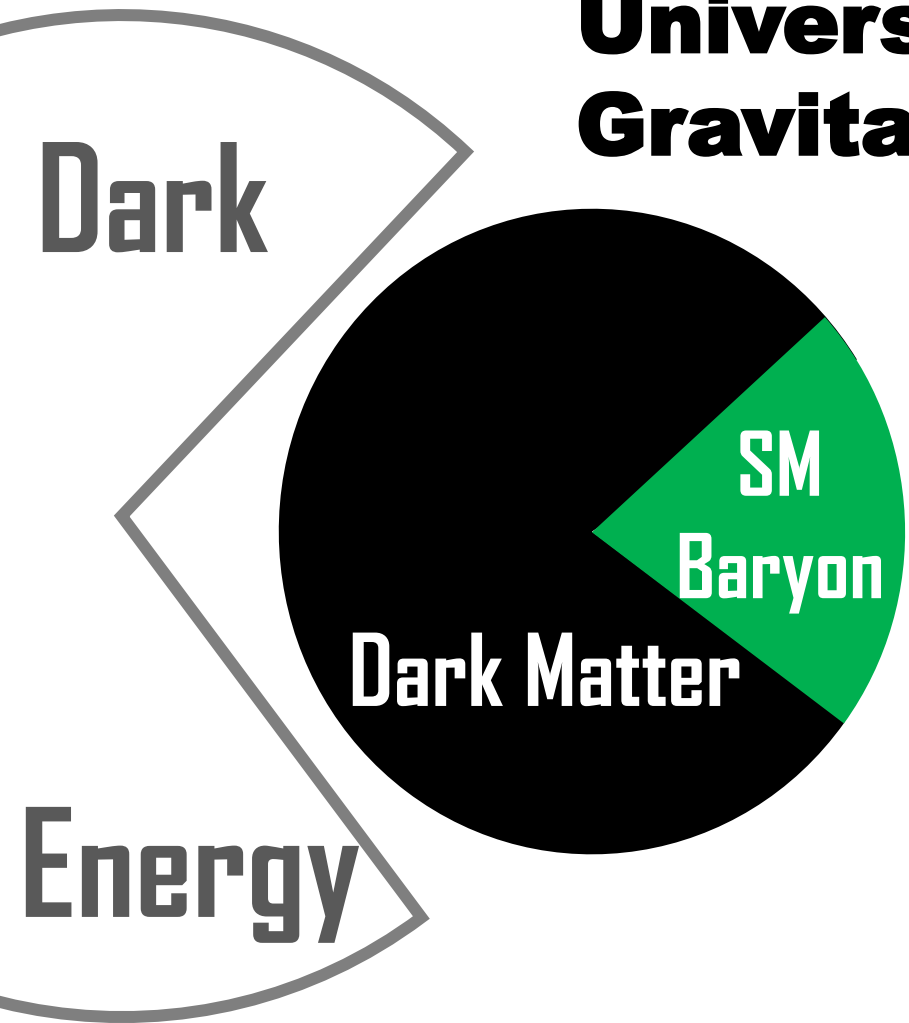
3rd GUTPC

HIAS

Xingang Chen, Nino Ephremidze,
LFL, Yi-Peng Wu, 2602.08781

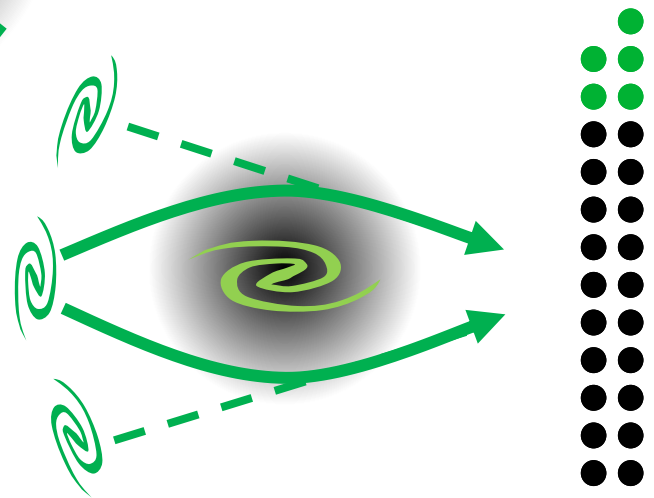
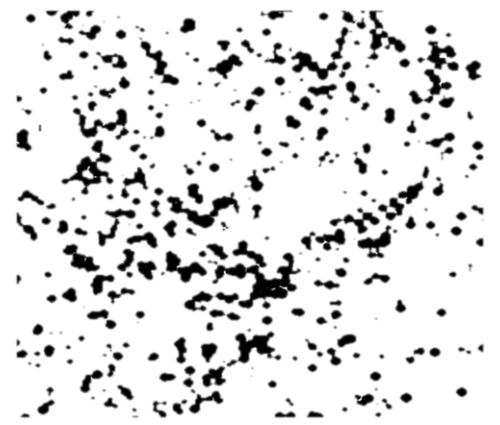
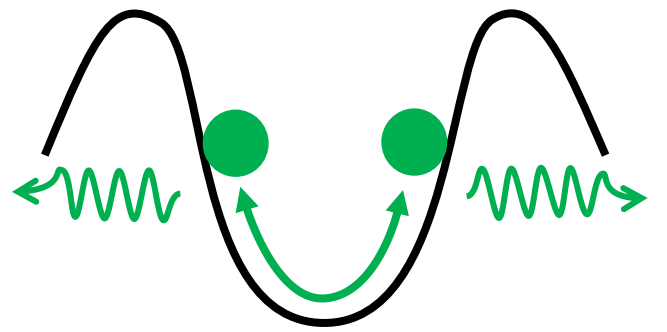


Components of Our Universe from Gravitational Effects



Probes

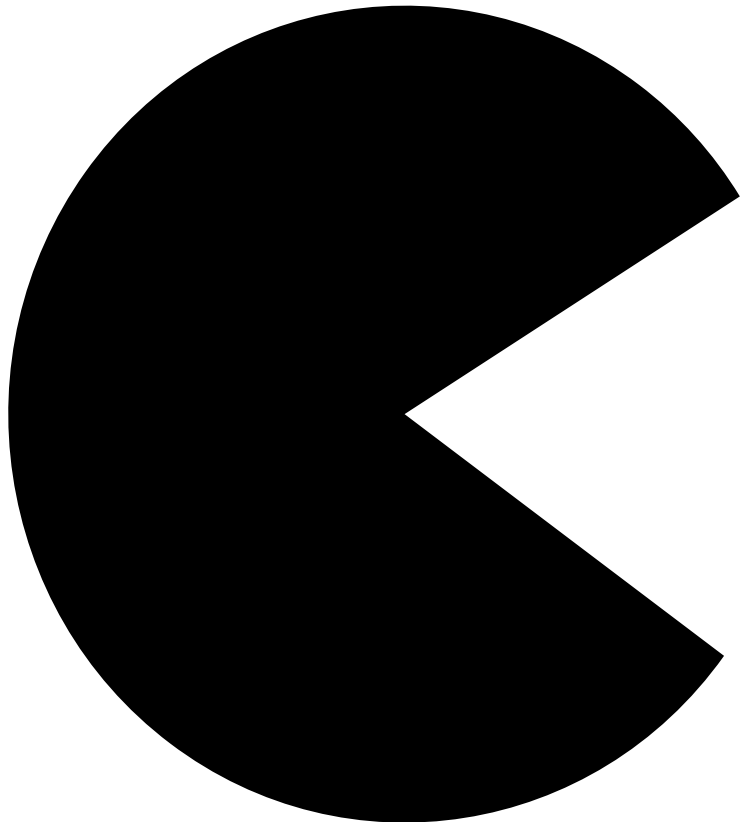
- CMB
- LSS/BAO
- Rotational curves
- Strong lensing
- Spectroscopy surveys



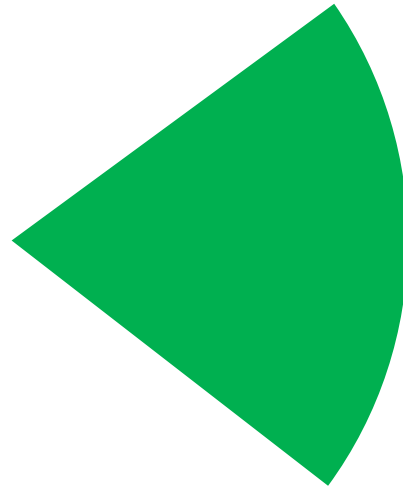
Baryogenesis: Sakharov Conditions

$$\eta \equiv \frac{n_B}{n_\gamma} \approx Y_B \equiv \frac{n_B}{s} \approx 10^{-10}$$

- Baryon-number violation
- Both C and CP violation
- Deviation from thermal equilibrium



"log scale"



See also: Peter Athron's talk



Affleck–Dine Mechanism

- ❑ Form a coherent scalar condensate with a large VEV (Often realized along SUSY flat directions).
- ❑ Efficient baryon production; can later dilute to the observed value.
- ❑ Hard to test at colliders → cosmology as the key probe.

