Probing the BSM physics with CMB precision cosmology: an application to supersymmetry

Yuki Watanabe
National Institute of Technology, Gunma College

with Ioannis Dalianis (NTUA)
Based on arXiv:1801.05736 (accepted by JHEP)

新学術領域「加速宇宙」シンポジウム

Why does the Universe accelerate? —Exhaustive study and challenge for the future

Tohoku University
Feb. 10, 2018

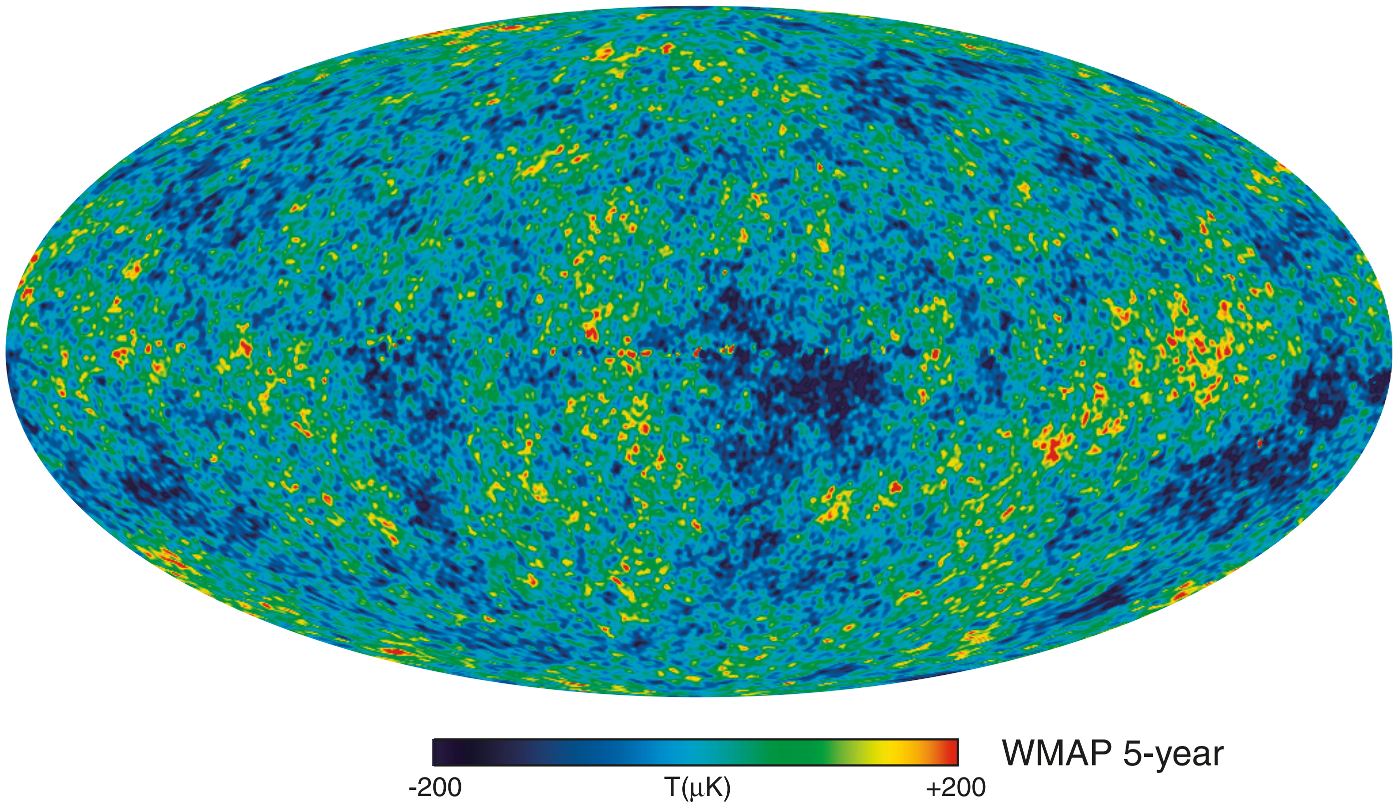
Outline

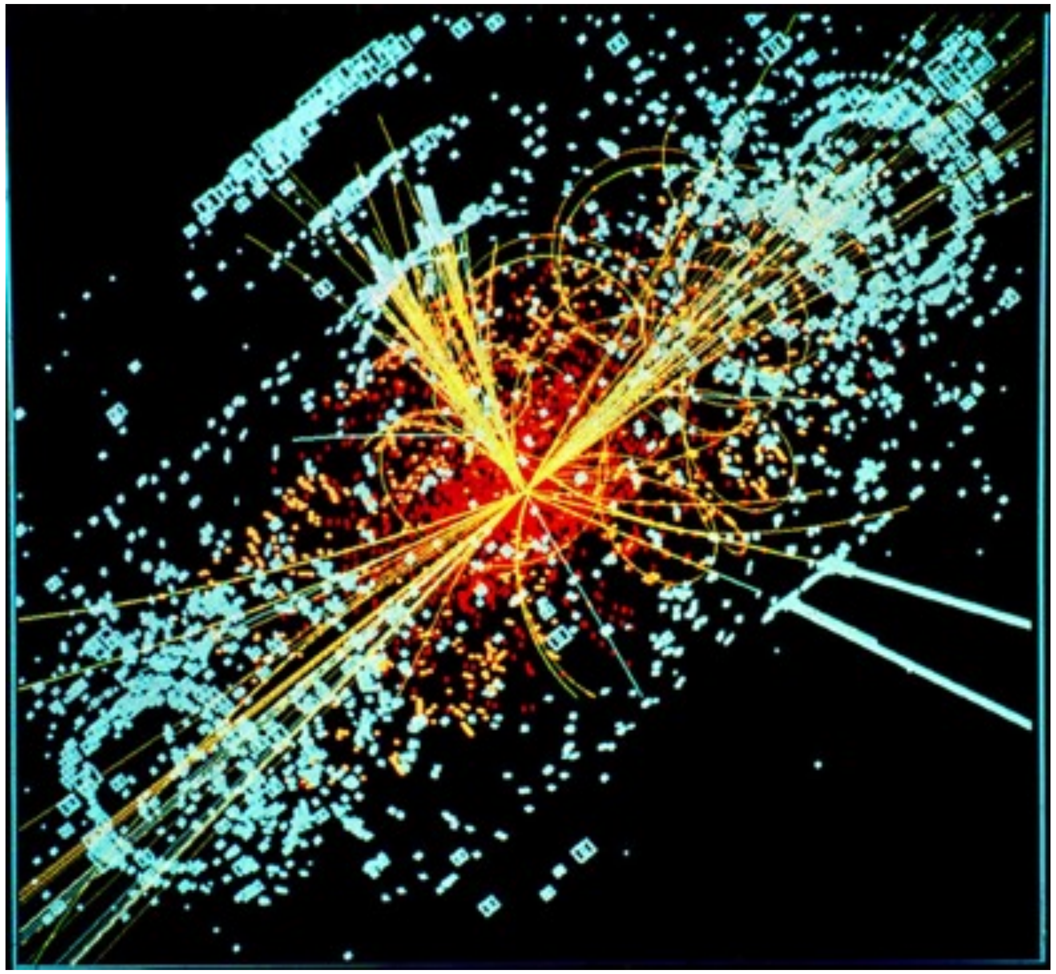
1. Introduction
2. CMB observables and the post-inflationary evolution
   — shift in (n_s, r) due to late entropy production
3. SUSY DM cosmology
   — gravitino, neutralino
4. Alternative cosmic histories and SUSY
   — diluter field X, low reheat temp., max dilution
5. A concrete example
   — $R+R^2$ (super)gravity inflation model
6. Conclusion

