Pure Natural Inflation

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Refs

Y. Nomura, T. Watari + Y 1706 hep-ph

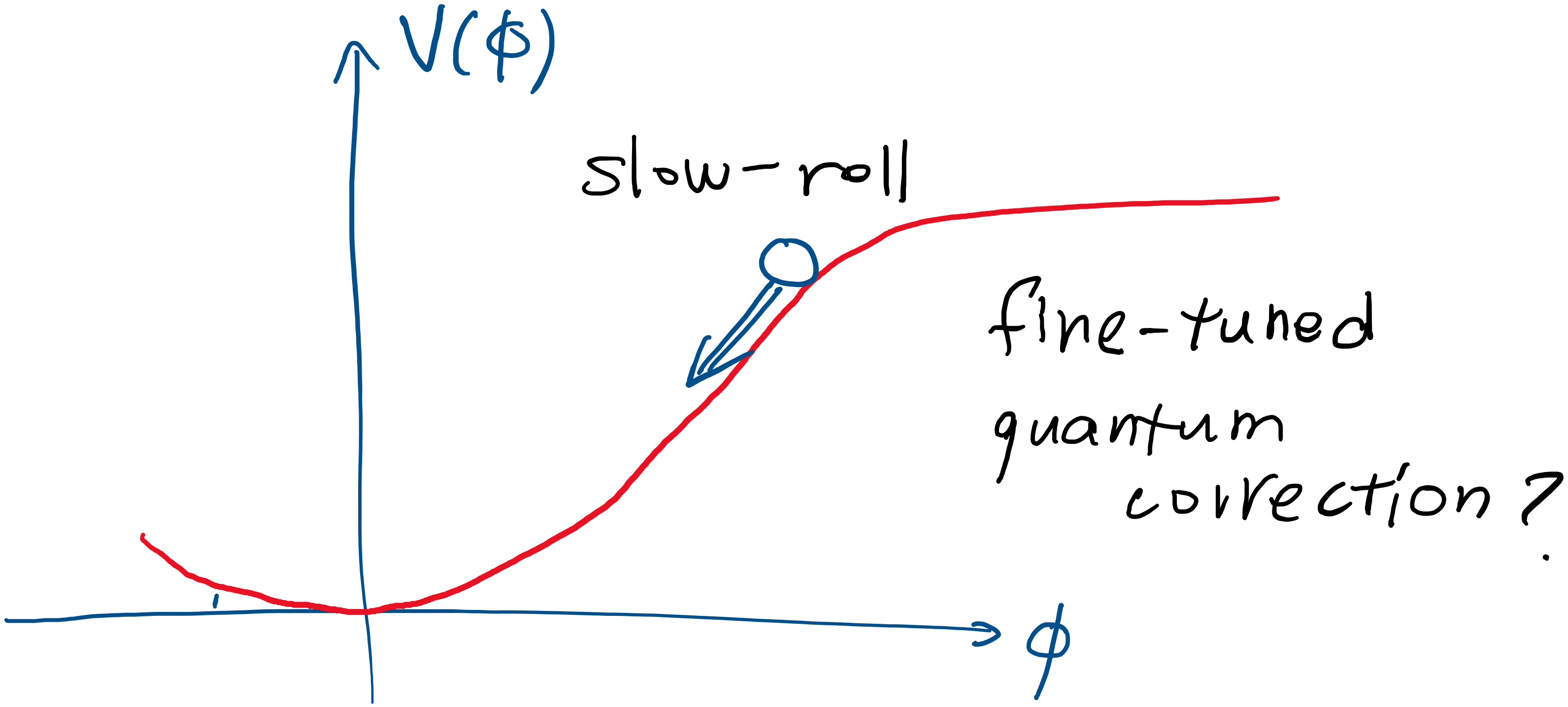
Y. Nomura + Y 1711 hep-ph

J.-P Hong, M. Kawasaki + Y 1711 astro-ph

cf. K. Yonekura + Y 1704 hep-th

inflationary paradigm — successful

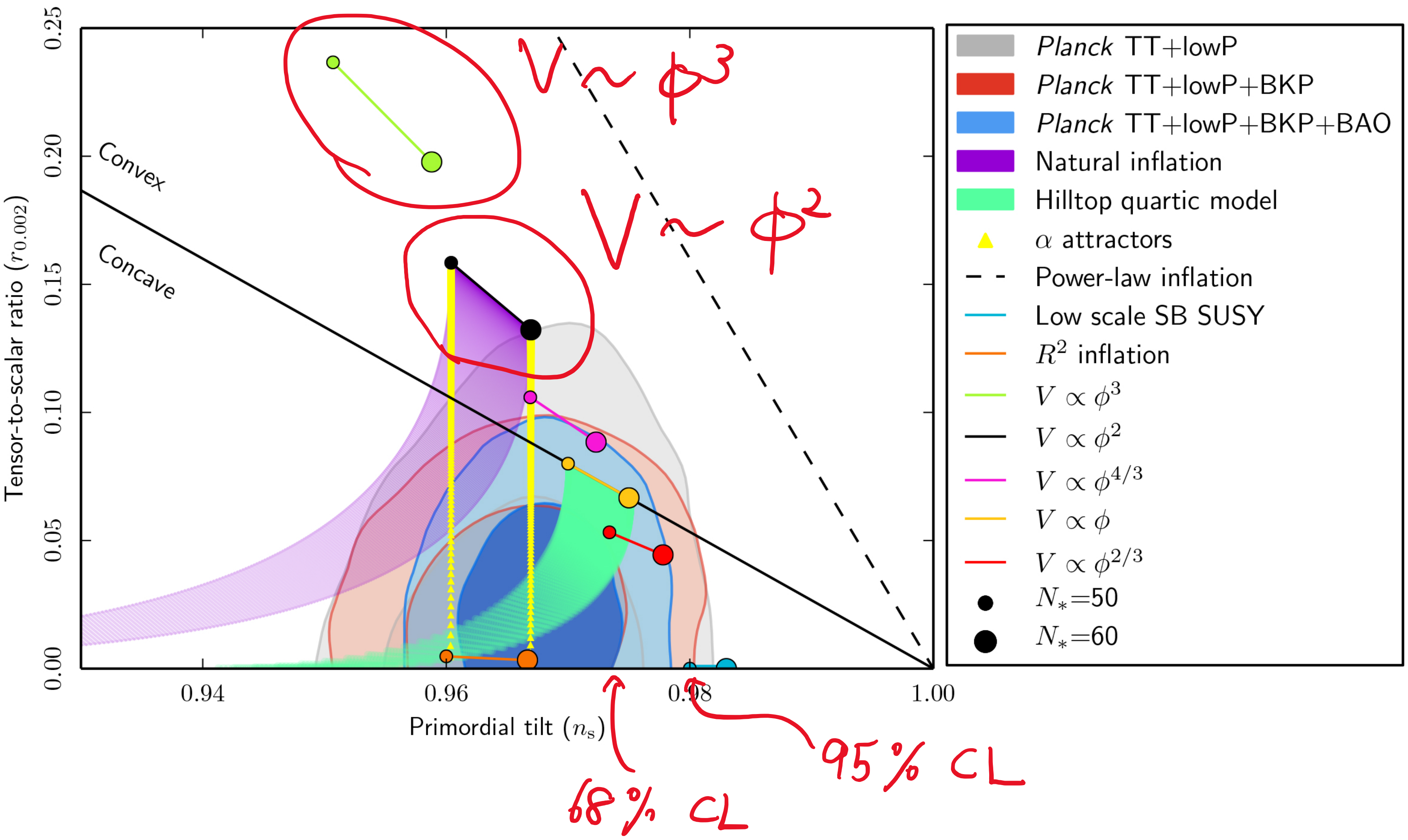
but which inflaton potential ?



"simplest" choices,

$V(\phi) = \phi^2, \phi^4$ disfavored!

