Chaotic Inflation and Affleck-Dine Baryogenesis

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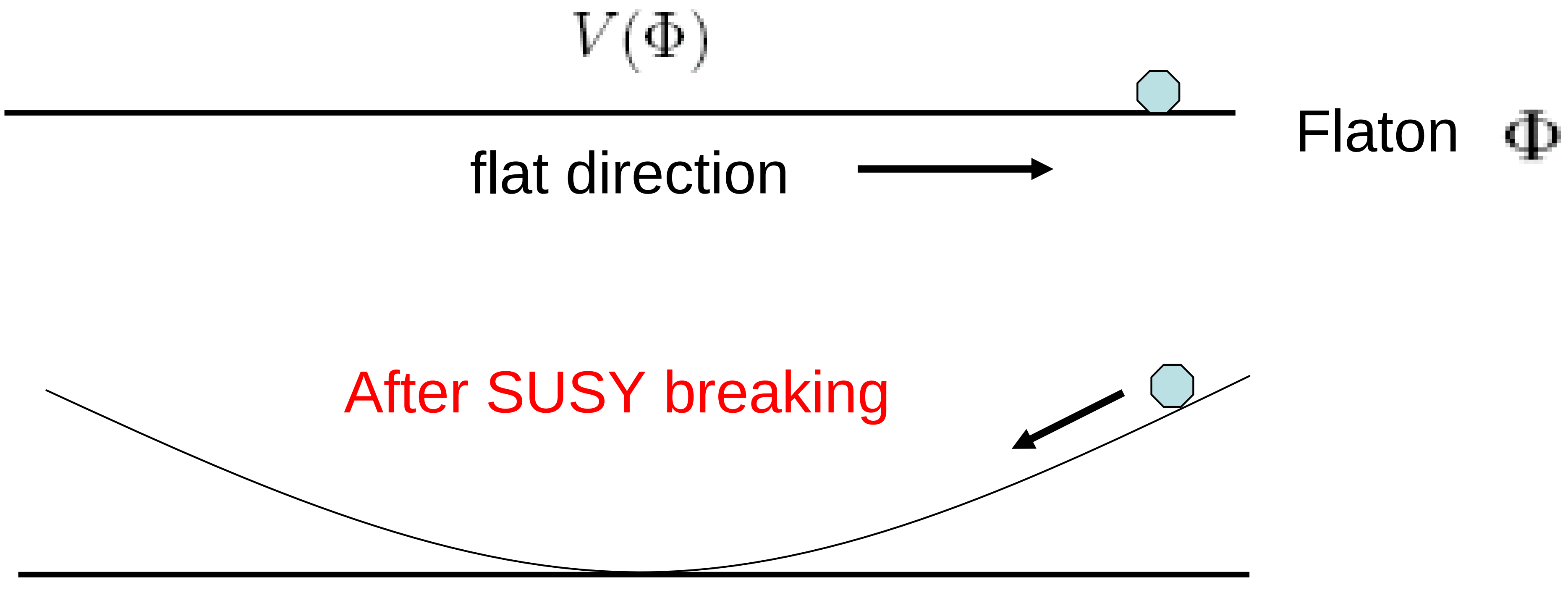
Flat Directions in Scalar Potential of MSSM

Non-zero vevs for squarks and sleptons

$$\langle \tilde{u}^c_3 \rangle = a, \qquad \langle \tilde{u}_1 \rangle = v; \qquad \langle \tilde{s}^c_2 \rangle = a,$$

$$\langle \tilde{\mu} \rangle = v; \qquad \langle \tilde{b}^c_1 \rangle = e^{i\xi}\sqrt{|v|^2 + |a|^2},$$



Affleck-Dine Baryogenesis

$$\mathcal{L} = \left(\partial_\mu \Phi^\dagger\right)\left(\partial^\mu \Phi\right) - V(\Phi),$$

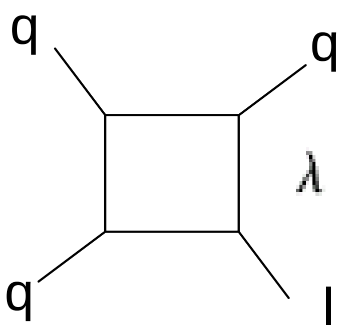
$$V(\Phi) = m_\Phi^2 \Phi^\dagger \Phi + i\lambda\left(\Phi^4 - \Phi^{\dagger 4}\right),$$

SUSY breaking scale

$$m_\Phi^2 = M_S^2$$

CP violating

with baryon or lepton number



$$\lambda \sim \epsilon M_S^2 / M_G^2$$

approximately conserved current

$$j_\mu = i(\Phi^\dagger \partial_\mu \Phi - (\partial_\mu \Phi^\dagger)\Phi)$$

$j_0 = n_B$

Classically, in an expanding universe, Φ obeys the equation of motion

$$\frac{d^2\Phi}{dt^2} + 3H\frac{d\Phi}{dt} + m_\Phi^2\Phi = 4i\lambda\Phi^{\dagger 3}, \tag{4}$$

where H is the Hubble parameter. With the initial conditions at $t = t_0$:

$$\Phi|_{t=t_0} = i\Phi_0 \quad \text{and} \quad \dot{\Phi}|_{t=t_0} = 0, \tag{5}$$

where Φ_0 is real and $\dot{\Phi} = d\Phi/dt$, it was found that the baryon number per particle at large times ($t \gg m_\Phi^{-1}$) in either a matter-dominated or a radiation-dominated universe is given by

$$r \simeq \lambda\Phi_0^2/m_\Phi^2. \tag{6}$$

$r \equiv n_B / n_\Phi >>$ observed $n_B/s \approx 10^{-10}$

Beyond classical: adding quantum fluctuations of Φ

$$\chi = a\Phi \qquad \chi = (1/\sqrt{2})(\chi_1 + i\chi_2)$$

H$\equiv$(da/dt)/a

dt = a d η

Split into mean field and quantum fluctuations

$$\chi_1(\mathbf{x},\eta) = \chi_1^0(\eta) + \tilde{\chi}_1(\mathbf{x},\eta)\,, \quad \langle\chi_1(\mathbf{x},\eta)\rangle = \chi_1^0(\eta)\,;$$
$$\chi_2(\mathbf{x},\eta) = \chi_2^0(\eta) + \tilde{\chi}_2(\mathbf{x},\eta)\,, \quad \langle\chi_2(\mathbf{x},\eta)\rangle = \chi_2^0(\eta)\,.$$