See also: Yuichiro Nakai and Wei Chao's talk

I. Affleck and M. Dine, Nucl. Phys. B 249 (1985) 361; M. Dine, L. Randall and S. D. Thomas, 9507453.....

$$j^\mu = i (\sigma^* \partial^\mu \sigma - \sigma \partial^\mu \sigma^*)$$

← Associated with B number through microscopic phys.



AD Potential

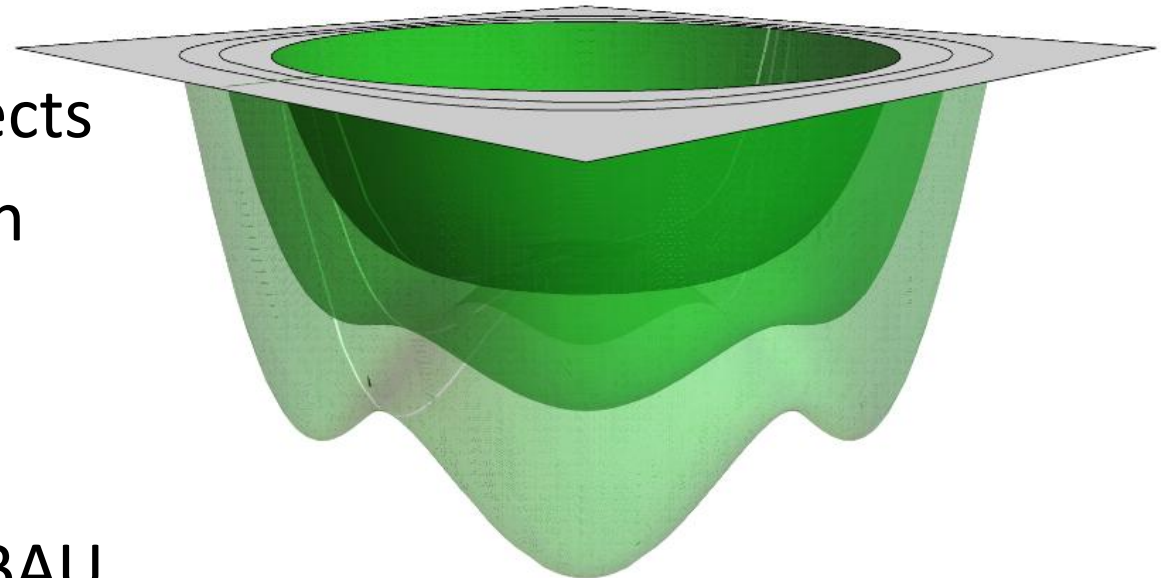
$$\sigma \equiv \frac{R}{\sqrt{2}} e^{i\theta}, \quad \xi \equiv |c_H|, \quad A \equiv |A| e^{i\delta}$$

$$U_{\text{FD}}(R, \theta) = (m_\sigma^2 - \xi H^2) \frac{R^2}{2} + \frac{\lambda^2}{2^{n-1}} \frac{R^{2(n-1)}}{\Lambda^{2(n-3)}} + \frac{\alpha}{n} \frac{\lambda}{2^{n/2-1}} \frac{H}{\Lambda^{n-3}} R^n$$

$$\alpha H \equiv c_A H \cos(n\theta) + A m_{3/2} \cos(n\theta + \delta)$$

- During inflation, effective potential selects a large radial VEV through coupling with the Hubble (equivalently the inflaton)

- Explicit CP breaking term to introduce BAU



Light and Heavy Modes Arises

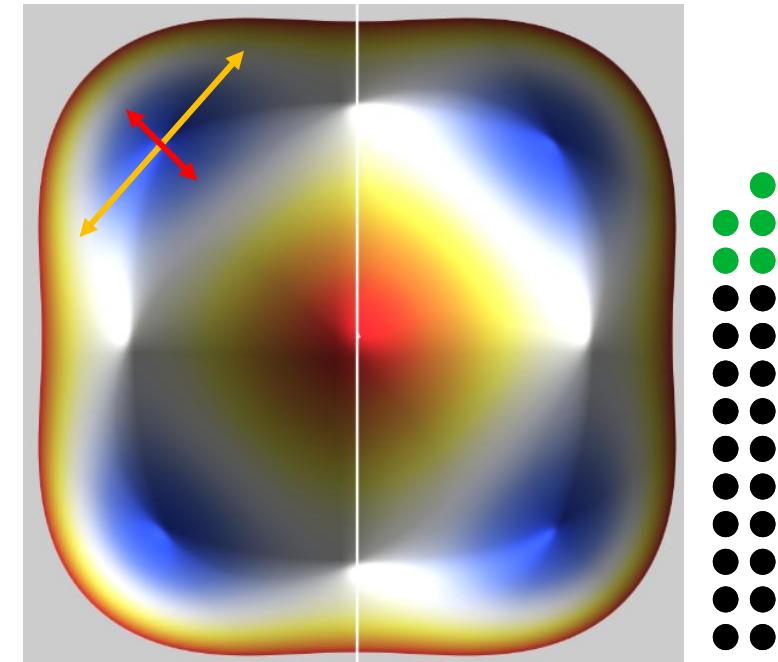
□ Radial fluctuation: much heavier than Hubble

□ Angular fluctuation: can be almost massless.

$$R_{\min} = \left(\frac{2^{n/2-1}}{\lambda} \Lambda^{n-3} X_{\min} H \right)^{\frac{1}{n-2}}$$

Large VEV compared to Hubble

Light and Heavy modes comparable with H
Coupled to each other

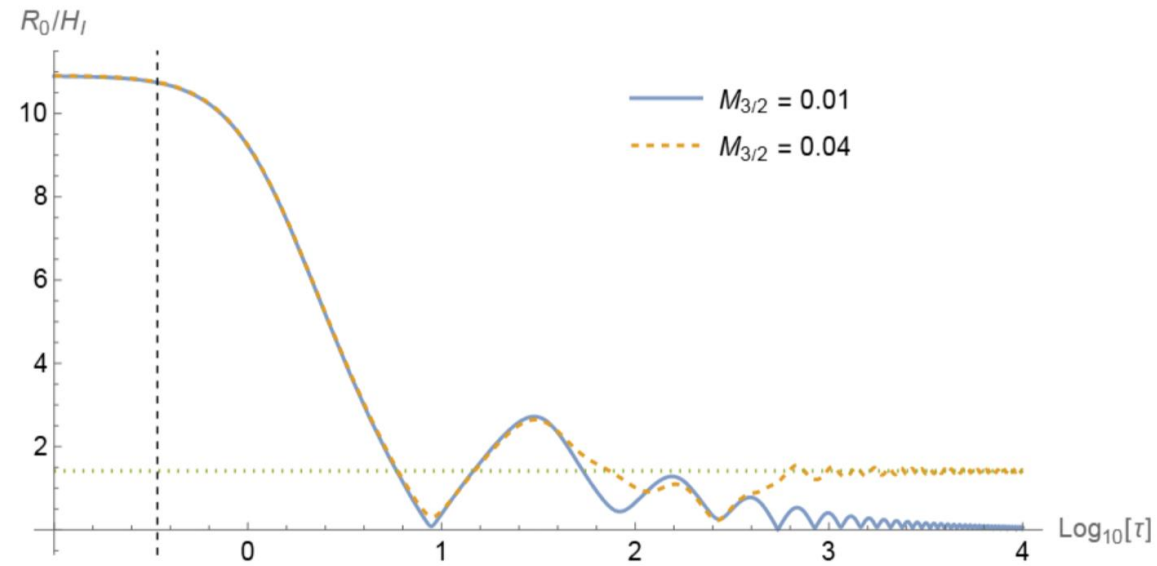
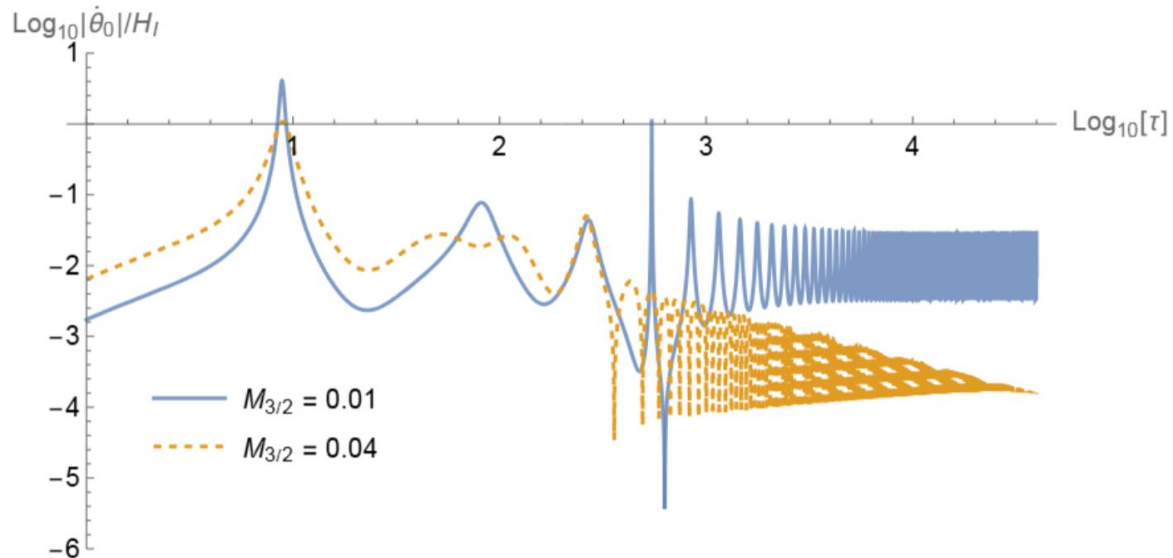


$$m_R^2 \equiv \partial_R^2 U_{\text{FD}} = (2n - 4) (\xi H^2 - m_\sigma^2) + (2 - n) \alpha_{\min} X_{\min} H^2,$$

$$m_\theta^2 \equiv \frac{1}{R_{\min}^2} \partial_\theta^2 U_{\text{FD}} = -n \alpha_{\min} X_{\min} H^2.$$

