A natural rescue of natural inflation

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Inflation & natural inflation

A. H. Guth, 1981

Inflation is a period of accelerated expansion

solves initial condition problems: flatness, horizon
seeds the inhomogeneities observed in CMB

The fine-tuning problem in inflation

F.C.Adams, K.Freese and A.H.Guth, 1991

to match various observational constraints, the height of the inflaton potential must be of a much smaller scale than that of the width

$$\chi \equiv \Delta V/(\Delta\phi)^4 \leq \mathcal{O}(10^{-6} - 10^{-8})$$

Natural inflation

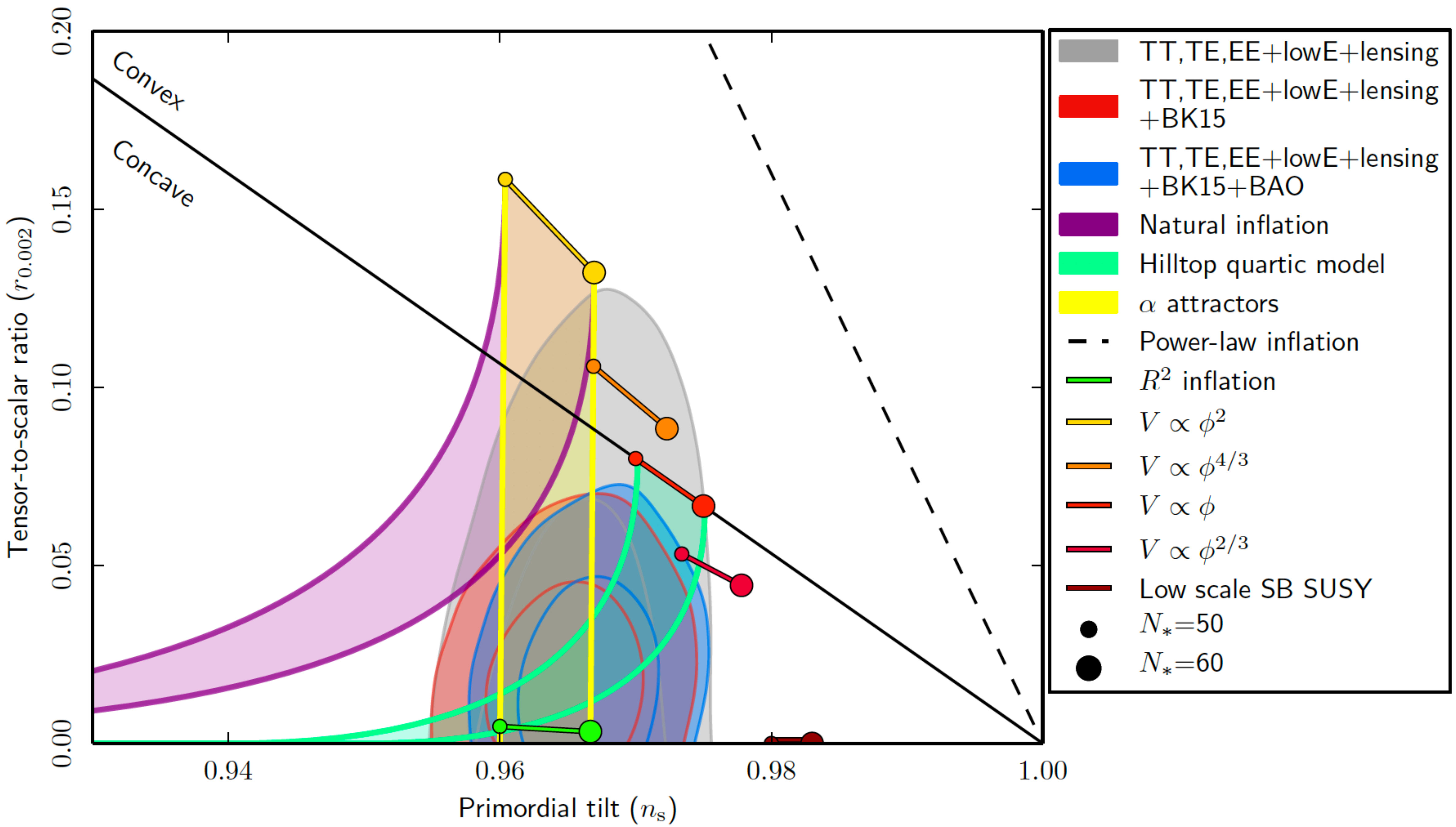
K. Freese, J. A. Frieman and A. V. Olinto, 1990;
F. C. Adams, J. R. Bond, K. Freese, J. A. Frieman and A. V. Olinto, 1992

inflaton~"axion"
shift symmetry -> flatness

$$V(\phi) = \Lambda^4 \left(1 + \cos\phi/f\right)$$

Natural flatness

Planck 2018 result



"Natural inflation (Freese et al. 1990; Adams et al. 1993) is strongly disfavoured by the Planck 2018 plus BK15 data"

