Taro Kunimitsu, JGRG 22(2012)111211

"Higgs Condensation in the inflationary universe"

RESCEU SYMPOSIUM ON

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Higgs Condensation in the Inflationary Universe

Research Center for the Early Universe (RESCEU)

Taro Kunimitsu

with Jun'ichi Yokoyama

PRD 86, 083541 (2012)

July 4, 2012

ATLAS Collaboration

$$m_H = 126.0 \pm 0.4 \pm 0.4 GeV$$

Phys.Lett. B 716, 1 (2012)

CMS Collaboration

$$m_H = 125.3 \pm 0.4 \pm 0.5 GeV$$

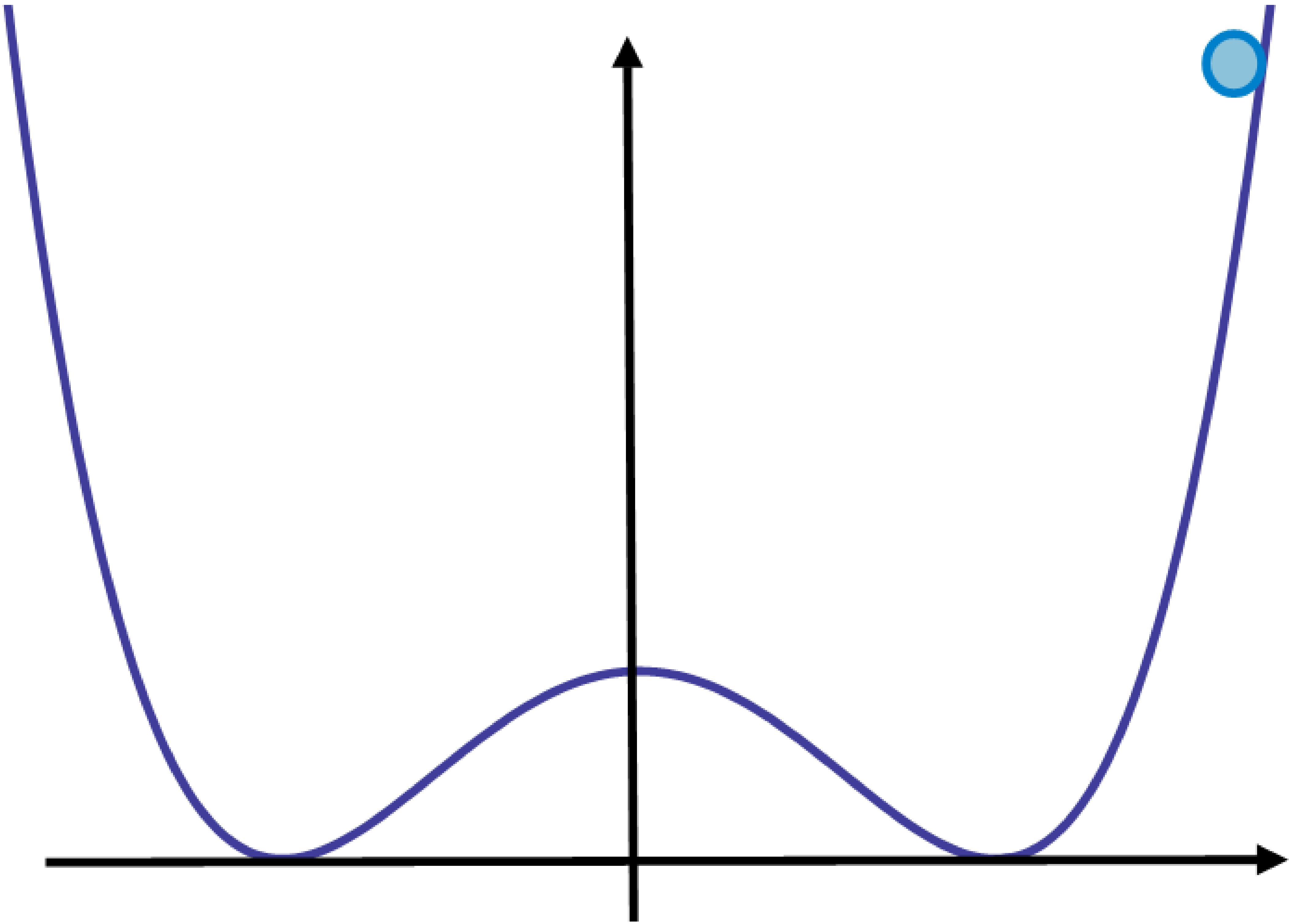
Phys.Lett. B 716, 30 (2012)