credit: NASA

CMB observations and BSM physics

- (n_s, r) precision measurements from CMB
- No signal of physics beyond the Standard Model (BSM) at the LHC

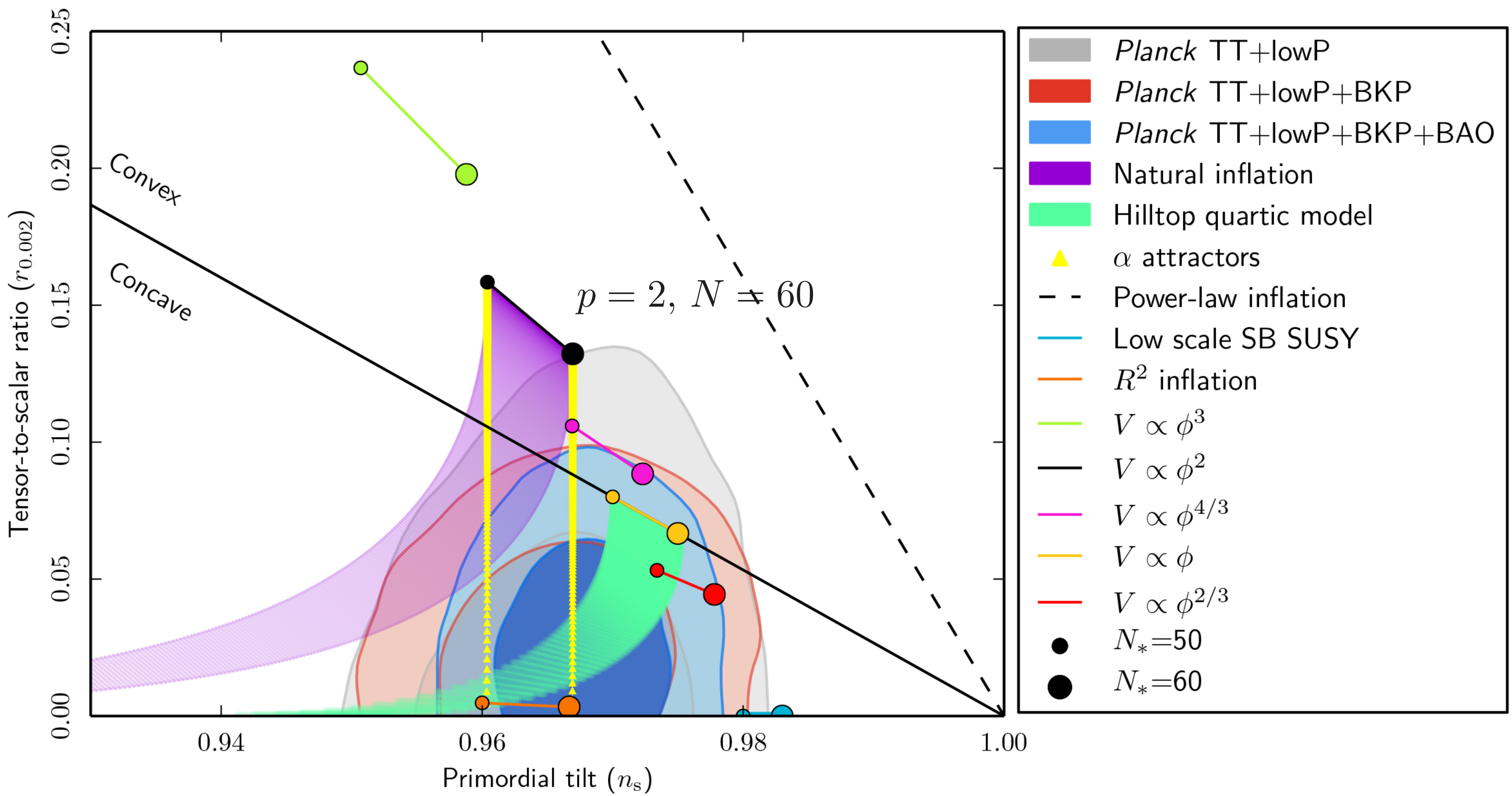




credit: NASA

CMB constraint on inflation models

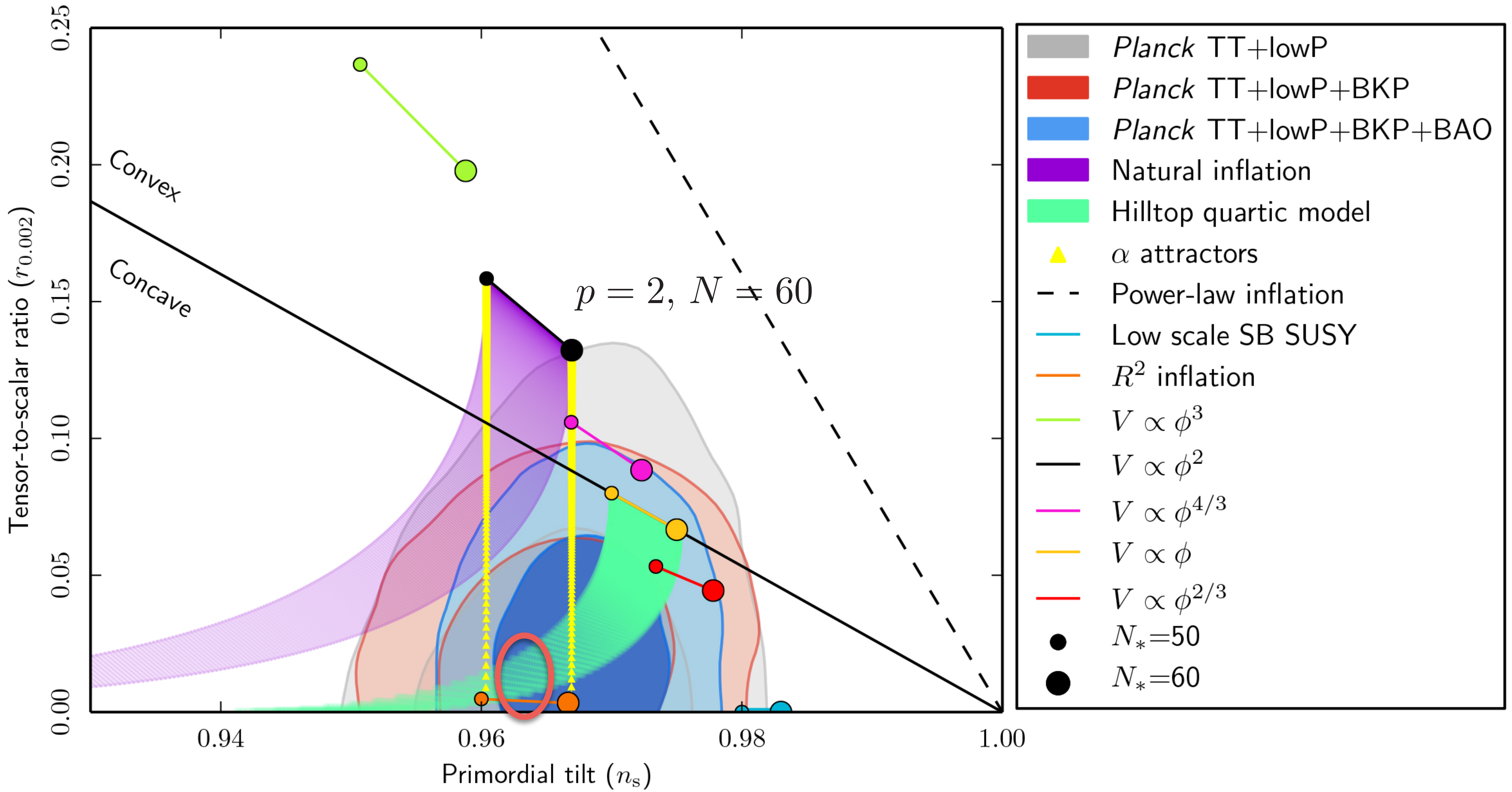