Warm inflation

A. Berera and L. Z. Fang, 1995;
A. Berera, 1995

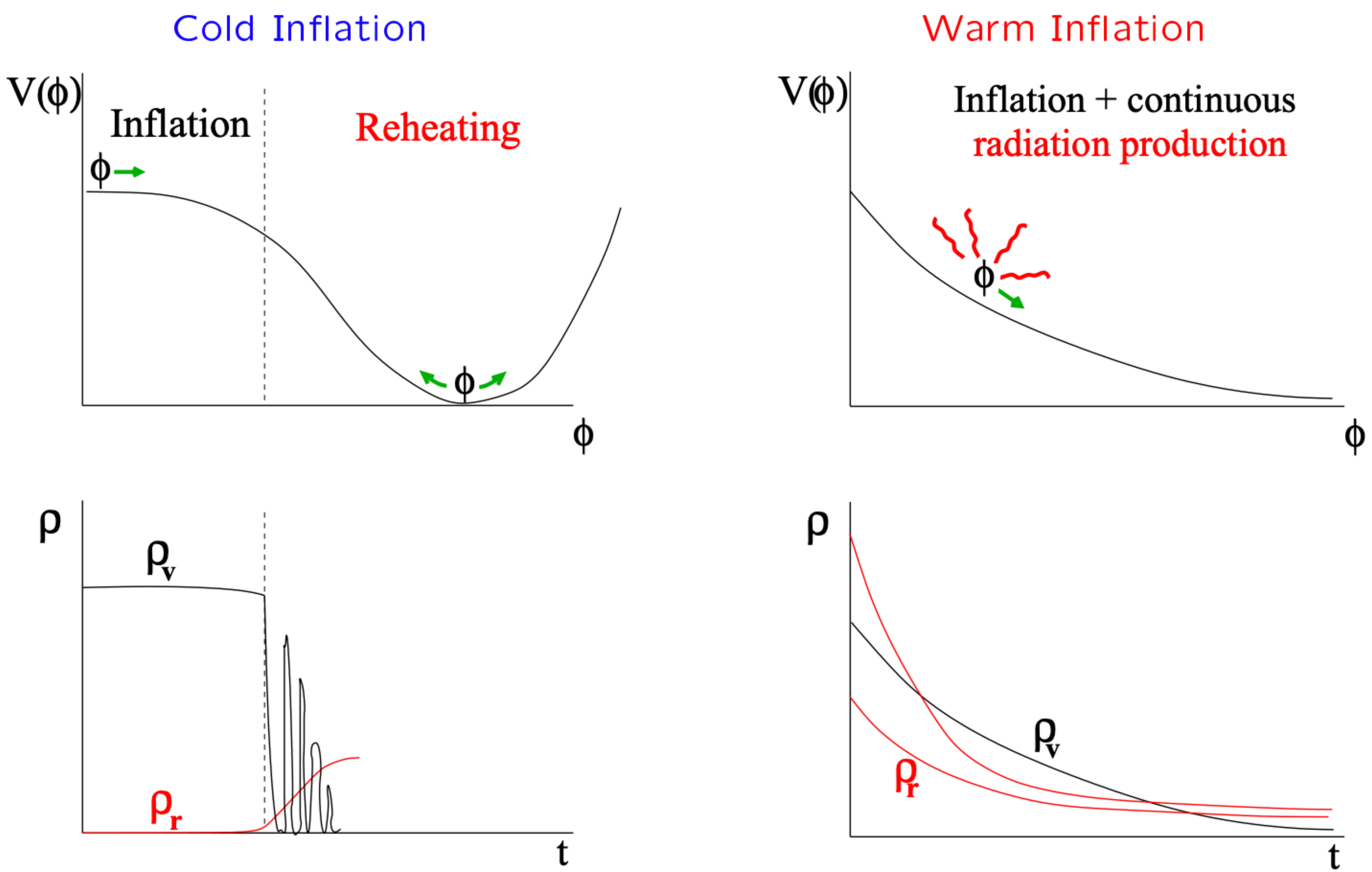


Figure from A. Berera, I. G. Moss, and R. O. Ramos, 2008
Original at A. Berera, Contemp. Phys. 47, 33 (2006)

No separate reheating

Warm inflation

Introduce a thermal friction term in inflaton's evolution

$$\ddot{\phi} + (3H + \Gamma)\dot{\phi} + V_{,\phi} = 0,$$

Γ **Dissipative coefficient**

The friction source thermal bath

$$\dot{\rho}_r + 4H\rho_r = \Gamma\dot{\phi}^2,$$

$$H^2 \simeq \frac{V}{3M_{\rm pl}^2}.$$

The slow-roll parameters

$$\epsilon_w \equiv \frac{\epsilon_V}{1+Q} = \frac{M_{\rm pl}^2}{2(1+Q)}\left(\frac{V_{,\phi}}{V}\right)^2;$$

$$\eta_w \equiv \frac{\eta_V}{1+Q} = \frac{M_{\rm pl}^2}{(1+Q)}\left(\frac{V_{,\phi\phi}}{V}\right);$$

$$\beta_w \equiv \frac{M_{\rm pl}^2}{(1+Q)}\left(\frac{\Gamma_{,\phi}V_{,\phi}}{\Gamma V}\right).$$

Dimensionless dissipative ratio

$$Q \equiv \Gamma/(3H)$$

With Q $\gg$ 1, the inflation gets prolonged!

Enough inflation for steeper potentials

The dimensionless primordial curvature power spectrum

$$\Delta_{\mathcal{R}}^2 = \left(\frac{H^2}{2\pi\dot{\phi}}\right)^2\left(1 + 2n_{\rm BE} + \frac{2\sqrt{3}\pi Q}{\sqrt{3+4\pi Q}}\frac{T}{H}\right)G(Q)$$

Primordial tensor power spectrum $\Delta_t^2 = \dfrac{2H^2}{\pi^2 M_{\rm pl}^2}$

Thermal friction leads to a suppressed r

Spectral tilt $n_s - 1 = \dfrac{d\ln\Delta_{\mathcal{R}}^2}{d\ln k} \simeq \dfrac{d\ln\Delta_{\mathcal{R}}^2}{dN}$

