INVISIBLES25

Affleck-Dine curvaton

based on arXiv: 2410.13712

with Aurora Ireland and Gordan Krnjaic

Takuya Okawa (SISSA)

Curvaton inflation

Add a scalar field that acts as a light spectator field during inflation ($m_\chi \ll H,\ \rho_\chi \ll \rho_{\rm tot}$)

K. Enqvist & M. S. Sloth, 0109214, D. H. Lyth & D. Wands, 0110002, T. Moroi & T. Takahashi, 0110096

- relaxes the requirements on the energy scale/the shape of the inflaton potential
- testability: may leave the observable local non-Gaussianity $f_{\rm NL}^{\rm local}$ and residual isocurvature
- after the inflation ends…

$$\rho_\chi \simeq {\rm const}\,. \quad (H \gg m_\chi)$$
$$\rho_\chi \propto a^{-3}\,(H \lesssim m_\chi)$$

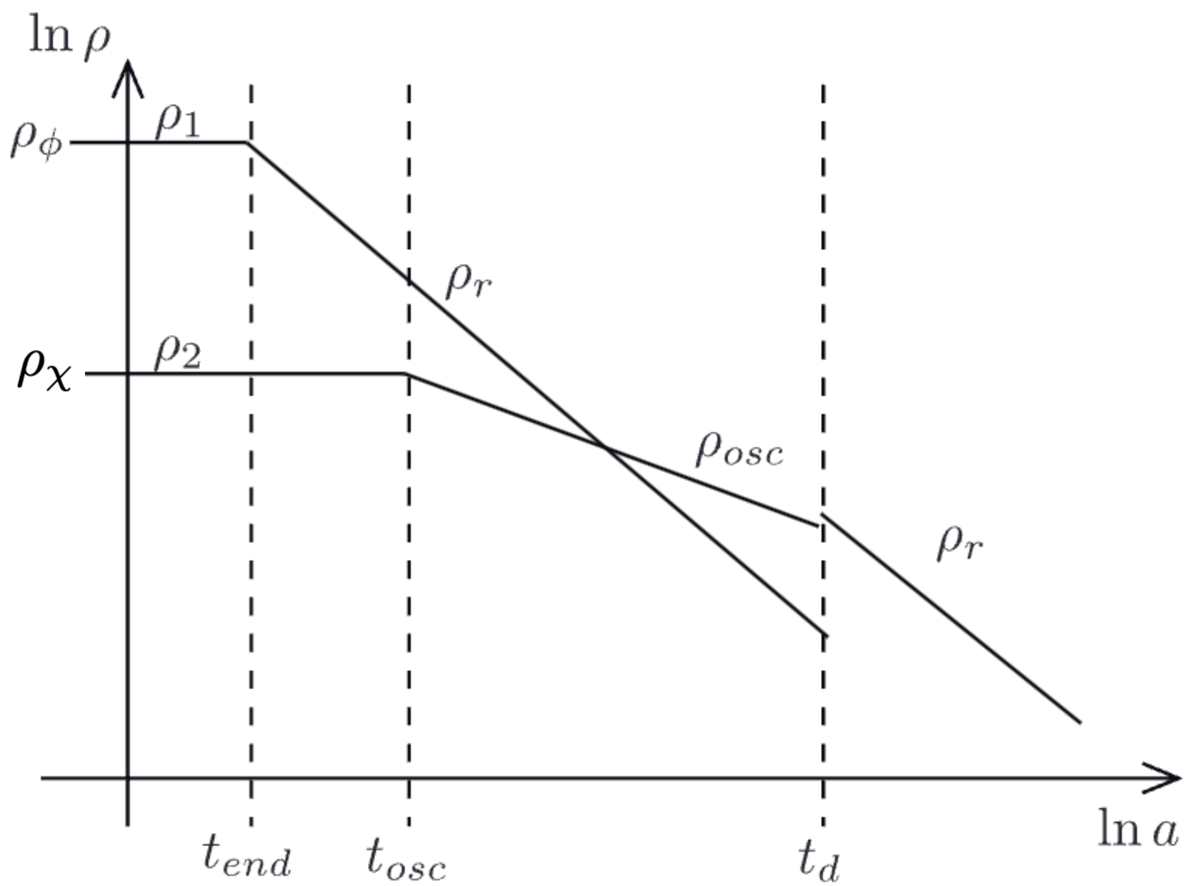


Image credit: K. Dimopoulos, K. Kohri, & T. Matsuda, 1201.6037

Affleck-Dine baryogenesis

Produce a nonzero baryon number from the angular motion of a complex scalar field carrying a baryon number