[Fig. from Planck 2015]



- Monomial potentials with p > 2 in GR are almost excluded.

CMB constraint on inflation models

[Fig. from Planck 2015]

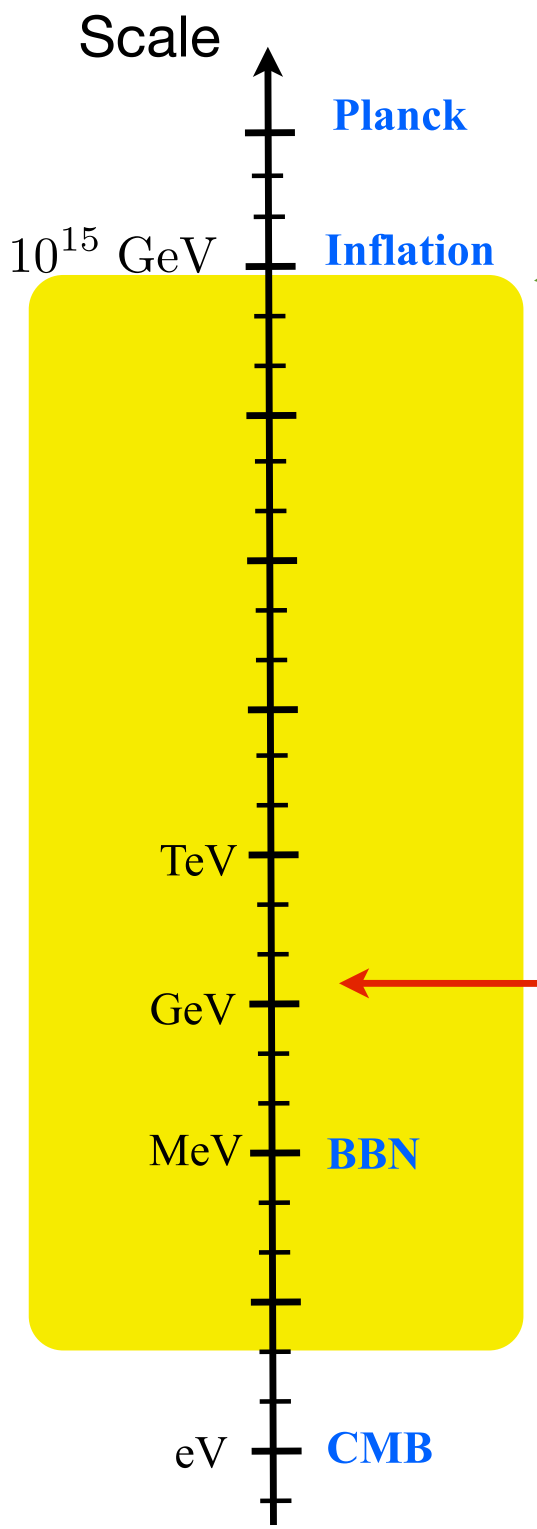


- Monomial potentials with p > 2 in GR are almost excluded.
- What if we could nail down to further precision?