Fourier modes

$$\tilde{\chi}_i(\mathbf{x},\eta) = \frac{1}{\sqrt{\Omega}}\sum_{\mathbf{k}} \tilde{\chi}_{i,\mathbf{k}}(\eta) e^{i\mathbf{k}\cdot\mathbf{x}}$$
$$= \frac{1}{\sqrt{\Omega}}\sum_{\mathbf{k}} [a_{i,\mathbf{k}} f_{i,\mathbf{k}}(\eta) + a^{\dagger}_{i,-\mathbf{k}} f^{*}_{i,-\mathbf{k}}(\eta)] e^{i\mathbf{k}\cdot\mathbf{x}},$$
$$i = 1, 2,$$

Mode functions

Mean fields EOM

$$\chi_1^{0''} + m_\chi^2(\eta)\chi_1^0 - 2\lambda[3(\chi_1^0)^2\chi_2^0 - (\chi_2^0)^3] - 6\lambda\chi_2^0(\langle\tilde{\chi}_1^2\rangle - \langle\tilde{\chi}_2^2\rangle) - 12\lambda\chi_1^0\langle\tilde{\chi}_1\tilde{\chi}_2\rangle = 0,$$

$$\chi_2^{0''} + m_\chi^2(\eta)\chi_2^0 + 2\lambda[3\chi_1^0(\chi_2^0)^2 - (\chi_1^0)^3] - 6\lambda\chi_1^0(\langle\tilde{\chi}_1^2\rangle - \langle\tilde{\chi}_2^2\rangle) + 12\lambda\chi_2^0\langle\tilde{\chi}_1\tilde{\chi}_2\rangle = 0.$$

Fourier modes EOM

$$\left[\frac{d^2}{d\eta^2} + k^2 + \mathcal{M}_{\chi_i}^2(\eta)\right] f_{i,\mathbf{k}}(\eta) = 0,$$

$$\mathcal{M}_{\chi_1}^2(\eta) = m_\chi^2(\eta) - 12\lambda\chi_1^0\chi_2^0 - 12\lambda\langle\tilde{\chi}_1\tilde{\chi}_2\rangle,$$

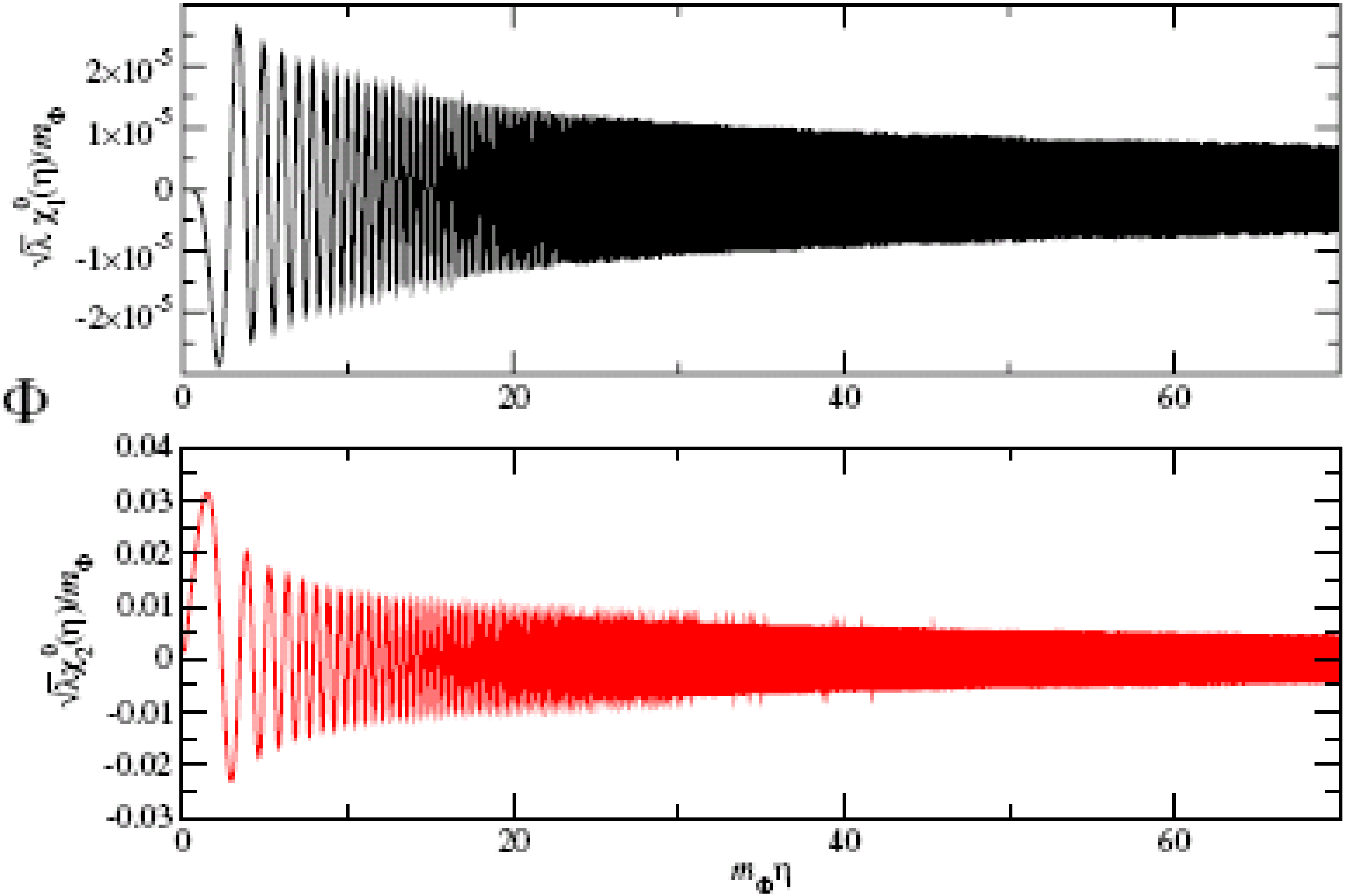
$$\mathcal{M}_{\chi_2}^2(\eta) = m_\chi^2(\eta) + 12\lambda\chi_1^0\chi_2^0 + 12\lambda\langle\tilde{\chi}_1\tilde{\chi}_2\rangle,$$