[Planck 2015]



* inflaton ϕ as axion

$$\mathcal{L} \supset \frac{1}{32\pi^2} \underbrace{\frac{\phi}{f}}_{\text{dynamical } \theta\text{-angle}} \underbrace{\mathrm{Tr}\, F_{\mu\nu} \tilde{F}^{\mu\nu}}_{\text{top. term in pure Yang-Mills}}$$

decay constant

$$\theta = \frac{\phi}{f}$$

* inflaton as axion

$$\mathcal{L} \supset \frac{1}{32\pi^2} \underbrace{\frac{\phi}{f}}_{\substack{\text{dynamical} \\ \theta\text{-angle}}} \mathrm{Tr}\, F_{\mu\nu} \tilde{F}^{\mu\nu} \qquad \left[\theta = \frac{\phi}{f} \right]$$

* perturbatively $V(\phi) = 0$ $\quad [\, \phi \to \phi + c \ \text{sym.} \,]$

  non-perturbatively

$$V(\phi) = \underbrace{\underbrace{\Lambda^4}_{\text{"dynamical scale"}} \left(1 - \cos\frac{\phi}{f} \right)}_{1\text{-inst.}} + \underbrace{\cdots\cdots}_{\text{multi-inst.}}$$

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  non-perturbatively

$$V(\phi) = \underbrace{\Lambda^4 \left(1 - \cos\frac{\phi}{f}\right)}_{\text{1-inst.}} + \underbrace{\cdots\cdots}_{\text{multi-inst.}}$$

"dynamical scale"

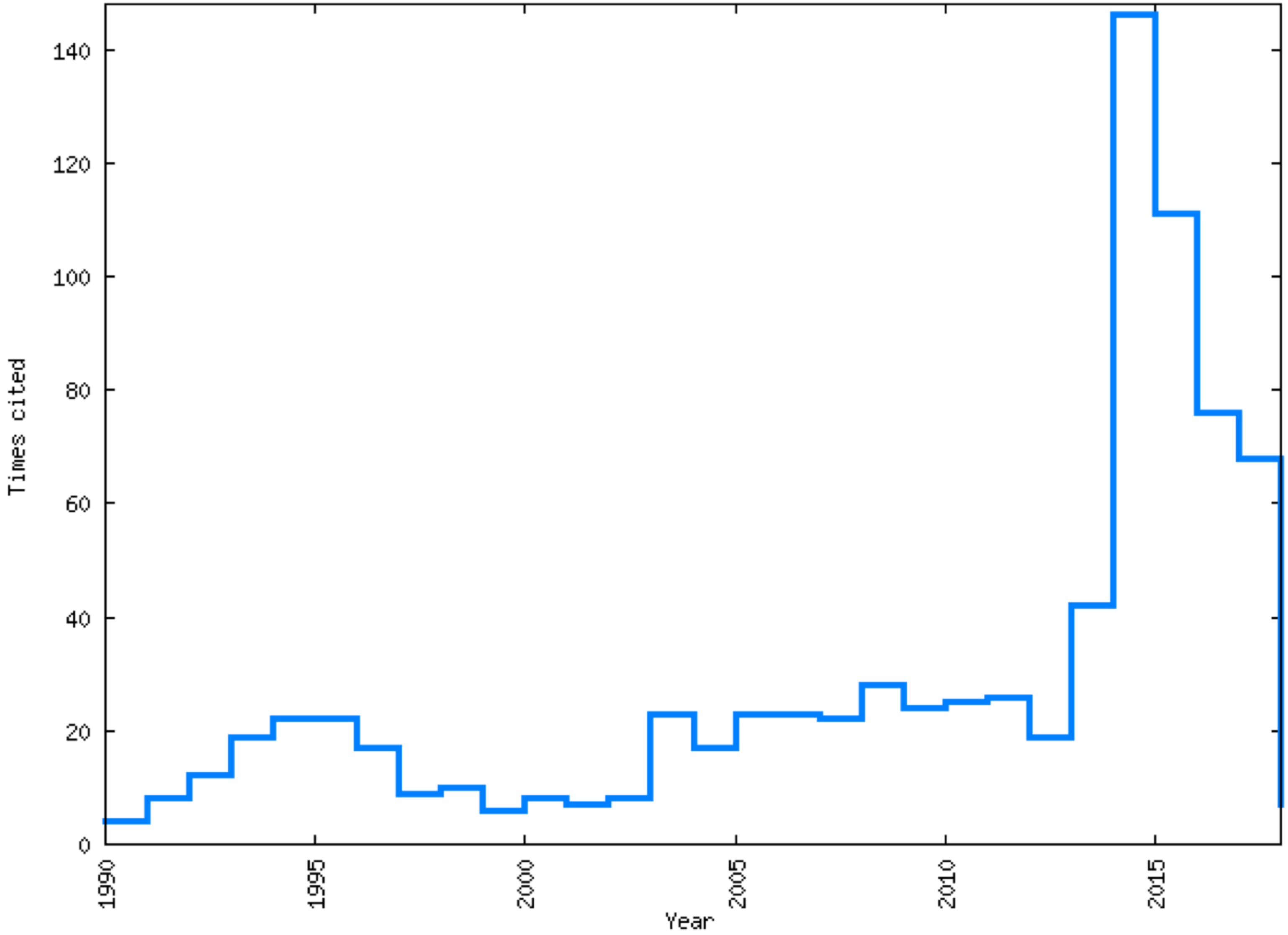
☺ flatness $(\phi \to \phi + c)$

☺ EFT $(\Lambda \ll M_{UV})$

☺ rather simple

☺ 1-parameter extension of $V \sim \phi^2$

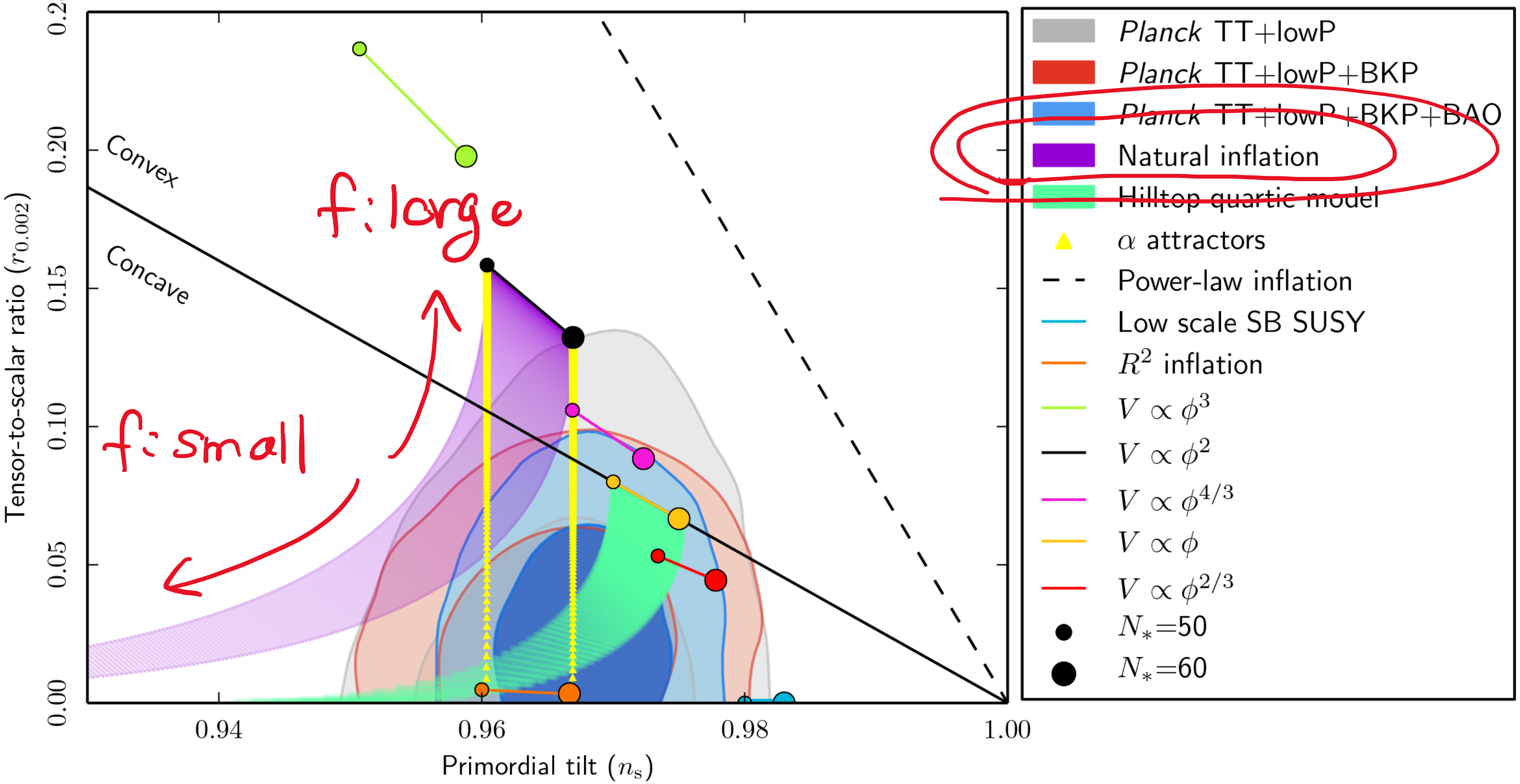
Citation counts of [Freese, Frieman, Olinto '90]
(natural inflation)