CMB uncertainties from the post-inflationary evolution

[Easther, Galvez, Ozsoy, Watson 2013]

Thermal History | **Alternative History**



$$N_* \equiv \int_{t_*}^{t_{\rm end}} H dt = \ln(a_{\rm end}/a_*)$$

Radiation Phase
(instant reheating)

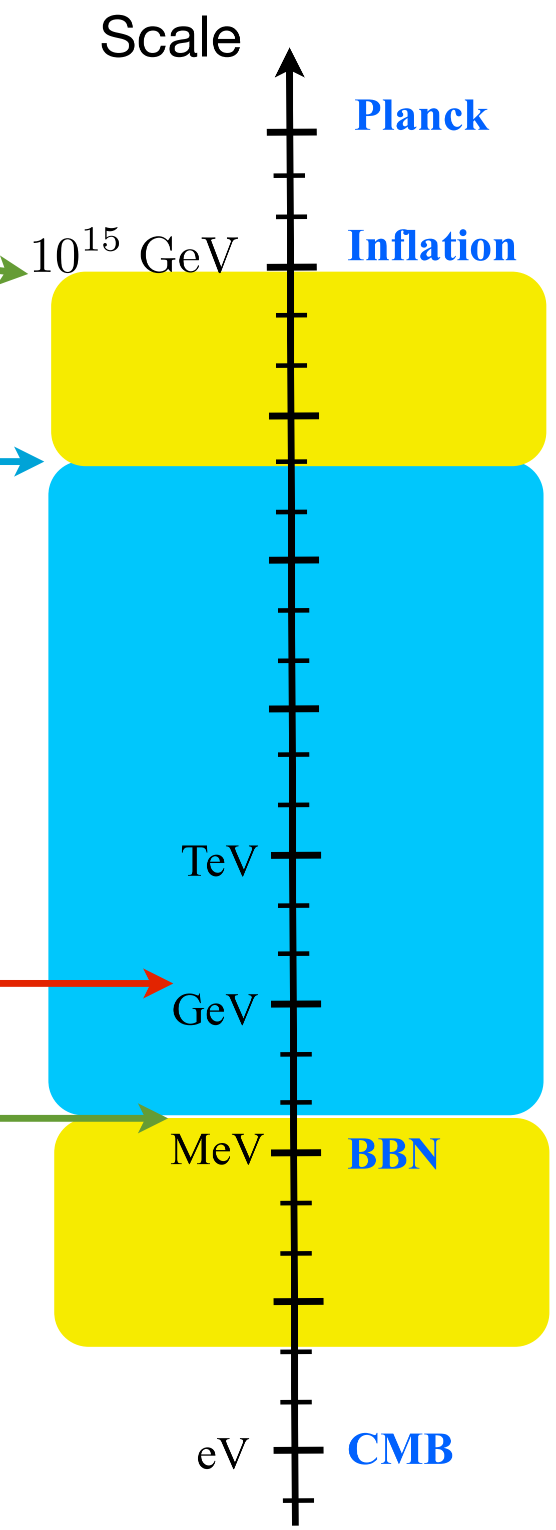
Scalar Oscillations Dominate

$$n_s(k_*) = 1 - \frac{\alpha}{N_*}$$

$$\Delta n_s = \alpha \frac{\Delta N}{N^2} = \frac{(1-n_s)^2}{\alpha} \Delta N$$

Thermal DM Freeze-out

Particles Decay and Reheat

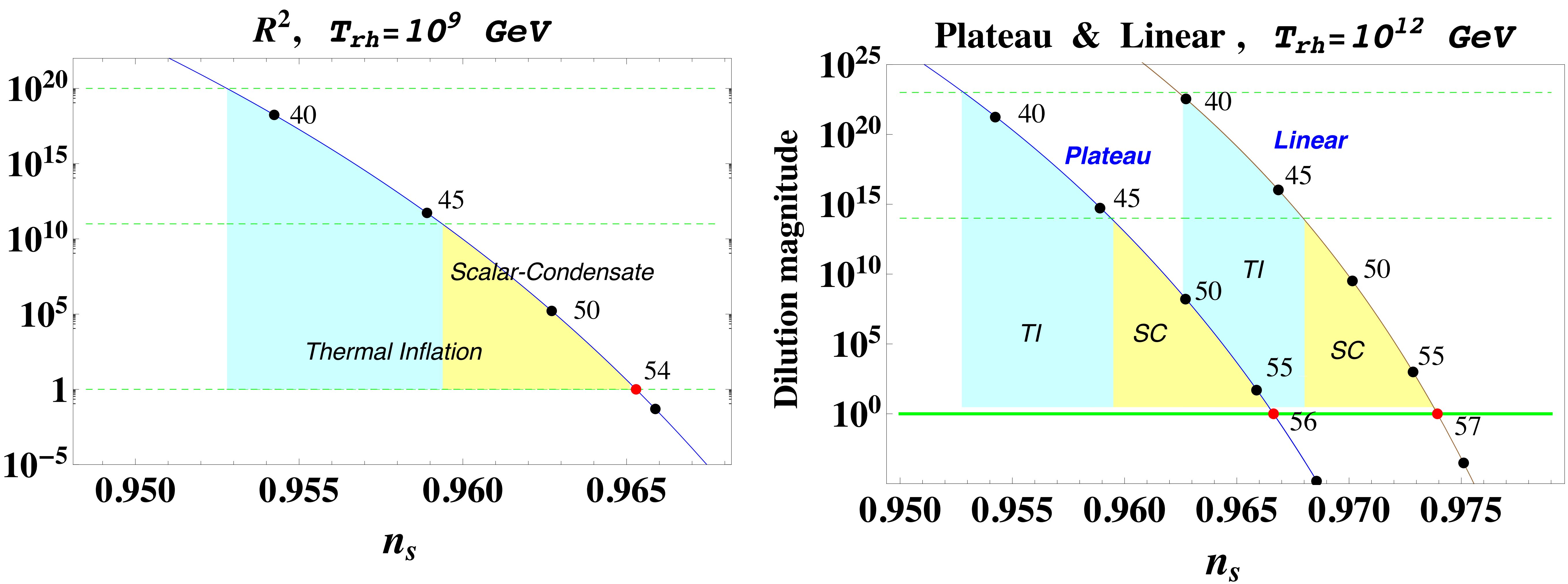


Shift in (ns, r) due to late entropy production

- After inflaton decay, a diluter field X (modulus, flaton) may dominate the universe until BBN. Decays of X produce **entropy**:

$$\Delta N_X = \frac{1}{3}\ln\left[\left(\frac{g_*(T_X^{\rm dom})}{g_*(T_X^{\rm dec})}\right)^{1/4} D_X\right] \equiv \frac{1}{3}\ln \tilde{D}_X$$

$$D_X \equiv 1 + \frac{S_{\rm after}}{S_{\rm before}} = 1 + \frac{g_s(T_X^{\rm dec})}{g_*(T_X^{\rm dec})}\frac{g_*(T_X^{\rm dom})}{g_s(T_X^{\rm dom})}\frac{T_X^{\rm dom}}{T_X^{\rm dec}} \simeq \frac{T_X^{\rm dom}}{T_X^{\rm dec}} \geq 1$$



Supersymmetric dark matter cosmology

Merits: Gauge coupling unification, stable dark matter, baryogenesis, stringy UV completion, …

1. Gravitino LSP
2. Neutralino LSP (WIMP)

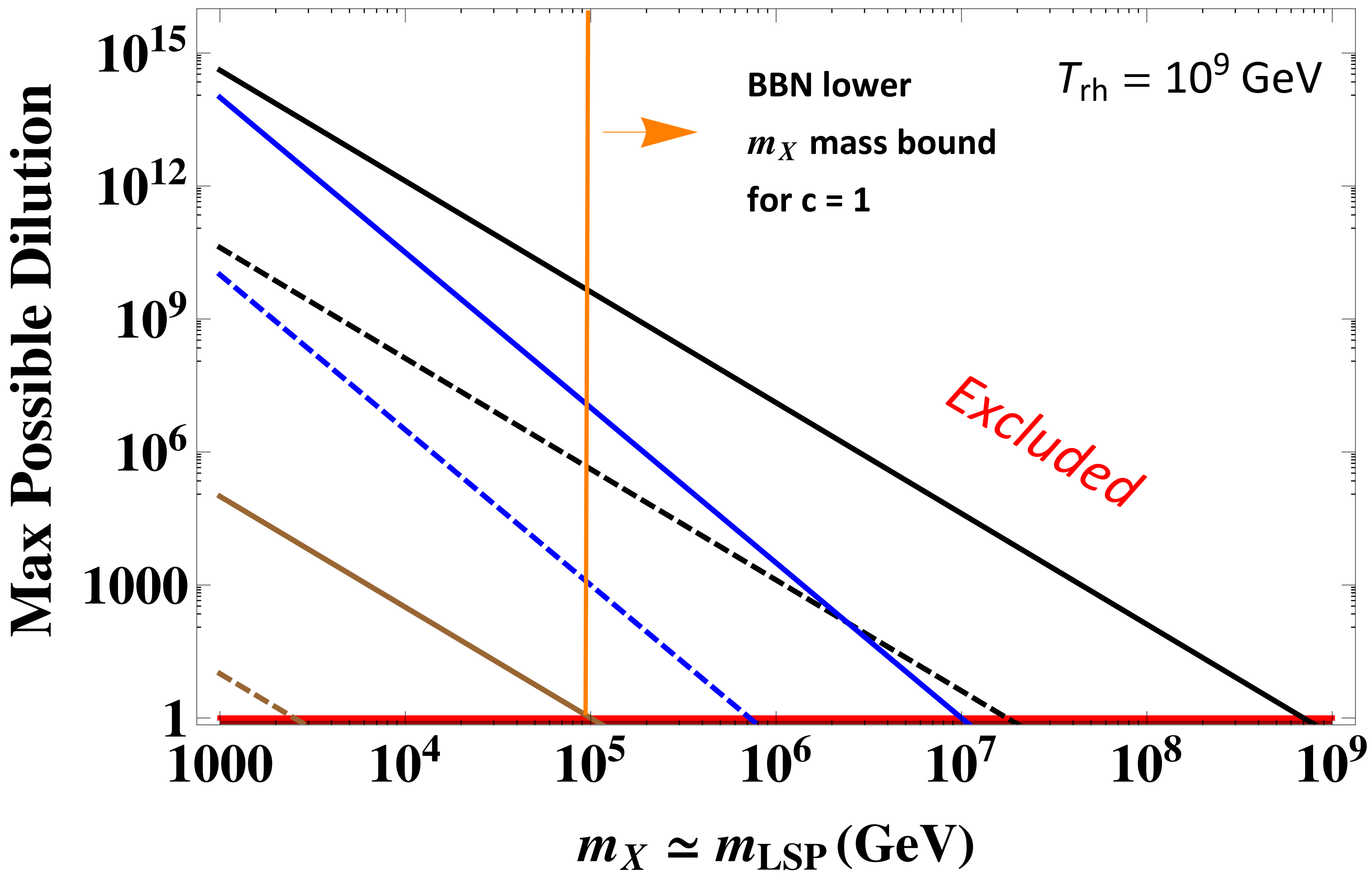
- Thermal DM (freeze out): thermal scatterings with the MSSM, messenger fields
- Non-thermal DM (freeze in): decays, thermal scatterings

