IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Non-Gaussianity from Radiation and/or CDM

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@ Asamushi-onsen, RESCEU/DENET summer school ``Dark Energy in the Universe"

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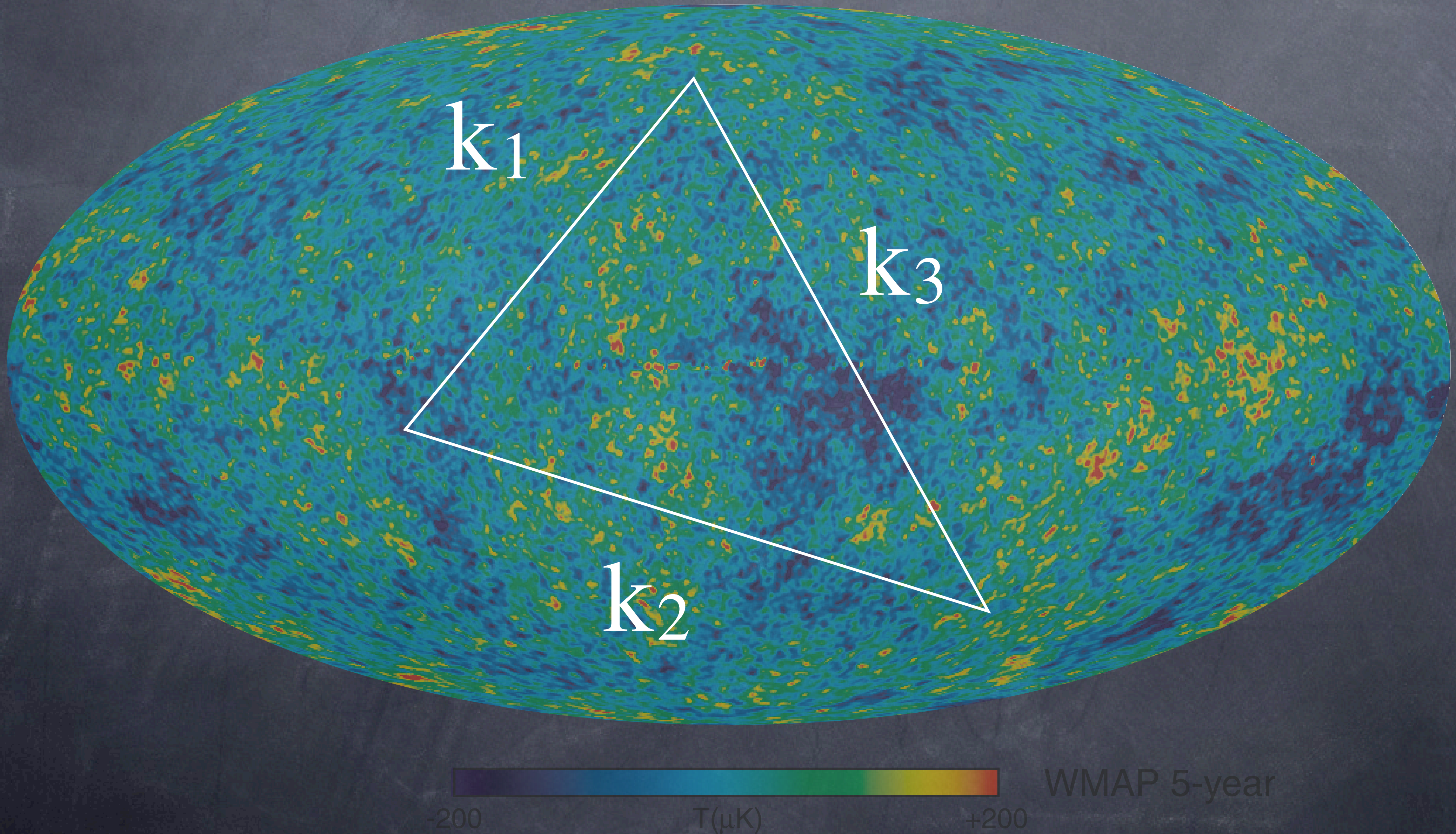
arXiv:0804.0425 (to appear in JCAP), T. Suyama and F.T.
arXiv:0808.0009, Kawasaki,Nakayama,Sekiguchi,Suyama,and F.T.

1. Introduction



Non-Gaussianity, if detected, will give us a clue on the origin of the density perturbations.

Except for NG, the std. slow-roll inflation seems to be perfectly consistent with the observations.

Does detection of NG mean that we are not on the right track?

Maybe one needs some radical modifications:
e.g.) DBI, ghost inflation, ekpyrotic etc..

Conservative modification is to add light scalar(s)!

Then, why does NG exist?

NG, although large, does not seem to play any important role in cosmology.

Non-Gaussianity may be simply common in theoretical space.

Symmetry

Guiding principle in modern physics.

In string theory, gauge and discrete symmetries are ubiquitous.

Scalar fields

SUSY

Boson ⟷ Fermion

scalar (0) fermion (1/2)