$$V(\phi) = \Lambda^4 \left[1 - \cos\left(\frac{\phi}{f}\right) \right]$$

☹ being disfavored by observations

[Planck 2015]



$$V(\phi) = \Lambda^4 \left[1 - \cos\left(\frac{\phi}{f}\right) \right] + \cdots$$

☹ theoretically **NOT CORRECT!**

(at least for pure YM @ $T = 0$)

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☹ theoretically NOT CORRECT!

(at least for pure YM @ $T=0$)

※ YM theory ; classically scale-invariant

IR problem : instanton gives divergent answer

large N

known since

[Witten '79, '81, ... '98]

holography

more recently

[Dubovsky - Lawrence - Roberts '11]

lattice

[Giusti - Petrorca - Taglienti '07]

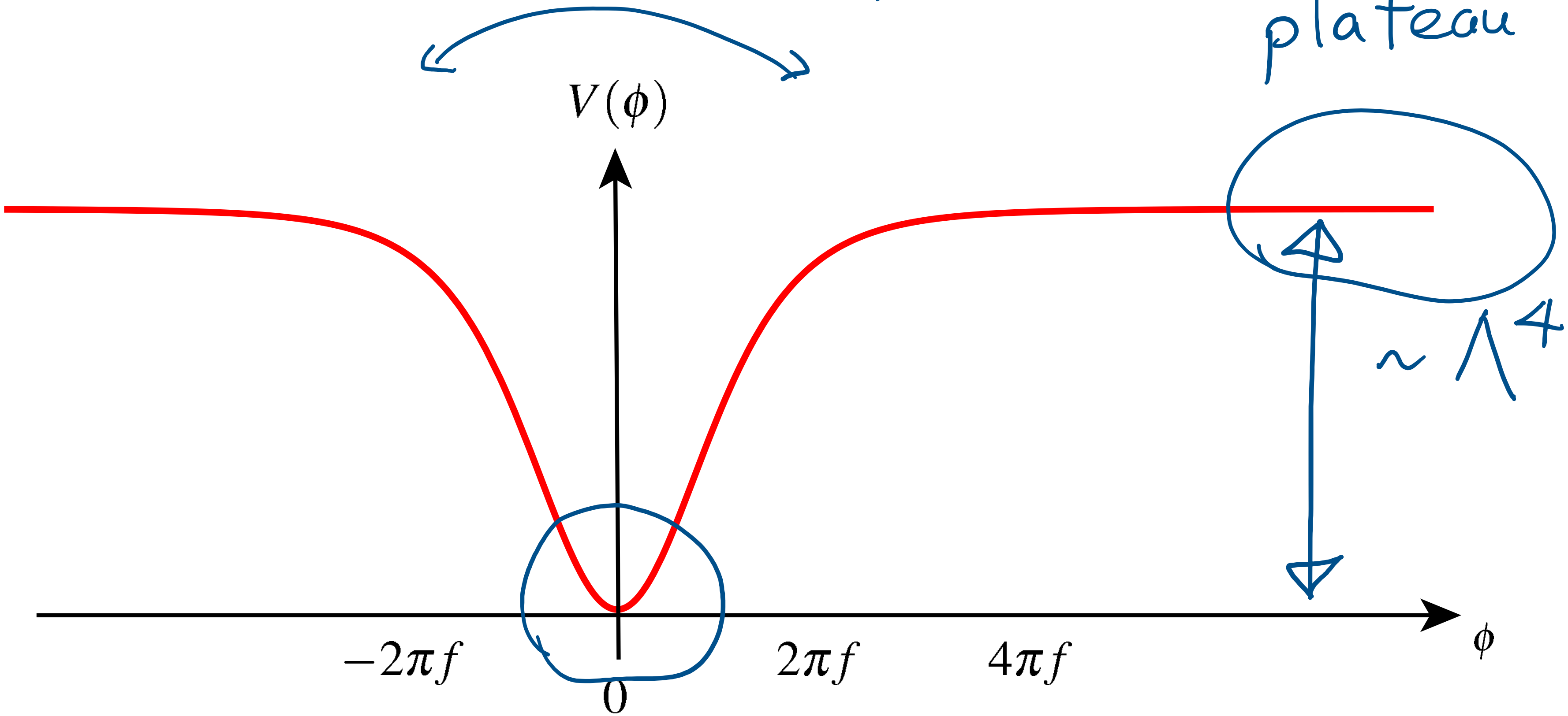
, ...

expected form of $V(\phi)$

[recall $\phi = \theta f$]