Post-inflationary evolution

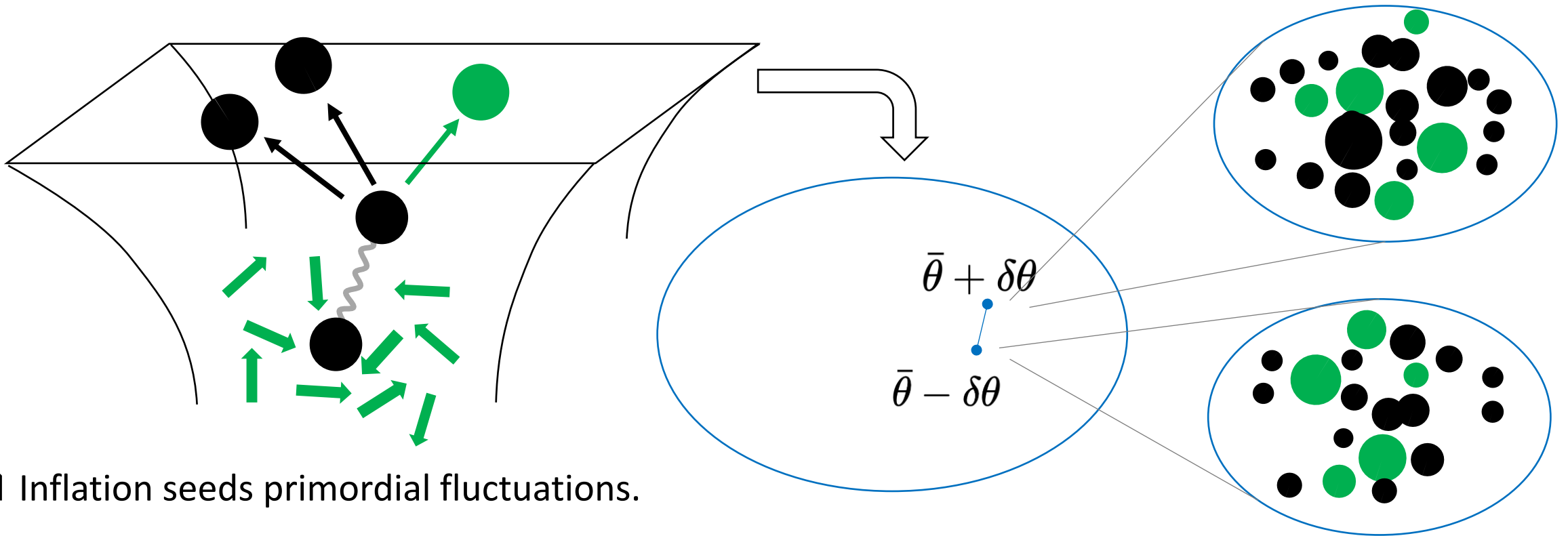
- ❑ After inflation, H decreases; the condensate starts dynamical evolution.
- ❑ A-terms induce torque in the angular direction.



- ❑ Rotation in field space corresponds to a nonzero baryon number density.
- ❑ Final baryon asymmetry depends on initial conditions and evolution.



Cosmology as a probe of high-energy physics: Lesson from the Axion Case



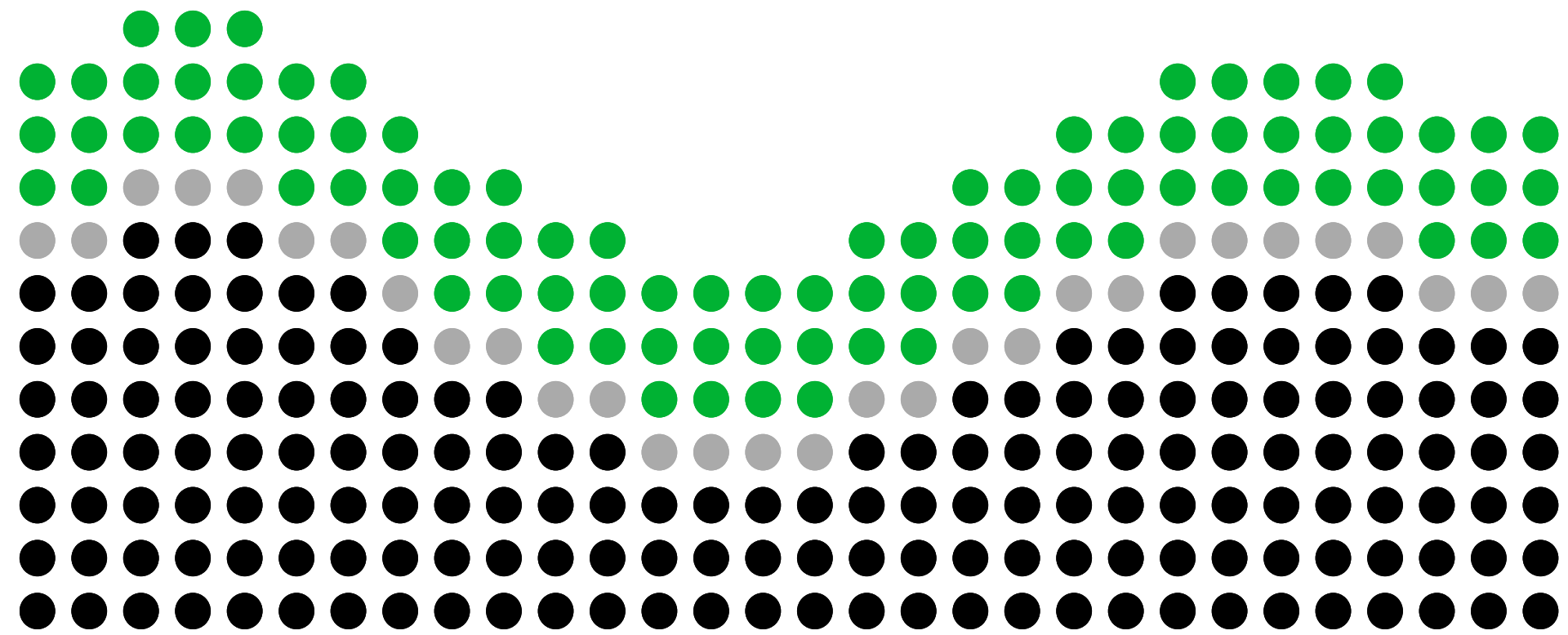
- Inflation seeds primordial fluctuations.
- Correlation functions can carry imprints of extra fields and interactions during inflation.

S. Lu, 2103.05958; X. Chen,
J. Fan, LFL, 2303.03406



Curvature vs. Isocurvature

□ Curvature or adiabatic: all species fluctuate together. The dominant mode observed today