$$\langle\tilde{\chi}_i^2\rangle(\eta) = \int \frac{d^3\mathbf{k}}{(2\pi)^3} \mid f_{i,\mathbf{k}}(\eta) \mid^2,$$

$$\langle\tilde{\chi}_1\tilde{\chi}_2\rangle(\eta) = \int \frac{d^3\mathbf{k}}{(2\pi)^3}\, 6i\lambda \int_{\eta_0}^{\eta} d\eta' \{[\chi_1^0(\eta')]^2 - [\chi_2^0(\eta')]^2\}[f_{1,\mathbf{k}}(\eta) f_{1,\mathbf{k}}^*(\eta') f_{2,\mathbf{k}}(\eta) f_{2,\mathbf{k}}^*(\eta') - \text{c.c.}].$$

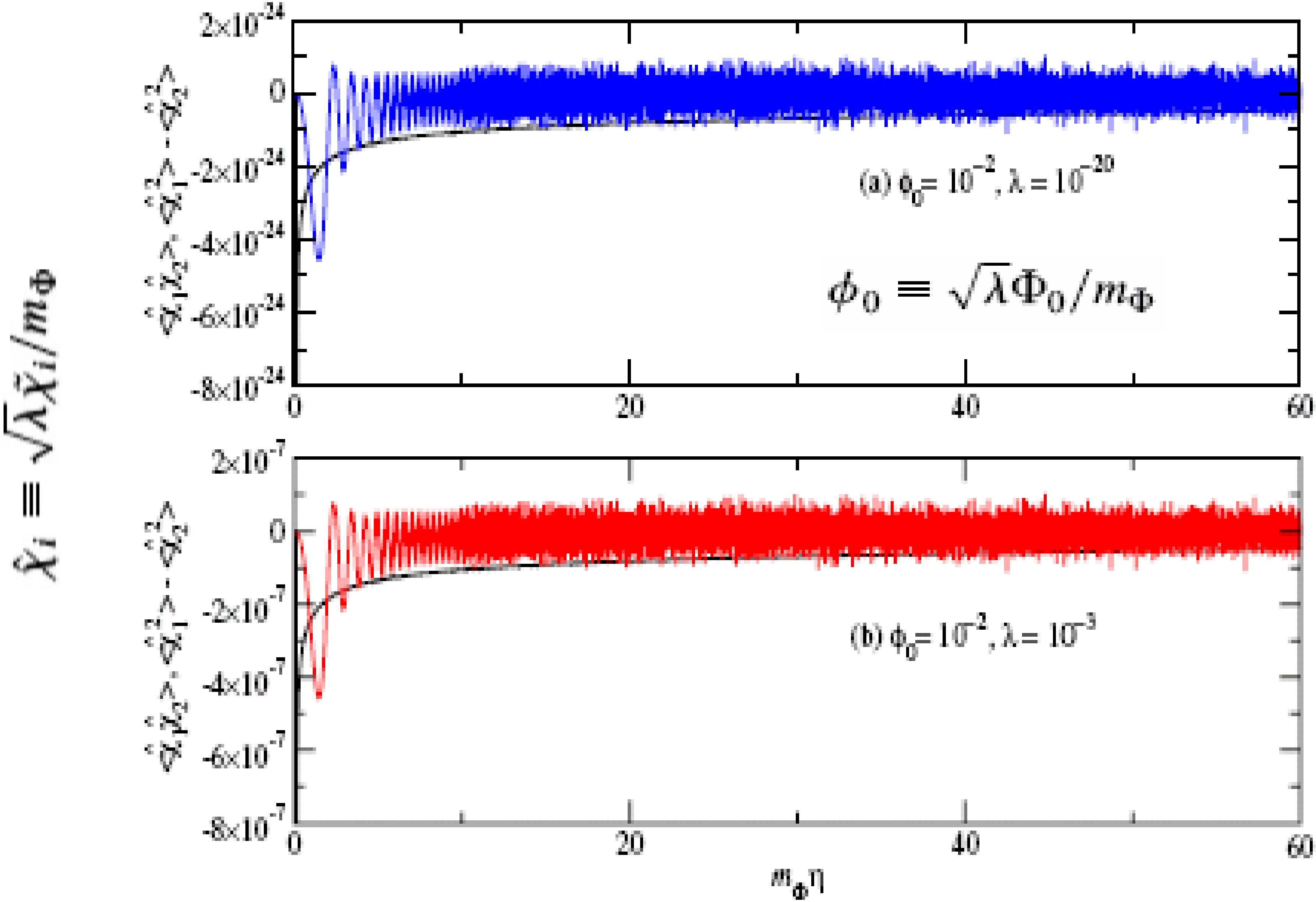
Time evolution of mean fields

$\chi = a\Phi$



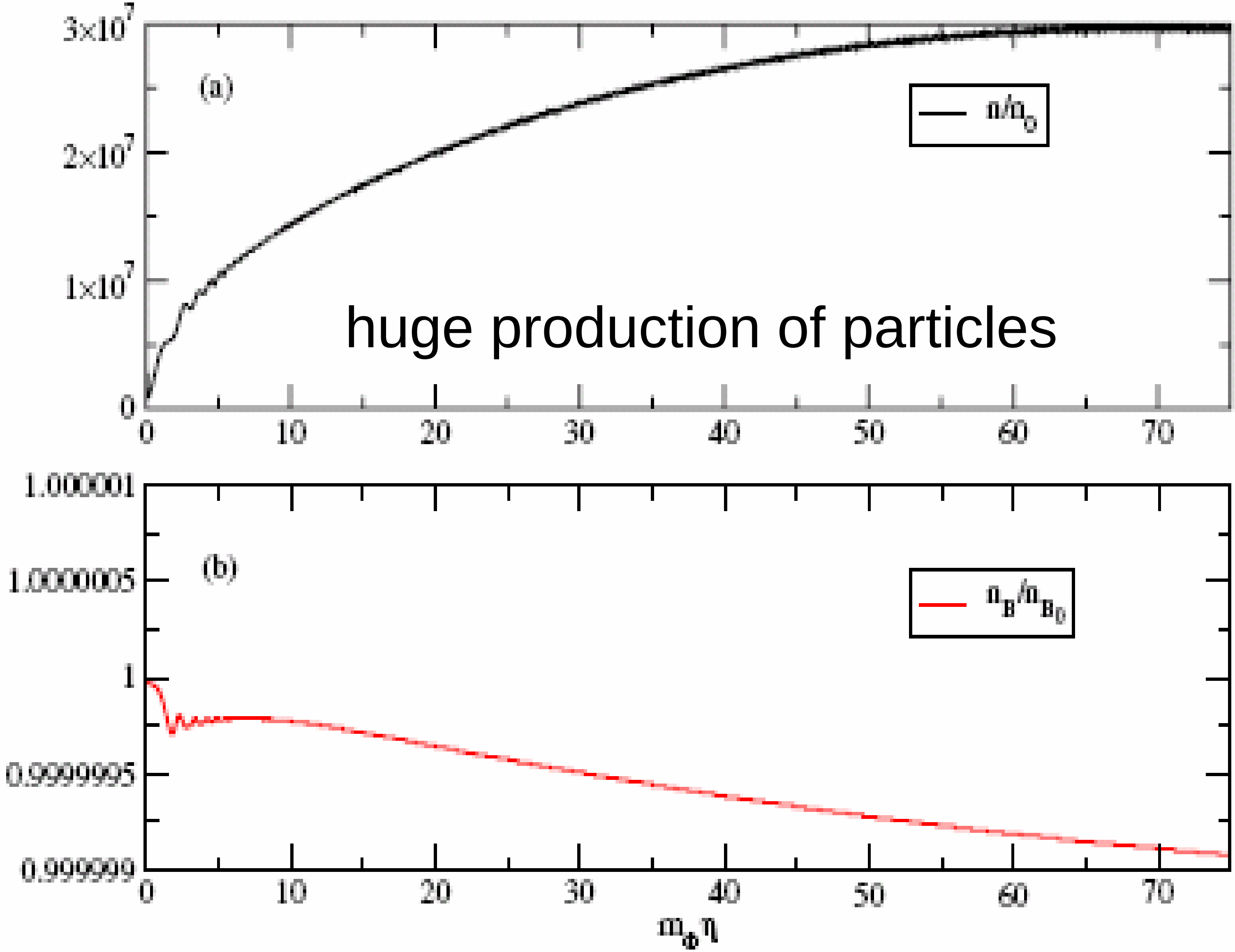
$\phi_0 \equiv \sqrt{\lambda}\Phi_0/m_\Phi = 10^{-2}$ and $\lambda = 10^{-3}$

Time evolution of correlations



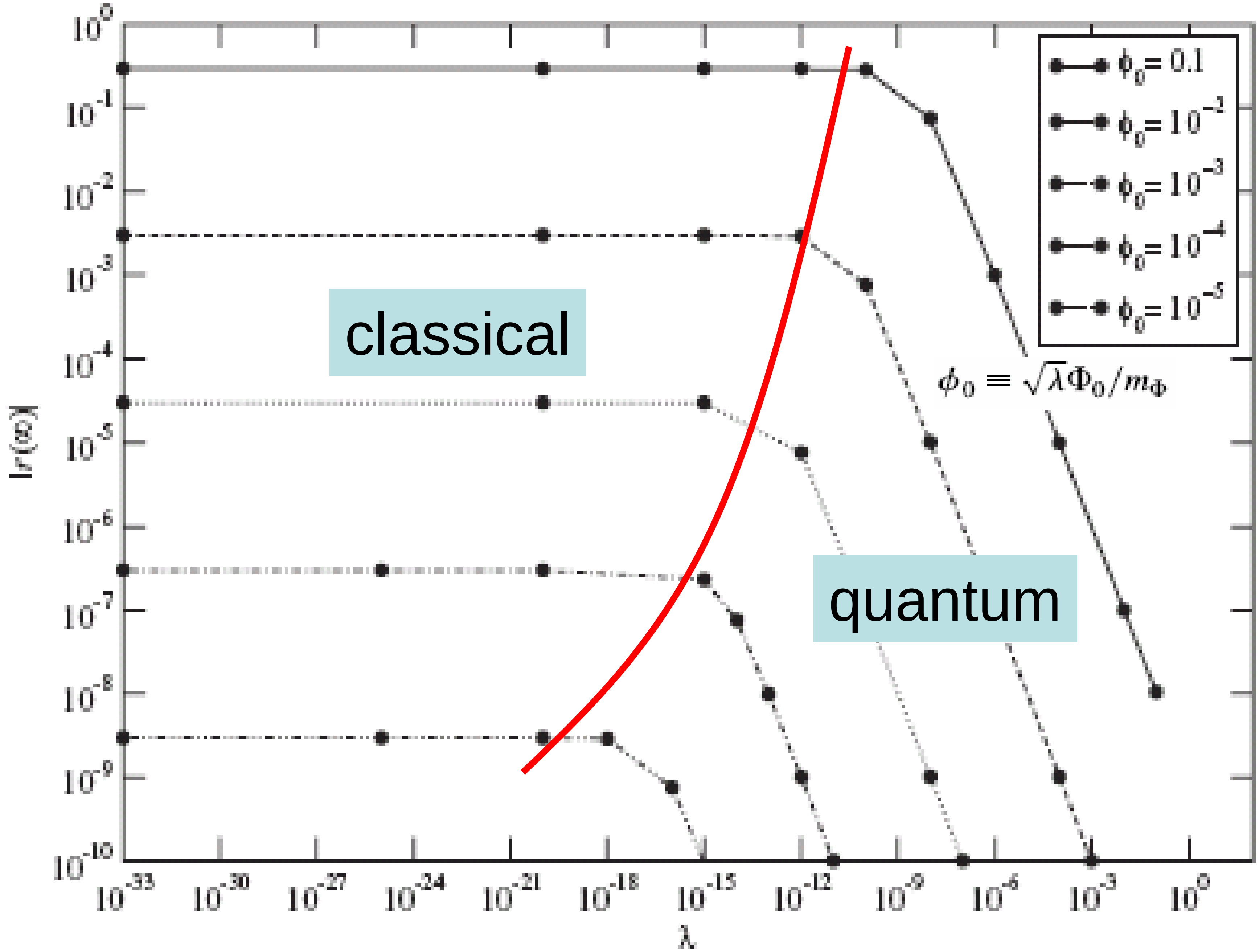
Time evolution of n_B and n (n_Φ)

