Inflationary Universe (project A01 status report)

Toward Understanding Physics/Mechanism of Inflation

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KEK, 9 March, 2017

A1 summary

Tomo Takahashi

- Future sensitivity for the runnings
- Strongly scale-dependent CMB power asymmetry

Jun'ichi Yokoyama

- Schwinger effect in the inflationary universe
- Entropic interpretation of Hawking-Moss instant

Masahide Yamaguchi

- Non-local N=1 supersymmetry

Kazunori Nakayama

- Higgs instability after inflation

Misao Sasaki

- Inflationary massive gravity

46 published papers in total
very active!

Tsutomu Kobayashi

- Generic instabilities of non-singular cosmologies

Shuichiro Yokoyama

- Isocurvature fluctuations in the curvaton

Talks

Teruaki Suyama

- GW150914 and primordial black holes

Poster

Inflation: current status

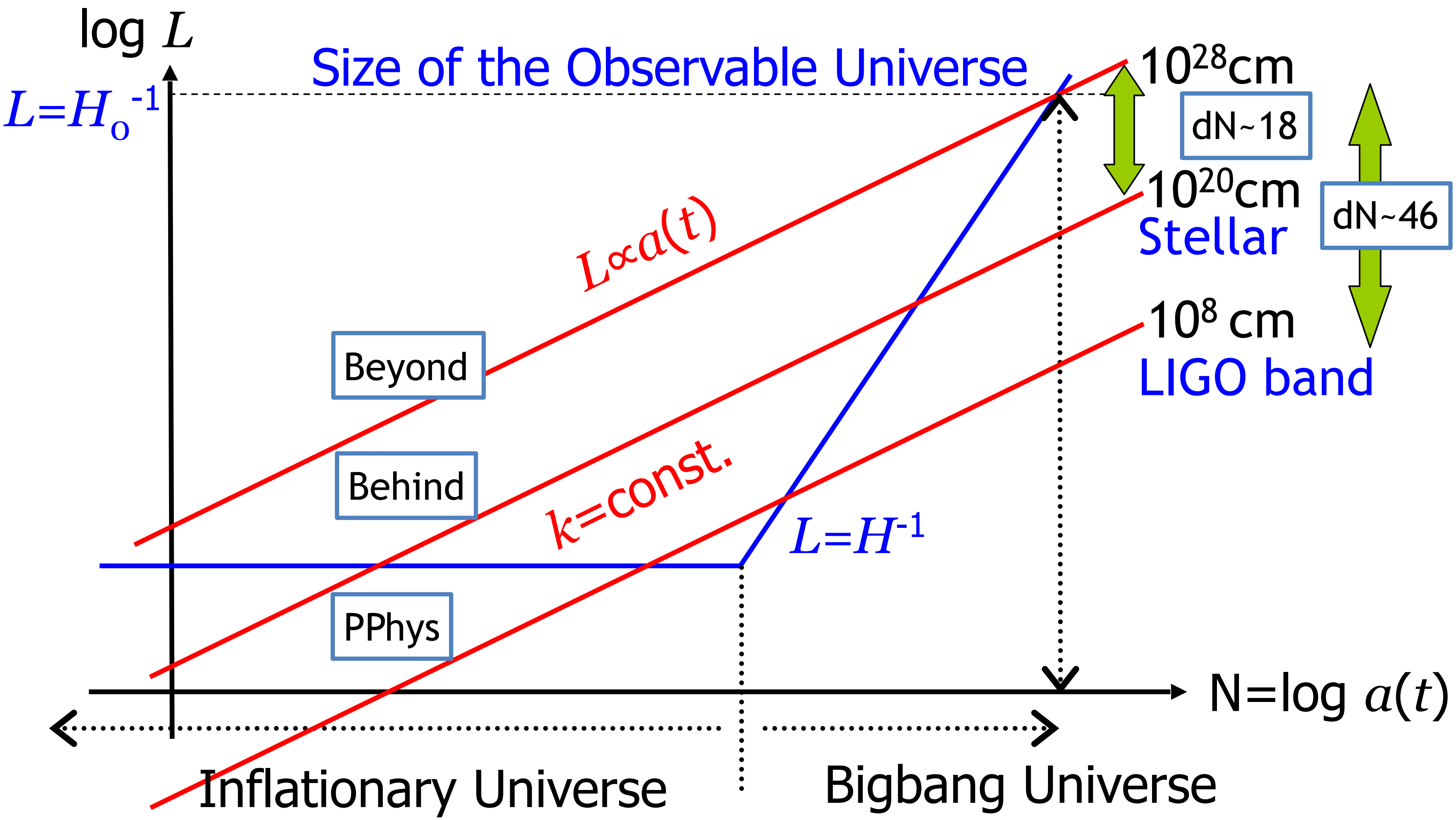
- scalar spectral index: $n_s<1$ at ~ 5 σ
- apparent hemispherical asymmetry in CMB 2-pt. fcn.
- tensor/scalar ratio: $r < 0.1$ implies $E_{inflation} < 10^{16}$ GeV
- simple, canonical models are on verge of extinction
  ($m^2\phi^2$ model excluded at > 2 σ)
- R^2 (Starobinsky) model seems to fit best. But why?
  (large R^2 correction but negligible higher order terms)
- f_{NL}^{local} <O(1) suggests (effectively) single-field slow-roll
  but f_{NL}^{local} =O(1) or scale-dep f_{NL}^{local} =O(10) not excluded

$\Downarrow$

some element of non-canonicality is needed

Theories/models? Observational tests/signatures?

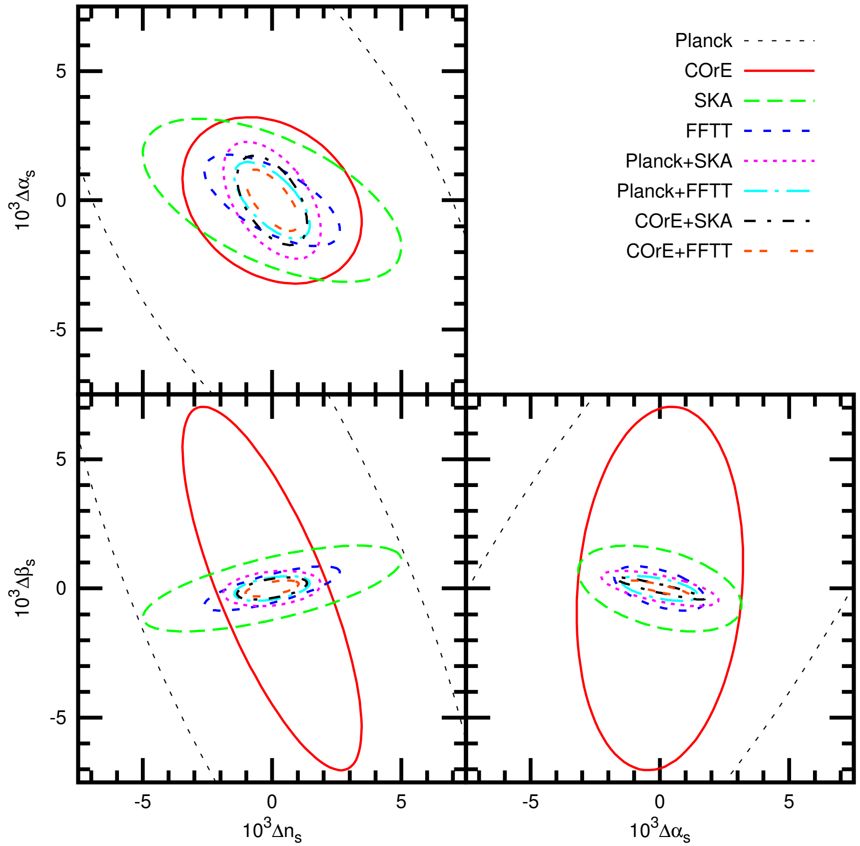
length scales of the inflationary universe



Future sensitivity for the runnings

[T.Sekiguchi, T.Takahashi, H.Tashiro, S.Yokoyama in prep.]