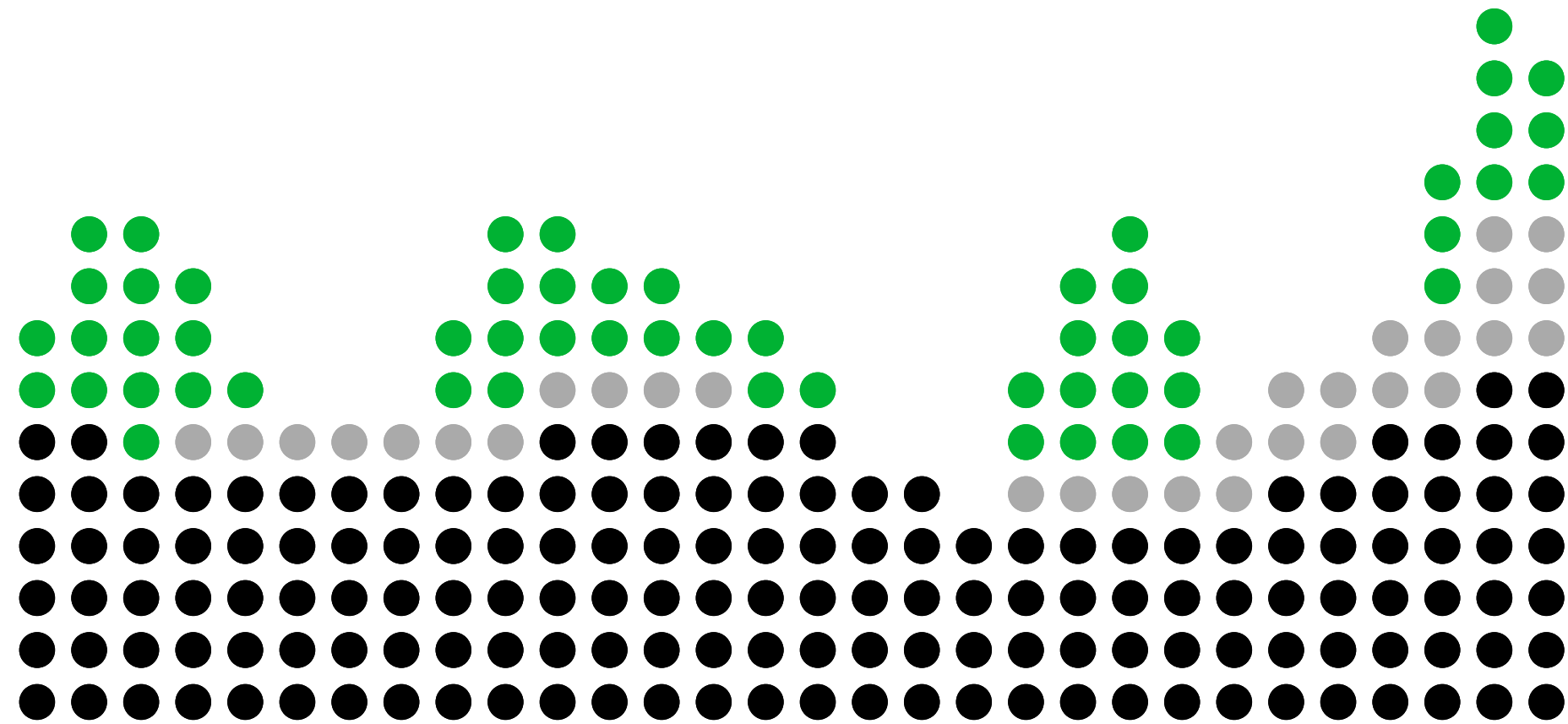


Curvature vs. Isocurvature

□ Isocurvature: relative composition fluctuates differently (to their dilution rates)

$$\zeta_i \equiv -\Phi - H \frac{\delta \rho_i}{\dot{\rho}_i}$$

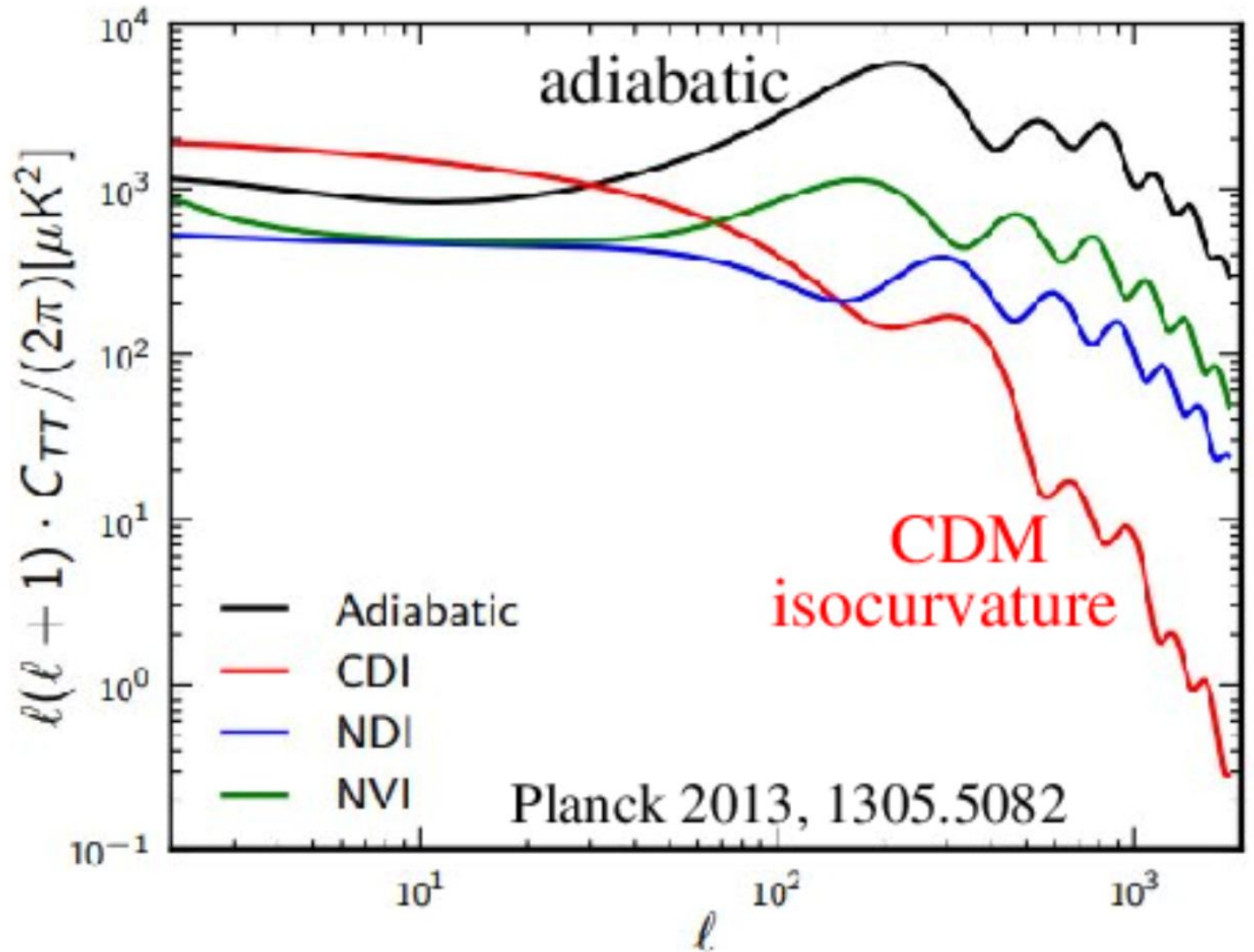
$$S_{ij} \equiv 3 [\zeta_i - \zeta_j]$$



S. Weinberg, 0302326;
I. Allali, P.
Chakraborty, J. Fan, M.
Reece, 2510.07371.....

Transfer to CMB

$$\text{CDI} \approx \text{BDI}$$



For compensated isocurvature, see e.g.:

D. Grin, O. Dore, M. Kamionowski, 1107.5047



Cosmic Blues: Blue-Tilted Spectra from a Semi-Light Field

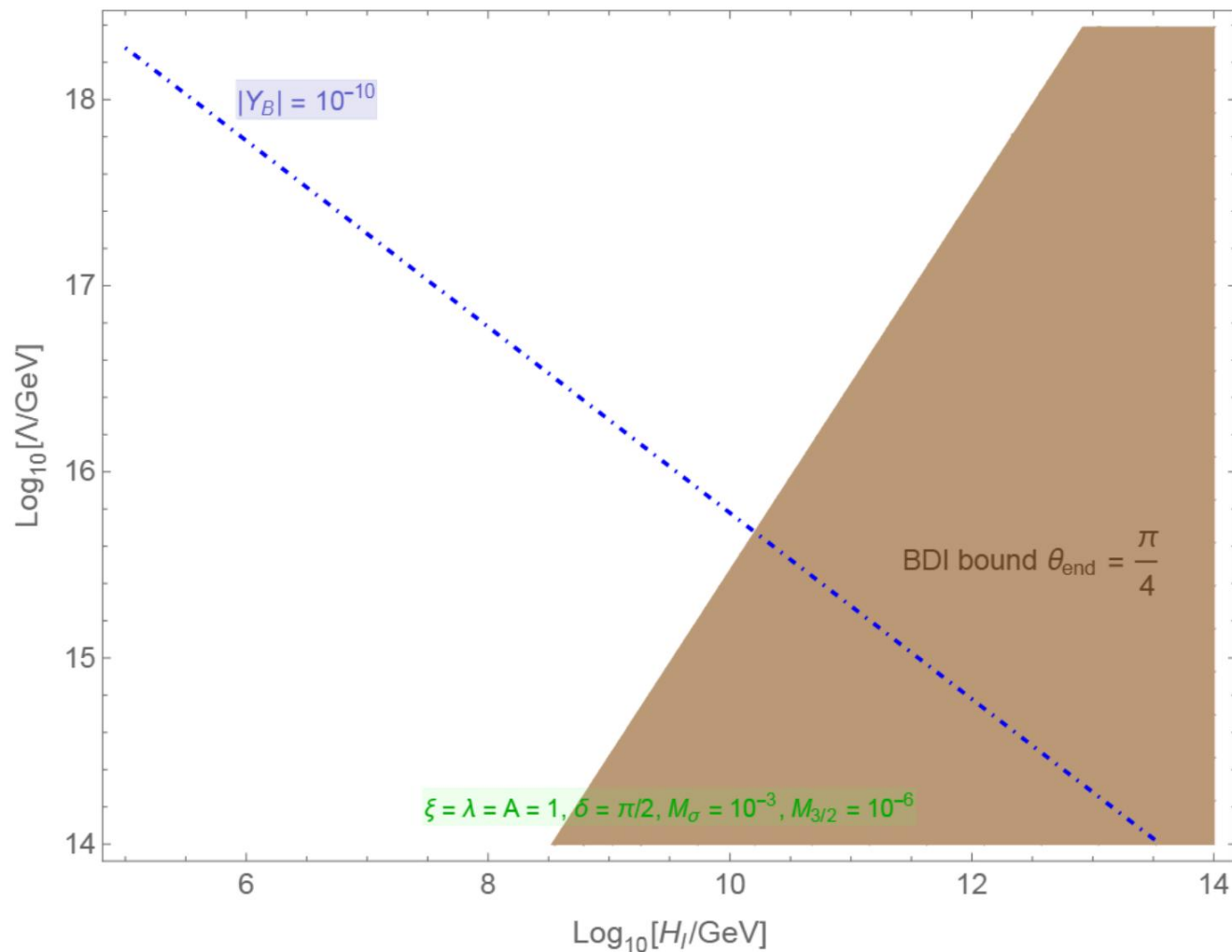
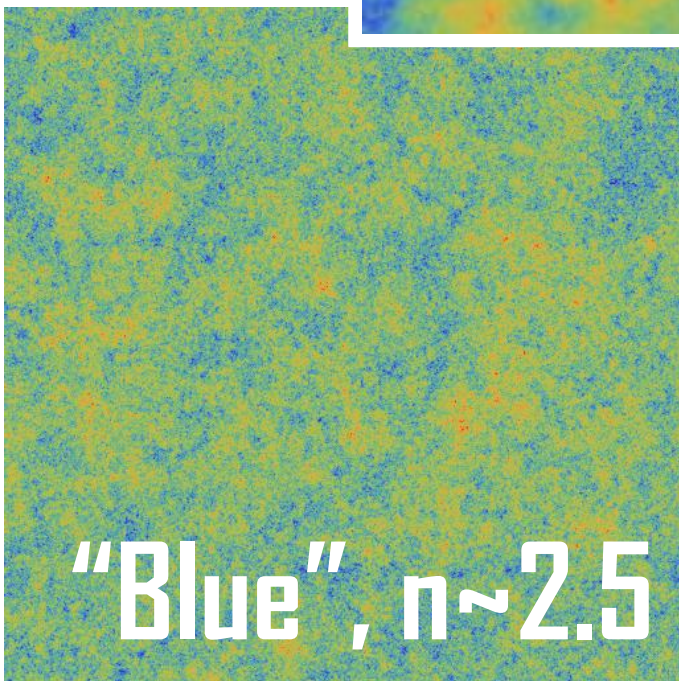
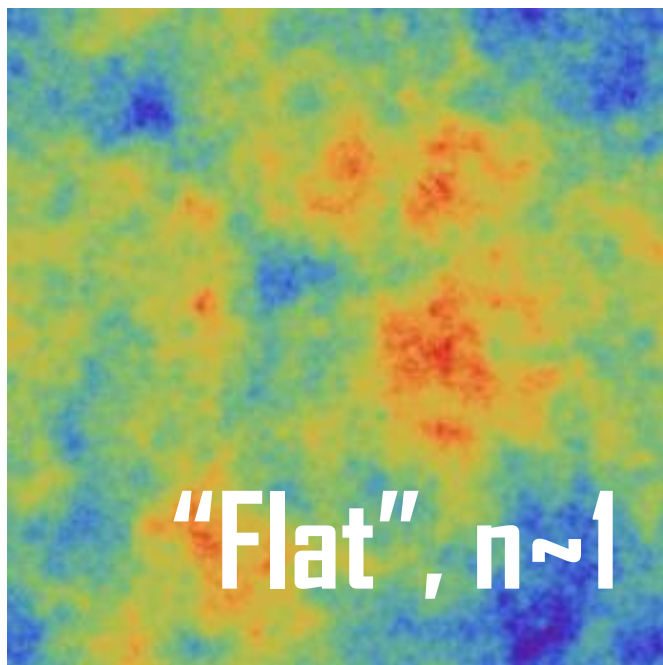


$$u_k(\eta) \equiv c_\theta (-k\eta)^{3/2} H_{\nu_\theta}^{(1)}(-k\eta)$$

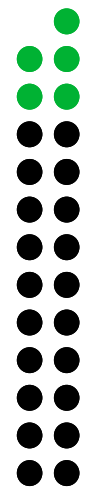
$$P_\theta(k, \eta) = \frac{k^3}{2\pi^2} \frac{H_I^2}{R_{\min}^2} |u_k(\eta)|^2$$

$$P_\theta(k, \eta_{\text{end}}) \propto \left(\frac{k}{k_{\text{end}}} \right)^{3-2\nu_\theta}$$



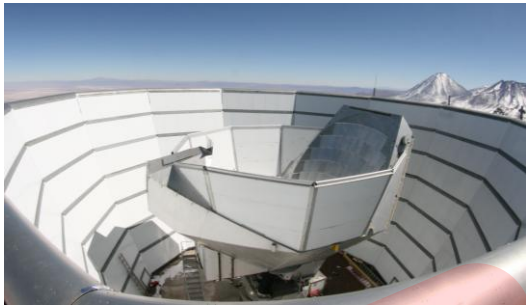


See also: S. Kasuya, M. Kawasaki, F. Takahashi, 0805.4245; S. Kasuya, M. Kawasaki, F. Takahashi, 0809.2242