$\frac{\text{total}}{\text{classical}}$



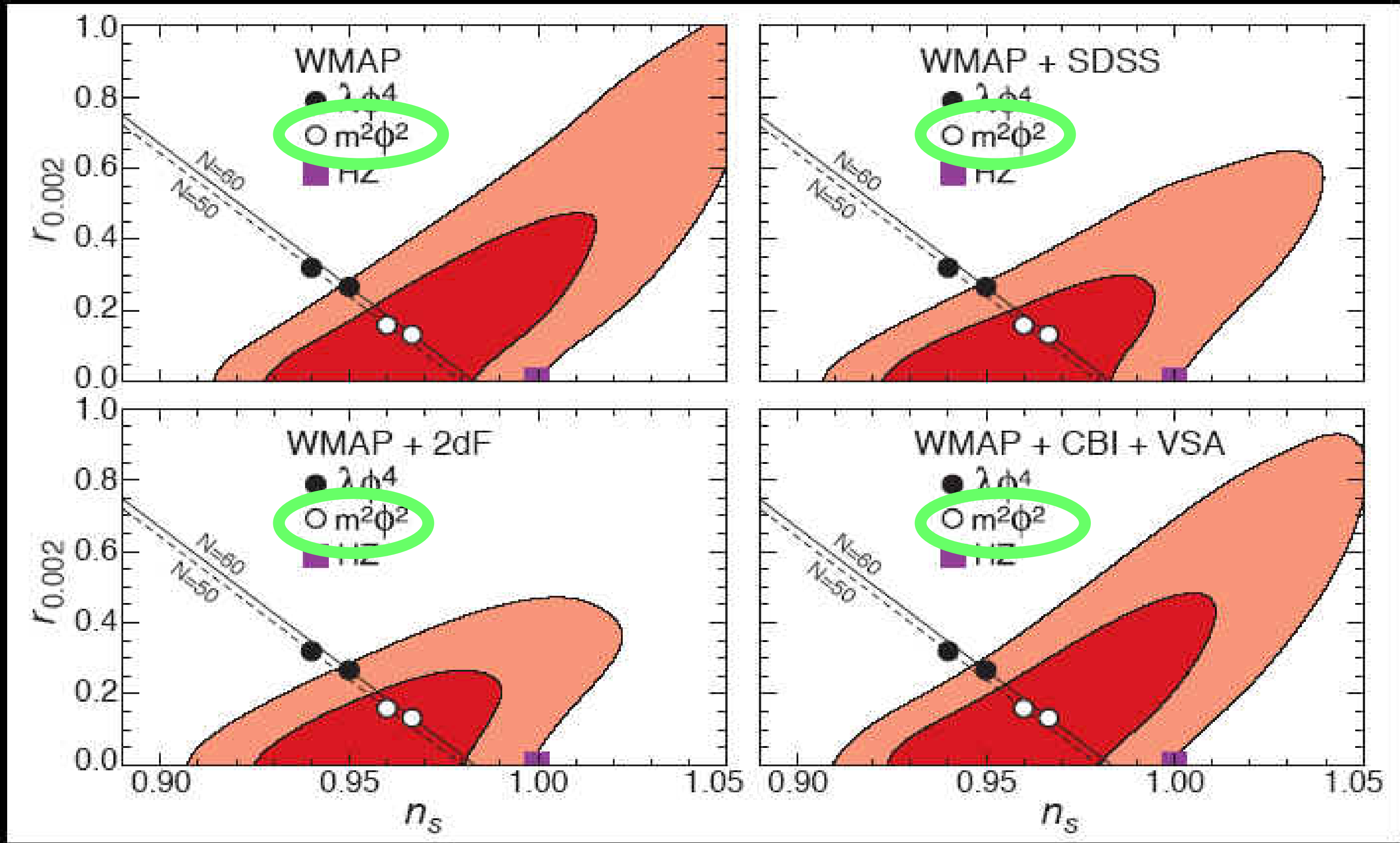
$\phi_0 \equiv \sqrt{\lambda}\Phi_0/m_\Phi$ $\quad \phi_0 = 10^{-2} \quad \lambda = 10^{-3}$

Ratio r (baryon to particle number density)