- Measurements of 21cm fluctuations from minihalos can probe small scale fluctuations (k~ O(10-100) /Mpc).



	$10^{-3}\Delta n_s$	$10^{-3}\Delta\alpha_s$	$10^{-3}\Delta\beta_s$
Planck	7.7	10.7	15.1
COrE	3.2	2.9	6.5
SKA	4.6	2.9	1.5
FFTT	2.4	1.6	0.79
Planck+SKA	1.7	2.0	0.63
Planck+FFTT	1.3	1.3	0.44
COrE+SKA	1.2	1.6	0.39
COrE+FFTT	0.95	1.1	0.28

$(k_{\rm ref} = 0.05\ {\rm Mpc}^{-1})$

Detailed scale-dependence of the power spectrum can be more precisely probed in the future.

Strongly scale-dependent CMB dipole asymmetry from open inflationary supercurvature fluctuations

[C.Byrnes, G.Domènech, M.Sasaki, T.Takahashi 1610.02650]

- Model: $\mathcal{L} = -\frac{1}{2}(\nabla\phi)^2 - V(\phi) - \frac{1}{2}f^2(\sigma)(\nabla\chi)^2 - \frac{1}{2}m_\chi^2\chi^2 - \frac{1}{2}(\nabla\sigma)^2 - V(\sigma)$

Mixing between σ and χ

[Kanno, Sasaki, Tanaka 1309.1350]

ϕ : inflaton → Inflationary expansion

χ : curvaton → Curvature perturbation

σ : supercurvature mode → Power asymmetry w/strong scale dependence

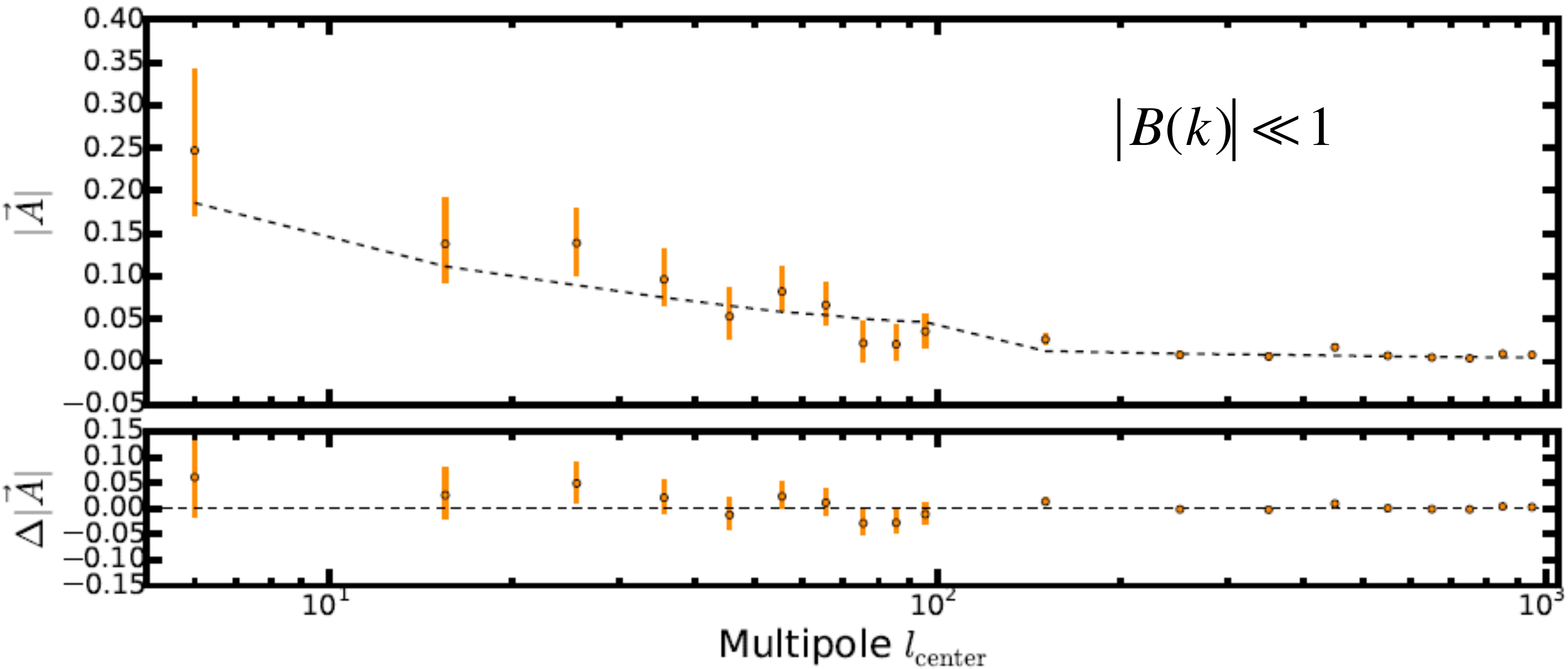
- Power spectrum: $P(k) = \frac{r_{\rm dec}^2}{9\pi^2}\frac{H^2}{\chi_*^2 f^2(\sigma_*)}\frac{(\chi'_{\rm osc})^2}{\chi_{\rm osc}^2}$

(Dipole and quadrupole asymmetries) $P(k) = P_{\rm iso}(k)\left(1 + 2A(k)\,\hat{\mathbf{n}}\cdot\hat{\mathbf{p}} + B(k)\,(\hat{\mathbf{n}}\cdot\hat{\mathbf{p}})^2\right)$

Observed scale-dependent power asymmetry

Aiola et al:1506.04405

$$P(k) = P_{\rm iso}(k)\left(1 + 2A(k)\,\hat{\mathbf{n}}\cdot\hat{\mathbf{p}} + B(k)\,(\hat{\mathbf{n}}\cdot\hat{\mathbf{p}})^2\right)$$



Dipole and quadrupole asymmetries

- Dipole asymmetry: $A(k) = \frac{\Delta \mathcal{P}_\zeta}{2\mathcal{P}_\zeta} = -\frac{\Delta\sigma}{\sigma}\frac{\sigma f_\sigma}{f}$
- Quadrupole asymmetry: $B(k) = \frac{\Delta^{(2)}\mathcal{P}_\zeta}{\mathcal{P}_\zeta} = \left(\frac{\Delta\sigma}{\sigma}\right)^2\left(3\frac{\sigma^2 f_\sigma^2}{f^2} - \frac{\sigma^2 f_{\sigma\sigma}}{f}\right)$

→ The scale-dependence comes from Δσ.