I Affleck & M Dine, Nuclear Physics B, (1985)

- a baryon number density stored in a field χ

$$n_B = iB_\chi(\dot{\chi}^*\chi - \chi^*\dot{\chi}) = B_\chi r^2\dot{\theta}$$

- a net baryon number

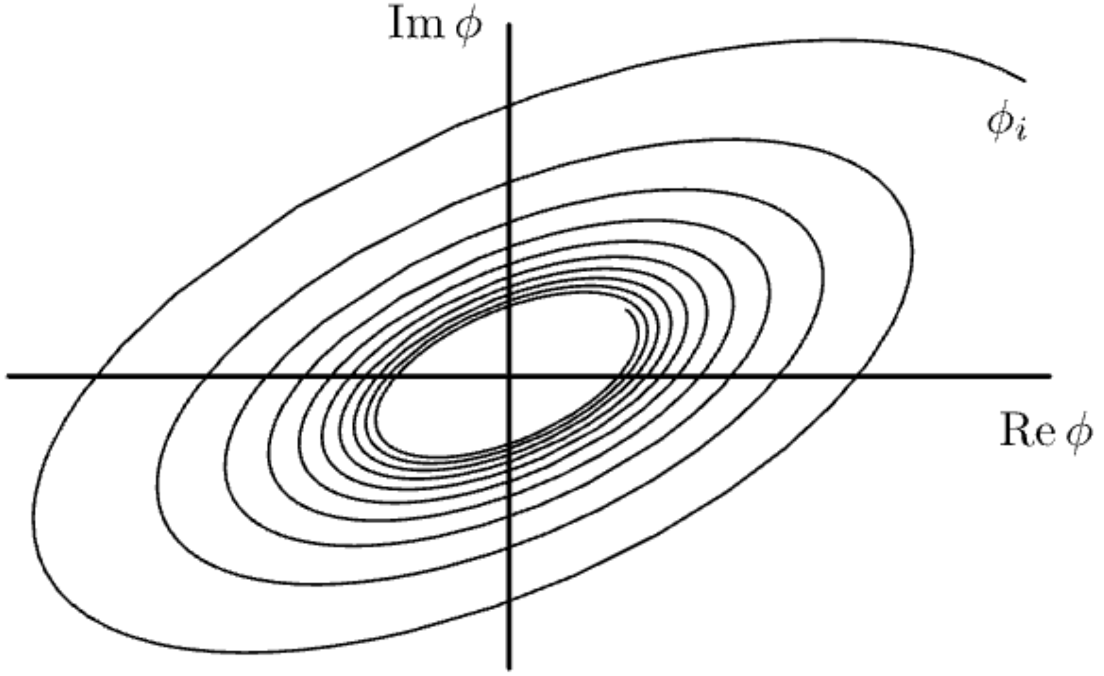
$$n_B(t) = \frac{\lambda' B_\chi}{2a^3(t)}\int_{t_i}^{t} dt' a^3(t')\, r^4(t')\sin[4\theta(t')]$$

e.g.)

$$S_\phi = \int d^4x\sqrt{-g}\left[g^{\mu\nu}\partial_\mu\phi^*\partial_\nu\phi - V(\phi)\right],$$

$$V(\phi) = m^2\phi^*\phi + \frac{\lambda}{2}(\phi^*\phi)^2 + \frac{\lambda'}{4}(\phi^4 + \phi^{*4}).$$

exerts torque



Combined model

Promote a curvaton to a complex scalar field, and let it serve as the Affleck-Dine field at the same time

$$S = \int d^4x\, a^3 \left(\frac{1}{2}\dot{r}^2 + \frac{1}{2} r^2 \dot{\theta}^2 - V(r,\theta) \right)$$

$$V(\chi) = m_\chi^2 |\chi|^2 + \frac{\lambda}{2}|\chi|^4 + \frac{\lambda'}{4}(\chi^4 + \chi^{*4})$$

$\chi \equiv re^{i\theta}/\sqrt{2}$: a complex scalar field with nonzero baryon number

+ inflaton field

7 parameters:

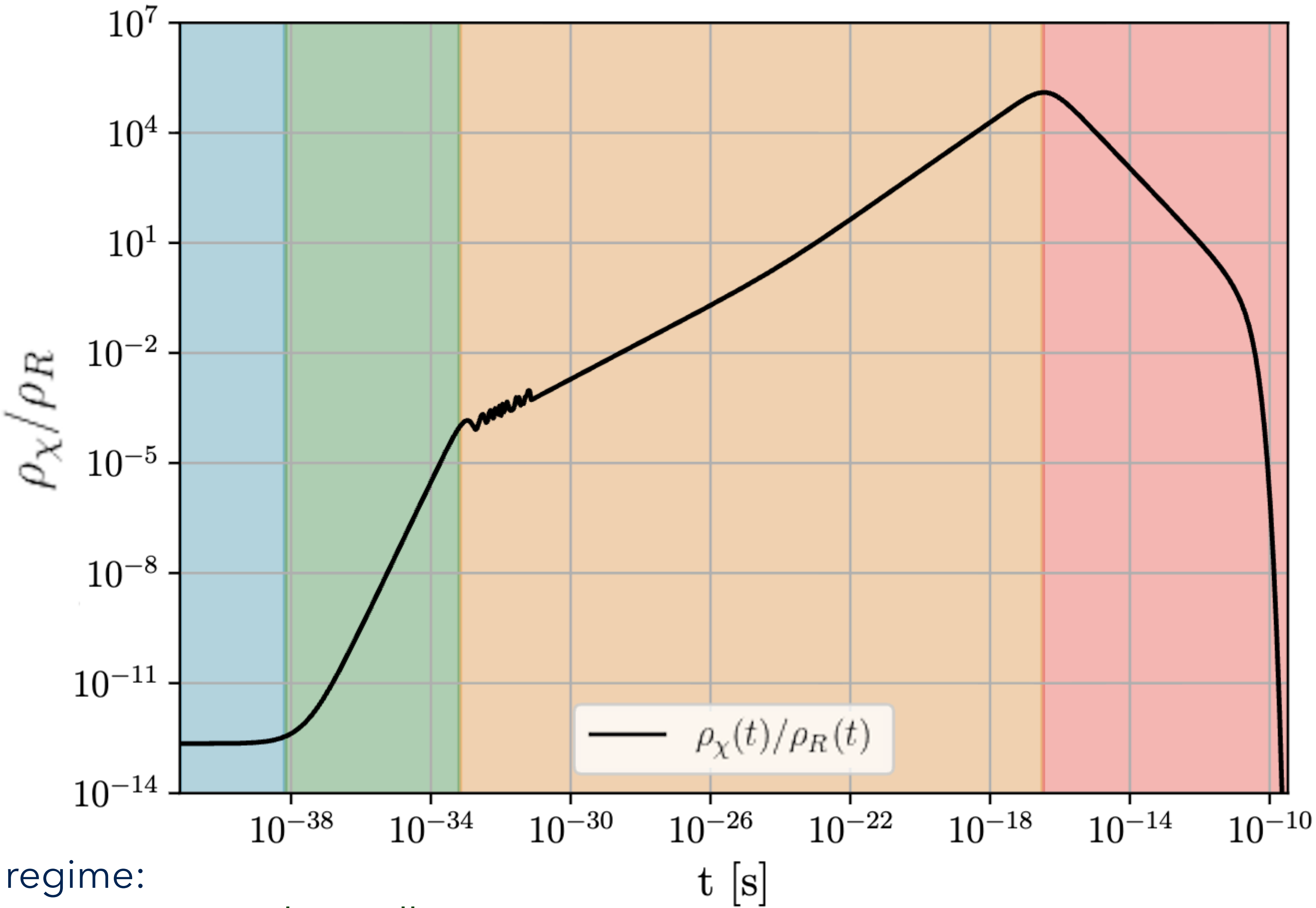
$m_\chi, r_{\rm init}, \theta_{init}, \lambda, \lambda'$,

Γ_χ: decay rate of a curvaton field

$H_{\rm inf}$: the Hubble parameter during the inflation

see also: C. Cheung & K. M. Zurek, 1105.4612
M. P. Hertzberg & J. Karouby, 1309.0010
J. M. Cline, M. Puel, & T. Toma, 1909.12300
R. T. Co, K. Harigaya, & A. Pierce, 2202.01785 etc.