Tensor-to-scalar ratio $r = \dfrac{\Delta_t^2}{\Delta_{\mathcal{R}}^2}$

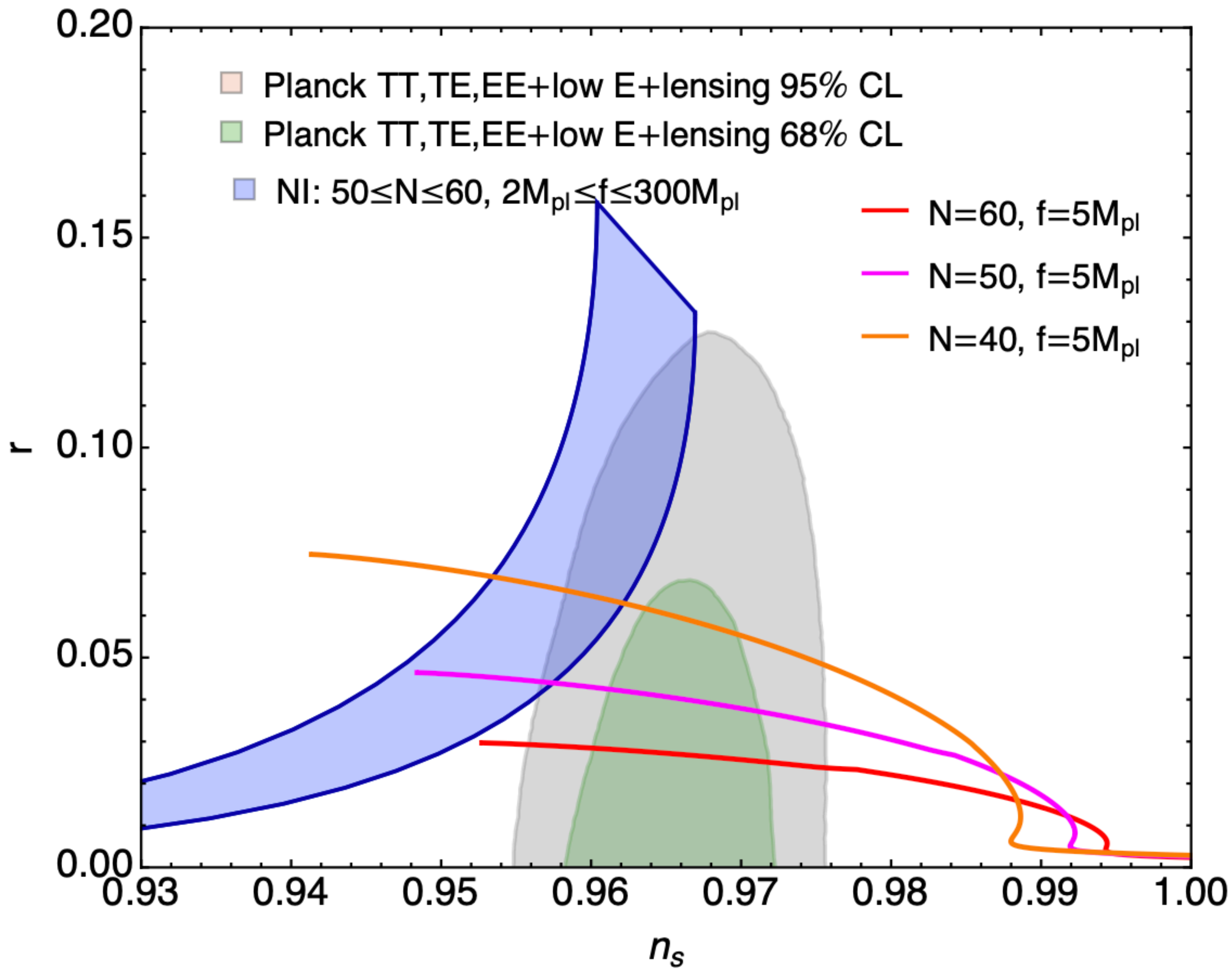
Warm-assisted natural inflation

Inflaton potential $V(\phi) = \Lambda^4 \left(1 + \cos\phi/f\right)$

Temperature-dependent dissipative coefficient $\Gamma \propto T^3$

Dimensionless parameter $c \propto Q(1+Q)^6 \quad Q \equiv \Gamma/(3H)$

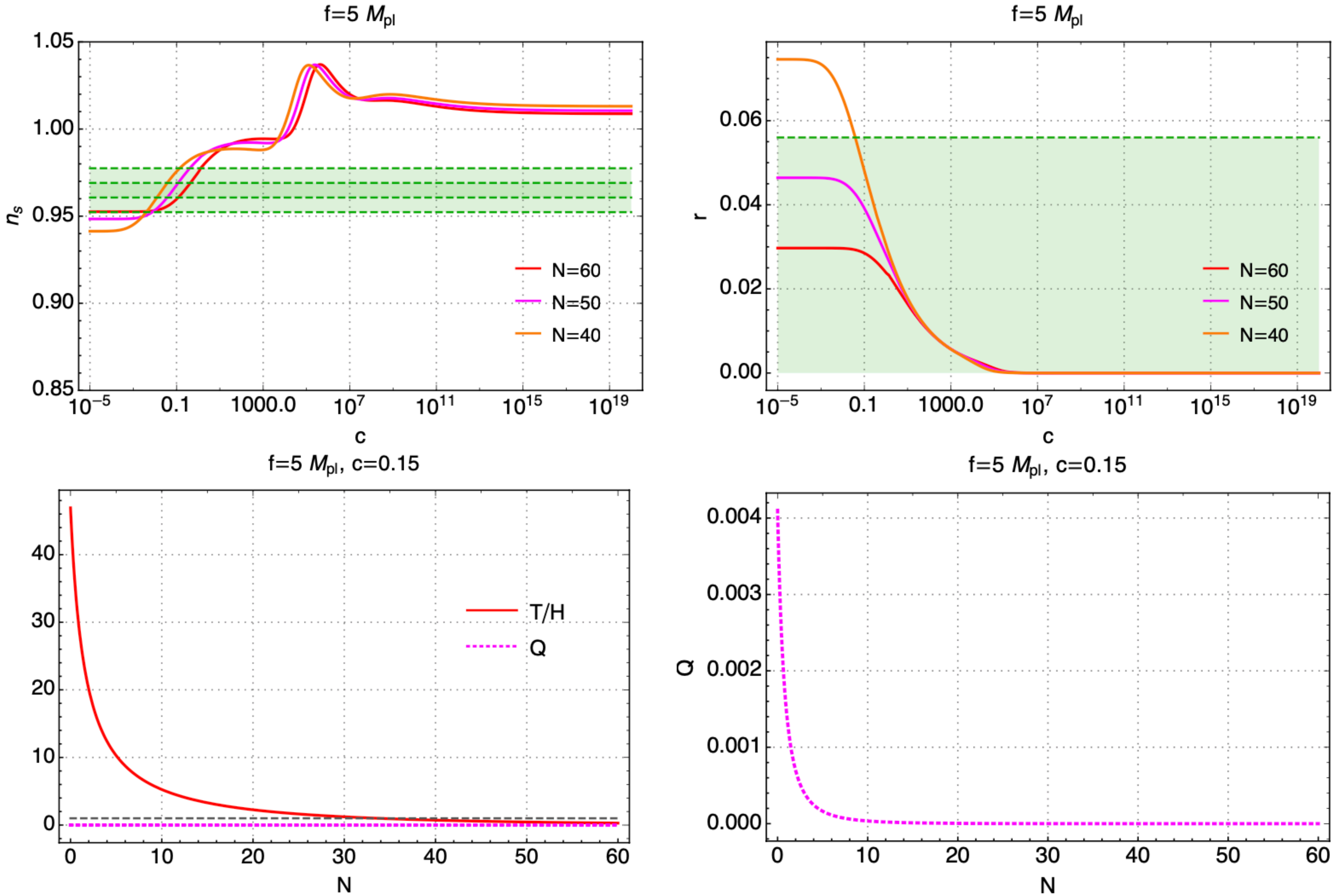
$\epsilon_w,\ \eta_w,\ \beta_w,\ Q,\ n_s,\ r$ **are all functions of** $c,\ f$



$f = 5M_{\rm pl}$ **and a varying** c

A better agreement with the Planck results!