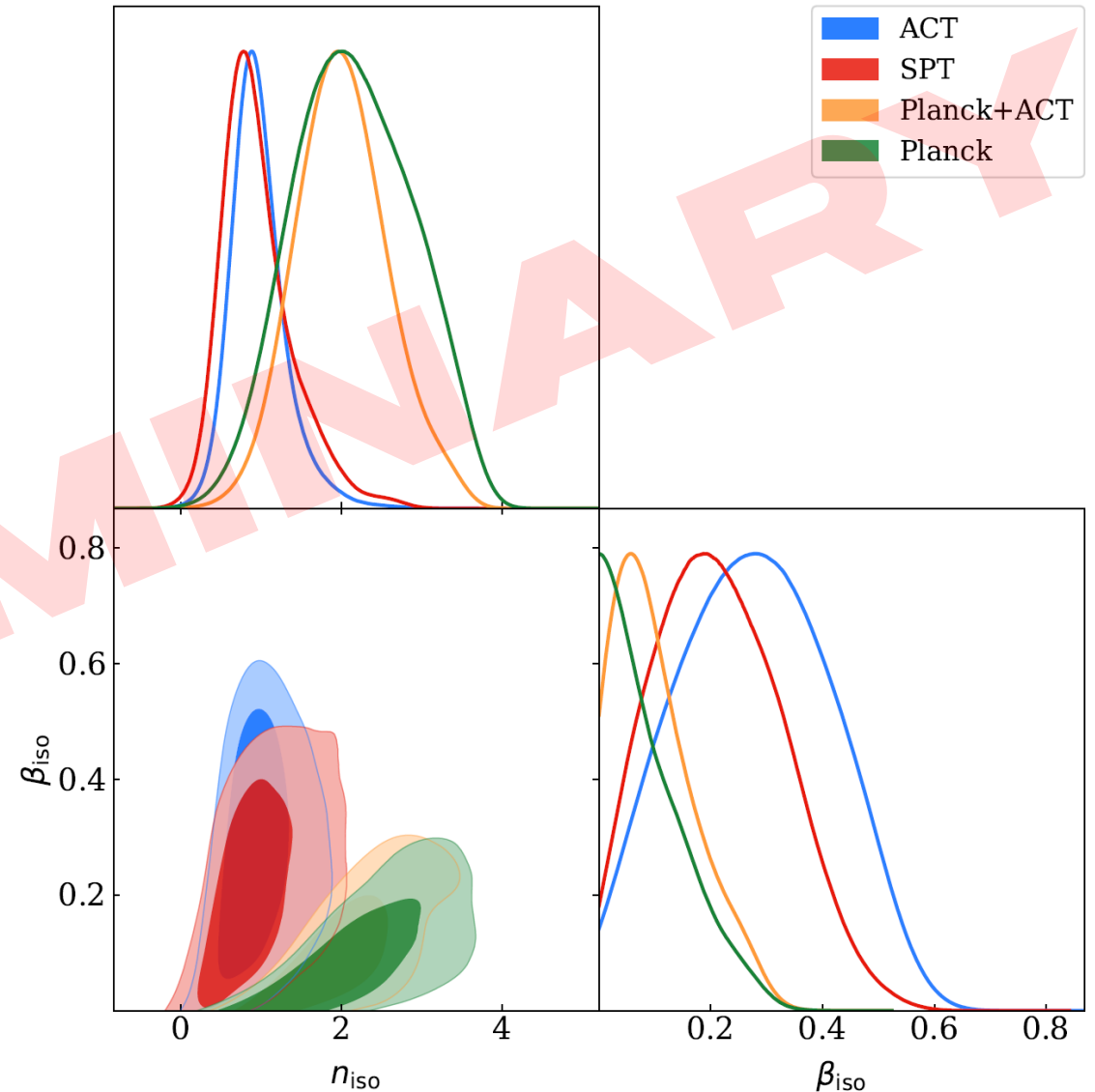


Latest Observation

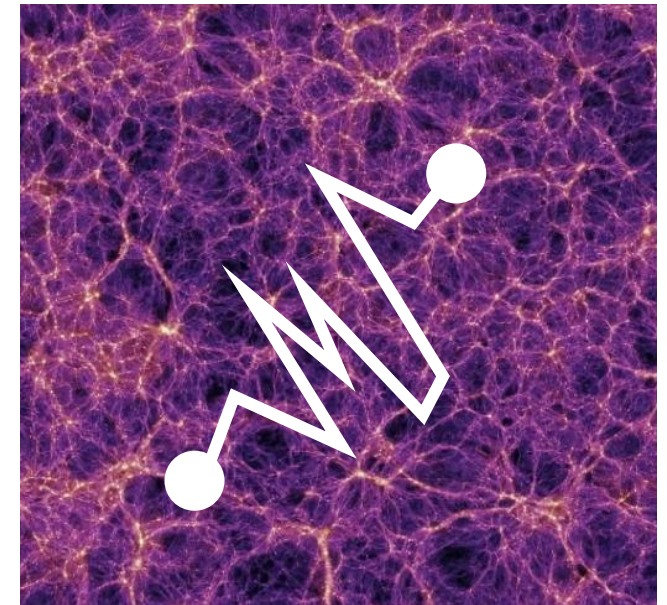
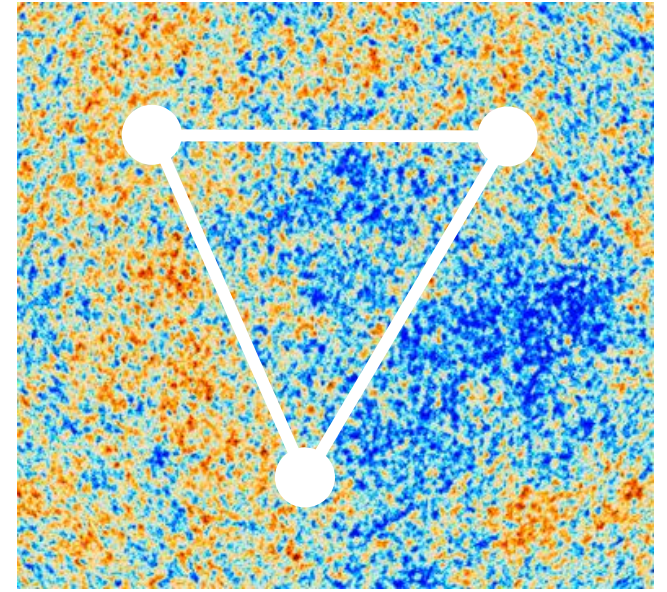
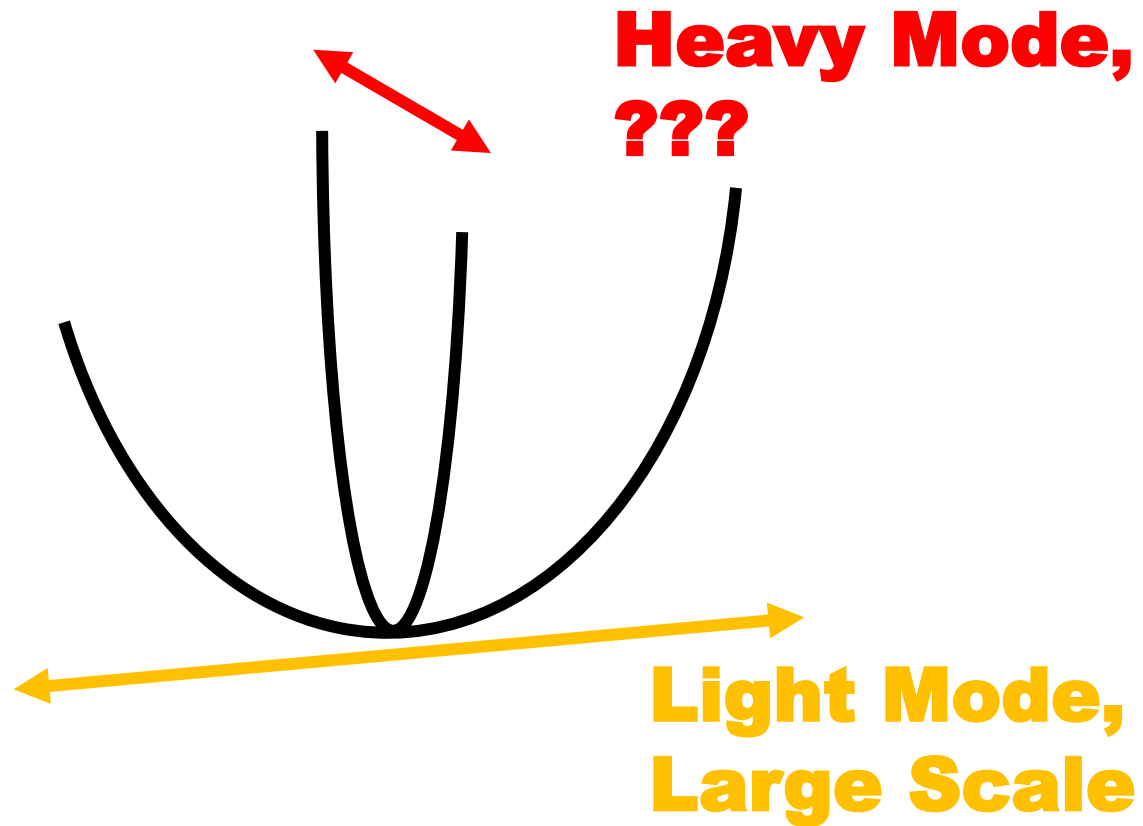
- ACT and SPT sensitive to smaller angular scales, constraining blue-tilted spectra better



M. Braglia, X. Chen, J. Fan, LFL, C. Petretti, P. Singh, in prep.

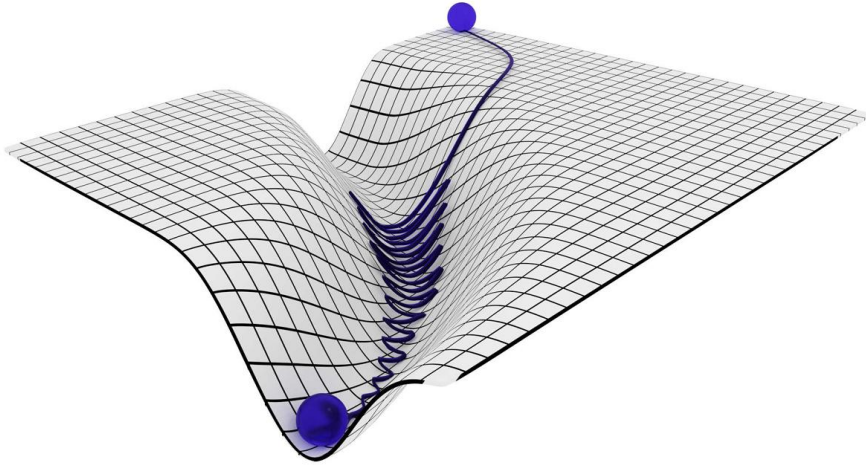


Primordial Non-Gaussianity & Primordial Features



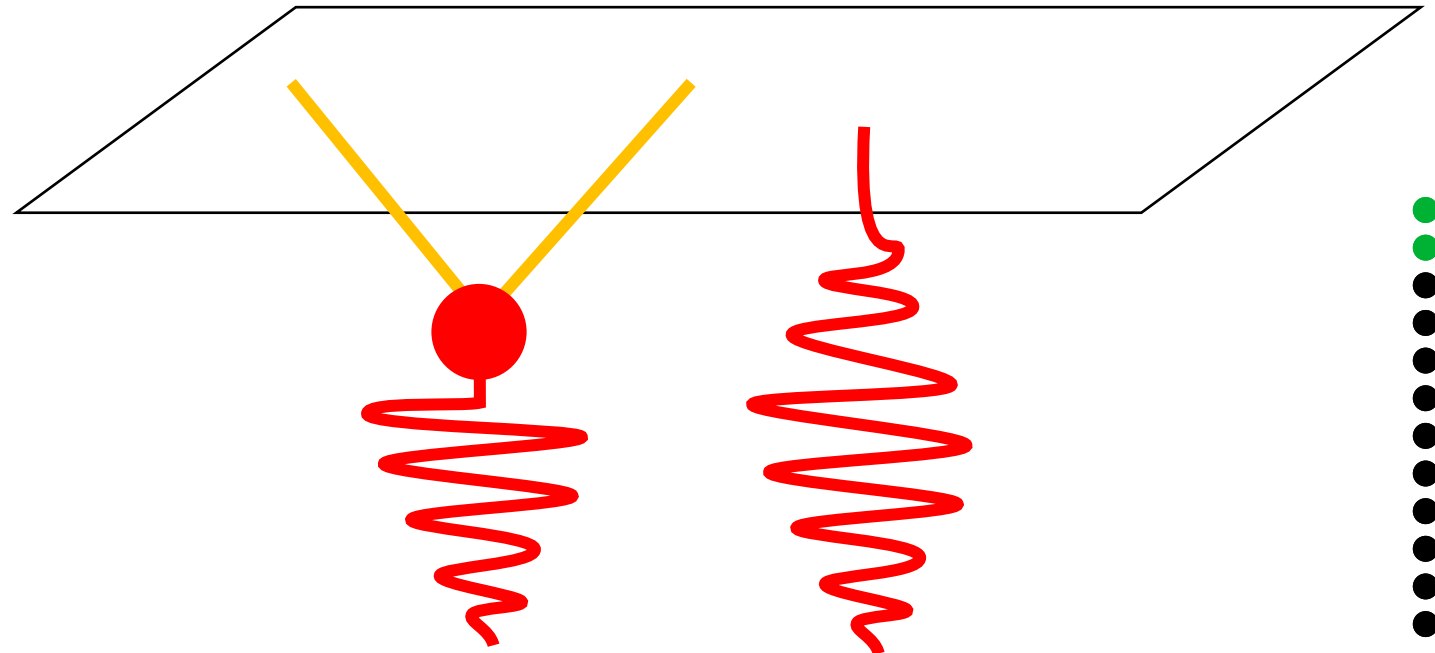
X. Chen, Y. Wang, 2009;
Arkani-Hamed, Maldacena, 2015