- $V(\sigma) = \frac{1}{2}m_\sigma^2\left(\sigma - \sigma_0\right)^2$ gives a slow-roll evolution for σ, but a strong scale scale-dependence for $\Delta\sigma$ at $\sigma \simeq \sigma_0$
- By assuming a simple form $f(\sigma) = \left(\frac{\sigma}{\sigma_0}\right)^\beta$, we obtain

$$A(k) \sim -\beta\frac{\Delta\sigma_0}{\sigma_0}\left(\frac{k}{k_0}\right)^{-\alpha} \quad \left(\beta = 1, \Delta\frac{\sigma_0}{\sigma_0} = 0.1\right)$$

$$B(k) = \left(\frac{\Delta\sigma}{\sigma}\right)^2\beta\left(2\beta+1\right) = A^2(k)\left(2+\beta^{-1}\right)$$

→

$$A(k) = 0.1(k/k_0)^{-1/2}$$

$$B(k) = 0.03(k/k_0)^{-1}$$

We can obtain large strongly scale-dependent dipole asymmetry, but small quadrupole asymmetry.

I. Schwinger effects in inflationary background

a. Fermionic Schwinger effect

Takahiro Hayashinaka, Tomohiro Fujita, Jun'ichi Yokoyama 1603.04165.

We studied creation of half-spin charged fermions under constant electric field in de Sitter space using the adiabatic regularization scheme.
As a result we found the induced current may become negative but unlike the cas of a charged scalar field, IR hyper conductivity is absent.

b. Point splitting regularization scheme

Takahiro Hayashinaka, Jun'ichi Yokoyama 1603.06172.

We then considered another regularization scheme, namely, point splitting metho for the case of a charged scalar field and compared with the adiabatic subtractio The result is in agreement with the adiabatic subtraction scheme. That is, IR hyp conductivity and negative induced current is not an artifact of regularization sche

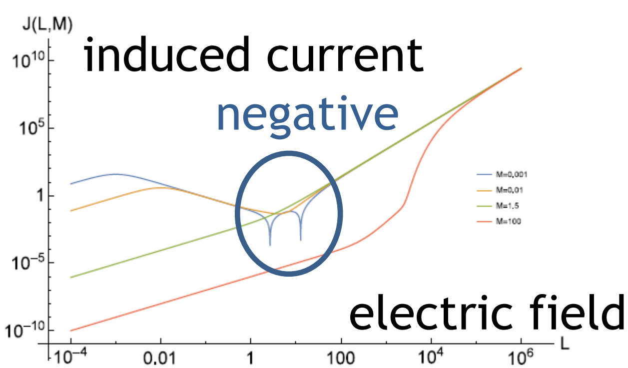
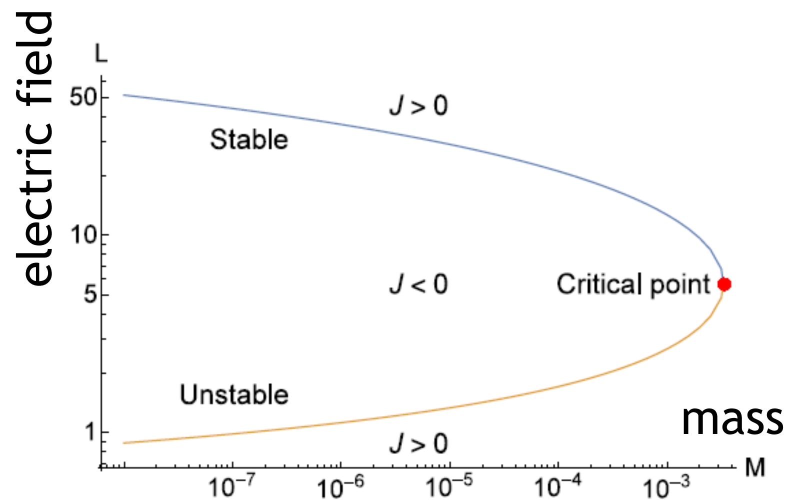


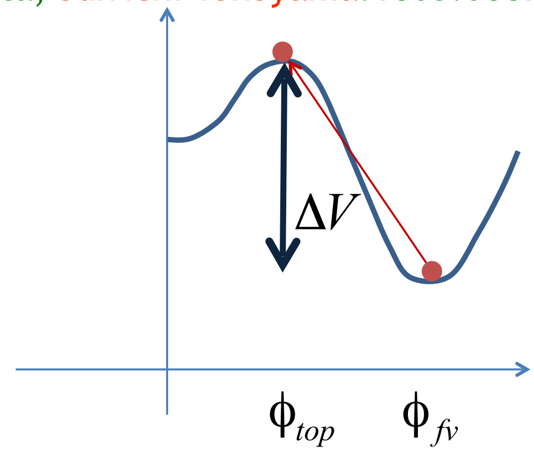
Figure 1. Absolute value of the renormalized current $J = \langle J \rangle / eaH^3$ is shown as a function of $L = eE/H^2$. Each line corresponds to different mass parameter $M = m/H$. Negative current is observed in $L = 1 \sim 10$ for $M = 0.001$ case.



II. Entropic interpretation of the Hawking-Moss bounce

Naritaka Oshita, Jun'ichi Yokoyama:1603.06671.

$$\Gamma_{\mathrm{fv}\to\mathrm{top}} = Ae^{-B_{\mathrm{HM}}} = A\exp\left[-I_{\mathrm{E}}(\phi_{\mathrm{top}}) + I_{\mathrm{E}}(\phi_{\mathrm{fv}})\right]$$
$$= A\exp\left[\frac{3}{8G^2}\left(\frac{1}{V(\phi_{\mathrm{top}})} - \frac{1}{V(\phi_{\mathrm{fv}})}\right)\right],$$



Thermal interpretation of Weinberg

$$B_{\mathrm{HM}} \simeq \frac{\Delta E}{T_{\mathrm{H}}}$$

$$\text{with } \Delta E = \frac{4\pi}{3}H^{-3}(\phi_{\mathrm{fv}})\Delta V \text{ and } T_{\mathrm{H}} = \frac{H(\phi_{\mathrm{fv}})}{2\pi}$$

This applies if and only if the difference of energy density is small, namely,

$$\Delta V/V(\phi_{\mathrm{fv}}) \equiv \left[V(\phi_{\mathrm{top}}) - V(\phi_{\mathrm{fv}})\right]/V(\phi_{\mathrm{fv}}) \ll 1$$

Euclidean action in ADM representation $d\tilde{s}^2 = N^2 d\tilde{t}^2 + h_{ij}(dx^i + \tilde{N}^i d\tilde{t})(dx^j + \tilde{N}^j d\tilde{t})$