$f = 5M_{\rm pl}$ results (continued)



N: # of e-folds before the end of inflation

Starts cold, evolves to warm. Weak all the time!

Microphysics origin of the dissipative coefficient

Kim V. Berghaus, Peter W. Graham, and David E. Kaplan, 2019

Consider axion-like coupling to gauge fields

$$\mathcal{L} = \frac{\alpha}{16\pi}\frac{\phi}{f_1}\tilde{G}_a^{\mu\nu}G_{\mu\nu}^a$$

At high temperatures, sphalerons are no longer suppressed, which give rise to topological charge fluctuations.

$$\Gamma_{\rm sphal} \sim \alpha^5 T^4$$

The dissipative coefficient is estimated from the sphaleron rate in thermal field theory as

$$\Gamma(T) = \frac{\Gamma_{\rm sphal}}{2f_1^2 T} \qquad \Gamma(T) = \kappa\alpha^5\frac{T^3}{f_1^2},$$

The estimation is valid for $m_\phi < \alpha^2 T$ and $H < \alpha^2 T$

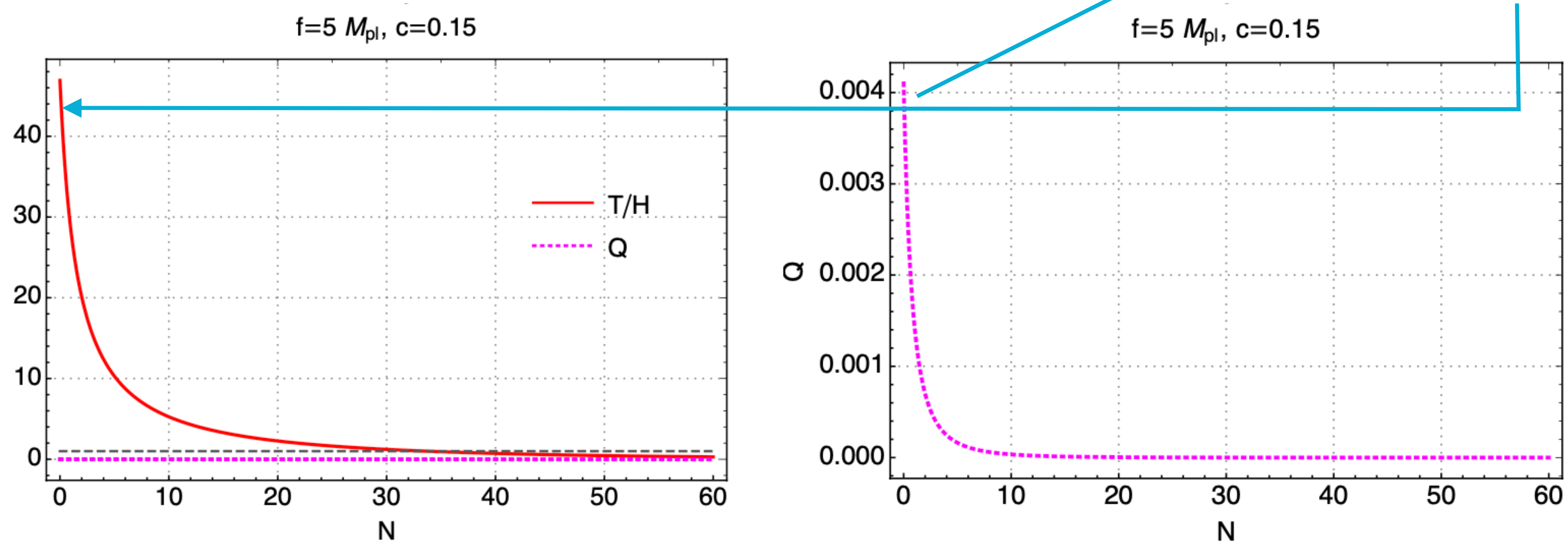
In strong dissipative regime (Q ≫1)

Tension with thermal field theory requirement

In our model, thermalized inflaton requires $\Gamma_{\phi g} > H$ $\quad \alpha < 10^{-2}\sqrt{Q}$ → $\alpha < 10^{-5}$

$$\Gamma_{\phi g} \simeq \frac{\alpha^3 T^3}{32\pi f_1^2} = \frac{1}{32\pi\kappa\alpha^2}\Gamma$$