Could the Higgs field have dominated the Universe？

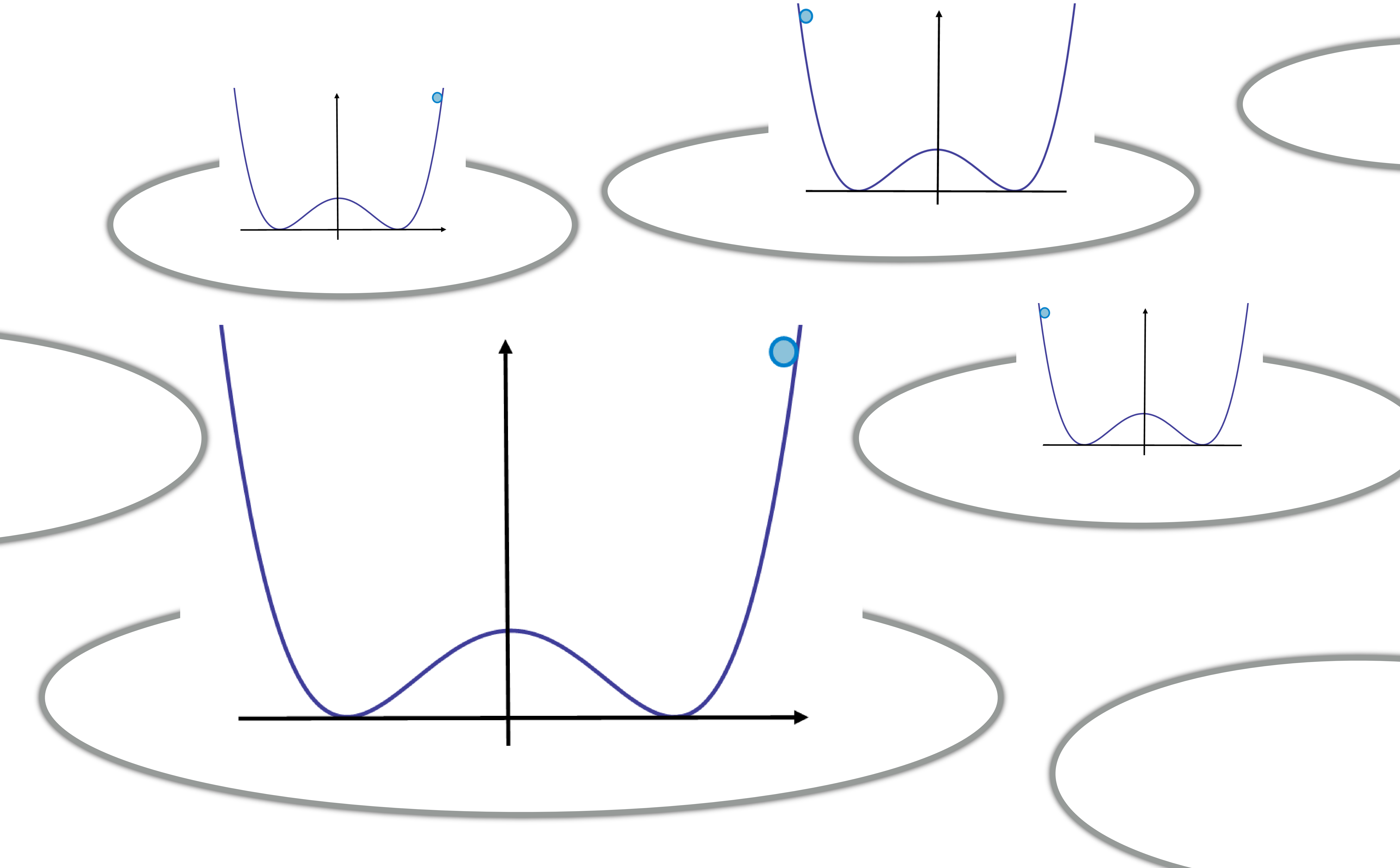
Could the Higgs field have dominated the Universe？