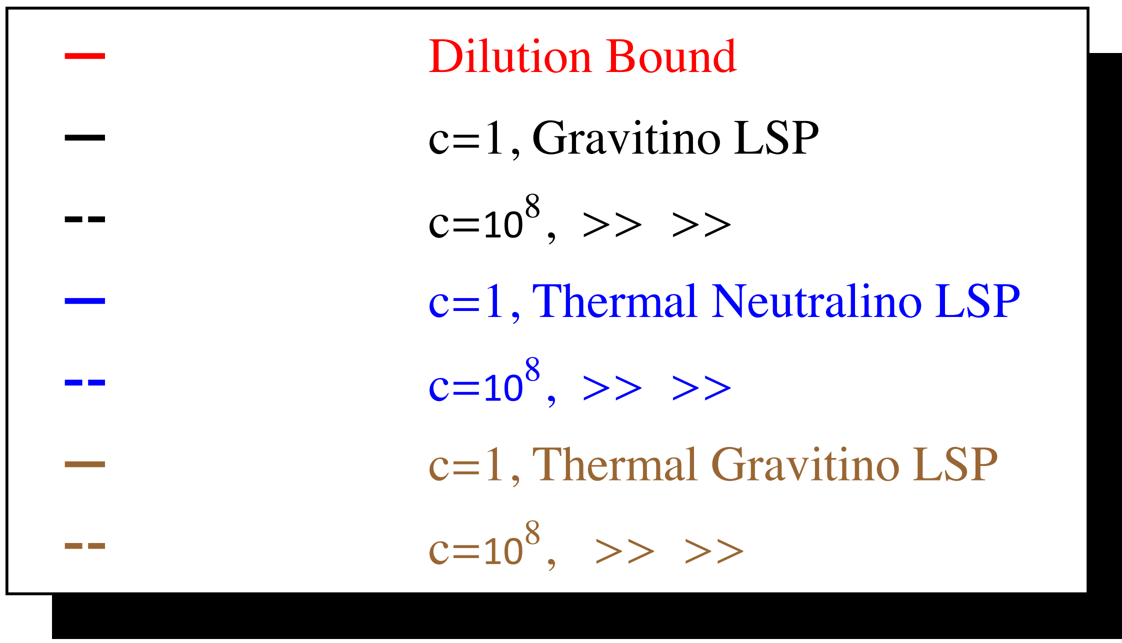
Light WIMP mass is disfavored by the LHC.
$\Omega_{\rm DM}h^2$ is severely constrained when **sparticle masses increase**:

$$\Omega_{3/2} \propto m_{3/2}^{\alpha} \left(\frac{m_{\tilde{g}}}{m_{3/2}}\right)^{\beta} \left(\frac{m_{\tilde{f}}}{m_{3/2}}\right)^{\gamma} T_{\rm rh}^{\delta}\,, \qquad m_{3/2} < m_{\tilde{g}}, m_{\tilde{f}}\,,$$

$$\Omega_{\tilde{\chi}^0} \propto m_{\tilde{\chi}^0}^{\tilde{\alpha}}\, m_{3/2}^{\tilde{\beta}} \left(\frac{m_{\tilde{f}}}{m_{3/2}}\right)^{\tilde{\gamma}} T_{\rm rh}^{\tilde{\delta}}\,, \qquad m_{\tilde{\chi}^0} < m_{3/2}, m_{\tilde{f}}$$

Alternative cosmic histories and SUSY





$$\Gamma_X = \frac{c}{4\pi}\frac{m_X^3}{M_{\rm Pl}^2}$$

★ High reheating temp. generally overproduce light LSP

→ Dilution of DM abundance is necessary: **diluter field X**

- If $D_X = 1$ then $T_{\rm rh} \lesssim \tilde{m}$ or $\tilde{m} \sim {\rm TeV}$
- If $\mathcal{O}({\rm TeV}) < (m_{\rm LSP}\,, \tilde{m}) < T_{\rm rh}$ then $D_X \geq D_X^{\rm min} \equiv \dfrac{\Omega_{\rm LSP}^<}{0.12\,h^{-2}}$

where $\tilde{m}$ the sparticle mass scale.

An example: Starobinsky R2 inflation

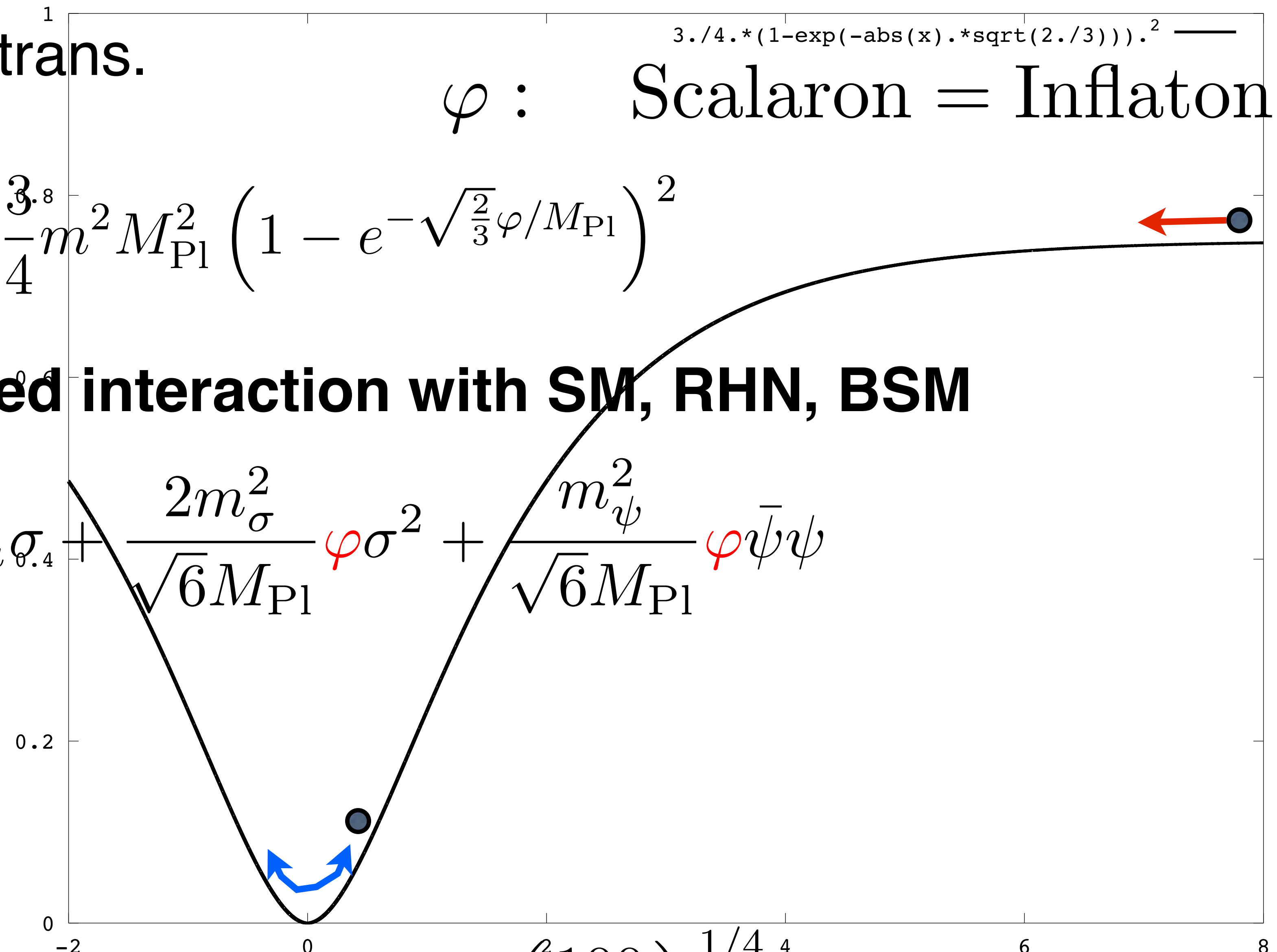
$$e^{-1}\mathcal{L} = -\frac{M_{\rm Pl}^2}{2}R + \frac{M_{\rm Pl}^2}{12m^2}R^2$$