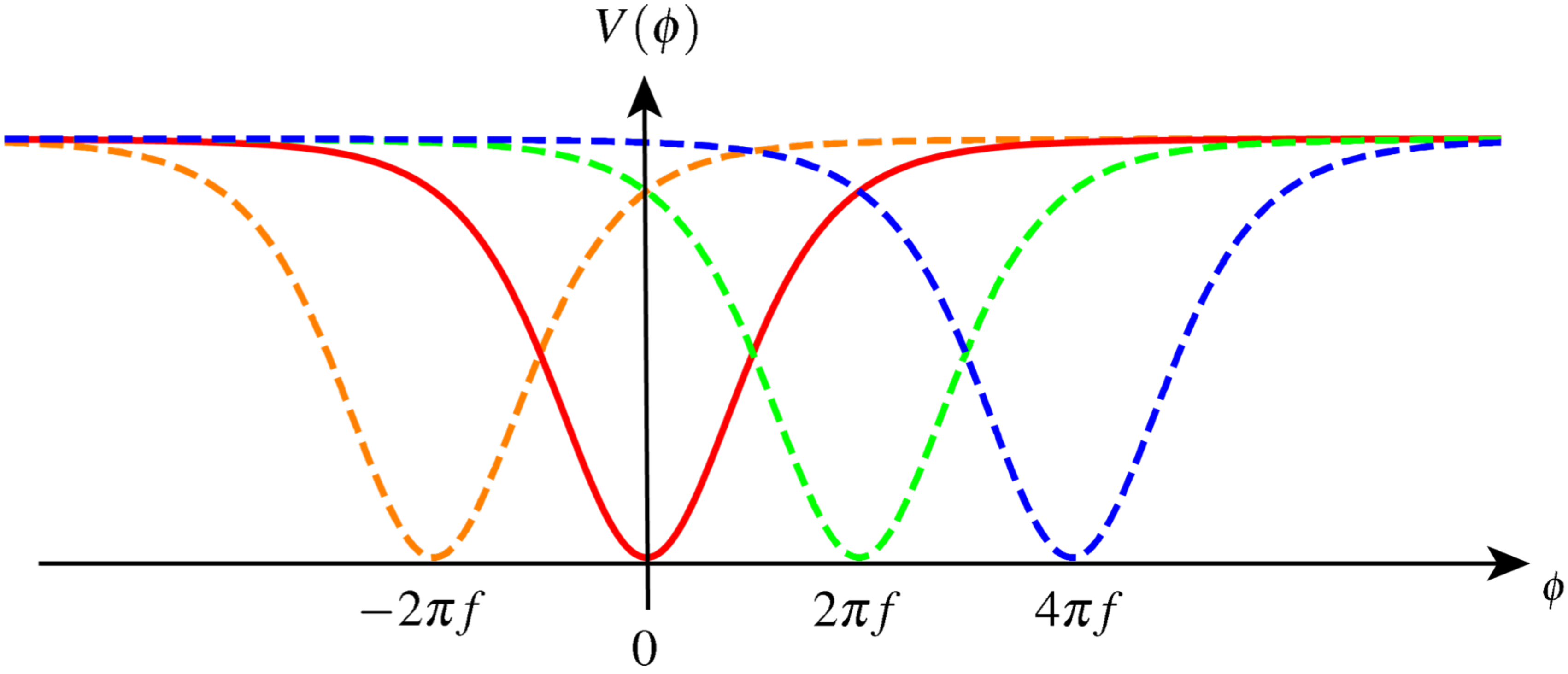
CP sym $\phi \to -\phi$

plateau



$V \sim \phi^2$

periodicity in θ recovered by
multiple metastable branches



[a version of monodromy inflation
Silverstein - Westphal ('08), Kaloper - Lawrence - Sorbo ('11), ...]

※ beaware tunneling in different branches

Our potential

[Nomura - Watari - Y '17]

$$V(\phi) = \underbrace{M^4}_{\text{overall scale}} \left[1 - \left(1 - \left(\frac{\phi}{\underbrace{F}_{\text{"effective" decay const. } (F \sim f)}} \right)^2 \right)^{-p} \right]$$

p ← power parametrize (strong-coupling effects)

☺ CP sym $\phi \to -\phi$ ☺ $V \sim \phi^2$ near $\phi \sim 0$

☺ $V(\phi) \longrightarrow$ const. at $\phi \to \pm\infty$

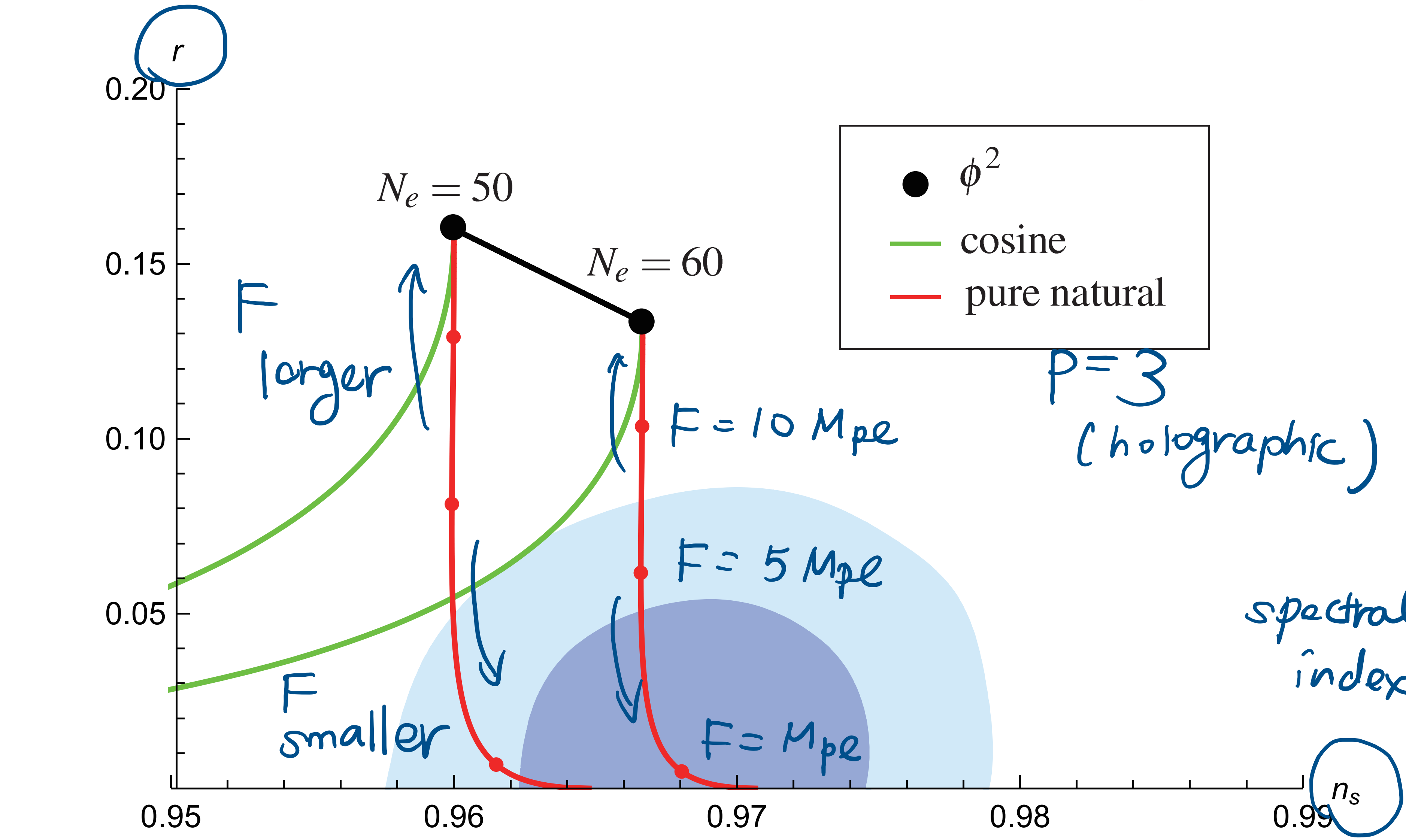
☺ $p=3$ for holographic QCD (w/ M_{KK} SU(N) YM $\lambda = g_{YM}^2 N$)

$$M^4 = \frac{\lambda N^2}{3^7 \pi^2} M_{KK}^4 , \quad F = \frac{8\pi^2 N}{\lambda} f$$

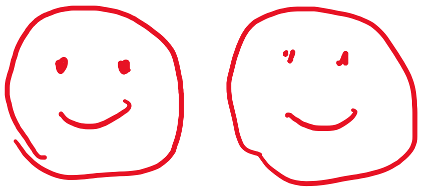
[Dubovsky, Lawrence, Roberts '11]

[Nomura - Watari - Y '17]

Wow!!