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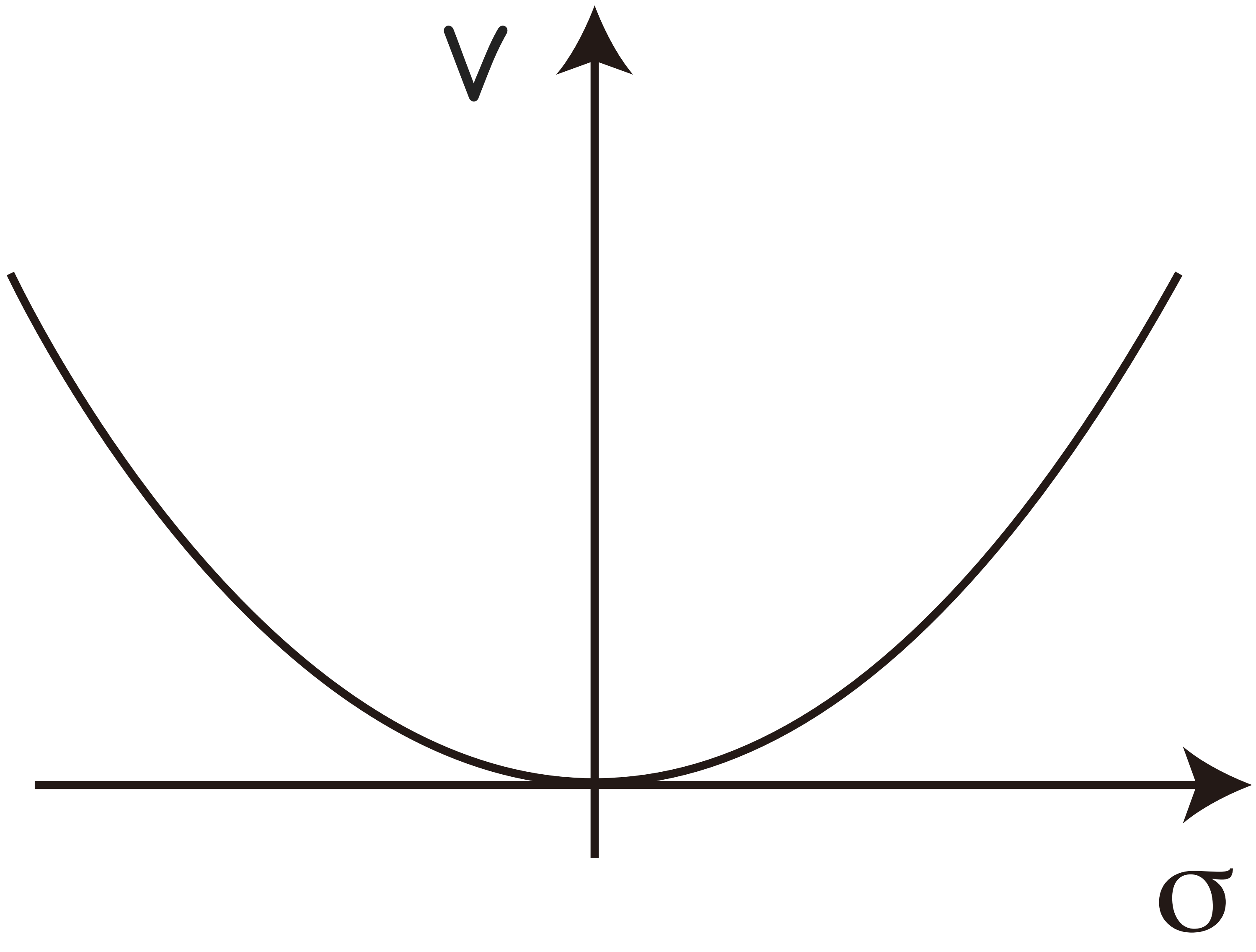
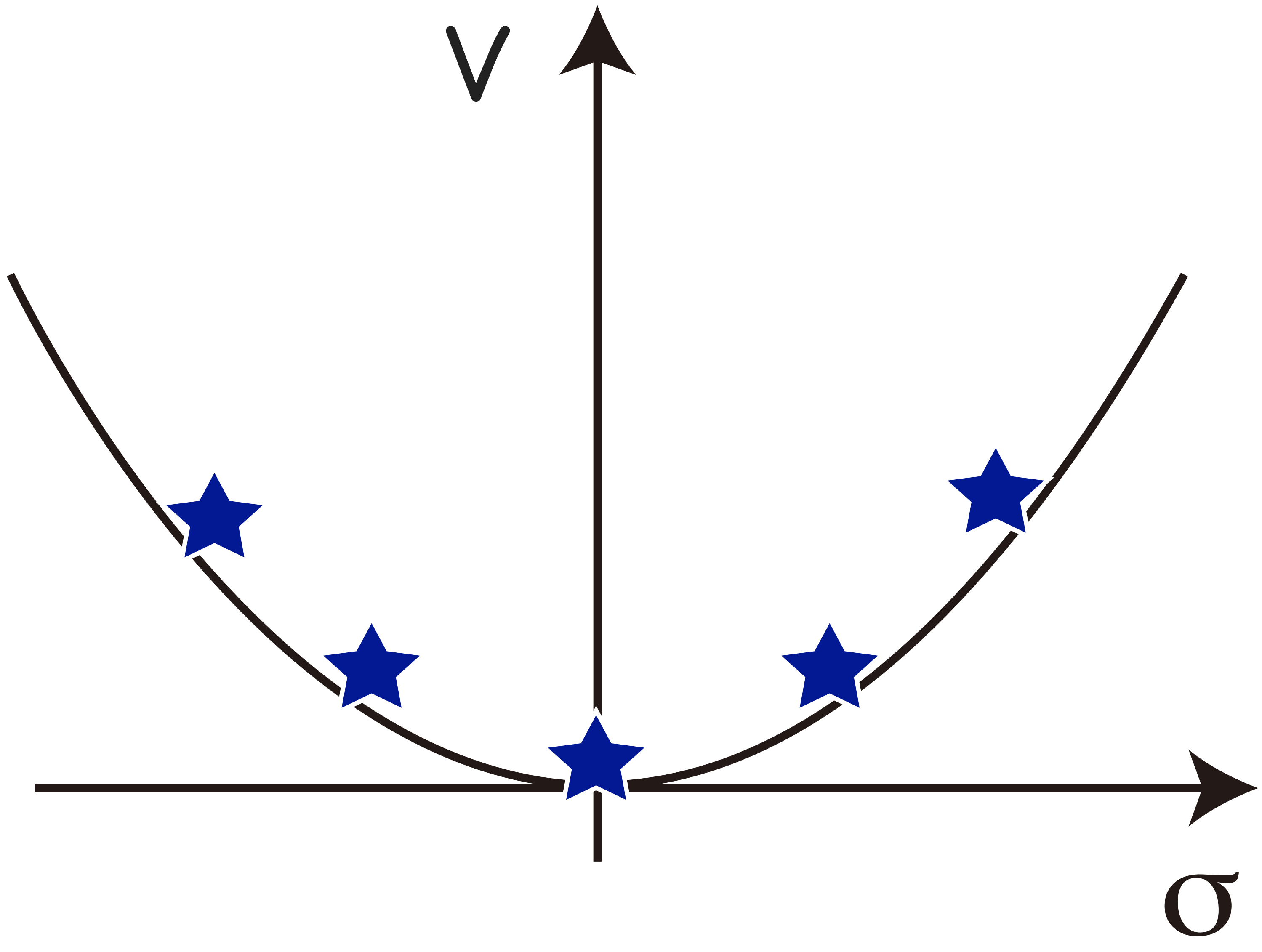
There are perhaps many scalars in nature, charged under some symmetries.