Clearly violates $H < \alpha^2 T$



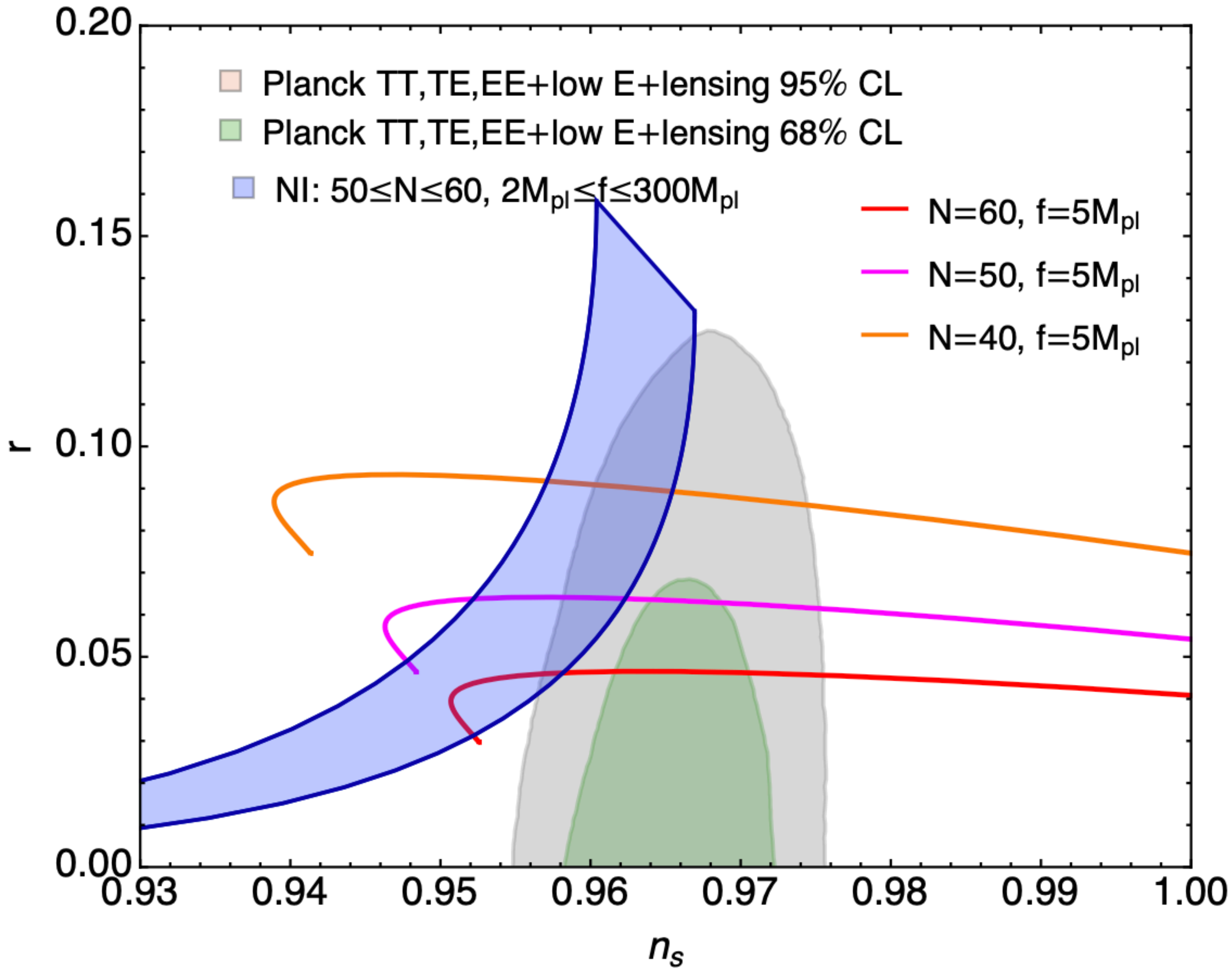
N: # of e-folds before the end of inflation

Not satisfy the condition, not necessarily ruled out

Not-thermalized inflaton?

Not-thermalized inflaton

Change the thermal distribution into $n \simeq \frac{\gamma_{\phi g}}{3+\gamma_{\phi g}} n_{\rm BE}$



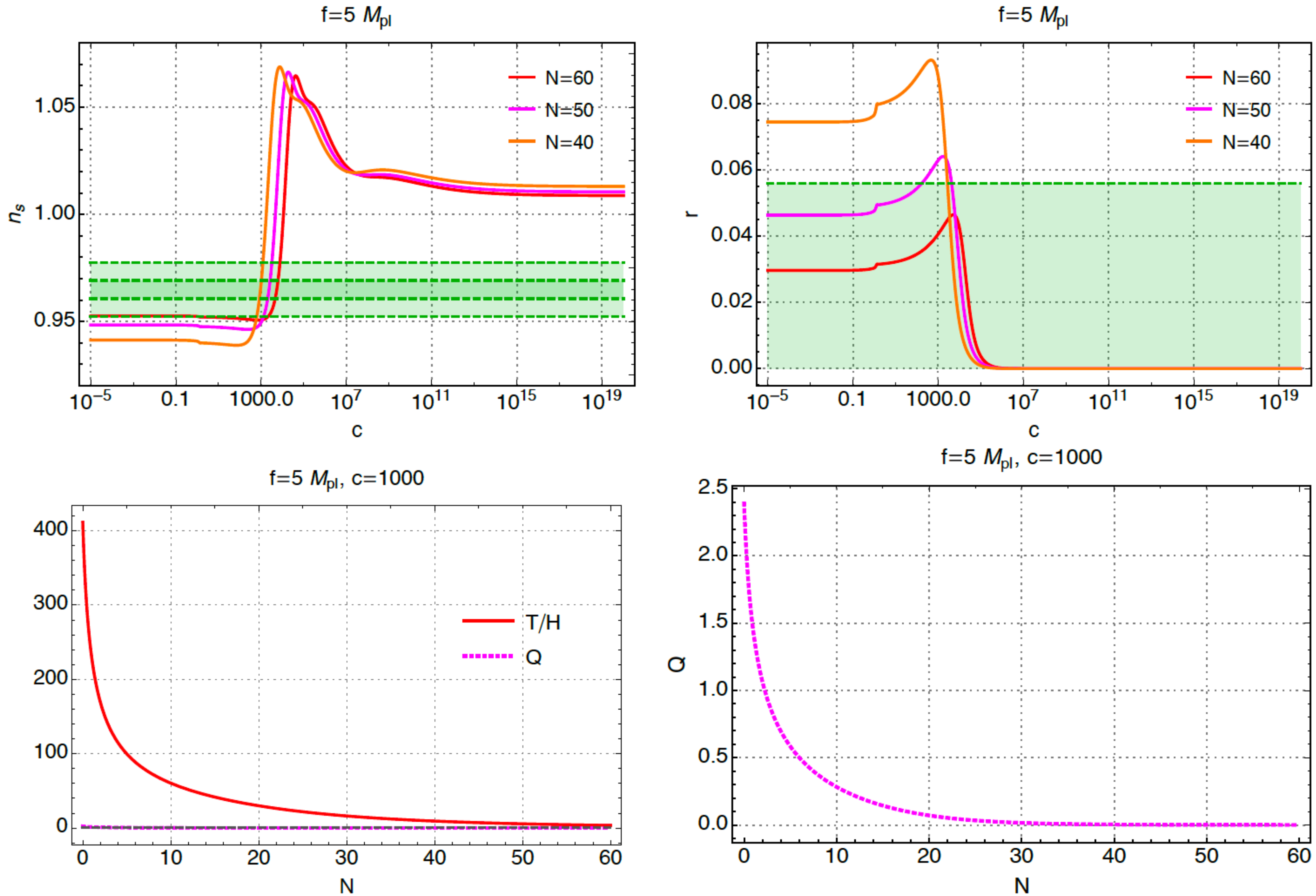
Better agreement with Planck results compared with cold NI!