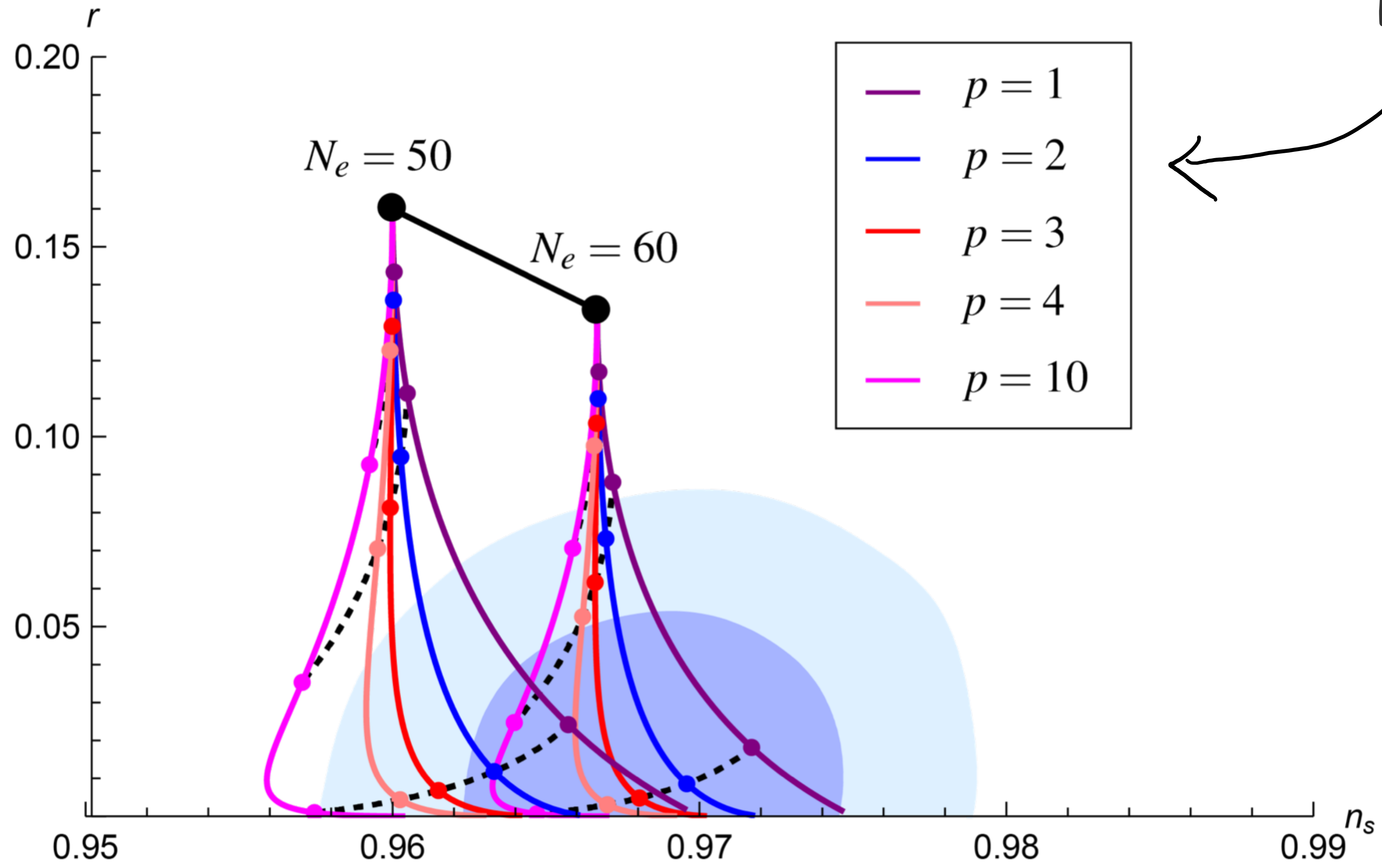


[Nomura-Watari-Y '17]



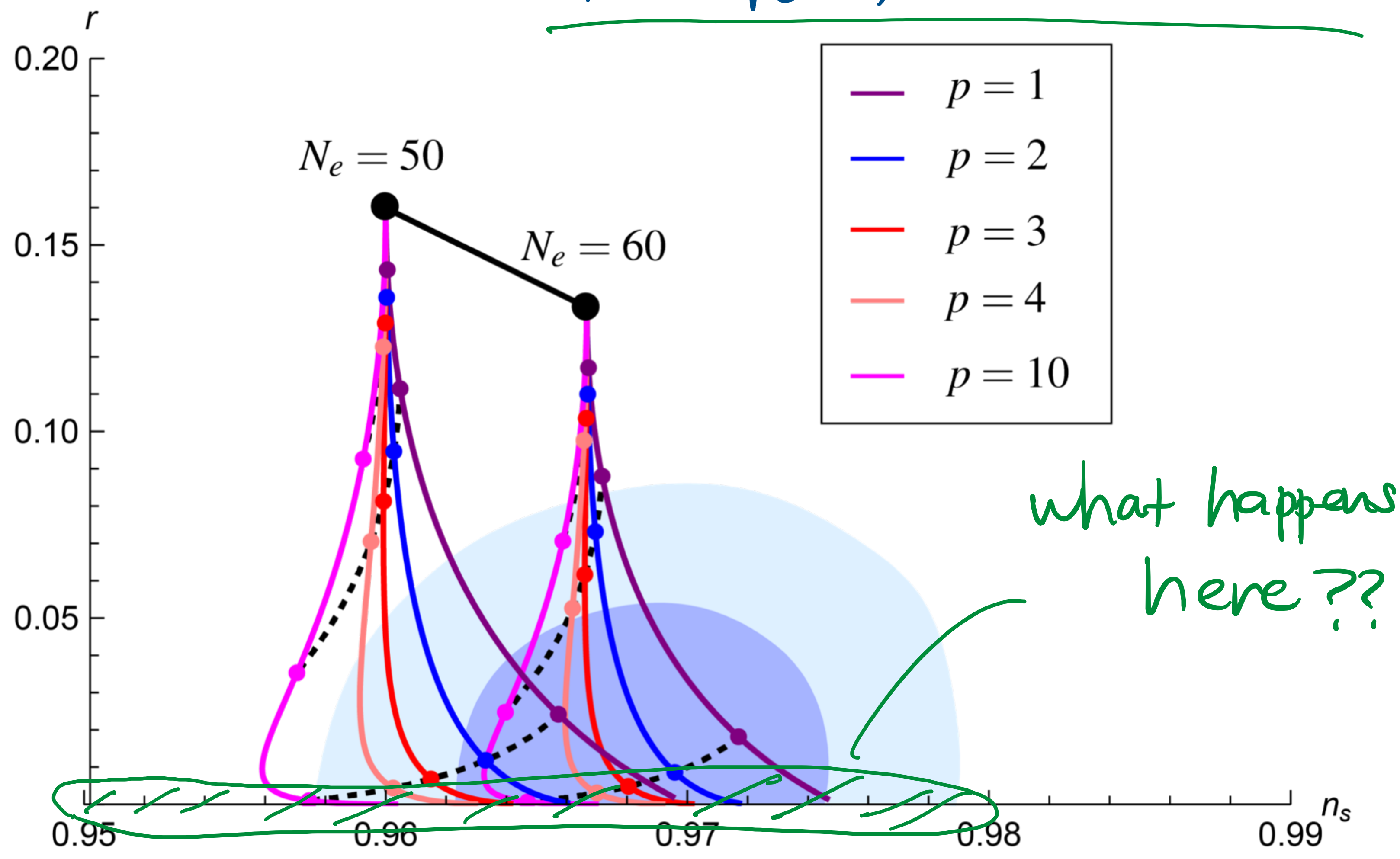
$$V = M^4 \left(1 - \left(\frac{\phi}{F}\right)^2\right)^{-p}$$