V
σ


V
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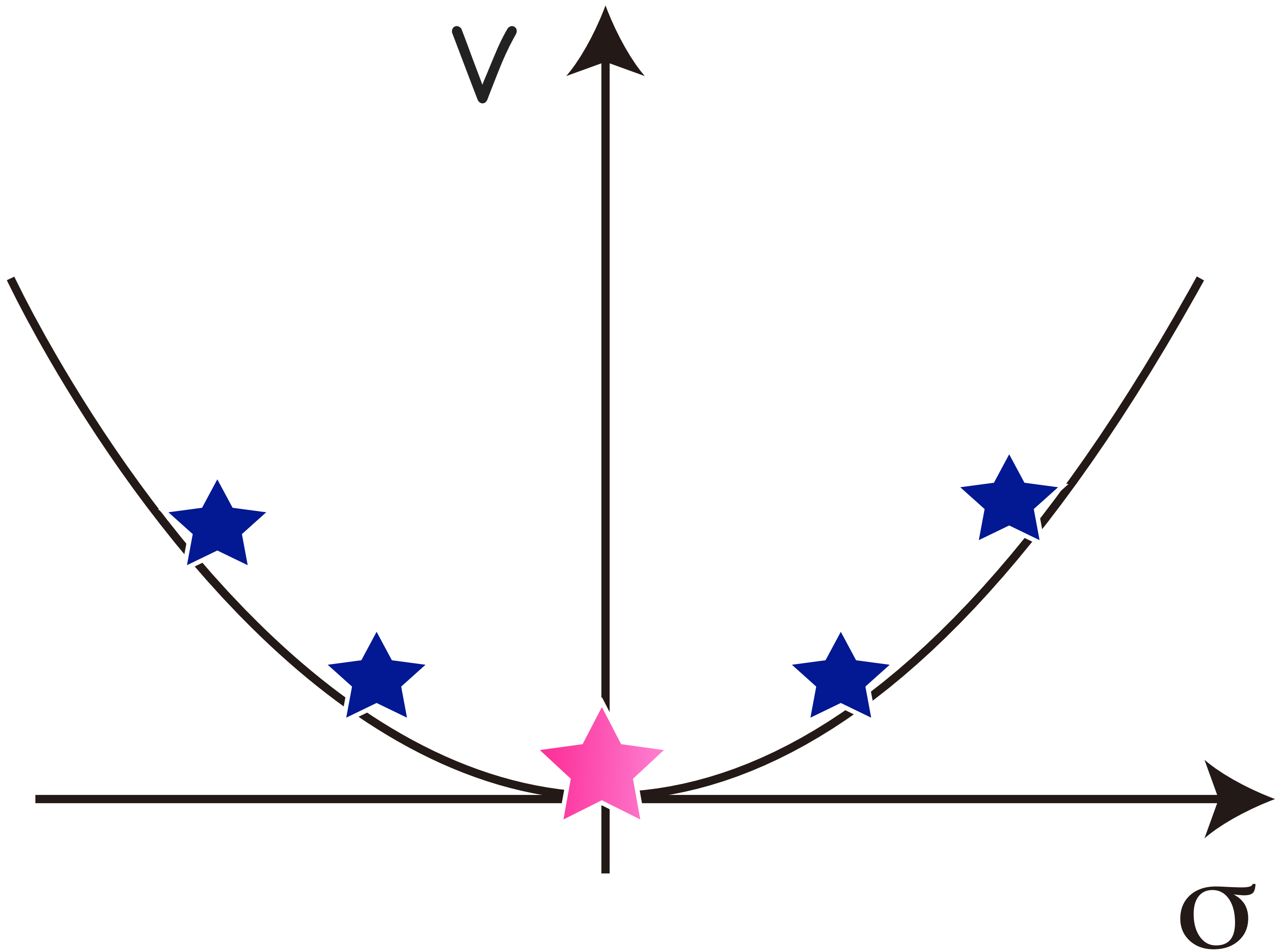
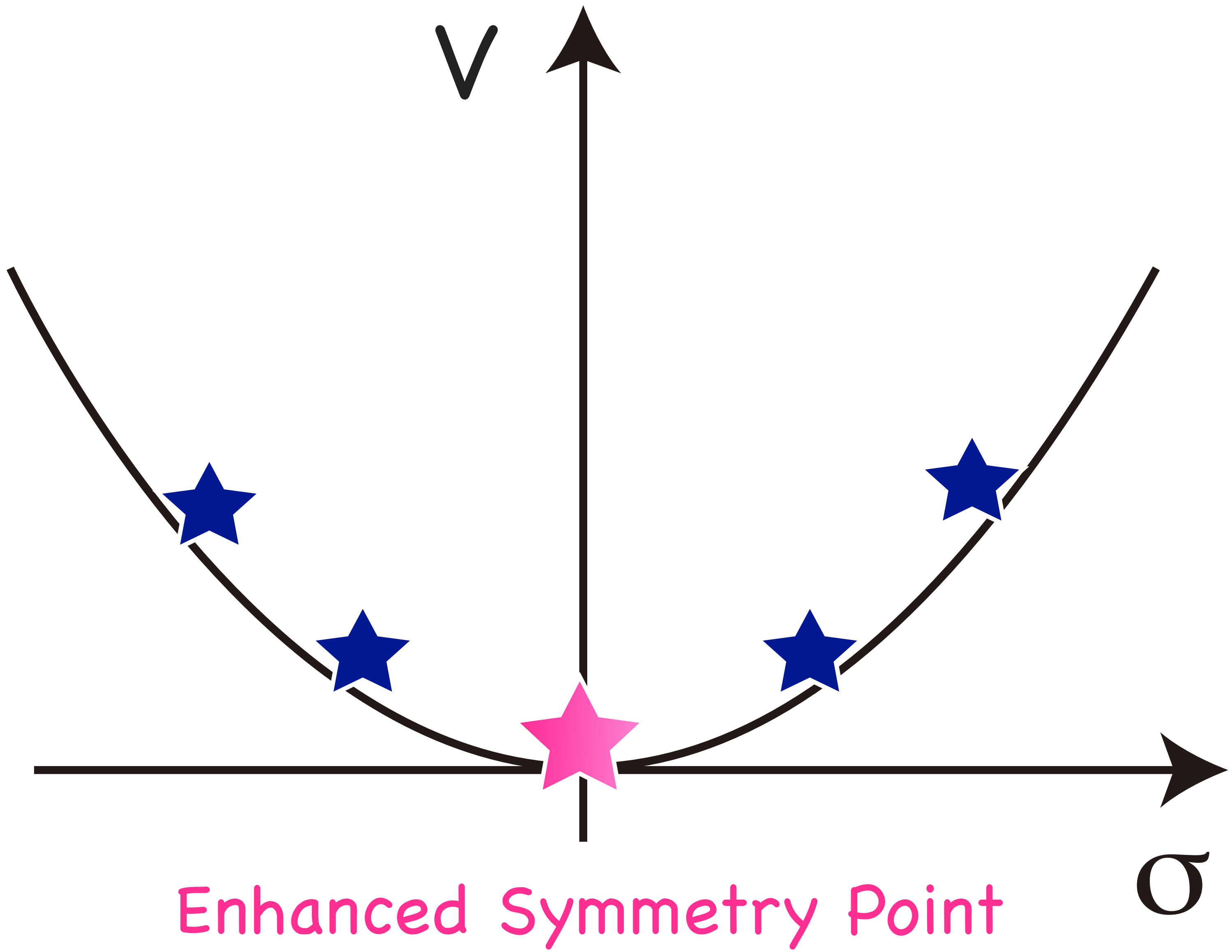
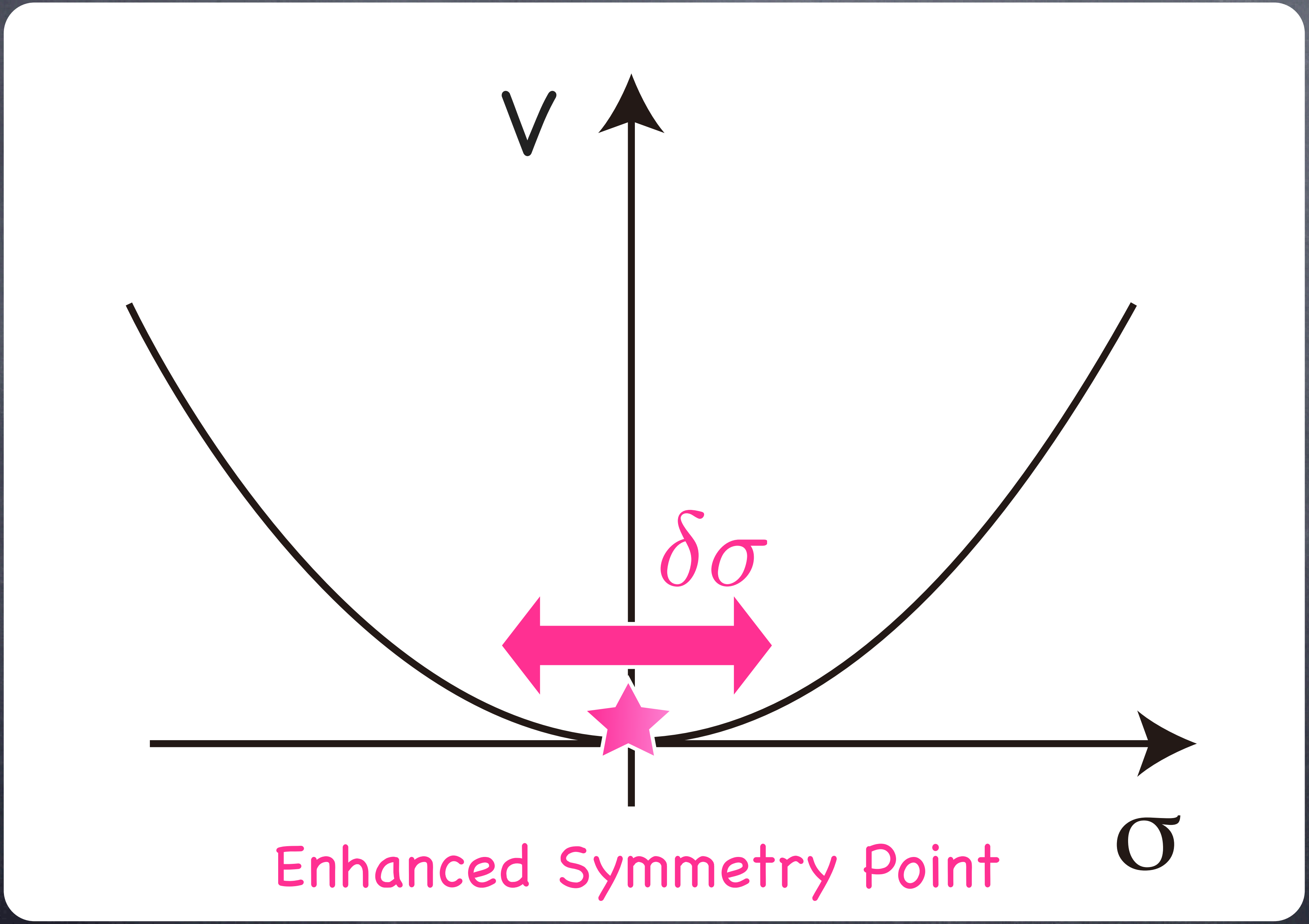