No better agreement with Planck results compared with thermalized inflaton?

Little excess: caused by differences in ϵ_w, $\beta_w$determining $\phi_{\rm end}$

Not-thermalized inflaton results

Prefers a lager c

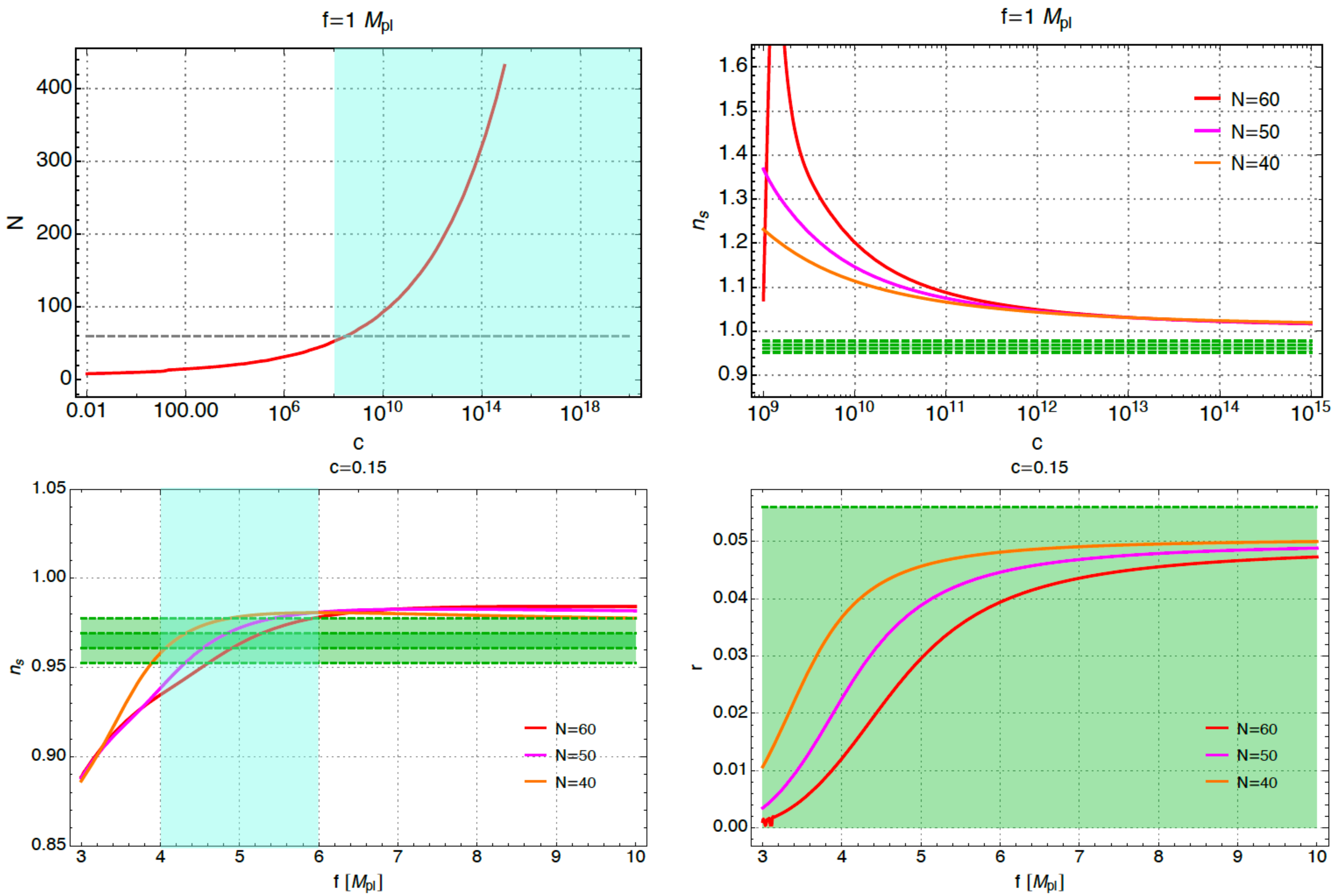


the tension with the thermal field theory requirement is much alleviated

Starts weakly, evolves to intermediate regime

A smaller decay constant f

$f > 1\ M_{\rm pl}$ **may have difficulty in embedding into a more fundamental theory**