(within the SM + Inflaton framework)

Higgs Field during inflation



Higgs Field during inflation




“Higgs
Condensation"

Stochastic Inflation

Starobinsky (1984,1986)

long-wave part

$$\varphi(\mathbf{x},t) = \bar{\varphi}(\mathbf{x},t)$$

$$+ \int \frac{d^3k}{(2\pi)^{\frac{3}{2}}} \theta(k - \epsilon a(t) H)$$

$$\times \left[a_{\mathbf{k}} \varphi_{\mathbf{k}}(t) e^{-i\mathbf{k}\cdot\mathbf{x}} + a^{\dagger}_{\mathbf{k}} \varphi^{*}_{\mathbf{k}}(t) e^{i\mathbf{k}\cdot\mathbf{x}} \right]$$

short-wave part

Stochastic Inflation

Starobinsky (1984,1986)

long-wave part

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$$+ \int \frac{d^3k}{(2\pi)^{\frac{3}{2}}} \theta(k - \epsilon a(t) H)$$

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short-wave part

Fokker-Planck equation

$$\frac{\partial \rho_1[\varphi(\mathbf{x},t)]}{\partial t} = \frac{1}{3H}\frac{\partial}{\partial \varphi}\{V'[\varphi(\mathbf{x},t)]\rho_1[\varphi(\mathbf{x},t)]\} + \frac{H^3}{8\pi^2}\frac{\partial^2 \rho_1[\varphi(\mathbf{x},t)]}{\partial \varphi^2}$$

Fokker-Planck equation

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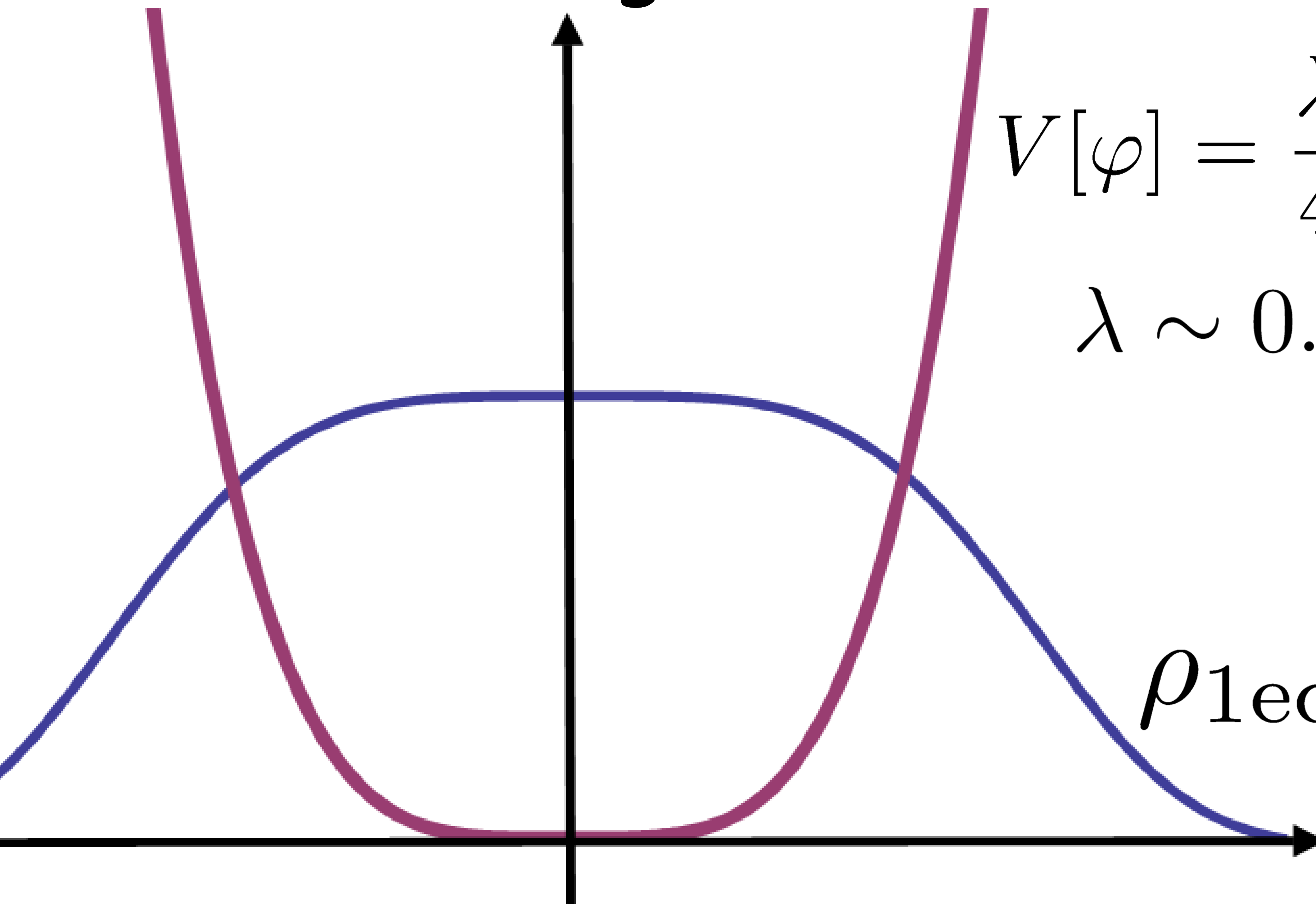
→ An equilibrium state exists