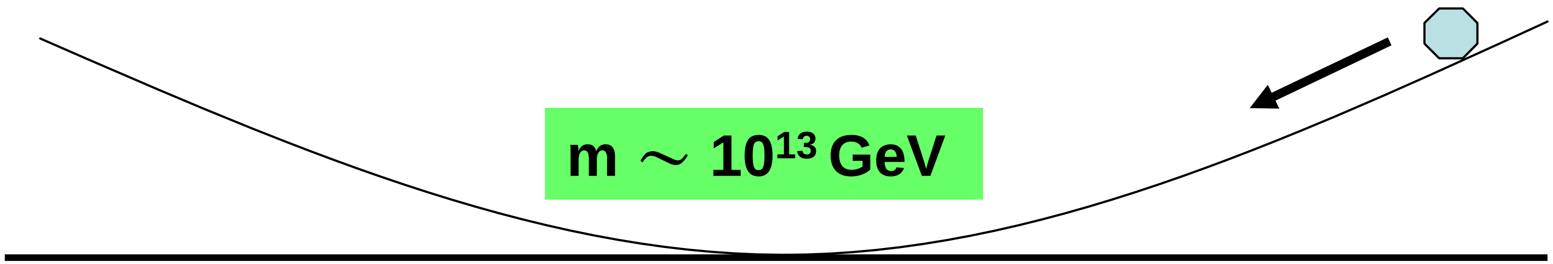
WMAP3 and chaotic inflation

r : tenor/scalar



Spectral index $n(k) - 1 = \frac{d \ln \mathcal{P}_{\mathcal{R}}}{d \ln k}$

Spergel et al (2006)



Affleck-Dine Baryogenesis

$$\mathcal{L} = \left(\partial_\mu \Phi^\dagger\right)\left(\partial^\mu \Phi\right) - V(\Phi),$$

$$V(\Phi) = m_\Phi^2 \Phi^\dagger \Phi + i\lambda\left(\Phi^4 - \Phi^{\dagger 4}\right),$$

SUSY

$$m_\Phi^2 = M_S^2 \text{ and } \lambda = \epsilon M_S^2/M_G^2$$

$$\epsilon = 10^{-3},\ M_S = 10^{-16} M_P,\ \ M_G = 10^{-1} M_P,$$

SPLIT SUSY

$$m_\Phi^2 = \tilde{m}^2 \text{ and } \lambda = \epsilon\, A / M_p$$

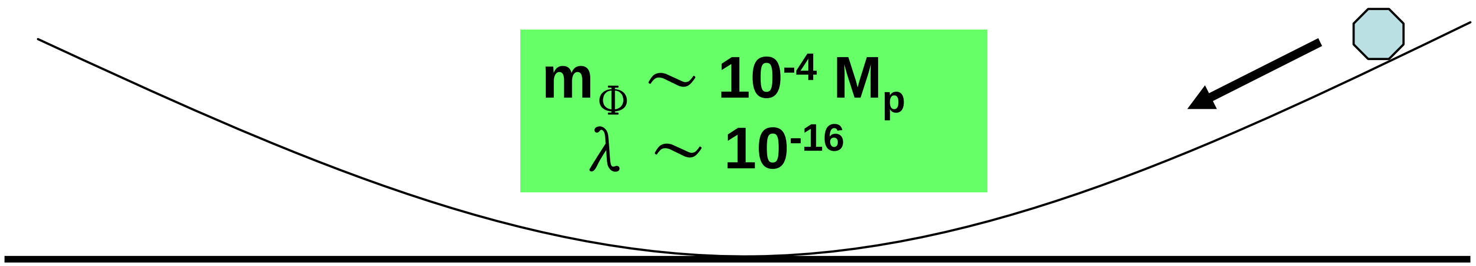
$$\epsilon = 10^{-1},\ \ \tilde{m} \lesssim 10^{13}\ \text{GeV},\ \ A \sim \text{TeV}.$$