Focus on Primordial Features



- Isocurvature condensate is CLASSICALLY displaced
- Classical feature carried out by semi-light fields while the heavy one dissipates by Hubble

X. Chen, M. Namjoo,
Y. Wang, 1411.2349;
X. Chen, R. Ebadi,
S. Kumar, 2205.01107

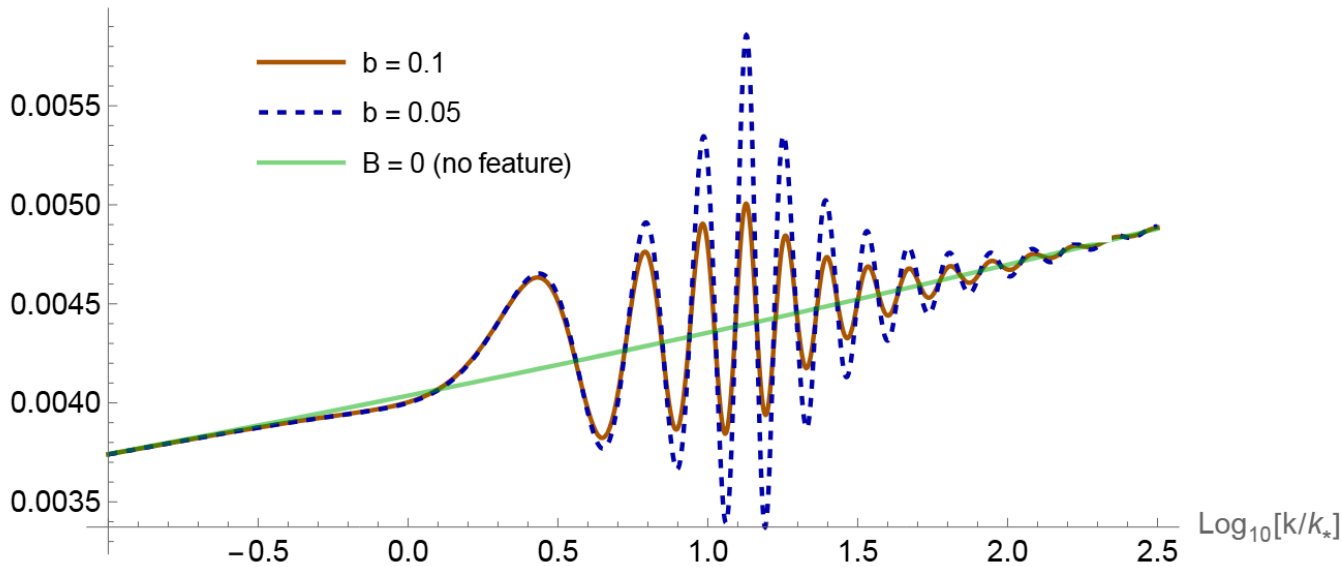


The Real “Cosmic Blues” as Music

$$\frac{\Delta P_\zeta}{P_{\zeta 0}} = -2i \int_{-\infty}^0 d\tau a^2 \tilde{R} \sigma_0 \left(u'_{k_1}{}^2 - k_1^2 u_{k_1}^2 \right) + \text{c.c.}$$

$$S_{\text{clock}} \approx \left. \frac{\Delta P}{P^{(0)}} \right|_{\text{clock,max}} \left(\frac{k}{k_{\text{max}}} \right)^{-3/2} \cos \left[M_R \ln \left(\frac{k}{k_{\text{max}}} \right) + \text{phase} \right]$$

$P_\theta(N_{\text{end}}) \times (R_{\text{end}}^2/H_I^2)$



Further EFT Couplings inspired by SUSY

$$K = I\bar{I} + \sigma\bar{\sigma} + \frac{c_I}{M_P^2} I\bar{I}\sigma\bar{\sigma} \quad I \equiv I_R e^{i\tilde{\phi}/f_I} / \sqrt{2}$$

$$\mathcal{L}_{\text{kin}} \supset \frac{1}{2} \left[1 + c_I \frac{|\sigma|^2}{M_P^2} \right] (\partial\phi)^2 + \left[1 + c_I \frac{I_R^2}{2M_P^2} \right] |\partial\sigma|^2 + ic_I \frac{I_R}{2M_P^2} \partial\phi (\sigma\partial\bar{\sigma} - \bar{\sigma}\partial\sigma)$$

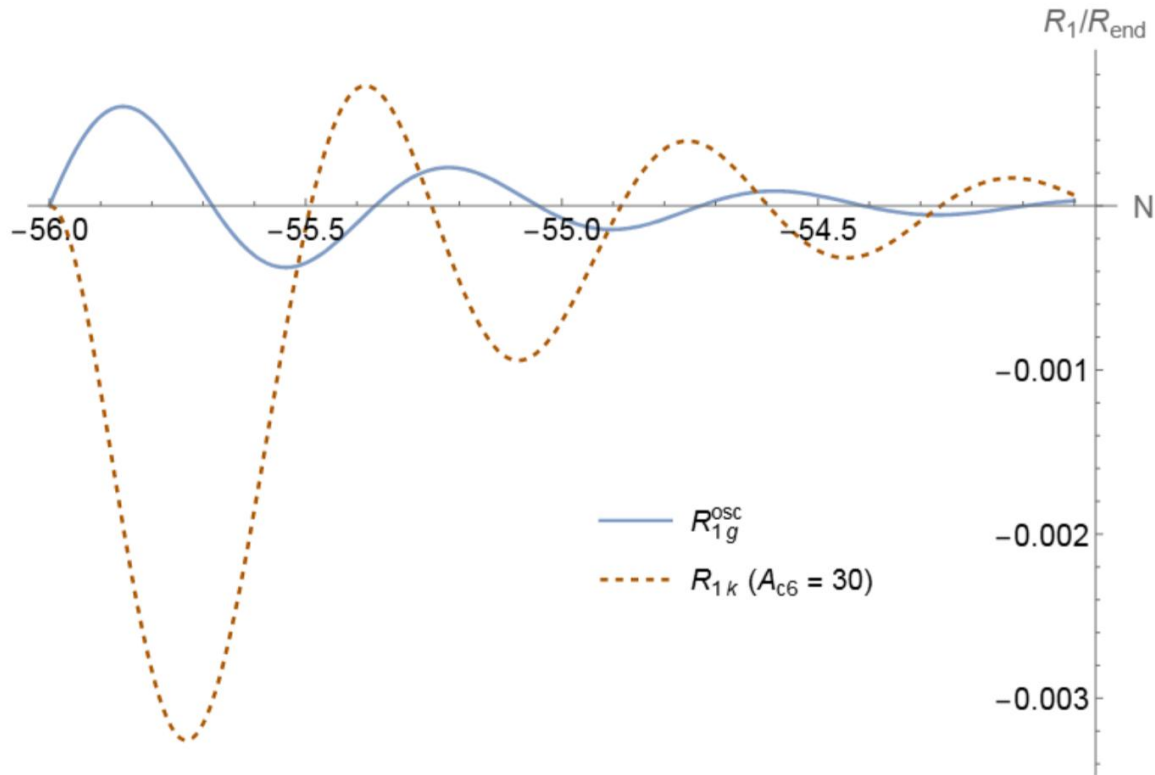
Obtain further derivative couplings with the inflaton

$$\begin{aligned} \mathcal{L} &= -\frac{1}{2} (\partial\phi)^2 - V(\phi) - |\partial\sigma|^2 - U_{\text{FD}}(\sigma) - c_6 \frac{|\sigma|^2}{\Lambda^2} (\partial\phi)^2, \\ &\approx -\frac{1}{2} \left(1 + c_6 \frac{R^2}{\Lambda^2} \right) (\partial\phi)^2 \\ &\quad - \frac{1}{2} (\partial R)^2 - \frac{1}{2} m_R^2 (R - R_{\text{end}})^2 - \frac{R^2}{2} (\partial\theta)^2 - \frac{R^2}{2} m_\theta^2 (\theta - \theta_{\text{end}})^2 \end{aligned}$$



Leading Oscillation from a Sharp Turn in Potential

Features with a "tunable" phase



$$\frac{R_{1g}}{R_{end}} \sim -\frac{B}{(n-2)M_R} \left(\frac{a}{a_*}\right)^{-3/2} \sin\left(M_R \ln \frac{a}{a_*}\right),$$

$$\frac{R_{1k}}{R_{end}} \sim 6c_6 B \frac{M_P^2}{\Lambda^2 M_R^2} \left(\frac{a}{a_*}\right)^{-3/2} \cos\left(M_R \ln \frac{a}{a_*}\right),$$