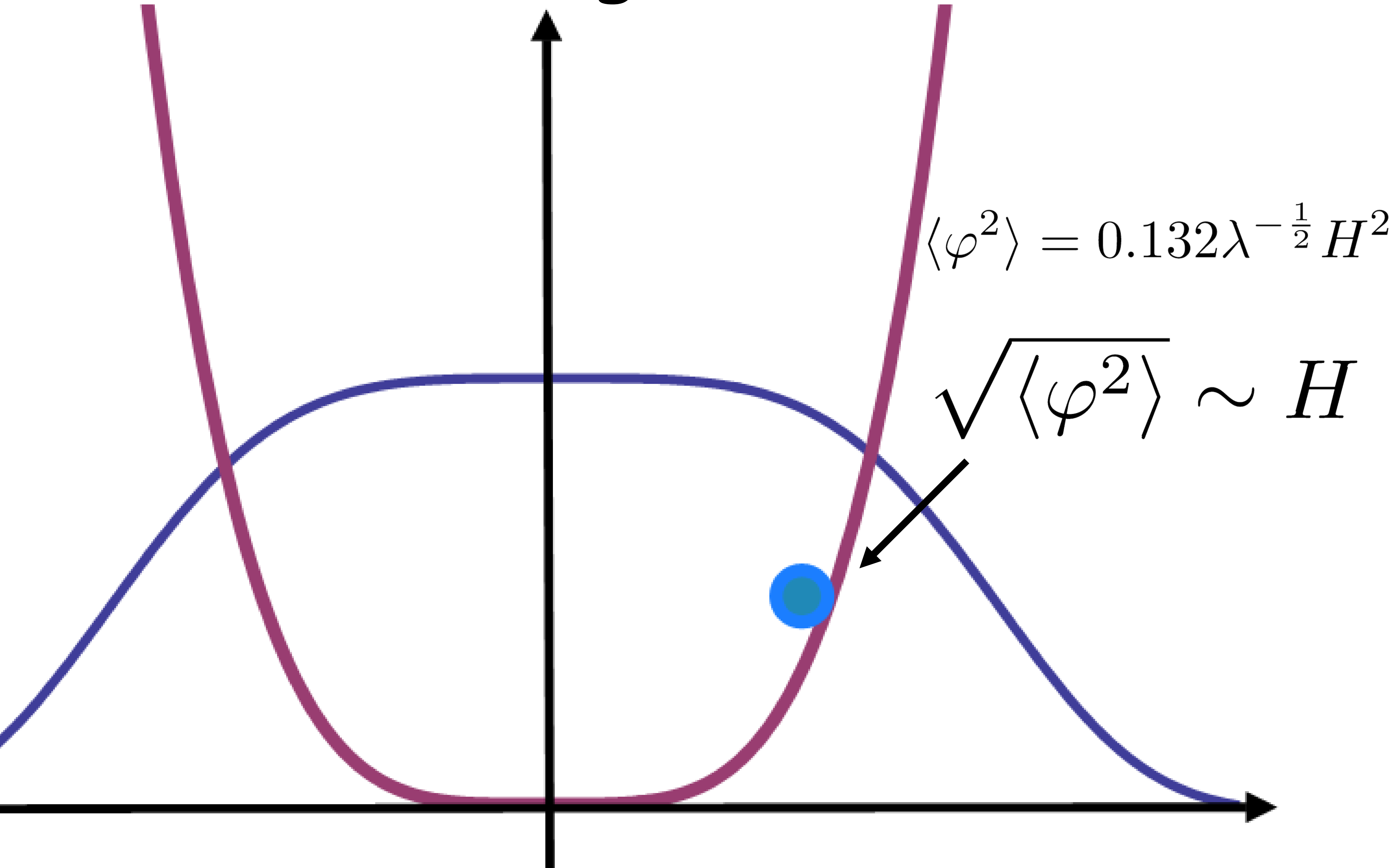
for $V[\varphi] = \frac{\lambda}{4}\varphi^4$