power



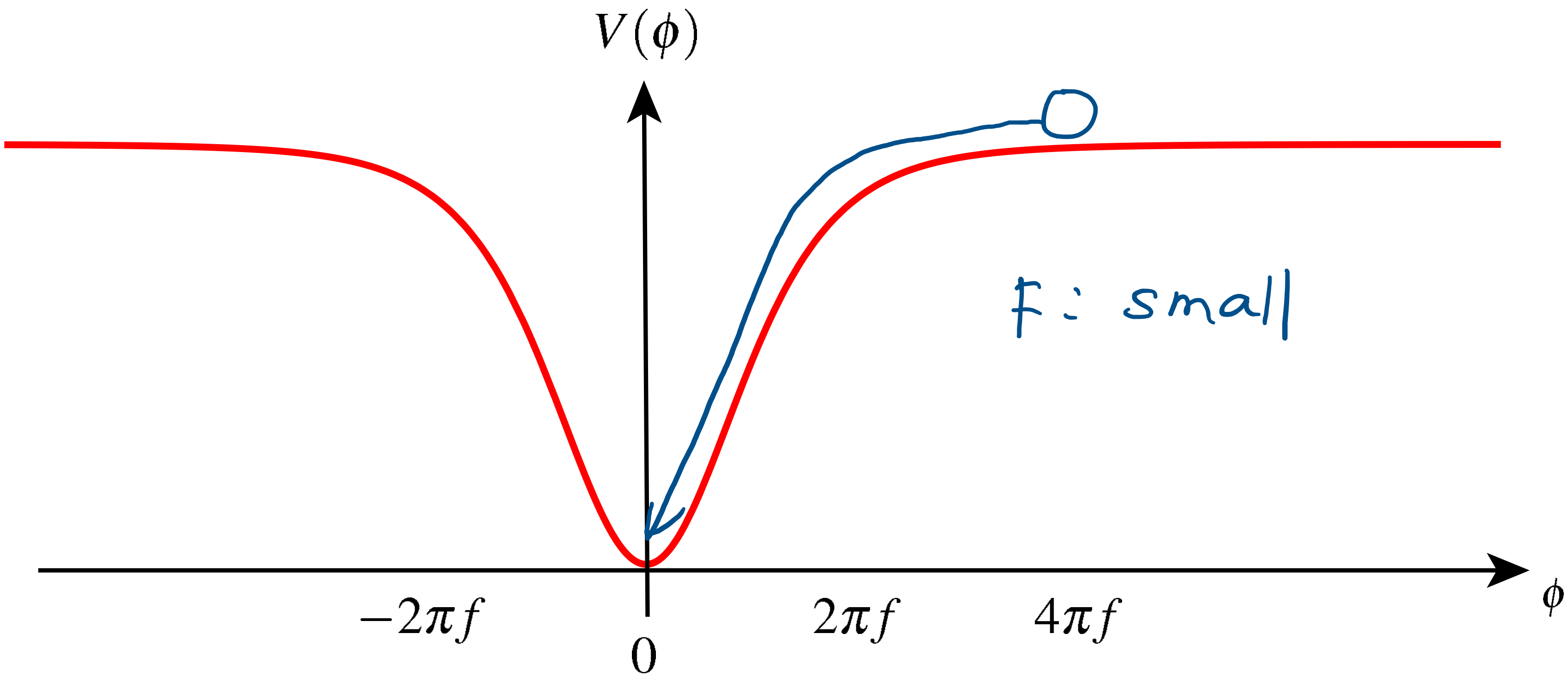
can we observe tensor modes in the near future?

$r \sim 10^{-3}$, or even 10^{-4}



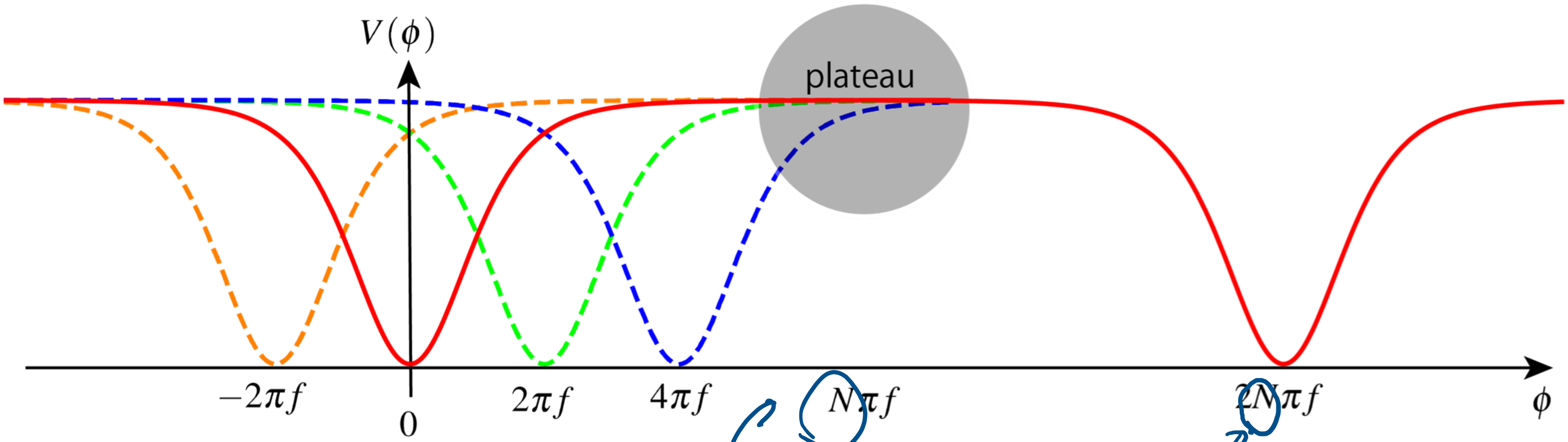
smaller r means smaller F

so that $\phi / F = \theta$ large



Finite N effects;

(# of metastable branches) = N (finite)



N metastable vacua

[cf. Yonekura-Y '17]