+ minimally coupled SM, RHN
+ *"desert"* or BSM

↓ conformal trans.

φ : Scalaron = Inflaton

$$e^{-1}\mathcal{L} = -\frac{M_{\rm Pl}^2}{2}R - \frac{1}{2}\partial\varphi\partial\varphi - \frac{3}{4}m^2 M_{\rm Pl}^2\left(1 - e^{-\sqrt{\frac{2}{3}}\varphi/M_{\rm Pl}}\right)^2$$



+ Planck-suppresed interaction with SM, RHN, BSM

$$\mathcal{L}_{\rm 3leg} = \frac{1}{\sqrt{6}M_{\rm Pl}}\varphi\partial^\mu\sigma\partial_\mu\sigma + \frac{2m_\sigma^2}{\sqrt{6}M_{\rm Pl}}\varphi\sigma^2 + \frac{m_\psi^2}{\sqrt{6}M_{\rm Pl}}\varphi\bar{\psi}\psi$$

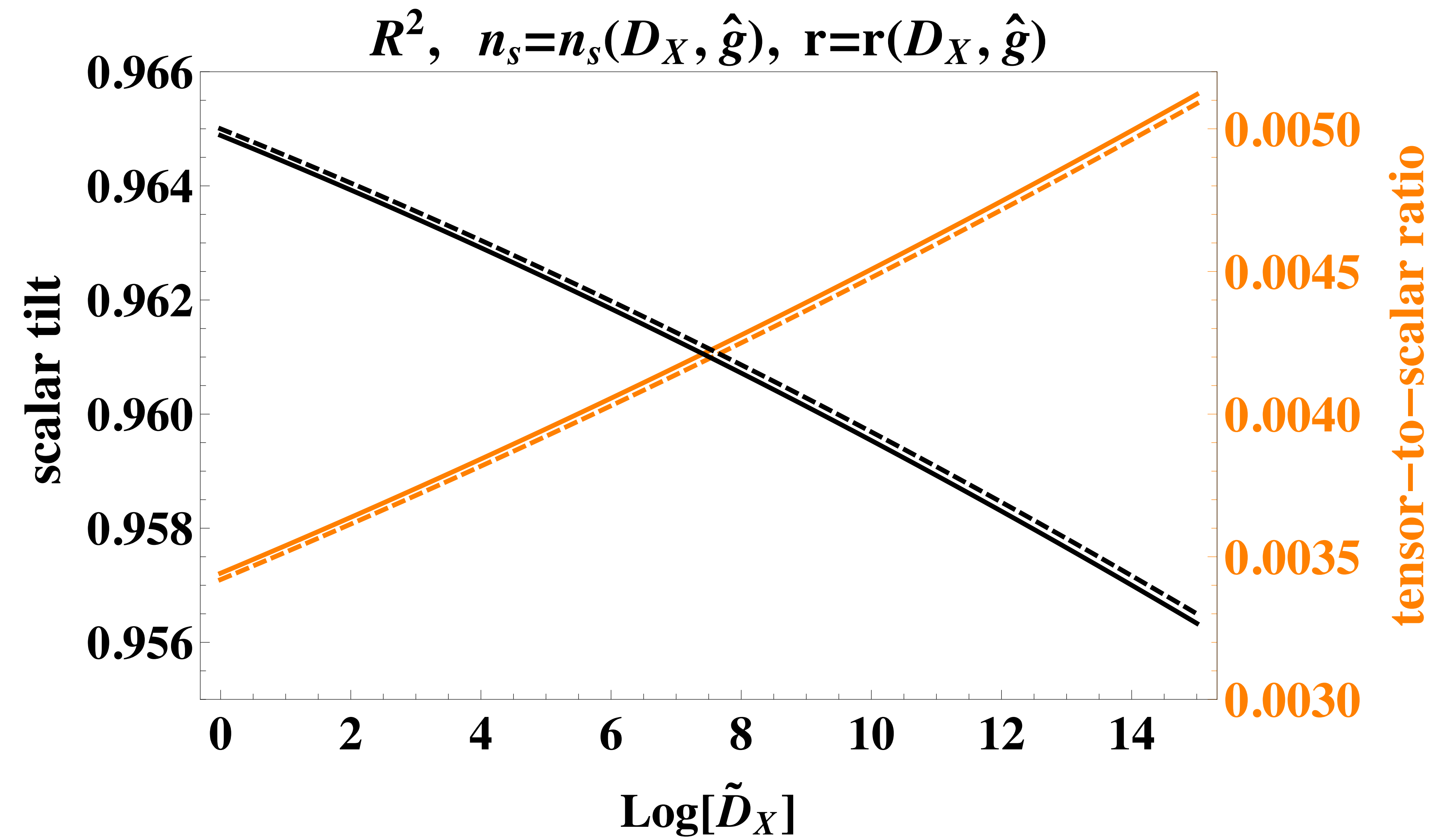
$$T_{\rm rh}|_{R^2} = \left(\frac{\pi^2}{90}g_{*\rm rh}\right)^{-1/4}\sqrt{\Gamma_{\rm inf}M_{\rm Pl}} \sim 10^9\,{\rm GeV}\left(\frac{100}{g_{*\rm rh}}\right)^{1/4}$$