$$\rho_{1\mathrm{eq}}(\varphi) = \left(\frac{32\pi^2\lambda}{3}\right)^{\frac{1}{4}} \frac{1}{\Gamma(\frac{1}{4})H} \exp\left(-\frac{3\pi^2\lambda\varphi^4}{3H^4}\right)$$

Probability distribution



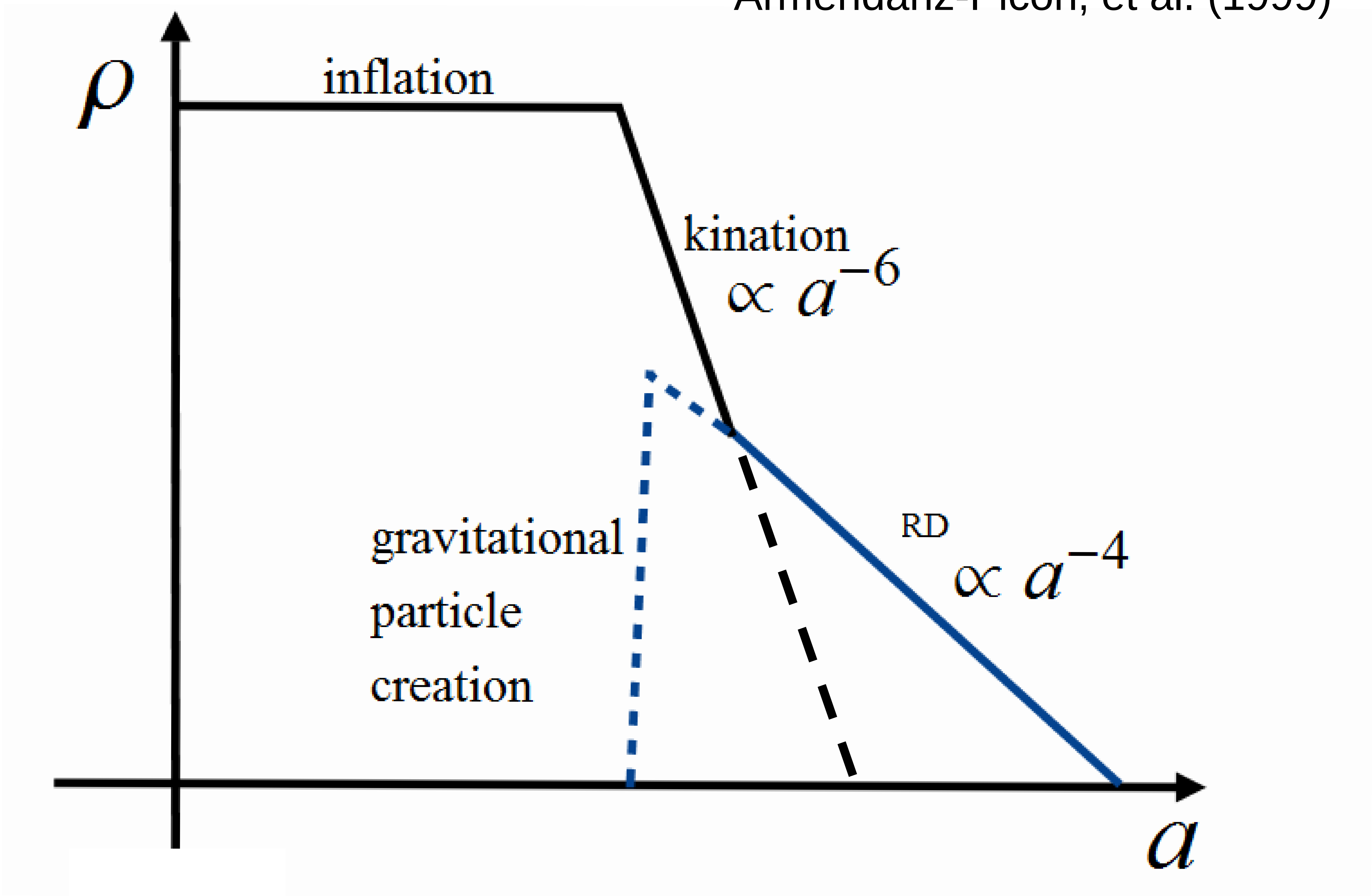
Probability distribution