V
σ


V
σ
Enhanced Symmetry Point

At the quantum level, a light scalar fluctuates during inflation.



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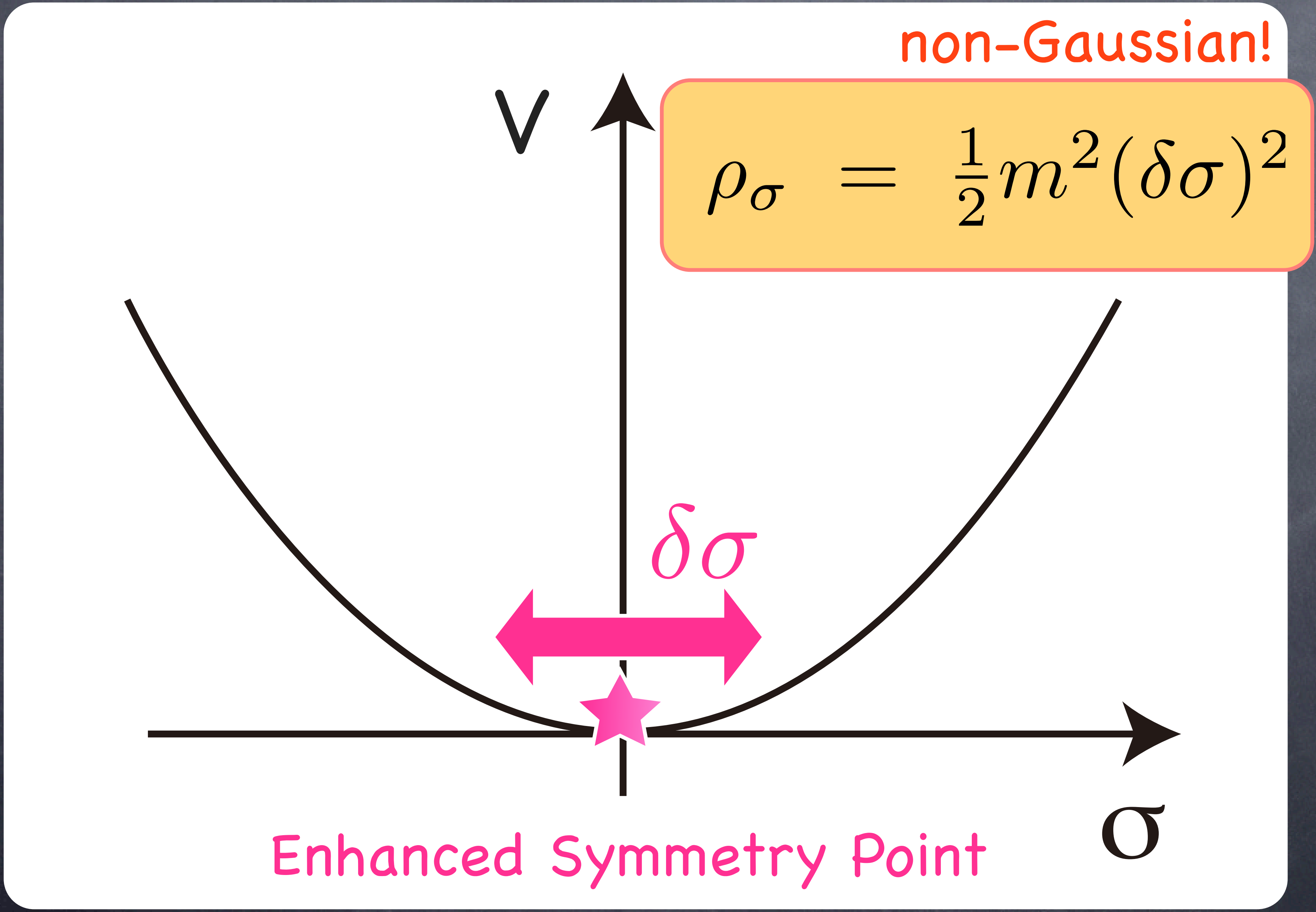