$\tilde{\ } =$ Euclidean quantity

$$I_{\mathrm{E}}^{(\mathrm{G})} = -\frac{1}{16\pi G}\int_{\mathcal{M}} d^3x d\tilde{t}\sqrt{\tilde{g}}(\tilde{R} + 2\Lambda)$$
$$= \int d\tilde{t}\left[\int_{\Sigma_{\tilde{t}}} d^3x\left(\tilde{\pi}^{ij}\partial_{\tilde{t}}h_{ij} + N\tilde{\mathcal{H}}^{(\mathrm{G})} - \tilde{N}^i\tilde{\mathcal{H}}_i^{(\mathrm{G})}\right) - \int_{\mathrm{S}} d^2x\sqrt{\sigma}\left(\frac{n^i\partial_i N}{8\pi G} - \frac{2}{\sqrt{h}}n_i\tilde{N}_j\tilde{\pi}^{ij}\right)\right]$$

$$I_{\rm E}^{(\rm G)} = -\frac{1}{16\pi G}\int_{\mathcal{M}} d^3x d\tilde{t}\sqrt{\tilde{g}}\,(\tilde{R}+2\Lambda)$$

vanishes if static

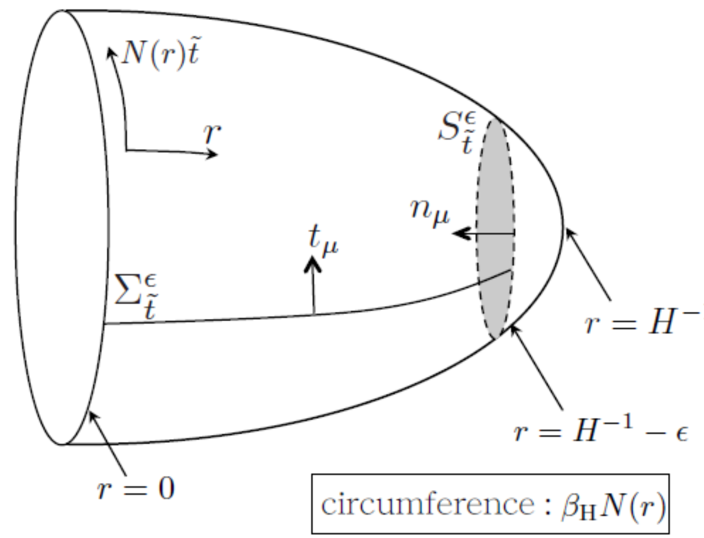
$$= \int d\tilde{t}\left[\int_{\Sigma_{\tilde{t}}} d^3x \boxed{\left(\tilde{\pi}^{ij}\partial_{\tilde{t}}h_{ij} + N\tilde{\mathcal{H}}^{(\rm G)} - \tilde{N}^i\tilde{\mathcal{H}}_i^{(\rm G)}\right)} - \int_{\rm S} d^2x\sqrt{\sigma}\left(\underline{\frac{n^i\partial_i N}{8\pi G}} - \frac{2}{\sqrt{h}}n_i\tilde{N}_j\tilde{\pi}^{ij}\right)\right]$$

only this surface term is relevant.

Calculate Euclidean de Sitter action using static coordinate

$$d\tilde{s}^2 = \tilde{g}_{\mu\nu}dx^\mu dx^\nu = \left(1-H^2r^2\right)d\tilde{t}^2 + \frac{dr^2}{1-H^2r^2} + r^2 d\Omega_{\rm II}^2$$

Introducing a hypothetical boundary near the horizon at $r = H^{-1} - \varepsilon$ and considering the condition that conical singularity is avoided, we find the surface contribution is given by



$$\lim_{\epsilon\to 0}\left[-\beta_H\int_{S_{\tilde{t}}^{\epsilon}} d^2x\sqrt{\sigma}\frac{n^i\partial_i N}{8\pi G}\right] = -\frac{A}{4G}, \qquad A \equiv \int_{S_{\tilde{t}}^{\epsilon}} d^2x\sqrt{\sigma}\bigg|_{\epsilon=0} = \frac{4\pi}{H^2}$$

horizon area

$$\lim_{\epsilon\to 0} n^i\partial_i\left[\beta N\right] = \beta H = 2\pi$$

Thus

$$I_{\rm E}^{(\rm tot)}(\phi_{\rm s}) = \underline{-\frac{A(\phi_{\rm s})}{4G}} = \frac{\pi}{GH^2} = \frac{3}{8G^2V(\phi_{\rm s})}$$

Entropy contribution only!

$$e^{-\frac{F}{T}} = e^{-\frac{E-TS}{T}} = e^S = W \text{ since } E = 0$$

Nonlocal N=1 Supersymmetry

Tetsuji Kimura, Anupam Mazumdar, Toshifumi Noumi, Masahide Yamaguchi, JHEP 1610 (2016) 022

Scalar fields play important roles in cosmology and particle physics.

$\Downarrow$

What is the most general theory including a scalar field without ghost instabilities ?

A higher derivative theory generally leads to ghost instabilities (Ostrogradski ghosts).

One of them is ghost

N.B. $\frac{\partial L}{\partial \phi} - \partial_\mu \left(\frac{\partial L}{\partial(\partial_\mu \phi)} \right) + \partial_\mu \partial_\nu \left(\frac{\partial L}{\partial(\partial_\mu \partial_\nu \phi)} \right) = 0. \Rightarrow \frac{i}{(p^2+m_1^2)(p^2+m_2^2)} = \frac{1}{m_2^2 - m_1^2}\left(\frac{i}{p^2+m_1^2} - \frac{i}{p^2+m_2^2} \right).$

(propagators)

Loophole: ① **A degeneracy theory like Galileon, Horndeski:**

② **To consider infinitely many higher derivatives (nonlocal theory):**

e.g. $e^{-\Box/\Lambda^2}(\Box - m^2)\phi = 0. \Rightarrow \frac{i}{e^{p^2/\Lambda^2}(p^2+m^2)}$ Only a pole of propagator appears with $p^2 = m^2$.

(e.g. Biswas, A. Mazumdar, W. Siegel 2006)

$\mathcal{N}$ = 1 (global) supersymmetric nonlocal theories in four dimension

($S = \int d^4x \, [\phi \, f(\Box)\phi^* - V(\phi, \phi^*)]$ $\Longrightarrow$ Supersymmetrization)

(Personal) motivation or question:

- Is it possible to construct (consistent) (global) SUSY nonlocal theories ?

  In which case does an auxiliary field F remain non-dynamical ?

- How is the mass (trace) formula (at tree level) modified ?

e.g. chiral multiplet

Off-shell:

φ(2), F(2) ⟷ ψ(4)

On-shell:

φ(2), F(0) ⟷ ψ(2)

$$\mathrm{STr}\, M^2 = \sum_J (-1)^{2J}(2J+1)m_J^2 = 0.$$

(even after SUSY breaking for a usual SUSY theory)

Summary

- We have constructed N = 1 supersymmetric non-local theory in four dimensions.