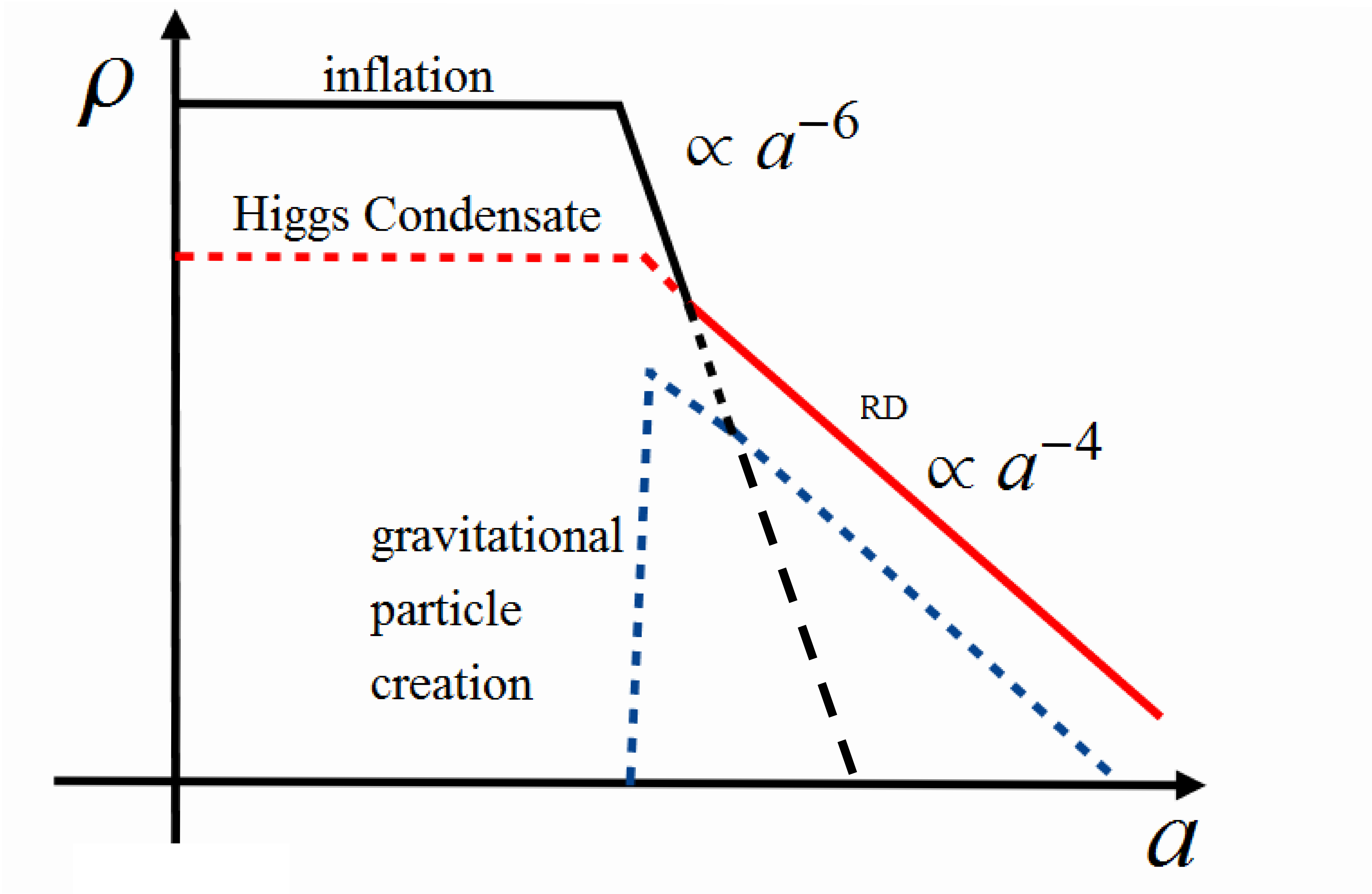

Inflation Model

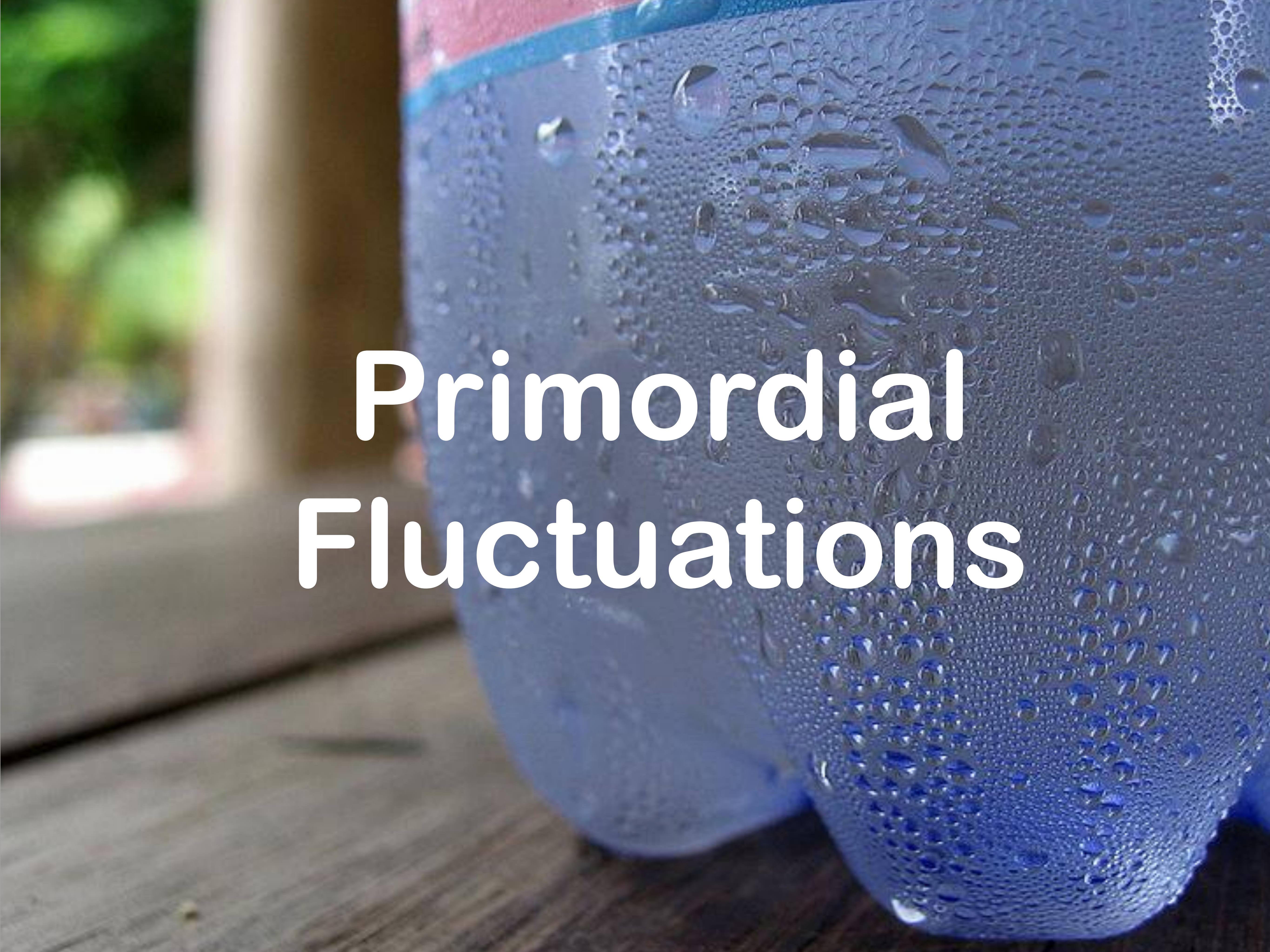
Model : k-inflation

Armendariz-Picon, et al. (1999)