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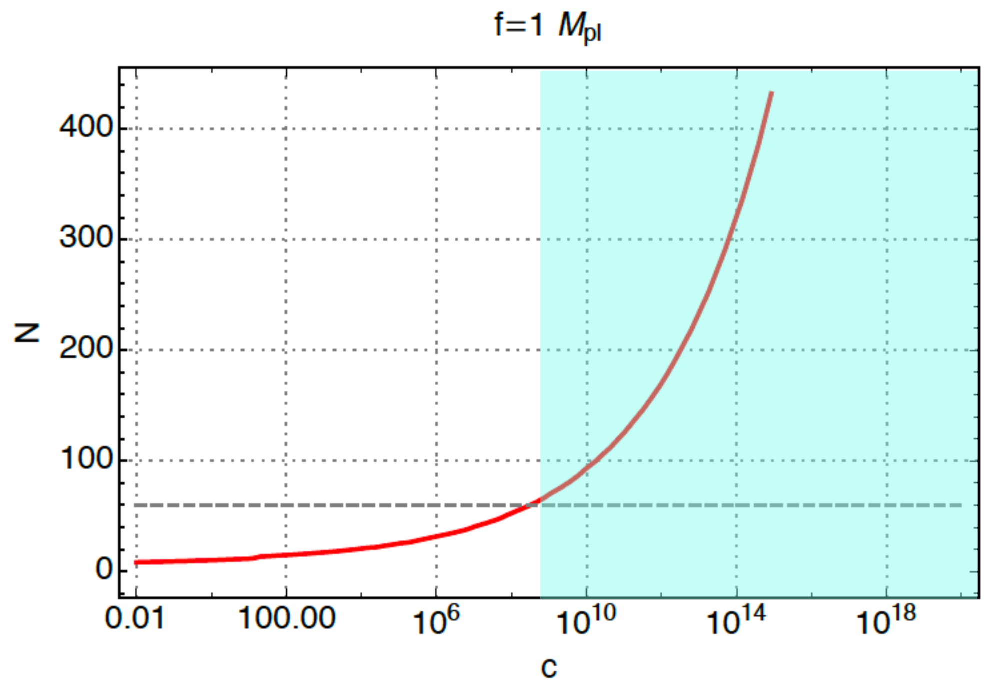
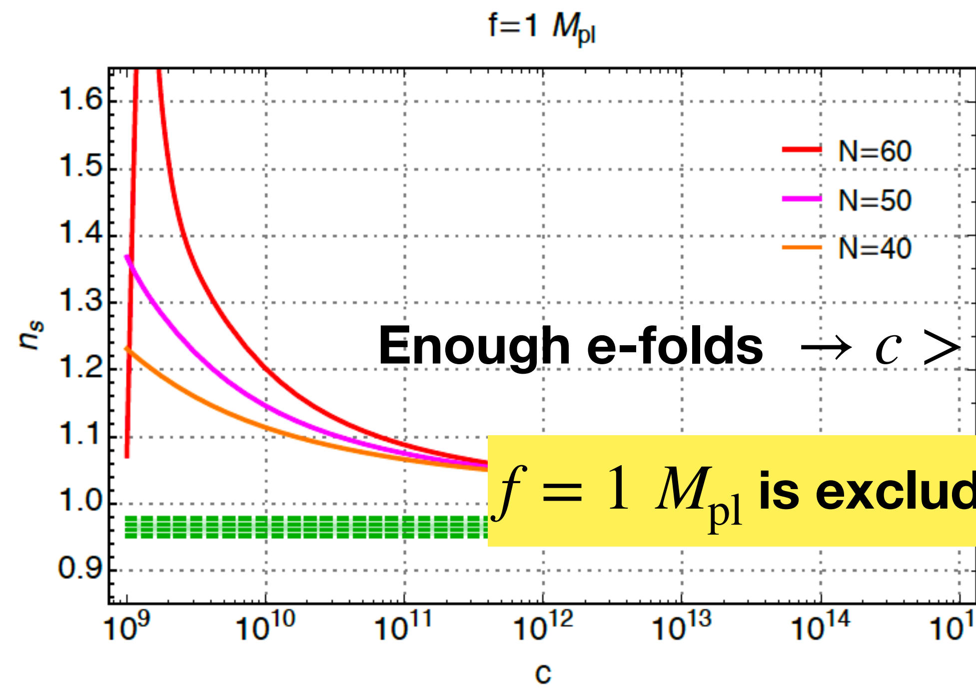
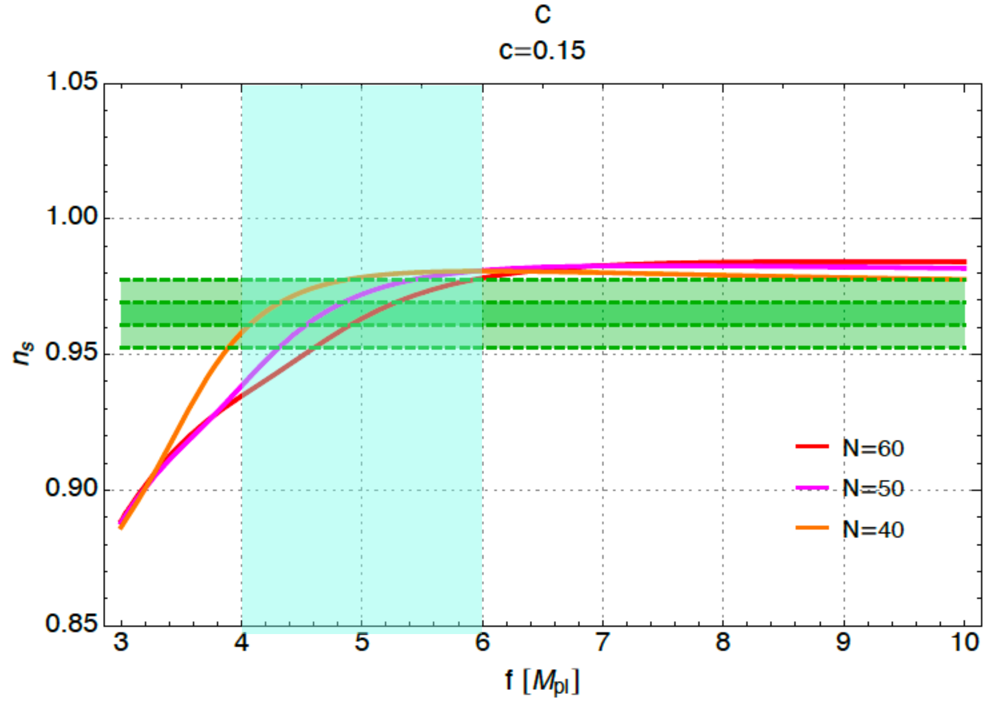
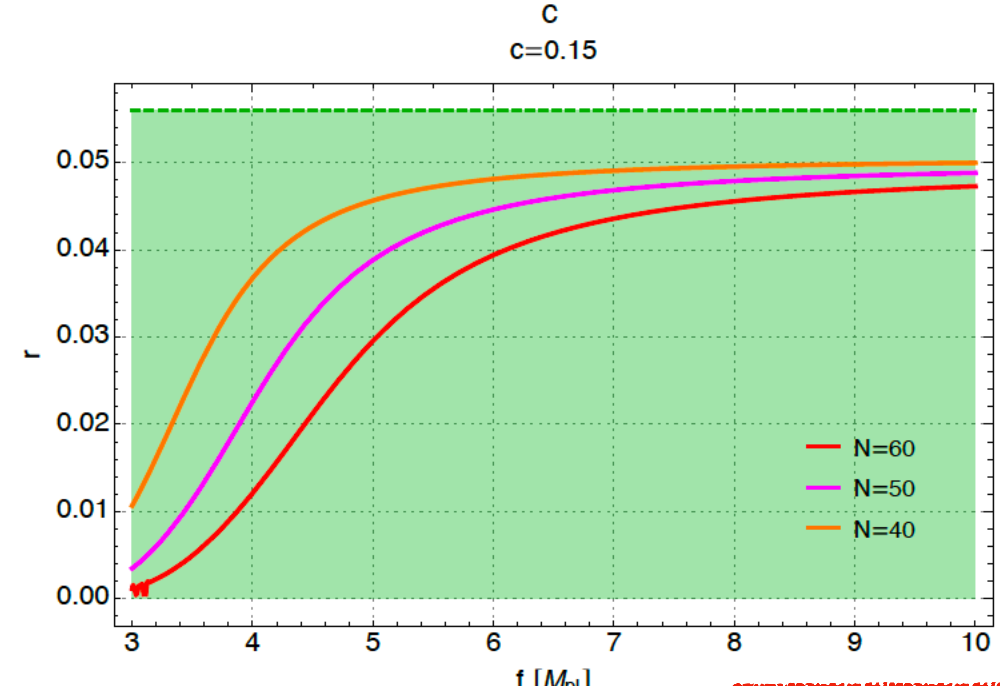