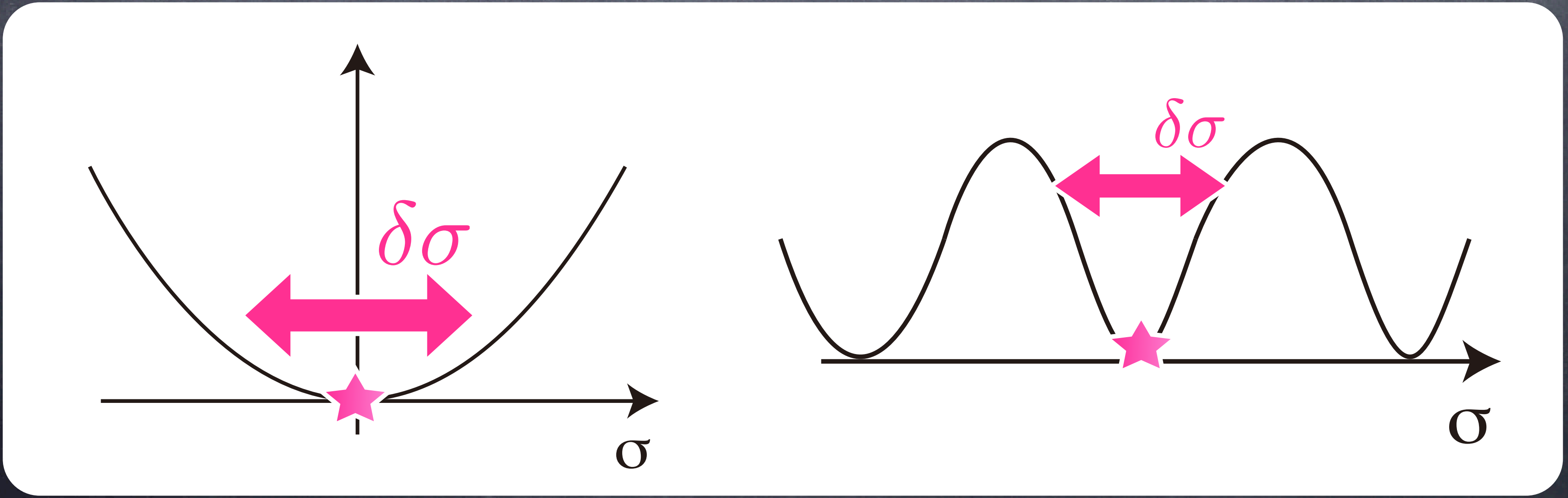
We name such a scalar ``ungaussiton''.

Ungaussiton:

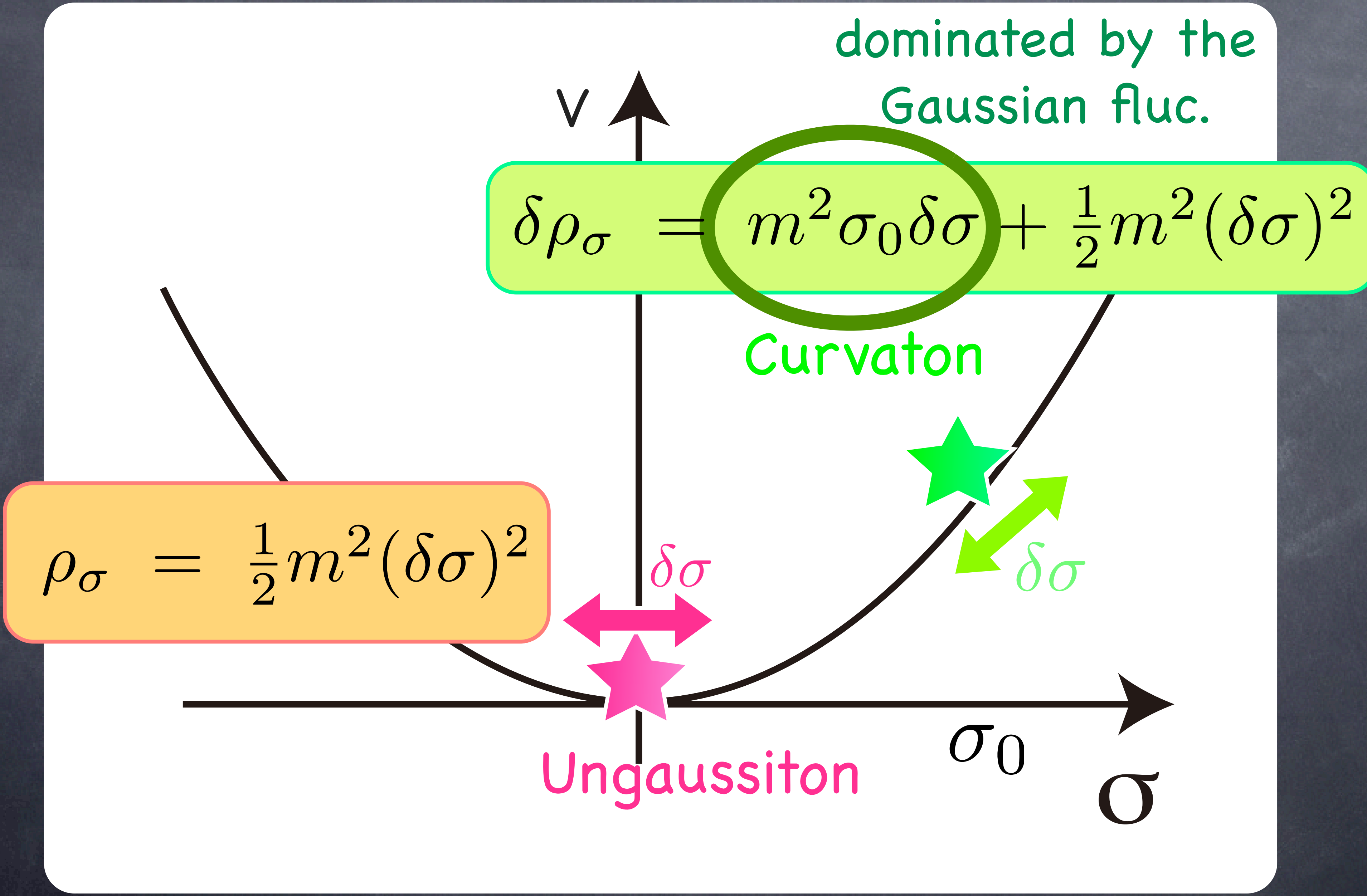
A scalar field dominantly produced by the quantum fluctuations, generating sizable non-Gaussianity in the density fluctuations.

e.g.)

The dominant Gaussian density perturbations are assumed to come from the inflaton.



Ungaussiton or Curvaton?



Related works in the past:

Linde, Mukhanov \`97, \`06, \`\`Curvaton web"

Durrer, Gasperini, Sakellariadou and Veneziano \`98,
Gasperini and Veneziano \`98, \`\`Seed mechanism"

Lyth \`05, \`\`The Bunch-Davies case"

What we did:

We have calculated the bi- and tri-spectrum from the ungaussiton, and derived a consistency relation between the two.

$$\tau_{\mathrm{NL}} \sim 10^3 f_{\mathrm{NL}}^{4/3}$$

This can be extended to higher corr. func. of any order.