A-term

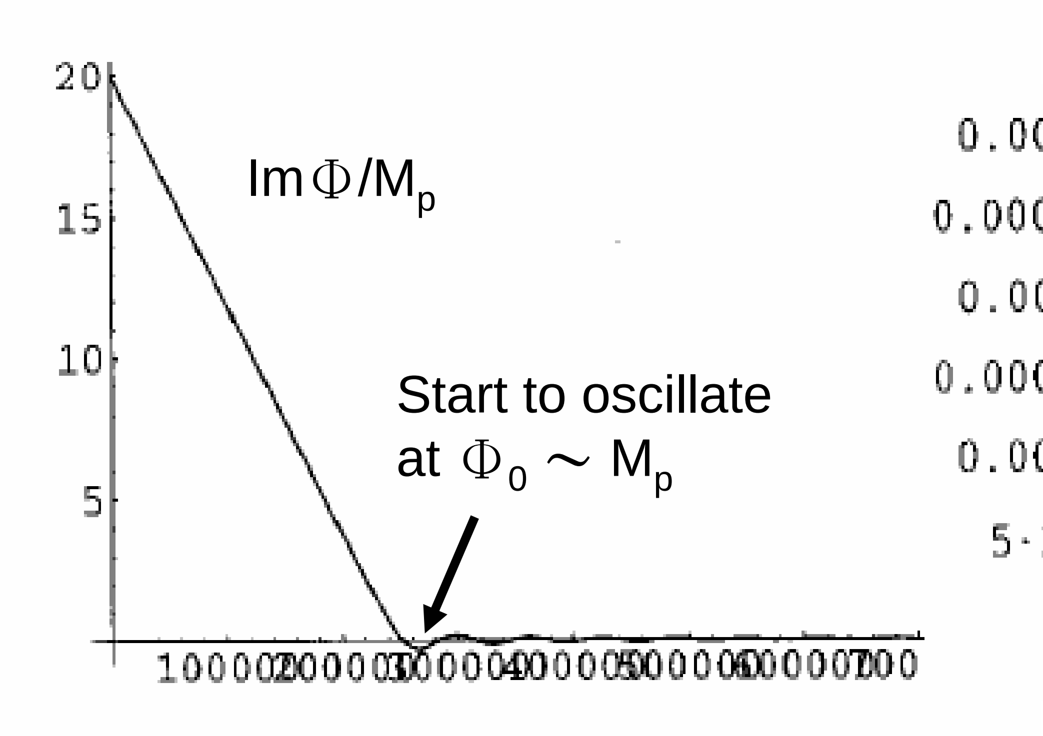
$\lambda\, \Phi^4$

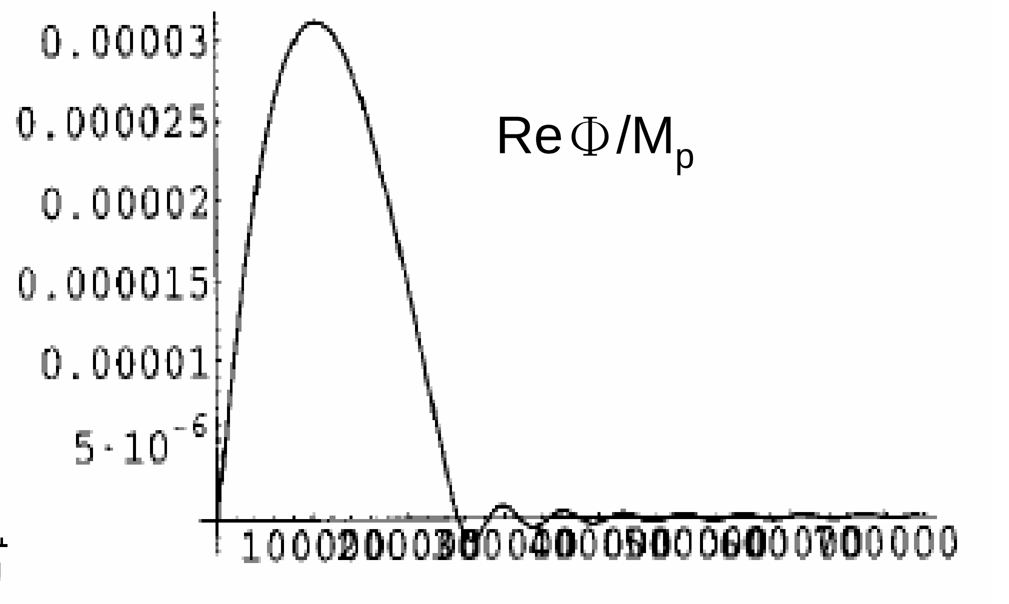
reduced Planck mass. $M_p = 2.4 \times 10^{18}$ GeV

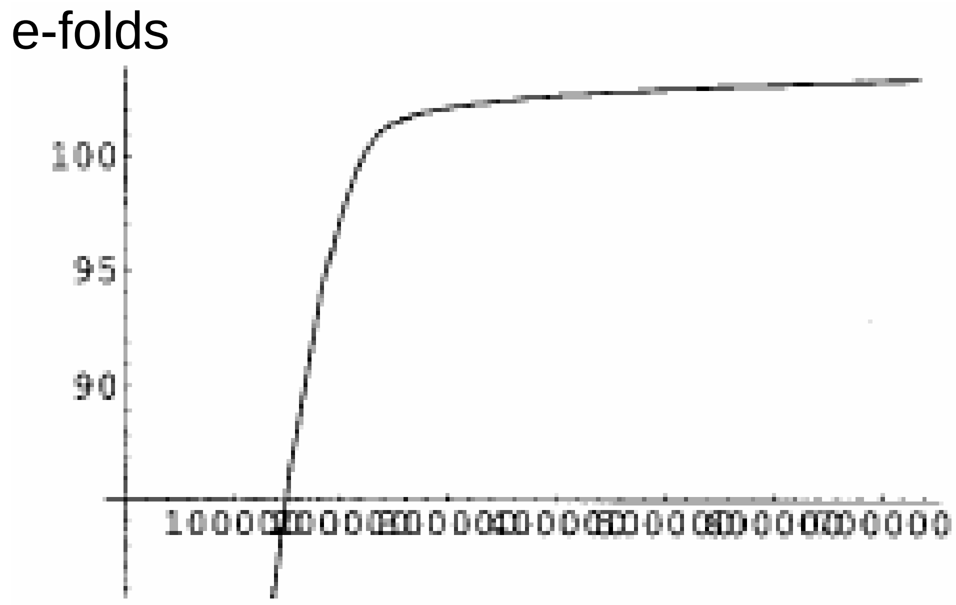
Affleck-Dine Baryogenesis and chaotic inflation



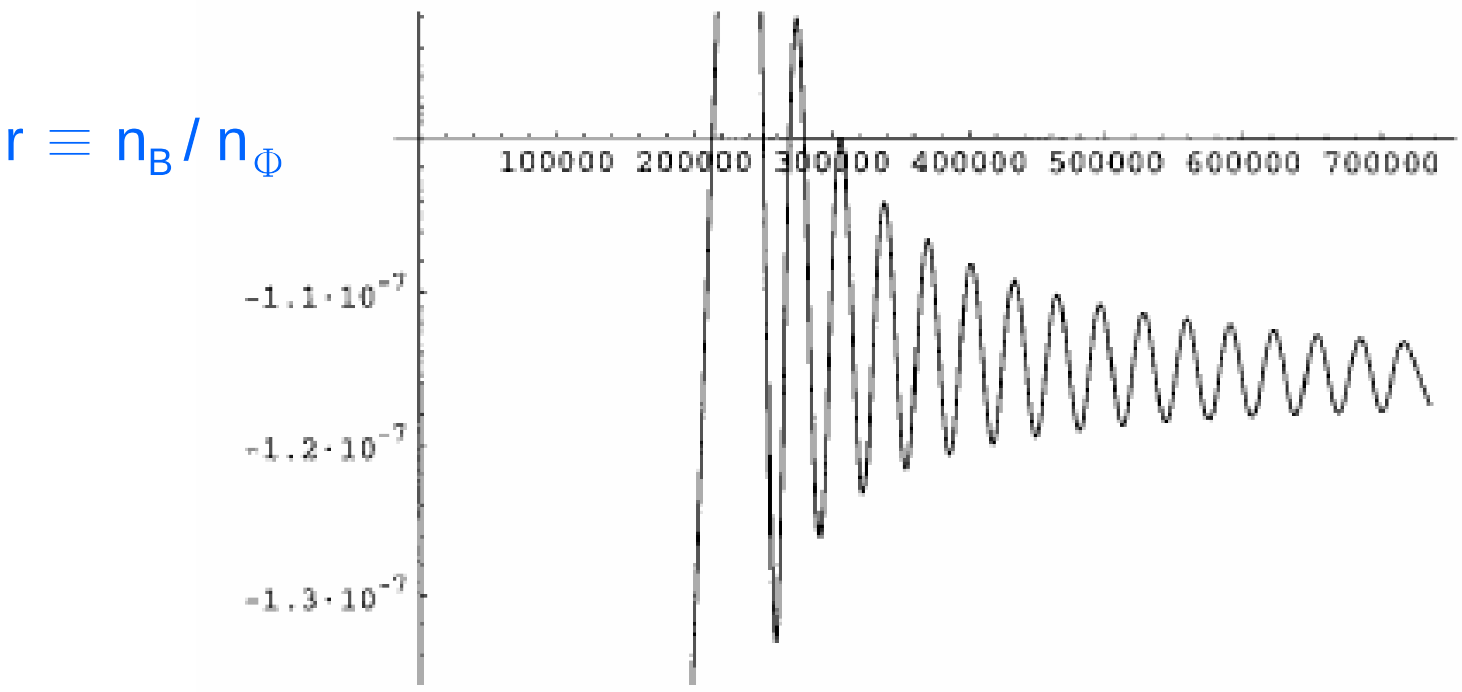
Initial conditions: ImΦ/M_p=20; ReΦ/M_p=0.