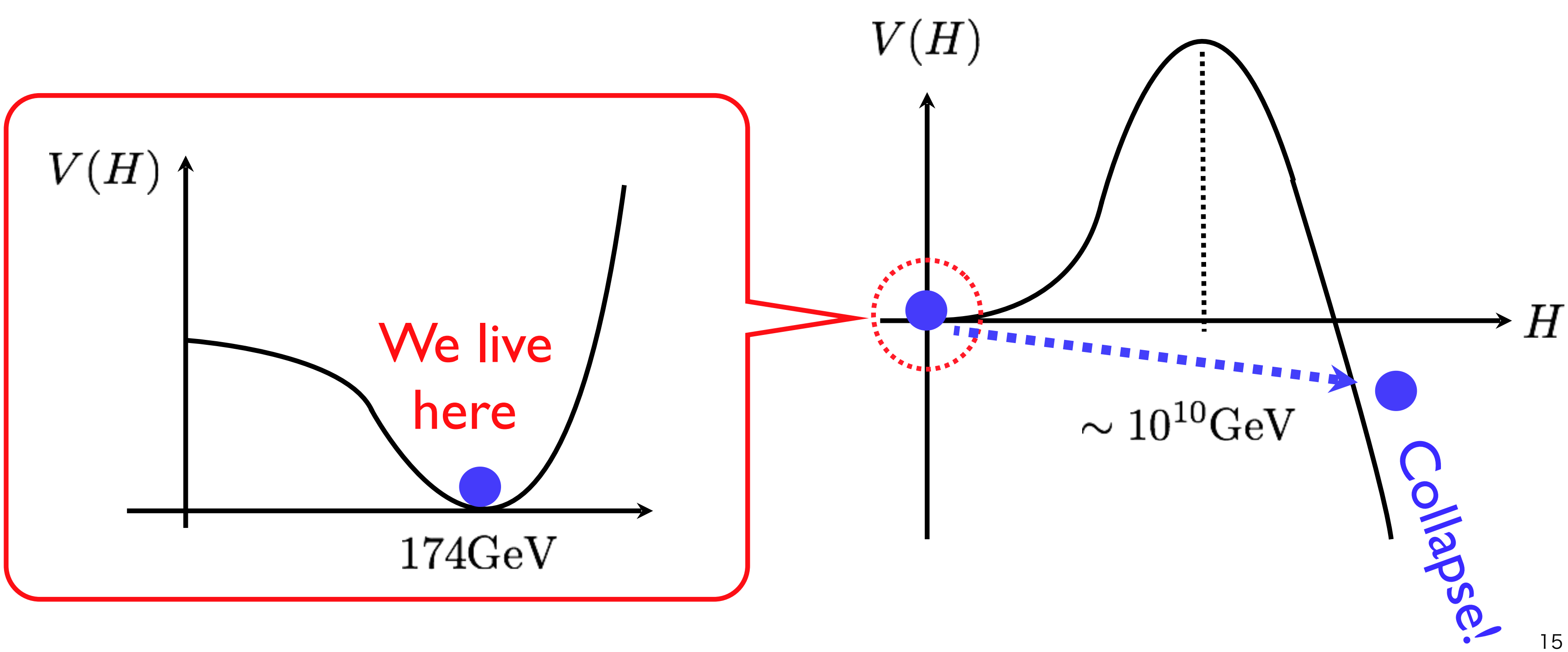
- We have derived the condition, in which an auxiliary field F remains non-dynamical, and the dynamical scalars and fermions are free from the ghost degrees of freedom.

- The mass formula is significantly modified.

Electroweak Vacuum Stability

Ema, Mukaida, Nakayama, 1602.00483

- Higgs boson is discovered at LHC. (Mass ~ 125GeV)
- Due to renormalization running, Higgs potential becomes negative at high energy.
- The present vacuum is meta-stable !



Higgs instability after inflation

- Higgs-inflaton coupling : (Mandatory to suppress de Sitter fluctuation)

$$\mathcal{L} \sim -c^2\phi^2|H|^2 \qquad \phi \ : \ \text{inflaton}$$

$$\mathcal{L} \sim \xi R|H|^2 \qquad R \ : \ \text{Ricci curvature}$$

$\longrightarrow$ **Parametric resonance of Higgs fluctuation during reheating**

- Higgs-inflaton couplings are constrained to avoid collapse of the vacuum

$$\boxed{\begin{gathered} 4\times 10^{-6} \lesssim c \lesssim 10^{-4} \\ \text{or} \quad 1 \lesssim \xi \lesssim 10 \end{gathered}}$$

Ema, Mukaida, Nakayama, 1602.00483

Massive Gravity?

The idea of massive gravity

- Gauge theory:

  Higgs VEV spontaneously breaks gauge symmetry

  ⇨ massive gauge field

- Gravity:

  Spontaneous broken general covariance

  ⇨ massive gravitons

dRGT gravity

Boulware-Deser (BD) ghost
must be removed

spin 2 = 2+2+1 (+1) dof
(tensor+vector+scalar)

This assumes however Poincare symmetry on flat background.
If $\exists$ no background, covariance should NOT be violated.

Spontaneous broken local Lorentz invariance
= existence of a preferred frame

⇨ massive tensor modes!?
(helicity 2)

Dubovsky's model

Dubovsky 2004

- 4 scalar (Stuckelberg) fields: $\varphi^a = (\varphi^0, \ \varphi^i)$

$$ds^2 = \eta_{ab} e_\mu^{(a)} e_\nu^{(b)} dx^\mu dx^\nu \ : \quad e_\mu^{(a)} \to \bar{e}_\mu^{(a)} = \Lambda^a{}_b(x) e_\nu^{(b)}, \quad \Lambda^a{}_b \in SO(3,1)$$

- VEV spontaneously breaks local SO(3,1) symmetry

$$e_\mu^{(a)} = \frac{\partial \varphi^a}{\partial x^\mu} : \ \varphi^a = \delta_\mu^a x^\mu \to e_\mu^{(a)} = \delta_\mu^a$$

- required symmetry (Poincare symmetry is not imposed)

$$\varphi^i \to \Lambda^i_j \varphi^j, \quad \varphi^i \to \ \varphi^i + \xi^i(\varphi^0); \quad \Lambda^i_j \in \text{global } SO(3)$$

- action: $S = \dfrac{M_P^2}{2} \int d^4x \left[R + m_g^2 f(X, Z^{ij}) \right]$ 2+1 dof (tensor+scalar)

$$X = g^{\mu\nu} \partial_\mu \varphi^0 \partial_\nu \varphi^0 = g^{00} = N^{-2}$$

Lapse fcn.

3-metric

$$Z^{ij} = g^{\mu\nu} \partial_\mu \varphi^i \partial_\nu \varphi^j - \frac{g^{\mu\alpha} \partial_\mu \varphi^0 \partial_\alpha \varphi^i g^{\nu\alpha} \partial_\nu \varphi^0 \partial_\beta \varphi^j}{X} = h^{ij}$$

only φ^0 becomes dynamical

Inflationary massive gravity: minimal model

- Identify φ^0 with inflaton: $\phi = \varphi^0$

$$S = \int d^4x \left[\frac{M_P^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) - \frac{9}{8} M_P^2 m_g^2(\phi) \frac{\delta Z^{ij} \delta Z^{ij}}{Z^2} \right]$$

$$\delta Z^{ij} = Z^{ij} - 3 \frac{Z^{ik} Z^{kj}}{Z}; \quad Z = Z^{ii}$$

$$\text{assumption:} \begin{cases} m_g^2 = H^2 & \text{during inflation} \\ m_g^2 = \frac{1}{2} \lambda \phi^2 & \text{during reheating} \end{cases}$$

- Symmetry:

$$\varphi^i \to \Lambda^i_j \varphi^j, \quad \varphi^i \to \lambda \varphi^i; \quad \Lambda^i_j \in \text{global } SO(3), \ \lambda = const.$$

These symmetries guarantees φ^i to be non-dynamical.

$$\because \quad \varphi^i = x^i + \delta\varphi^i : \quad \delta\varphi^i = w^{ij}(t) x^j + v(t) x^i + O(1), \quad w^{ij} = -w^{ji}$$

at leading order in gradient expansion

tensor spectrum

- during inflation $0 < m_g^2 = H^2$

$$P_T(k) = \frac{2H^2}{\pi^2 M_P^2}\left(\frac{k}{k_f}\right)^{2m_g^2/3H^2}$$ at the end of inflation $k_f = a(t_f)H(t_f)$

spectral index: $n_T \approx -2\varepsilon + \dfrac{2m_g^2}{3H^2};\ \varepsilon = -\dfrac{\dot{H}}{H^2}$

if $\dfrac{m_g^2}{3H^2} > \varepsilon$, blue-tilted!