k-inflation with Higgs




Primordial
Fluctuations

Fluctuations

We want

$$\mathcal{P}(k) \sim 10^{-9}$$

Fluctuations

$$\Xi_{\Delta_h}(r) \equiv \left\langle \frac{\delta\rho_h(r)}{\rho_h} \frac{\delta\rho_h(0)}{\rho_h} \right\rangle$$

$$\simeq 4(Har)^{-0.178\sqrt{\lambda}}$$

Fluctuations

Fourier Transform

$$P_V(k) \simeq 14\sqrt{\lambda}k^{-3}$$

$$\mathcal{P}_V(k) \equiv \frac{4\pi k^3}{(2\pi)^3} P_V(k) \sim \sqrt{\lambda} \sim 0.1$$

$$\lambda \sim 0.01$$

Fluctuations

We get

$$\mathcal{P}(k) \sim \mathcal{P}_V(k)$$
$$\sim 0.1$$

Too Large!

Summary

Higgs condensation

→Dominates the Universe in k-inflation

→We Showed that the fluctuations are too large

backups

Fokker-Planck equation

$$\frac{\partial \rho_1[\varphi(\mathbf{x},t)]}{\partial t}$$

$$= \frac{1}{3H}\frac{\partial}{\partial \varphi}\{V'[\varphi(\mathbf{x},t)]\rho_1[\varphi(\mathbf{x},t)]\} + \frac{H^3}{8\pi^2}\frac{\partial^2 \rho_1[\varphi(\mathbf{x},t)]}{\partial \varphi^2}$$

Probability Distribution Function

$\rightarrow$ An equilibrium state exists

Starobinsky, Yokoyama (1994)

for $$V[\varphi] = \frac{\lambda}{4}\varphi^4$$

$$\rho_{1\mathrm{eq}}(\varphi) = \left(\frac{32\pi^2\lambda}{3}\right)^{\frac{1}{4}} \frac{1}{\Gamma(\frac{1}{4})H} \exp\left(-\frac{3\pi^2\lambda\varphi^4}{3H^4}\right)$$

Correlation time/length

$$t_c \simeq 76.2 H^{-1}$$

$$a(t) r_c \simeq e^{37.4} H^{-1}$$

During inflation

$$\varphi \sim H_{\rm inf}$$

$$\rho_{\rm inf} \sim H_{\rm inf}^2 M_P^2$$

$$\rho_h \sim \lambda H_{\rm inf}^4$$

When does Oscillation start?

$$\rho_h \sim \lambda H_{\rm inf}^4$$

$$\rho_{\rm inf} \sim H_*^2 M_P^2 \quad \leftarrow H_*^2 \sim \lambda H_{\rm inf}^2$$

$$\rightarrow \quad \frac{\rho_h}{\rho_{\rm inf}} \sim \frac{H_{\rm inf}^2}{M_P^2} \sim \mathcal{P}_t < 10^{-9}$$

Gravitational particle production

$$\rho_r = \frac{9H_{\mathrm{inf}}^4}{32\pi^2 a^4} \ln\left(\frac{1}{H_{\mathrm{inf}}\Delta t}\right)$$

$$\ln\left(\frac{1}{H_{\mathrm{inf}}\Delta t}\right) \sim 1$$

Energy density

$$\rho_r = \frac{9NH_{\rm inf}^4}{32\pi^2}\left(\frac{m_{\rm eff}}{H_{\rm inf}}\right)^{\frac{4}{3}} \simeq 1.59\times 10^{-3} N H_{\rm inf}^4$$

$$\rho_{\rm cond} = \frac{3H_{\rm inf}^4}{32\pi^2} \simeq 9.50\times 10^{-3} H_{\rm inf}^4$$