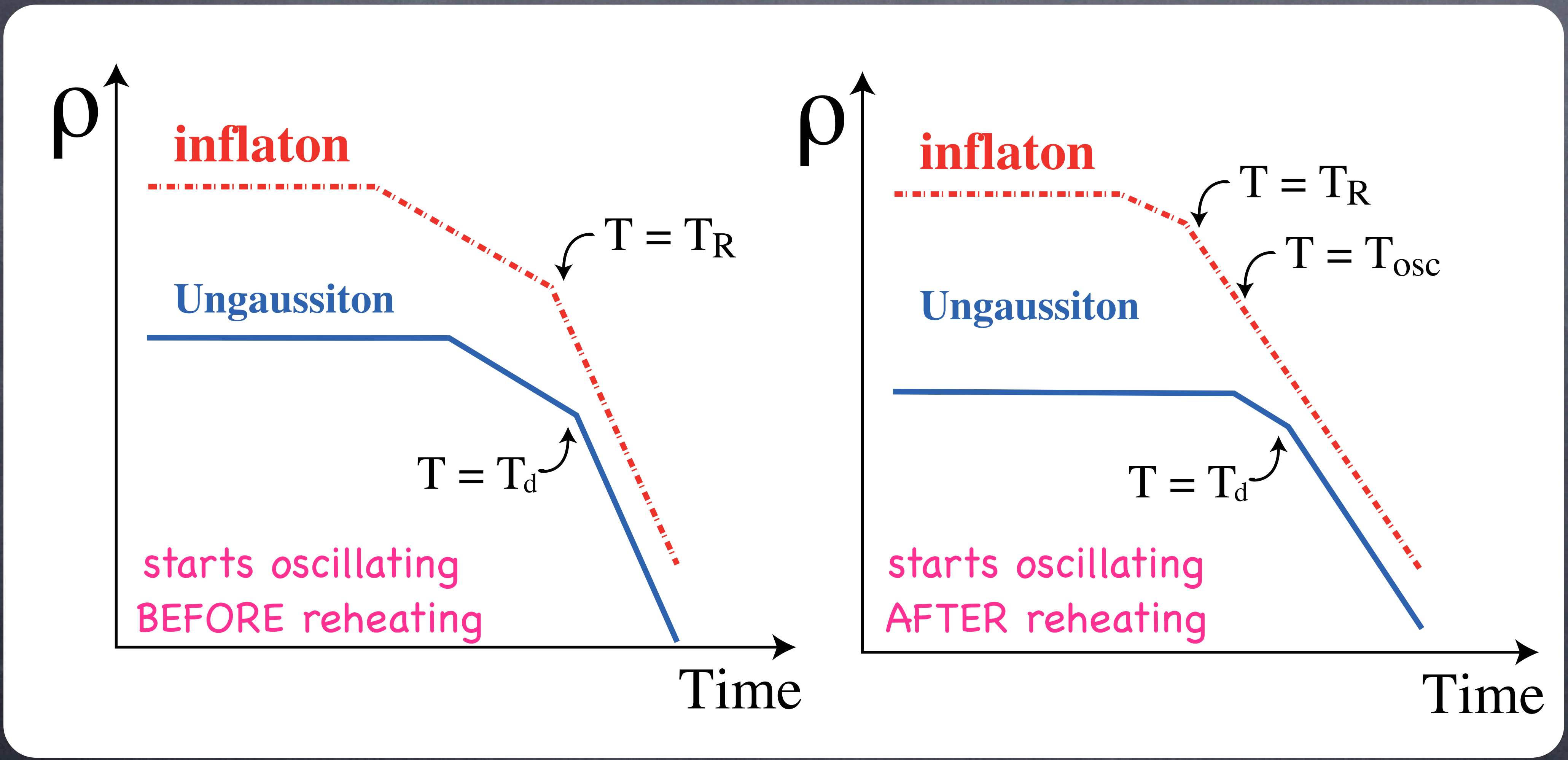
We have derived constraints on the inflationary scale and the reheating/decay temperatures. In particular, one needs

$$\mathrm{H}_{\mathrm{inf}} \gtrsim 10^{10}\mathrm{GeV}$$

for sizable NG.

2.Ungaussiton Mechanism

The thermal history



$$\delta\rho_\sigma = \frac{1}{2} m^2 (\delta\sigma)^2 \qquad \delta\sigma = \frac{H_{\rm inf}}{2\pi}$$

Power spectrum, bispectrum, trispectrum:

$$\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \rangle_c = (2\pi)^3 \delta(\vec{k}_1 + \vec{k}_2)\, P_\zeta(k_1),$$

$$\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \rangle_c = (2\pi)^3 \delta(\vec{k}_1 + \vec{k}_2 + \vec{k}_3)\, B_\zeta(k_1, k_2, k_3),$$

$$\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \zeta_{\vec{k}_4} \rangle_c = (2\pi)^3 \delta(\vec{k}_1 + \vec{k}_2 + \vec{k}_3 + \vec{k}_4)\, T_\zeta(\vec{k}_1, \vec{k}_2, \vec{k}_3, \vec{k}_4),$$

$\mathrm{B}_\zeta \neq 0$ and/or $\mathrm{T}_\zeta \gg P_\zeta^2$

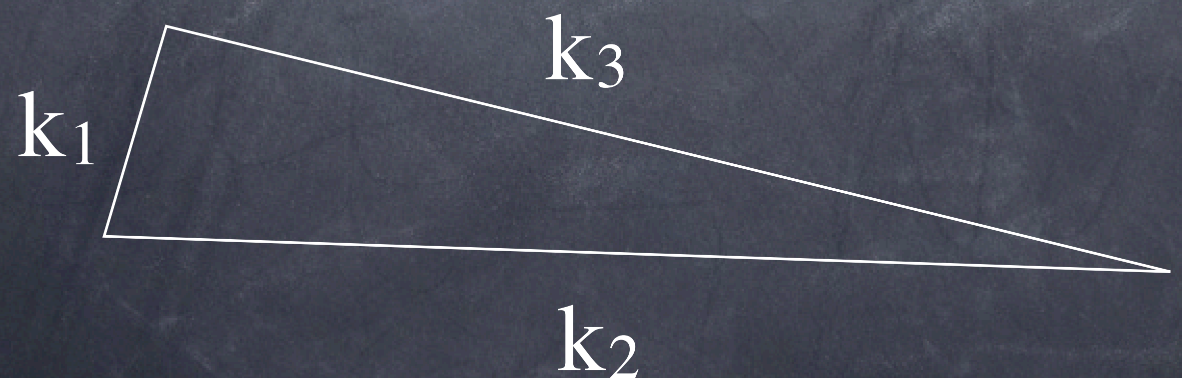
Non-Gaussianity!

$\mathrm{f_{NL}}$ and τ_{NL}

$$B_\zeta(k_1,k_2,k_3) = \frac{6}{5} f_{\mathrm{NL}} (P_\zeta(k_1)P_\zeta(k_2) + 2 \text{ perms.}),$$

$$T_\zeta(\vec{k}_1,\vec{k}_2,\vec{k}_3,\vec{k}_4) = \tau_{\mathrm{NL}} (P_\zeta(k_{13})P_\zeta(k_3)P_\zeta(k_4) + 11 \text{ perms.})$$

In the squeezed config., we can approximately express B and T in terms of $\mathrm{f_{NL}}$ and τ_{NL}.



δN formalism

Starobinsky `85, Sasaki, Stewart, `96
Sasaki, Tanaka, `98 Lyth, Malik, Sasaki `04

On sufficiently large scales, the curvature perturbation on the uniform density surface is equal to the prtb. in the e-folding number between the u.d.s. and the initial flat slicing.

$$\zeta \approx N_\phi \delta\phi_* + N_\sigma \delta\sigma_* + \frac{1}{2} N_{\sigma\sigma} \delta\sigma_*^2 + \frac{1}{6} N_{\sigma\sigma\sigma} \delta\sigma_*^3 + \cdots ,$$

$$N_\phi = \frac{\partial N}{\partial \phi} \qquad \delta\phi_* \sim \delta\sigma_* \sim \frac{H_I}{2\pi}$$

ϕ : inflaton

σ : ungaussiton

The coefficients are determined by the background evolution!