Results



decay regime

$\rho_\chi \propto e^{-\Gamma_\chi t}$

$\rho_R \propto a^{-4}$

inflationary regime:

$\rho_\chi \simeq \text{const}\,.$

$\rho_R \simeq \text{const}\,.$

slow-roll regime:

$\rho_\chi \simeq \text{const}\,.$

$\rho_R \propto a^{-4}$

oscillation regime

$\rho_\chi \propto a^{-3}$ (quadratic), $\rho_\chi \propto a^{-4}$ (quartic)

$\rho_R \propto a^{-4}$

Results

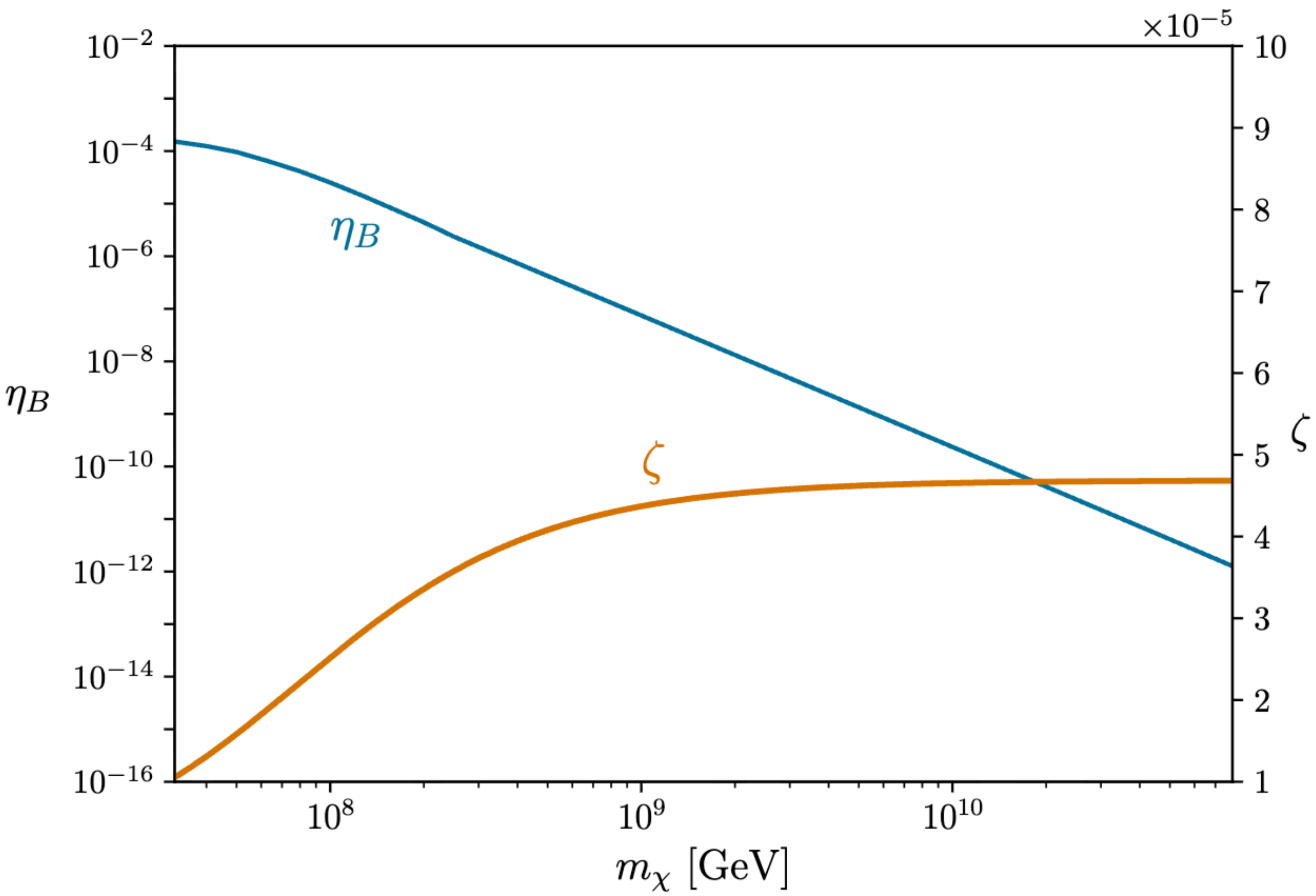
Observation-consistent ζ, $f_{\rm NL}^{\rm local}$, η_B, r_T, and α_{II} are realizable by choosing parameters $\{m_\chi, \Gamma_\chi, H_{\rm inf}, r_{\rm init}, \theta_{init}, \lambda, \lambda'\}$ conveniently