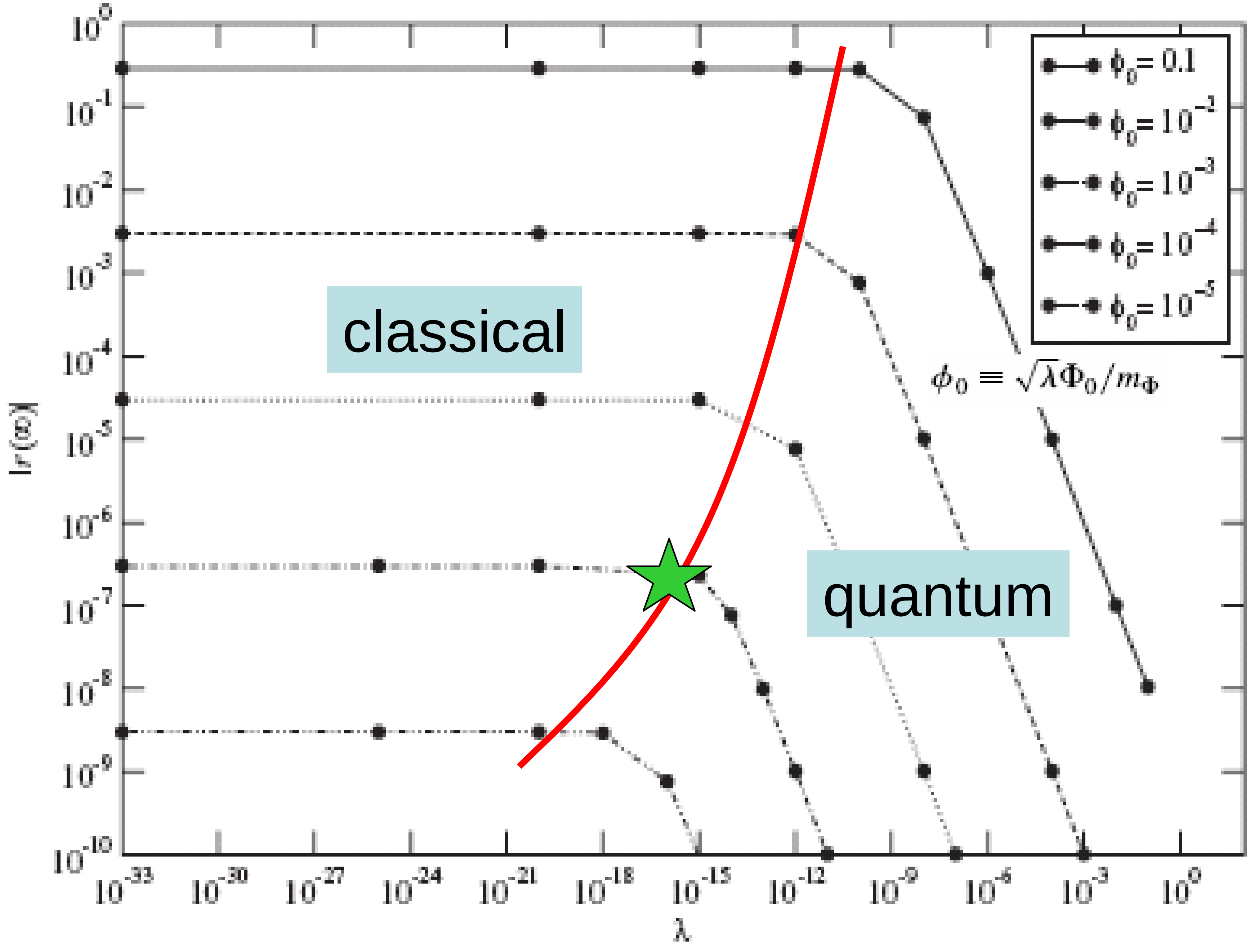


e-folds
100
95
90



$r \equiv n_B / n_\Phi$
100000 200000 300000 400000 500000 600000 700000
-1.1·10^-7
-1.2·10^-7
-1.3·10^-7

Ratio r (baryon to particle number density)



Summary

- Propose a 2-in-1 model "Complex Chaotic Inflation" to accommodate inflation as well as baryogenesis
- Realized in Split SUSY models with
  $m \sim 10^{13}$ GeV
- Future work: including quantum fluctuations, adiabatic and isocurvature density perturbations during inflation