Bispectrum

$$\frac{6}{5} f_{\rm NL} \simeq \frac{1}{N_\phi^4} \left(N_\sigma^2 N_{\sigma\sigma} + N_{\sigma\sigma}^3 \mathcal{P}_\sigma \log(k_b L) \right) ,$$

Trispectrum

$$\tau_{\rm NL} \simeq \frac{1}{N_\phi^6} \left(N_\sigma^2 N_{\sigma\sigma}^2 + N_{\sigma\sigma}^4 \mathcal{P}_\sigma \log(k_t L) \right) ,$$

After some calculations,

Bispectrum

$$\frac{6}{5}f_{\rm NL} = \frac{\alpha^6}{216}\left(\frac{\pi}{2}\right)^{3/2}\mathcal{P}_\zeta\epsilon^3\left(\frac{\Gamma_\sigma}{m_\sigma}\right)^{-3/2}\left\{\left(\frac{\bar{\sigma}}{H_I/2\pi}\right)^2 + \log(k_b L)\right\},$$

Trispectrum

$$\tau_{\rm NL} = \frac{\pi^2\alpha^8}{5184}\mathcal{P}_\zeta\epsilon^4\left(\frac{\Gamma_\sigma}{m_\sigma}\right)^{-2}\left\{\left(\frac{\bar{\sigma}}{H_I/2\pi}\right)^2 + \log(k_t L)\right\},$$

Consistency relation

$$\tau_{\rm NL} \approx 1 \times 10^3\, C\, f_{\rm NL}^{4/3}\,;$$

$$C \equiv \frac{\frac{\bar{\sigma}^2}{(H_I/2\pi)^2} + \log k_t L}{\left(\frac{\bar{\sigma}^2}{(H_I/2\pi)^2} + \log k_b L\right)^{4/3}}.$$

Intuitive derivation of the consistency relation.

ζ contains $\mathrm{N}_{\sigma\sigma}(\delta\sigma)^2$

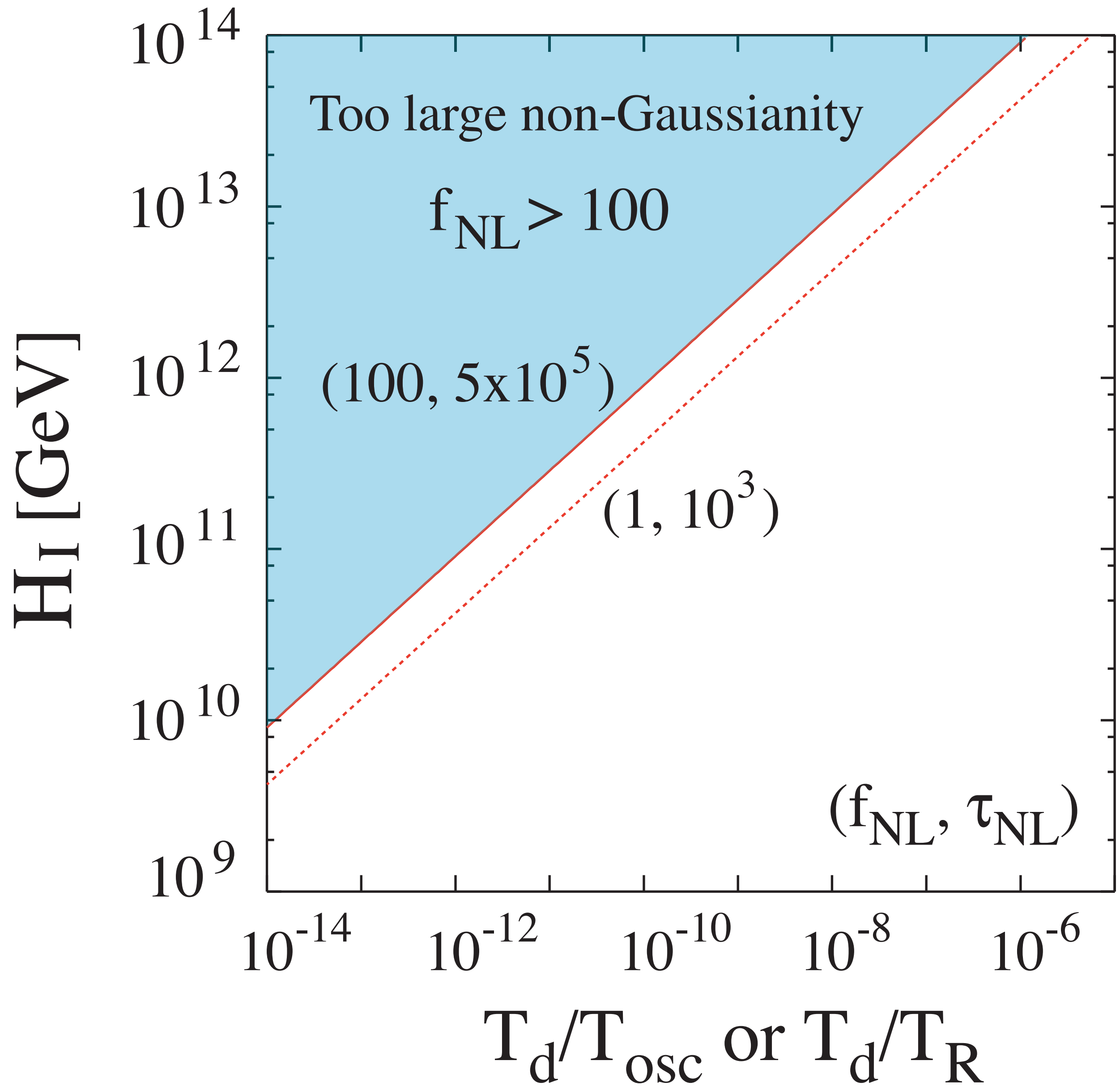
$$\langle\zeta\zeta\zeta\rangle \sim N_{\sigma\sigma}^3 \left\langle(\delta\sigma)^2\right\rangle^3$$

$$\langle\zeta\zeta\zeta\zeta\rangle \sim N_{\sigma\sigma}^4 \left\langle(\delta\sigma)^2\right\rangle^4$$

Noting $\langle\zeta\zeta\zeta\rangle \sim f_{\mathrm{NL}}\, P_\zeta^2$ and $\langle\zeta\zeta\zeta\zeta\rangle \sim \tau_{\mathrm{NL}}\, P_\zeta^3$

$$\tau_{\mathrm{NL}} \sim P_\zeta^{-\frac{1}{3}} f_{\mathrm{NL}}^{\frac{4}{3}} \sim 10^3 f_{\mathrm{NL}}^{\frac{4}{3}}$$

Cosmological constraint:



Candidates for the ungaussiton:

Moduli with enhaced symmetry points,

Right-handed sneutrino,

MSSM flat directions w/ Q-balls

etc.

Conclusion

- A detection of NG suggests that the source of the NG may be common in nature. A light scalar fluctuating around the origin can naturally generate large NG.