Three benchmark models:

	Model 1	Model 2	Model 3
m_χ/GeV	10^9	10^{10}	10^{11}
Γ_χ/GeV	10^{-13}	10^{-13}	10^{-13}
$H_i/M_{\rm pl}$	1×10^{-6}	1×10^{-7}	2×10^{-9}
r_i/H_i	1×10^{4}	5×10^{3}	10^{4}
$\theta_i/(\pi/8)$	1.1	1.1	1.1
λ	10^{-20}	10^{-20}	10^{-10}
λ'	10^{-24}	10^{-17}	10^{-9}
ζ [10^{-5}]	-2.3	4.6	2.2
$f_{\rm NL}^{\rm local}$	-0.88	-0.88	-0.87
η_B [10^{-10}]	4.9	2.6	3.1
r_T	1.1×10^{-3}	3.0×10^{-6}	5.1×10^{-9}
α_{II}	1.1×10^{-3}	7.4×10^{-4}	7.8×10^{-4}

Illustrate the behaviors of η_B and ζ

e.g.) as a function of m_χ in Model 2



Backup

Non-Gaussianity (local type)

$$f_{\rm NL} = \frac{5[\beta^4 f_{\chi_R}^2 (2C - 3A) + \beta^2 f_{\chi_R} f_{\chi_I} E + f_{\chi_I}^2 (2D - 3B)]}{6(\beta^2 f_{\chi_R}^2 + f_{\chi_I}^2)^2}$$

where

$$f_\gamma = \frac{4\Omega_\gamma}{4\Omega_\gamma + 3\Omega_{\chi_R} + 3\Omega_{\chi_I}}\,,$$
$$f_{\chi_R} = \frac{3\Omega_{\chi_R}}{4\Omega_\gamma + 3\Omega_{\chi_R} + 3\Omega_{\chi_I}}\,,$$
$$f_{\chi_I} = \frac{3\Omega_{\chi_I}}{4\Omega_\gamma + 3\Omega_{\chi_R} + 3\Omega_{\chi_I}}\,.$$

$$\begin{aligned} A &= f_{\chi_R}\,, \\ B &= f_{\chi_I}\,, \\ C &= 3 f_{\chi_R}(1 - f_{\chi_R})^2 + 3 f_{\chi_R}^2 f_{\chi_I}\,, \\ D &= 3 f_{\chi_I}(1 - f_{\chi_I})^2 + 3 f_{\chi_I}^2 f_{\chi_R}\,, \\ E &= -6 f_{\chi_R} f_{\chi_I}(2 - f_{\chi_R} - f_{\chi_I})\,. \end{aligned}$$

$$\beta = \frac{\bar{\chi}_I}{\bar{\chi}_R} = \tan\theta\,,$$

K. Enqvist and S. Nurmi, 0508573

Isocurvature perturbation

(squared) baryon isocurvature fluctuation:

$$\left\langle \left(\frac{\delta T}{T} \right)^2 \right\rangle_{\rm iso} \simeq \frac{144\gamma^2}{225\pi^2} \frac{\Omega_B^2}{\Omega_m^2} \frac{H_i^2}{r_i^2} \cot^2(4\theta_i) \,.$$

adiabatic temperature fluctuation:

$$\left\langle \left(\frac{\delta T}{T} \right)^2 \right\rangle_{\rm adi} \sim \frac{1}{25} \mathcal{P}_\zeta \,,$$

Planck TT,TE,EE+lowE+lensing data constraints (95% C.L.):

$$\alpha_{\mathcal{I}\mathcal{I}} < 1.7 \times 10^{-2} \,.$$

where

$$\alpha_{\mathcal{I}\mathcal{I}} \equiv \frac{\langle (\delta T/T)^2 \rangle_{\rm iso}}{\langle (\delta T/T)^2 \rangle_{\rm adi} + \langle (\delta T/T)^2 \rangle_{\rm iso}} \,.$$