- Lyth bound

$\Delta\phi\ ;\ 15M_P r^{1/2}$: distance traveled by ϕ during inflation

$r = \dfrac{P_T(k)}{P_S(k)};\ 16\varepsilon$ for standard slow-roll inflation

if $r > 0.001$, ϕ travels more than Planck distance

beyond validity of QFT?

resonant GW amplification

Lin & MS '15

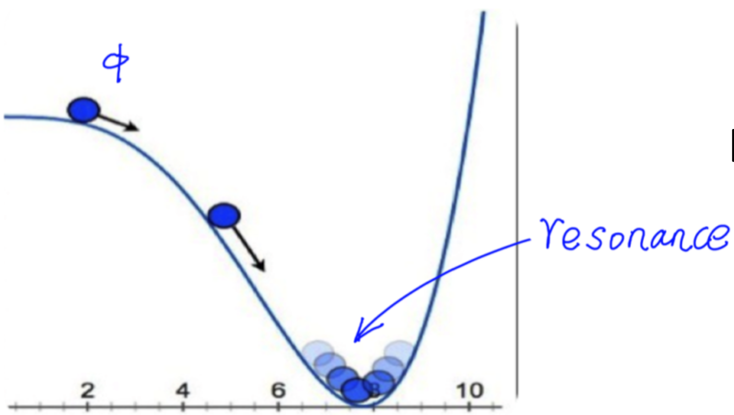
$$m_g^2 = \frac{1}{2}\lambda\phi^2;\ \phi = \phi_f \left(\frac{a_f}{a}\right)^{3/2} \sin(Mt + \theta) e^{-\Gamma Mt}$$ after inflation

M : inflaton mass

ΓM : decay (reheating) rate

- Mathiew-like eq. for $k/a << H < m_g$

$$\ddot{\gamma}_k + 3H\dot{\gamma}_k + \left(m_g^2(\phi) + \cancelto{0}{\frac{k^2}{a^2}} \right)\gamma_k = 0$$

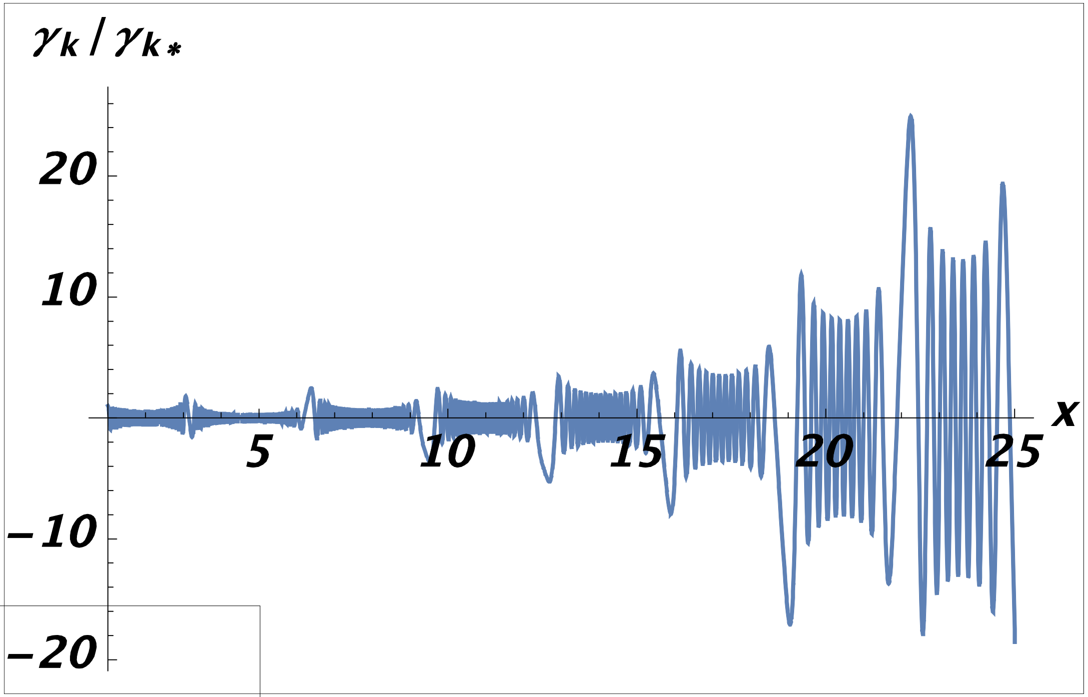


$$\left[\frac{d^2}{dx^2} + \frac{2}{x}\frac{d}{dx} + \frac{\xi e^{-\Gamma x}}{x^2}\sin^2(x) \right]\gamma_k = 0$$

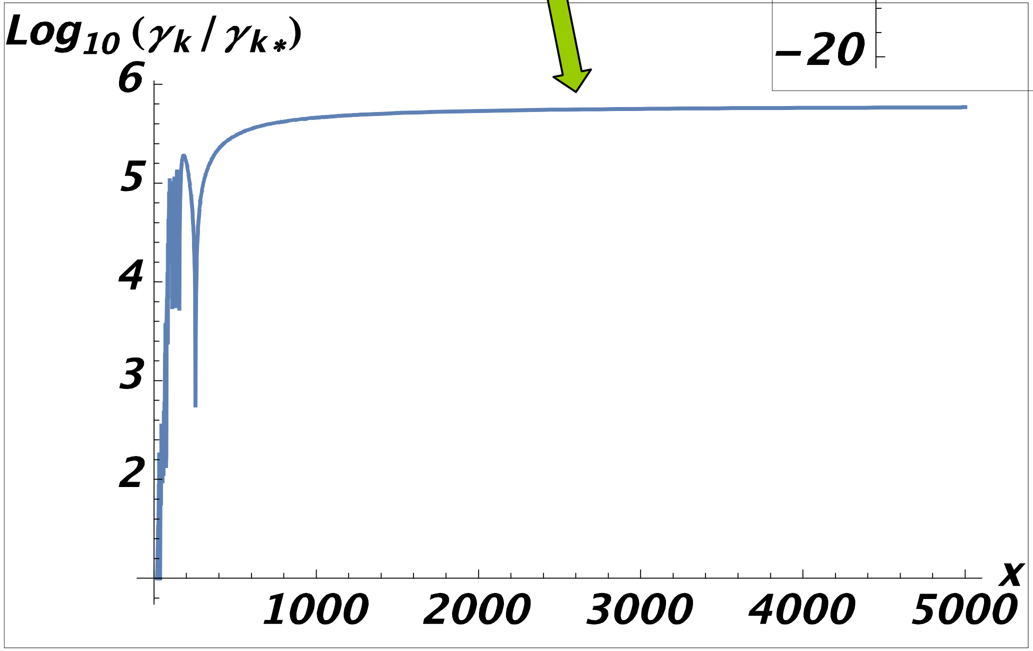
$$x = Mt,\ \xi = \frac{\lambda\phi_f^2}{3\pi M^2}$$

broad parametric resonance for $\dfrac{\xi e^{-\Gamma Mx}}{x^2} \gg 1$

broad parametric resonance



amplified by
a factor ~ 10^6!