Enough e-folds $\to c > 10^9 \to n_s > 1$

$f = 1\ M_{\rm pl}$ is excluded by $n_s > 1$





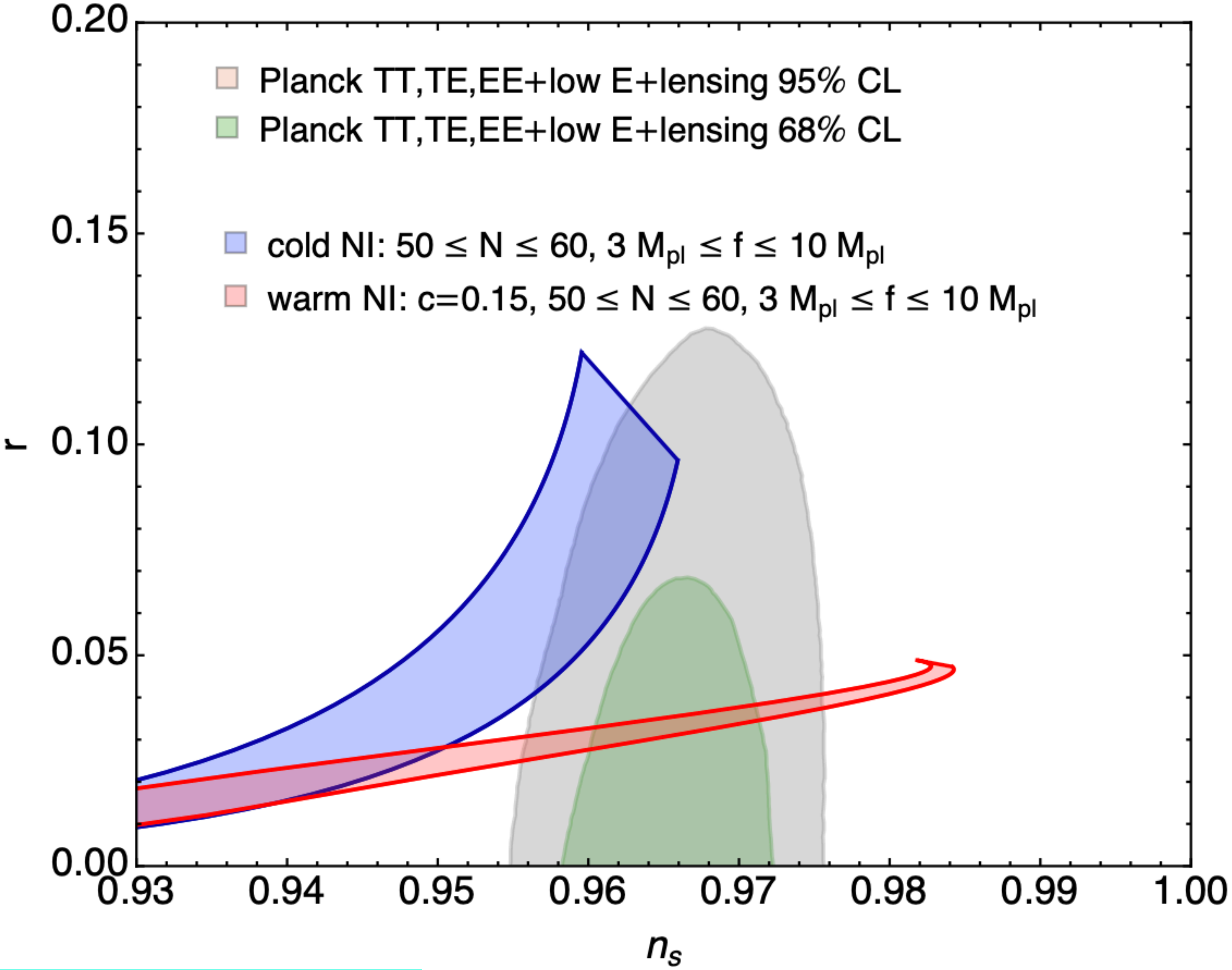
$f < 1\ M_{\rm pl}$ is excluded

For fixed c, n_s grows with f

Also find large $c \to n_s > 1$ for $f < 1\ M_{\rm pl}$

Last comparison with cold NI & Planck results

Thermalized inflaton, fixed c



A slightly blue-tilted n_s
Suppressed r
Shrinked parameter space

Warm dissipative effects bring NI into better agreement with the Planck 2018 results

Conclusions

- A weak dissipative effect with cubic T dependence is enough to rescue natural inflation
- A sub-Planckian decay constant is excluded
- Microphysics origin of the dissipative coefficient
  - Axion-like coupling to gauge fields
    - Weak regime - tension with the thermal field theory requirement
    - Not-thermalized inflaton alleviates the tension, but fits worse than thermalized case

Thank you for your attention.

$f = 5M_{\rm pl}$ slow roll parameters, $\phi_{\rm end}$, and ϕ_*