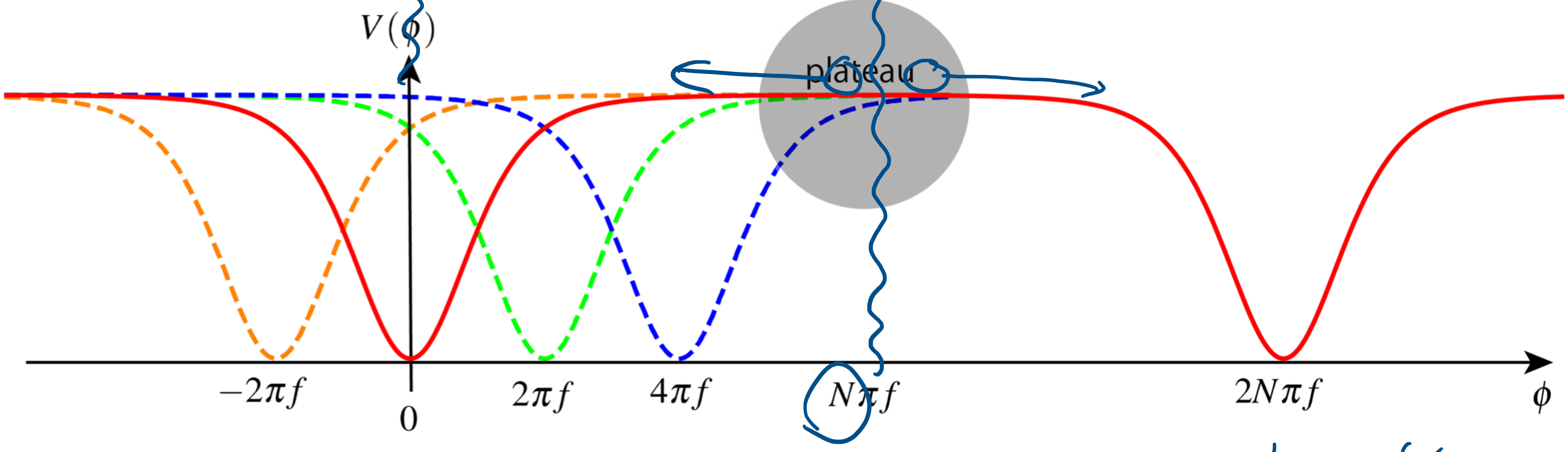
$\mathbb{Z}_N$ center sym confinement

Finite N effects; bound on field value $\longrightarrow$ lower bound on F

$\downarrow$

lower bound on r

$\phi_{hor} \lesssim \phi_{max}$



local minimum

N metastable vacua

another minimum

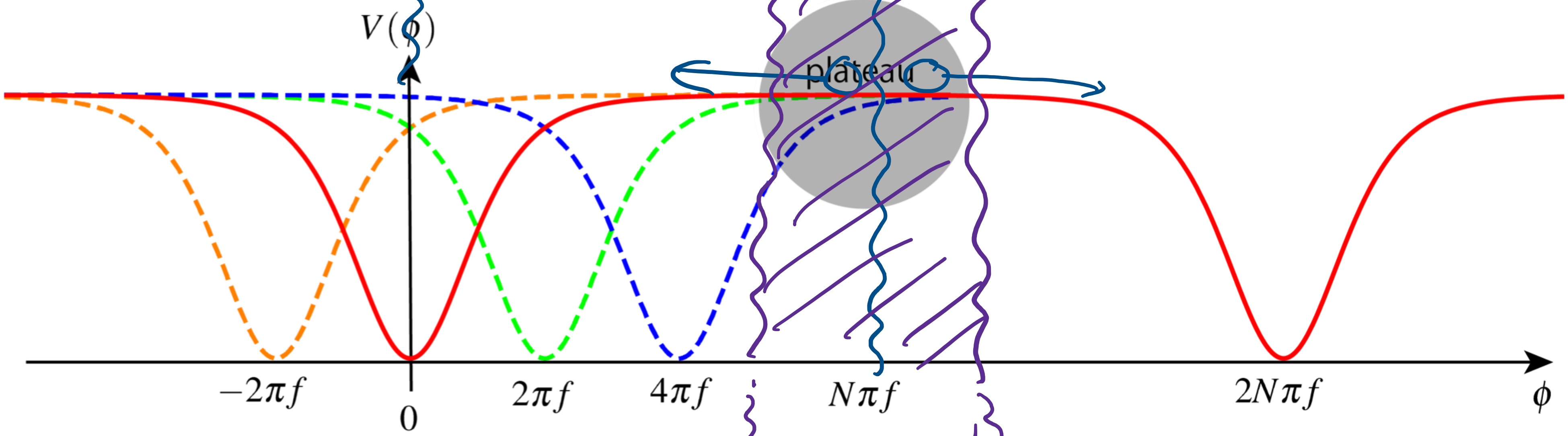
[cf. Yonekura–Y '17]

Finite N effects; bound on field value $\longrightarrow$ lower bound on F

$\downarrow$

lower bound on r

$\phi_{hor} \lesssim \phi_{max}$



local minimum

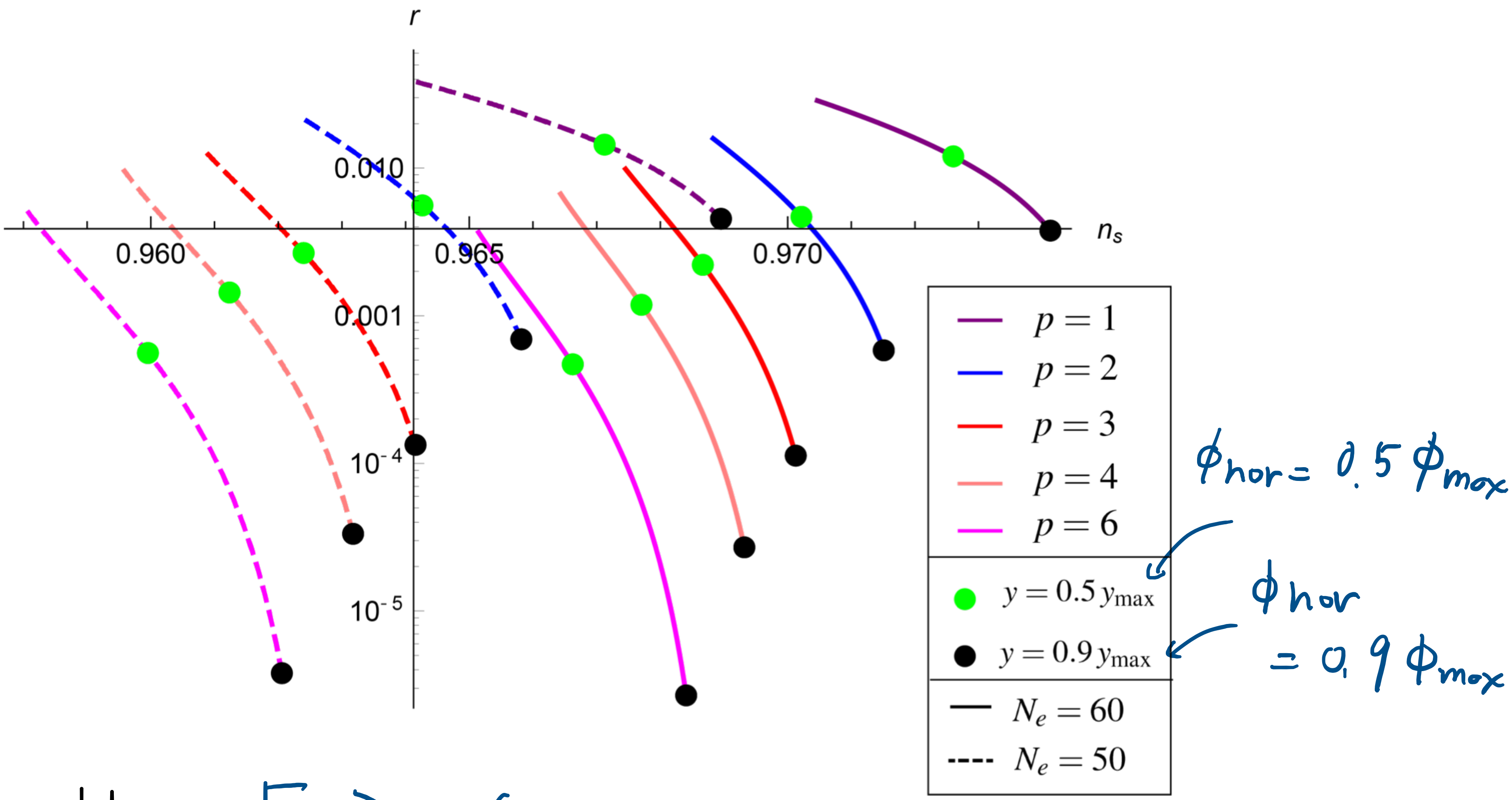
another minimum

new inflation-like

our potential trustable

lower bound on r [Nomura - Y '17]

(if we stay away from top of the potential)