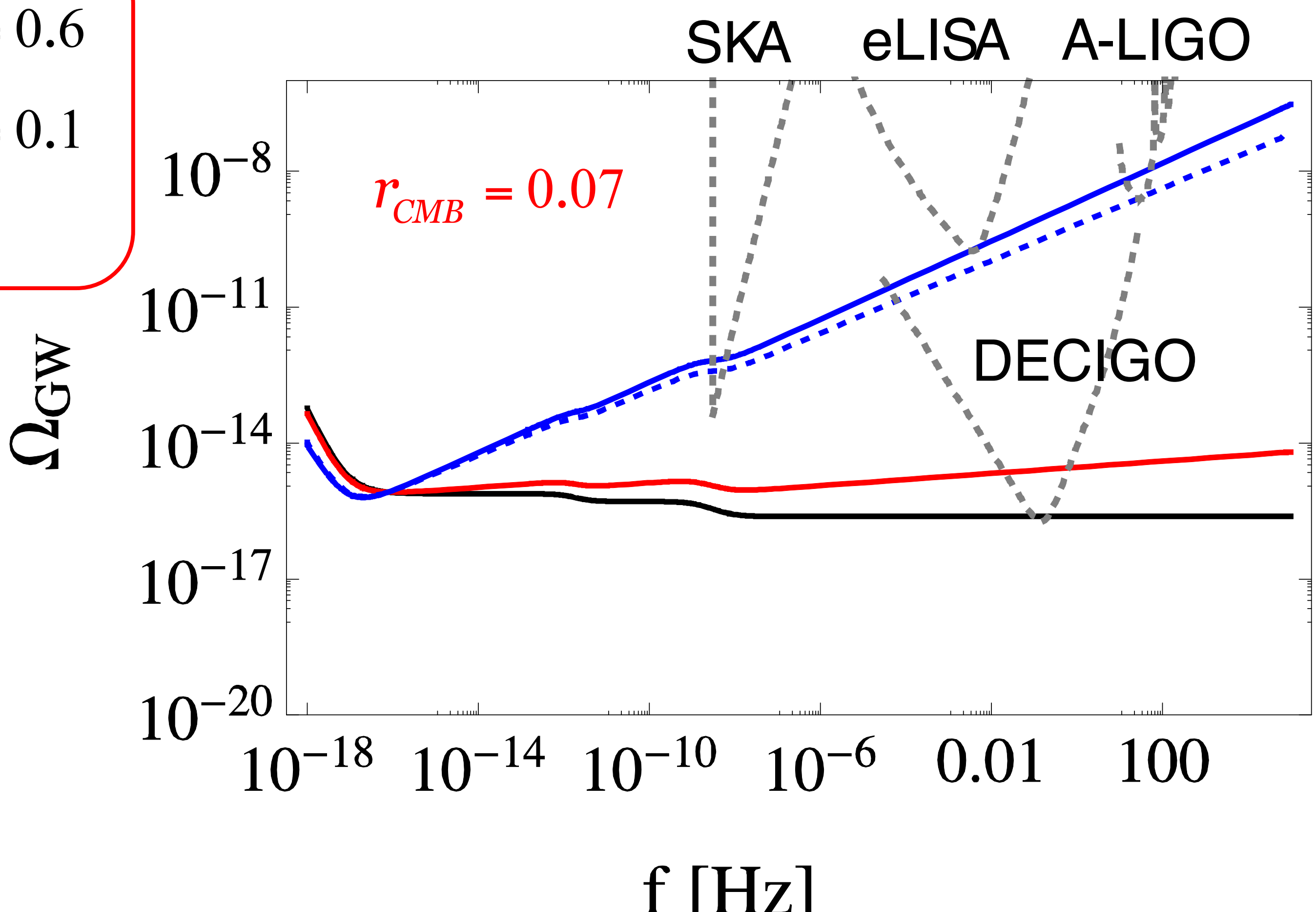
$$\xi = \frac{\lambda \phi_f^2}{3\pi M^2} = 10^6, \ \Gamma = 0.05$$

detectable blue-tilted GW spectrum

Kuroyanagi, Lin, MS & Tsujikawa '17 (in prep)

- (blue) : $m_g^2 / H^2 = 0.6$
- (red) : $m_g^2 / H^2 = 0.1$
- (black) : $n_T = 0$

$$n_T \approx \frac{2m_g^2}{3H^2}$$



non-Gaussianity?

Domenech, Hiramatsu, Lin, MS, Shiraishi & Wang '17

- 3rd order Hamiltonian in $\delta\phi = 0$ spatially isotropic gauge:

$$H_{\rm int} = -L_{\rm int} \supset \lambda_{SST} M_P^2 \varepsilon \int d^3x \; a \; \gamma_{ij} \partial_i \mathcal{R}_c \partial_j \mathcal{R}_c + \cdots$$

$$\lambda_{SST} = \frac{m_g^2}{4\varepsilon H^2} + \lambda$$

$$\propto \delta Z^{ij} \nabla^\mu \varphi^i \nabla^\nu \varphi^j \partial_\mu \phi \partial_\nu \phi$$

coupling term that could appear in low-energy EFT from (unknown) UV physics

- 3-pt fcn:

$$\left\langle \gamma^{-s}_{\boldsymbol{k}_1} \mathcal{R}_{\boldsymbol{k}_2} \mathcal{R}_{\boldsymbol{k}_3} \right\rangle = (2\pi)^3 \delta^{(3)}\left(\sum \boldsymbol{k}_i\right) \frac{\lambda_{SST} H^4}{4\varepsilon M_P^4} \frac{e^s_{ij} k_{2i} k_{3j}}{\prod k_i^3} \left(k_t - \frac{\sum_{i<j} k_i k_j}{k_t} - \frac{k_1 k_2 k_3}{k_t^2} \right)$$