- If the ungaussiton is responsible for large NG, there is a consistency relation:

$$\boxed{\tau_{\rm NL} \sim 10^3 f_{\rm NL}^{4/3}}$$

- In addition, the inflation scale should be large enough:

$$\boxed{{\rm H_{inf}} \gtrsim 10^{10}{\rm GeV}}$$

Non-Gaussianity from CDM isocurvature fluctuations

Kawasaki, Nakayama, Sekiguchi, Suyama, FT

$$\langle S_{ij\vec{k}_1} S_{ij\vec{k}_2} \rangle \equiv (2\pi)^3 P_{Sij}(k_1) \delta(\vec{k}_1 + \vec{k}_2),$$

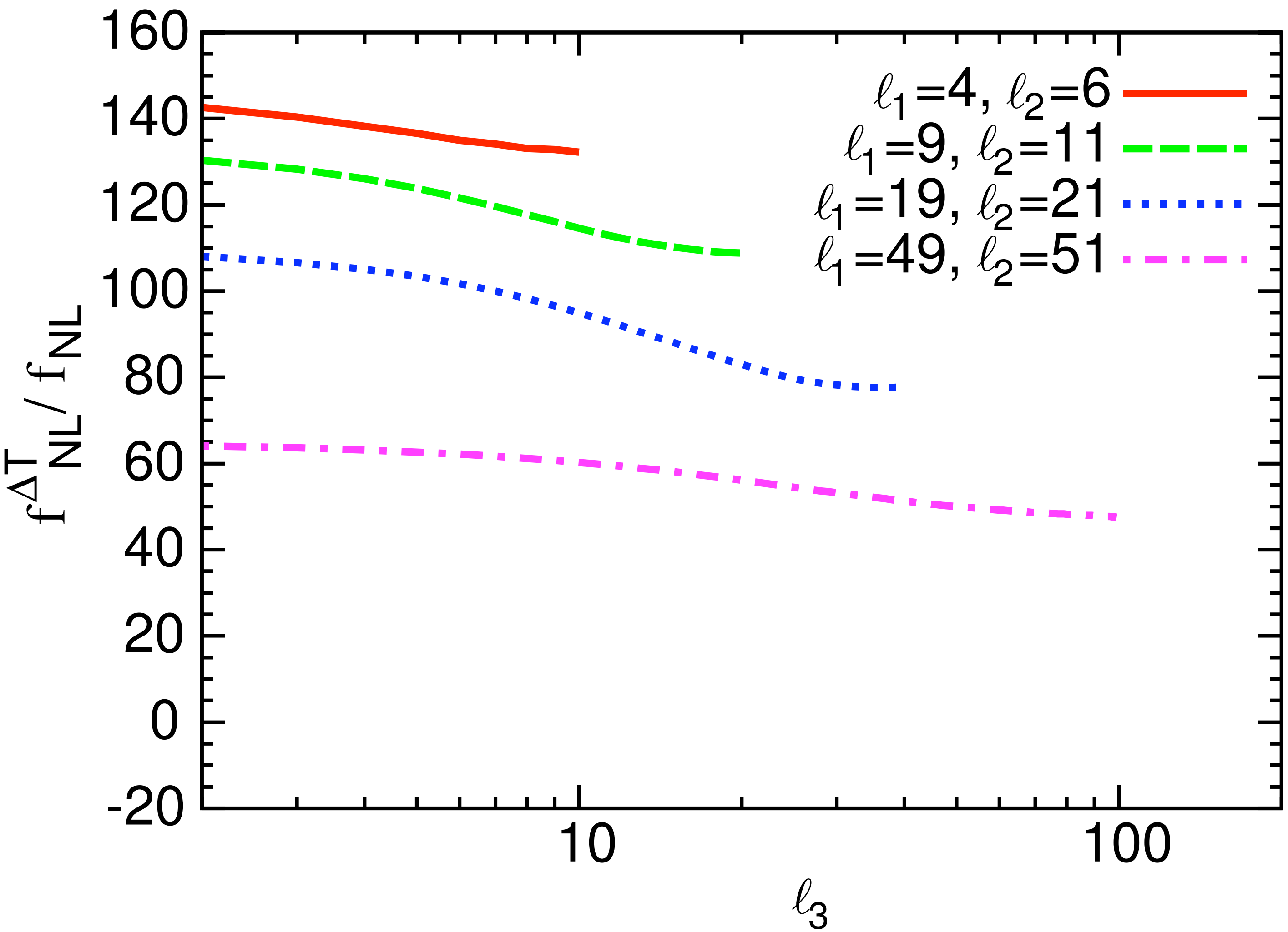
$$\langle S_{ij\vec{k}_1} S_{ij\vec{k}_2} S_{ij\vec{k}_3} \rangle \equiv (2\pi)^3 B_{Sij}(k_1, k_2, k_3) \delta(\vec{k}_1 + \vec{k}_2 + \vec{k}_3).$$

$$B_S(k_1, k_2, k_3) \equiv f_S [P_S(k_1) P_S(k_2) + 2\,\mathrm{perms.}].$$

$f_S \rightarrow f_{NL}$ curv. pertb.

$f_S \rightarrow f_{NL}^{\Delta T}$ temp. pertb.

Due to the nature of the isocurvature perturbations, non-Gaussianity in the CMB is enhanced at large scales.



Kawasaki, Nakayama, Sekiguchi, Suyama, FT, arXiv:0808.0009

Non-Gaussianity may come from the QCD axion?

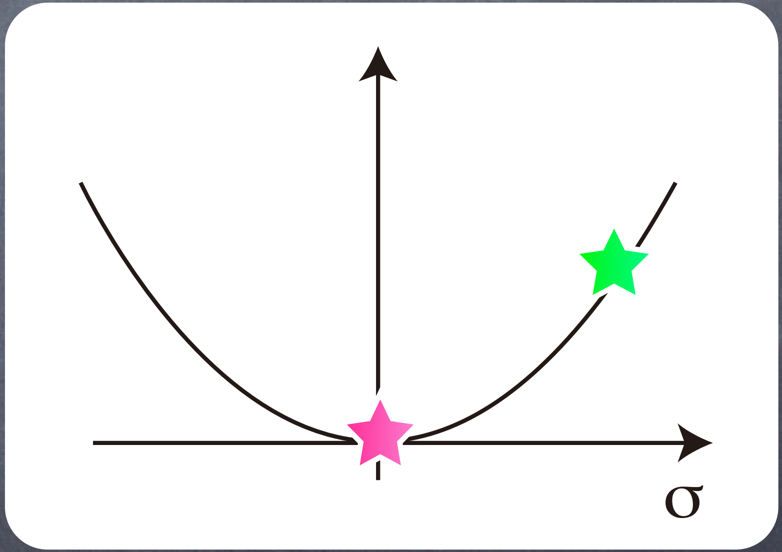
We will see...

Back-up slides

How can a light scalar be trapped around the origin?

If the inflation lasts long enough, the distribution approaches the Bunch-Davies expression:

$$\langle \sigma^2 \rangle \sim \frac{H^2}{m}$$



If the `homogeneous' part does not vanish, it is like a curvaton. If it vanishes, it is a ungaussiton.

1. The last stage of the inflation may have lasted only for N = 50-60. Before the last inflation, the scalar may have settled down at the origin due to some dynamics (thermal mass, preheating, Hubble-induced mass, etc.)

2. The mass of the scalar may not be much lighter than the Hubble parameter (cf. eta problem in sugra). Then it is possible that the scalar happens to be around the origin in our universe.

3. Or, the origin may be chosen by the anthropic arguments.