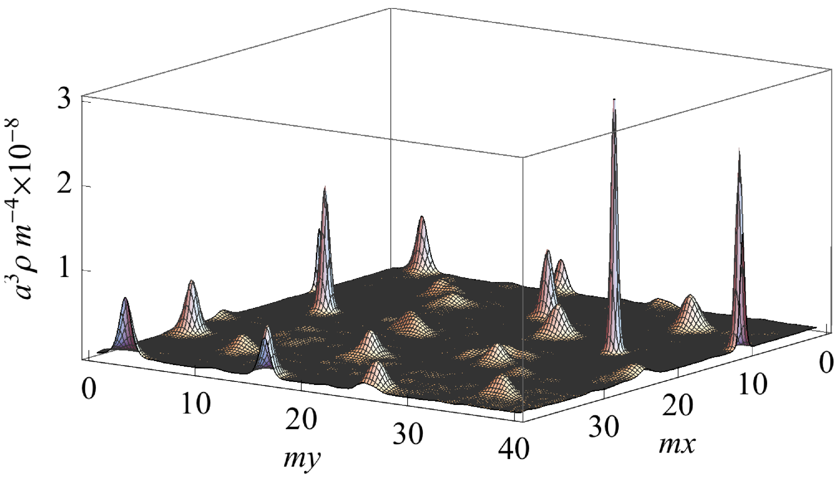
roughly $F \gtrsim O(0.1\,M_{pl})$

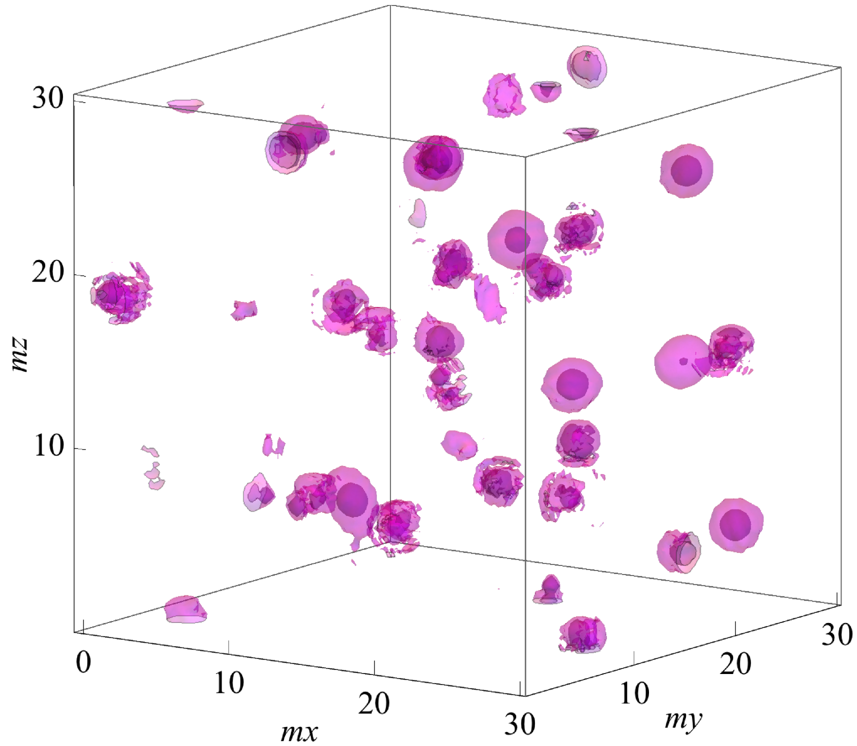
* For $F \lesssim O(0.1 M_{pl})$

we find spatially inhomogeneities (oscillons)

[Hong, Kawasaki + Y ($p>0$)
also Amin et al ('11) ($p<0$)]

analytical/numerical
(LatticeEasy)



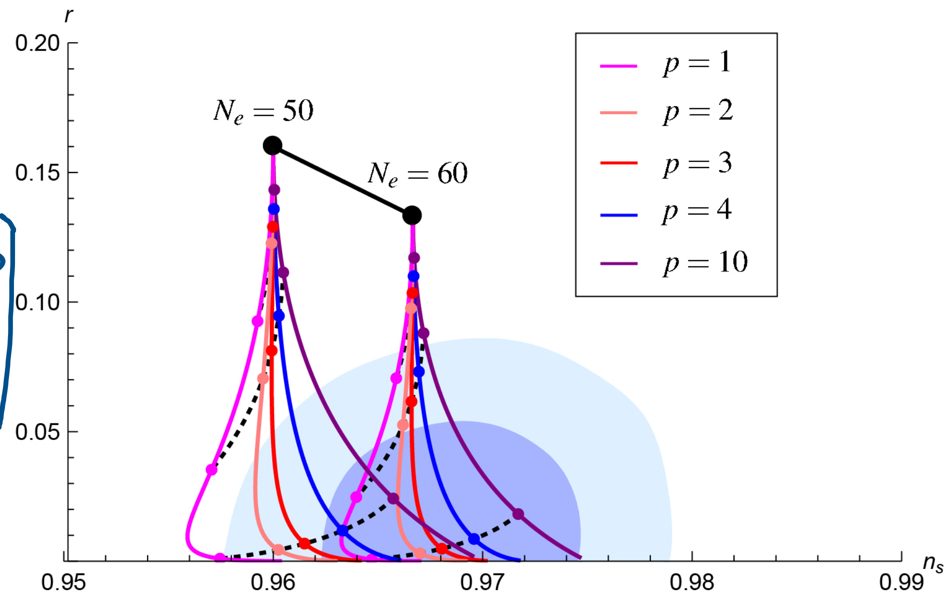


implications? GW? baryo/leptogenesis?
[also in progress]

Summary

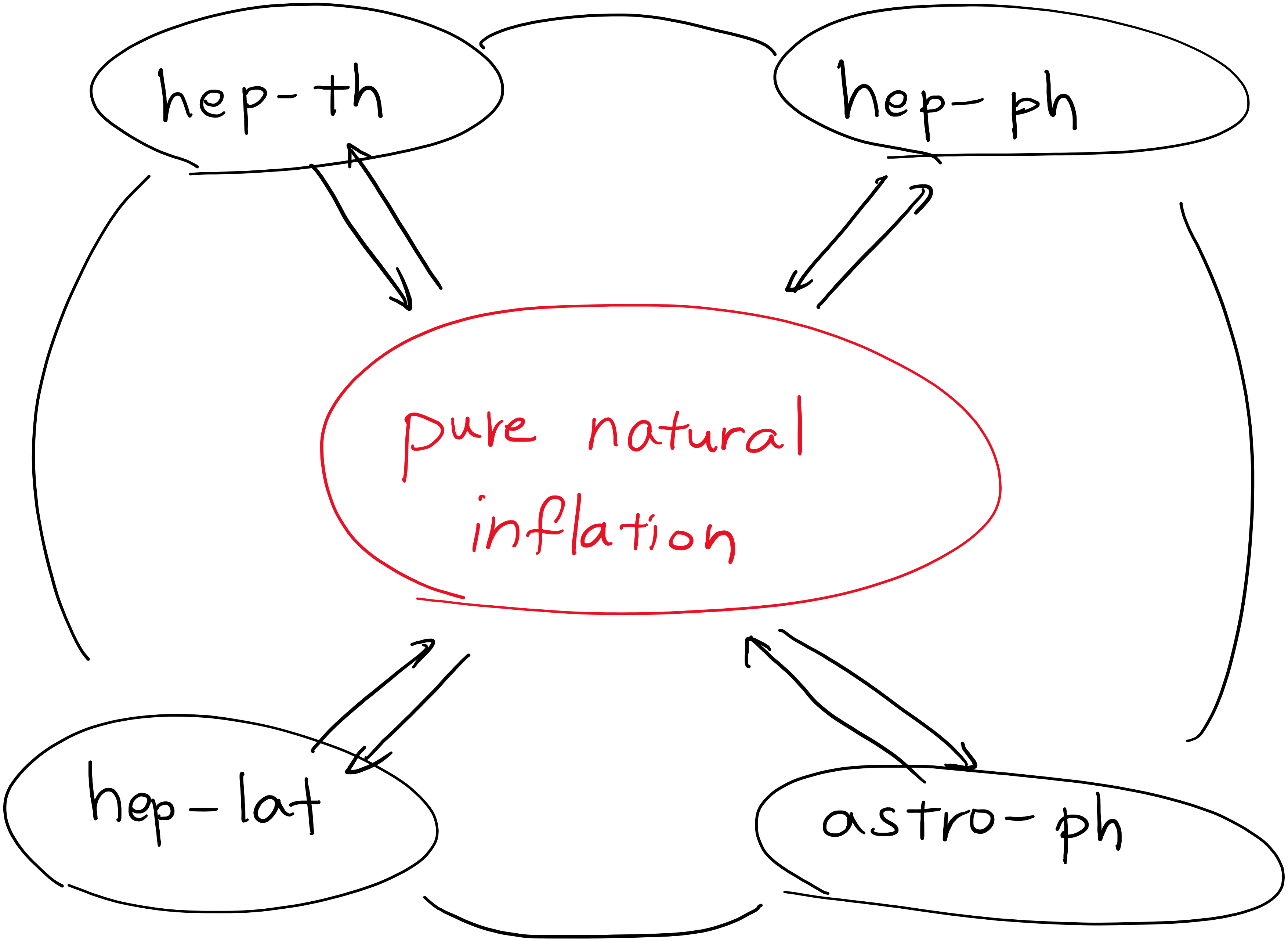
* natural inflation for pure Yang-Mills, when done correctly is in complete agreement with data ☺☺

$$V(\phi) = M^4\left[1 - \left(1 - \left(\frac{\phi}{F}\right)^2\right)^{-p}\right]$$



* $F \gtrsim O(0.1\, M_{pl}) \longrightarrow$ tensor modes

$F \lesssim O(0.1\, M_{pl}) \longrightarrow$ oscillons


hep-th
hep-ph
pure natural inflation
hep-lat
astro-ph