$$k_t = k_1 + k_2 + k_3$$

dominates CMB 3-pt fcn if $\lambda_{SST} >> 1$

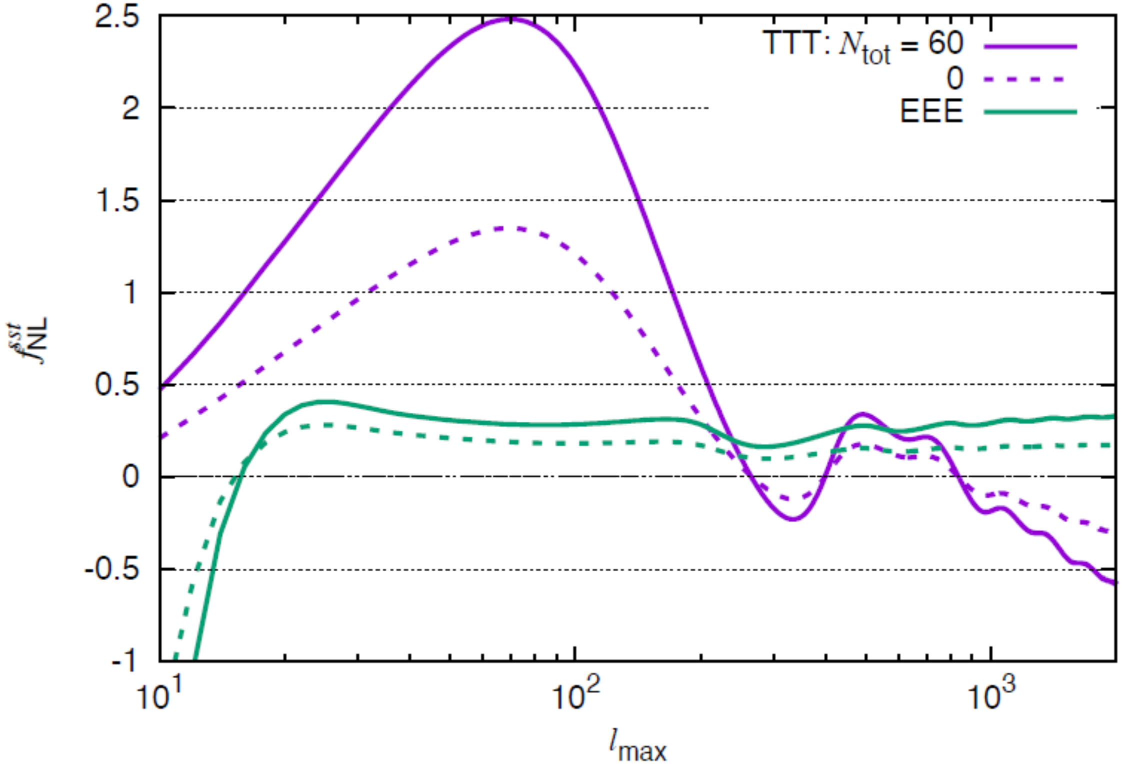
scale-dependent non-Gaussianity

$$\langle \delta T \delta T \delta T \rangle \propto \langle \gamma_{ij} \partial_i \mathcal{R}_c \partial_j \mathcal{R}_c \rangle$$

$\gamma_{ij} \propto a^{-1}$ after horizon re-entry

small scale modes re-enters horizon earlier

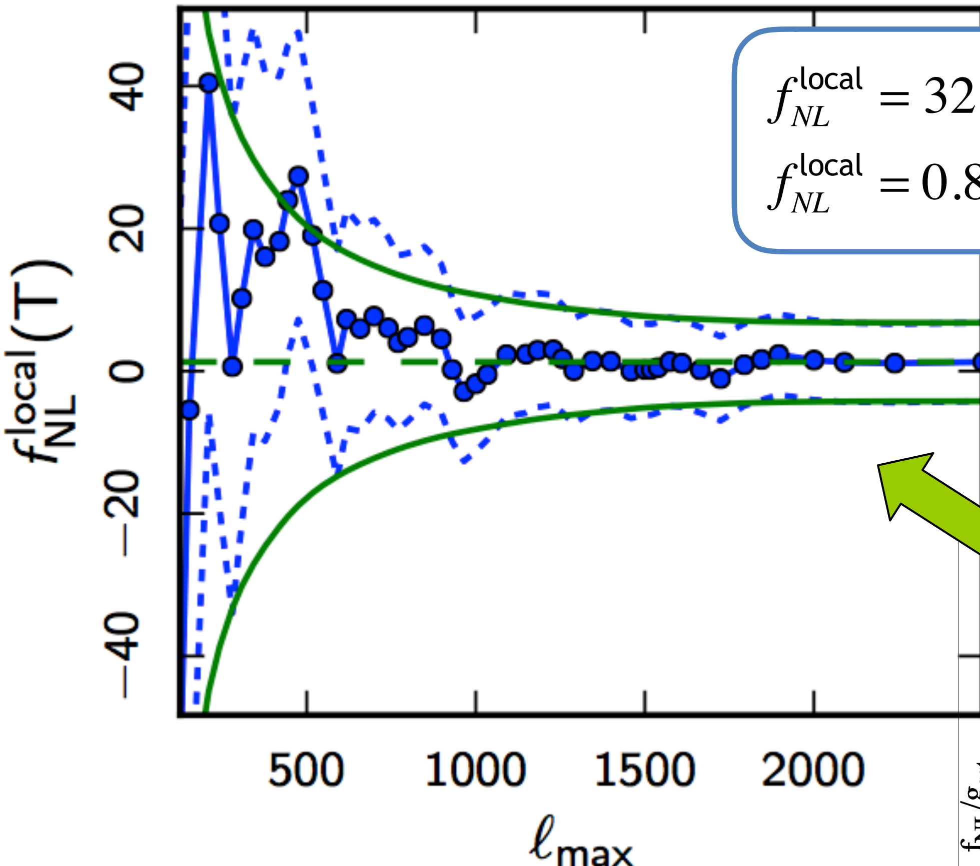
➡ large ℓ multipoles are suppressed



ℓ_{max} dependence of f_{NL}^{local}

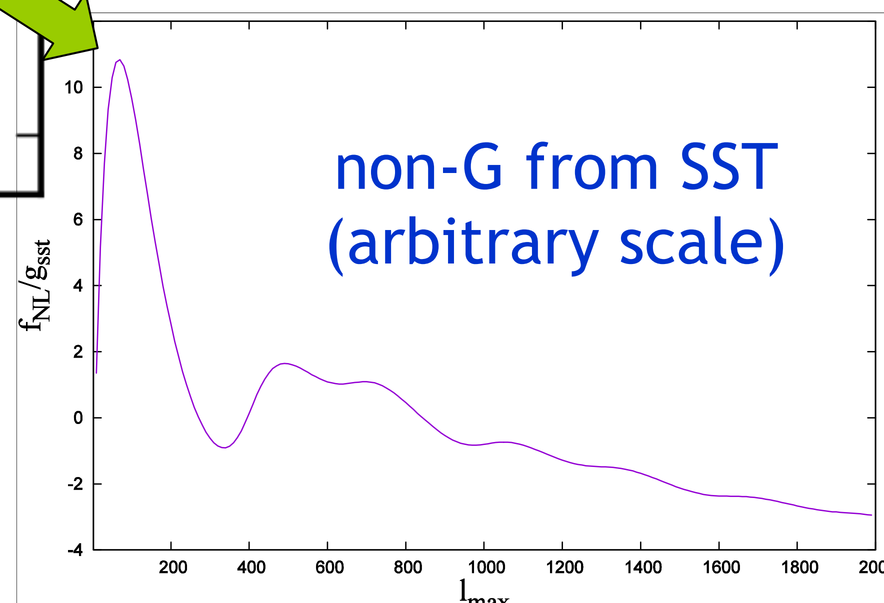
$\lambda_{SST} = 100, \ \varepsilon = 0.01$

WMAP 2010/Planck 2015



$$f_{NL}^{\text{local}} = 32 \pm 21 \quad \text{for} \quad \ell_{\max} \sim 500 \quad \text{WMAP 2010}$$

$$f_{NL}^{\text{local}} = 0.8 \pm 5.0 \quad \text{for} \quad \ell_{\max} \sim 2500 \quad \text{Planck 2015}$$



Summary

- ➢ Inflation is a natural platform for modified gravity

  Inflation = scalar-tensor theory

- ➢ GW (tensor mode) can become massive during inflation without encountering BD ghost problem

  symmetry: $\varphi^i \to \Lambda^i_j \varphi^j,\ \varphi^i \to \lambda \varphi^i;\ \Lambda^i_j \in SO(3),\ \lambda = const.$

- GW can be parametrically amplified during reheating evading Lyth bound even if $r > 0.001$

- GW spectrum may be blue-tilted

  primordial GW may be detectable by LIGO/Virgo/KAGRA…

  Sachiko Kuroyanagi, Chunshan Lin, MS, Shinji Tsujikawa, in prep.

- 3rd order int can give rise to sizable scale-dependent non-Gaussianity

$\exists$ already a hint in WMAP/Planck data ⇨ $\boxed{\text{needs further tests!}}$

Guillem Domenech, Chunshan Lin, MS, in prep.