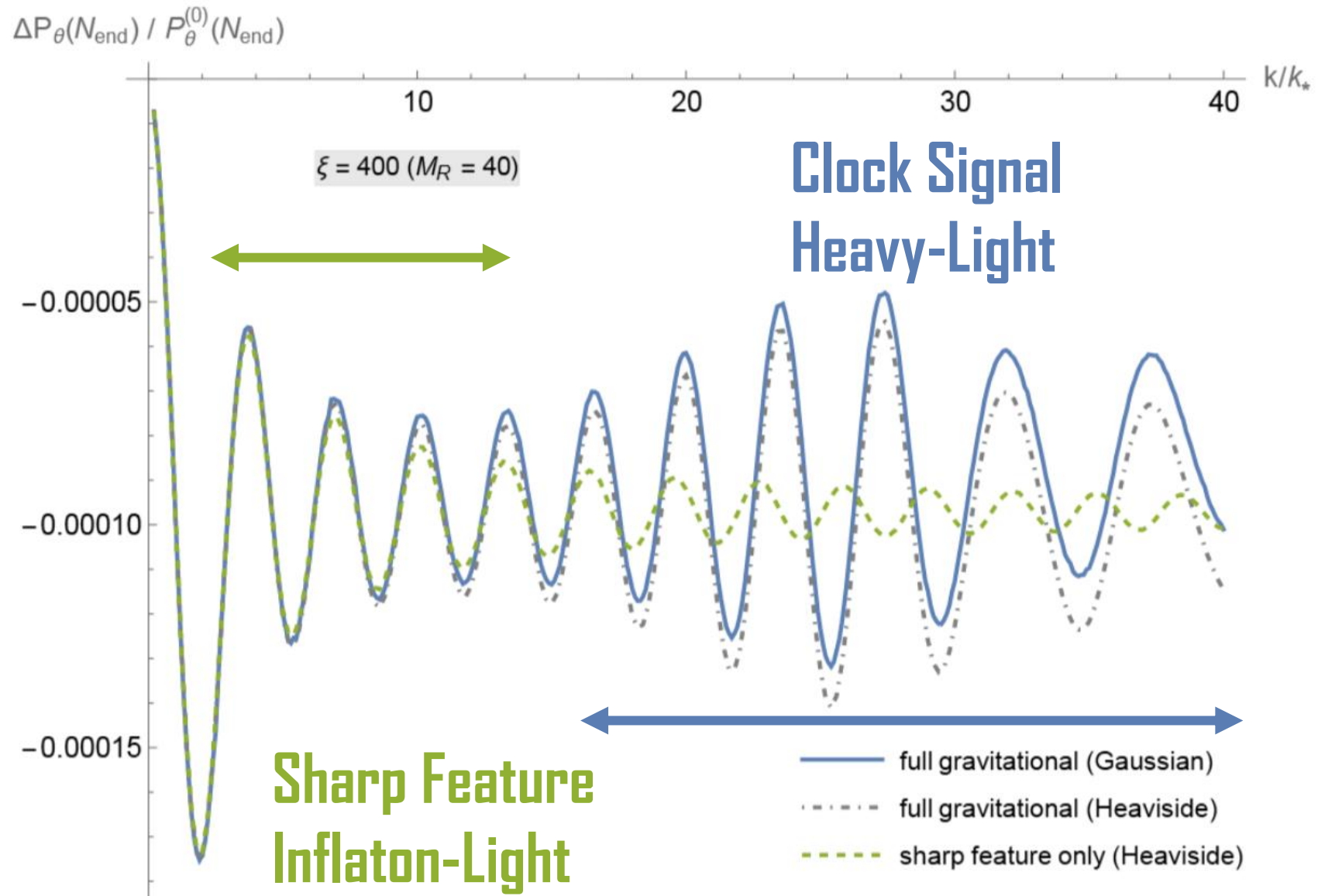
□ Numerically solvable with the above input oscillation

$$\delta\theta_k'' + \left(3 + \frac{H'}{H} + 2\frac{R_b'}{R_h}\right) \delta\theta_k' + \left(\frac{k^2}{a^2 H^2} + \frac{m_\theta^2}{H^2}\right) \delta\theta_k = 0,$$

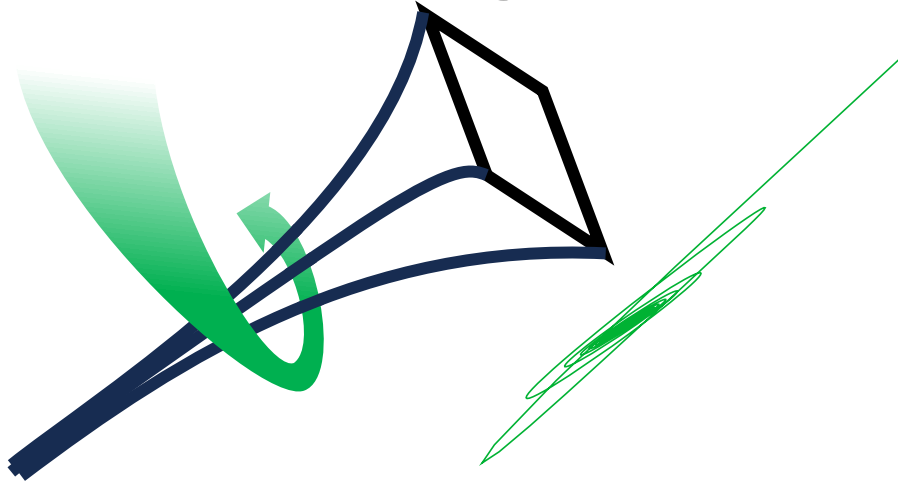
$$P_\theta(k, \eta_{end}) = \frac{k^3}{2\pi^2} |\delta\theta_k(\eta_{end})|^2 = \frac{H_I^2}{R_{end}^2} \frac{k^3}{2\pi^2} |u_k(-1/k_{end})|^2.$$



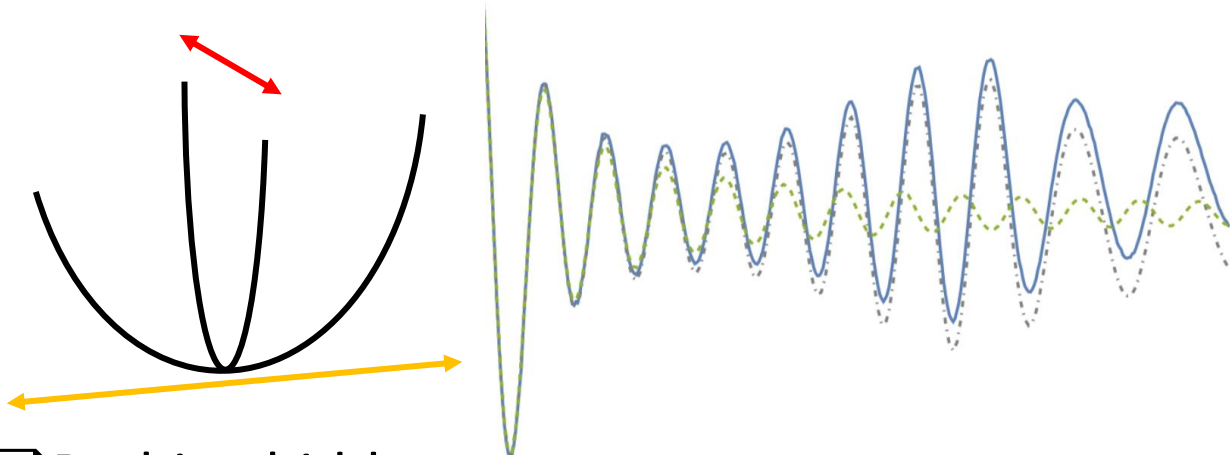
Numerical Solution



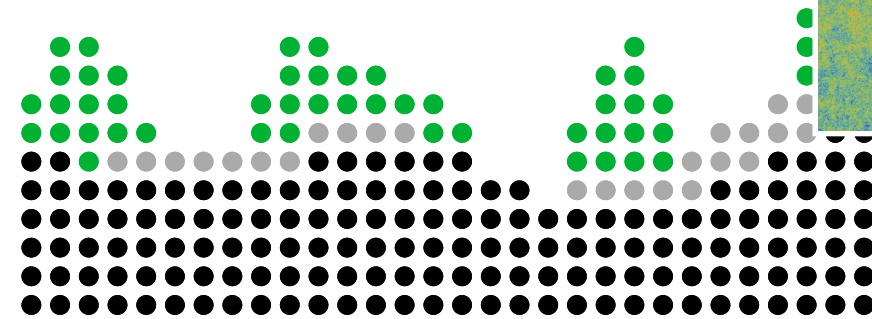
Summary and Outlook



- ❑ AD baryogenesis often needs interaction with the inflaton sector



- ❑ Probing hidden potential structure through (classical) primordial features



- ❑ Blue baryon number isocurvature arise from light mode fluctuations

I. Allali, X. Chen,
J. Fan, LFL, in prep.



- ❑ May affect halo and galaxy formation at smaller scales