An example: Starobinsky R2 inflation

$$n_s^{(\mathrm{th})}\Big|_{R^2} = 0.965\,,$$

$$r^{(\mathrm{th})}\Big|_{R^2} = 0.0034$$

$$N^{(\mathrm{th})} = 54$$



$$N_*\big|_{R^2} = 55.9 + \frac{1}{4}\ln\epsilon_* + \frac{1}{4}\ln\frac{V_*}{\rho_{\mathrm{end}}} + \frac{1}{12}\ln\left(\frac{g_{*\mathrm{rh}}}{100}\right) + \frac{1}{3}\ln\left(\frac{T_{\mathrm{rh}}}{10^9\ \mathrm{GeV}}\right) - \Delta N_X$$

An example: Starobinsky R2 inflation

$$\mathcal{L} = -3M_P^2 \int d^4\theta\, E \left[1 - \frac{4}{m^2}\mathcal{R}\bar{\mathcal{R}} + \frac{\zeta}{3m^4}\mathcal{R}^2\bar{\mathcal{R}}^2\right]$$

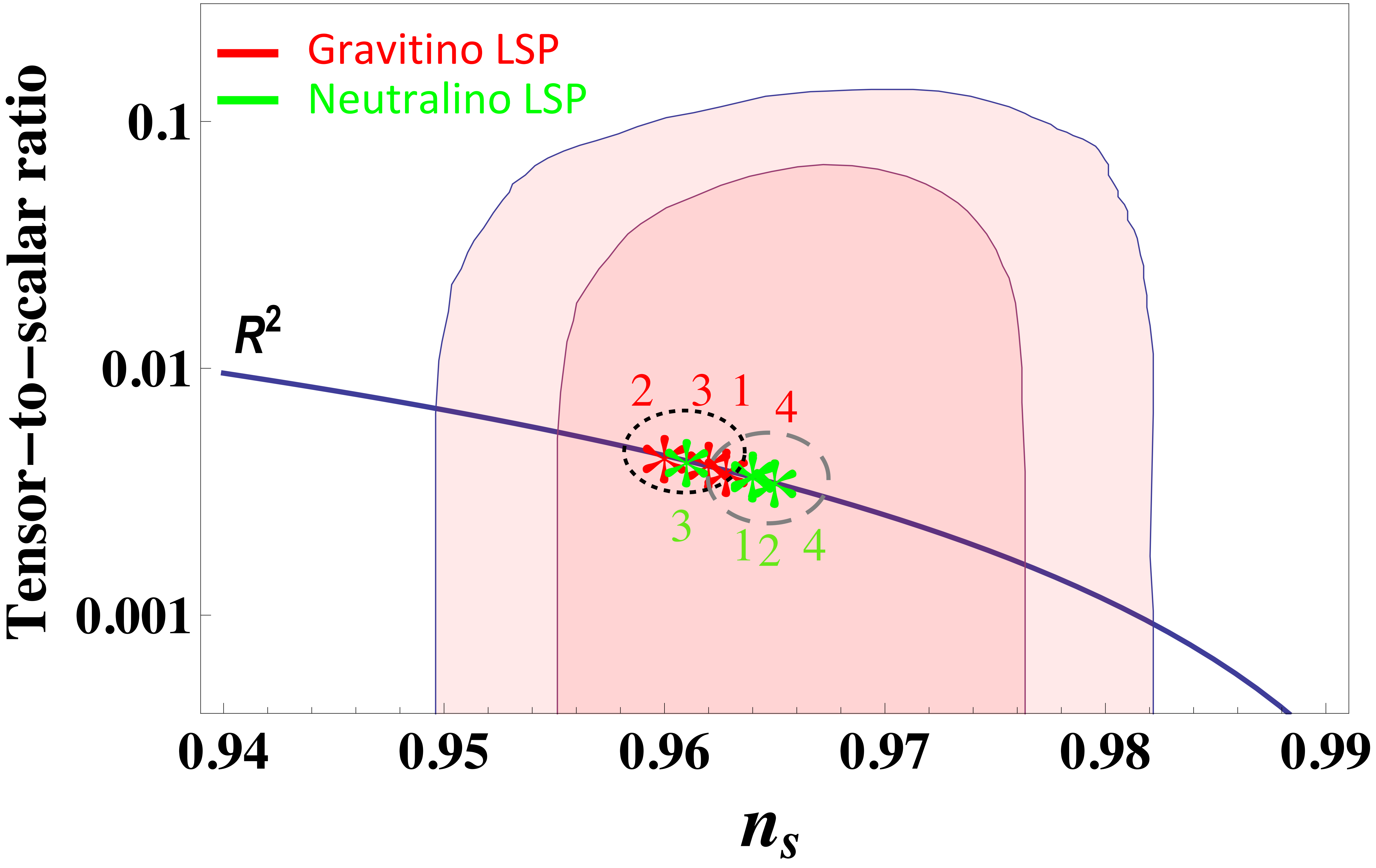
↓ dual description

Two chiral superfields T, S + standard SUGRA (+ SUSY breaking field Z)
Real component of T = Inflaton

#	m_Z	$m_{\tilde{g}}$	$m_{\tilde{f}}$	$m_{3/2}$ (LSP)	D_X	N_*	n_s	r	Origin
1	10^4	10^4	10^4	10^2	$10^4\vert_{\rm min}$	$51\vert_{\rm max}$	$\mathbf{0.963}\vert_{\rm max}$	$\mathbf{0.0038}\vert_{\rm min}$	Th
2	10^4	10^4	10^5	10^3	$10^{10}\vert_{\rm min}$	$46\vert_{\rm max}$	$\mathbf{0.960}\vert_{\rm max}$	$\mathbf{0.0044}\vert_{\rm min}$	Th
3	10^6	10^5	10^6	10^4	$10^6\vert_{\rm min}$	$49\vert_{\rm max}$	$\mathbf{0.962}\vert_{\rm max}$	$\mathbf{0.0041}\vert_{\rm min}$	Non-th
4	10^3	10^3	10^4	10	1	54	**0.965**	**0.0034**	Th

#	m_Z	$m_{3/2}$	$m_{\tilde{f}}$	$m_{\tilde{\chi}^0}$ (LSP)	$D_{(X)}$	N_*	n_s	r	Origin
1	10^7	10^6	10^6	10^3	$10^2\vert_{\rm min}$	$52\vert_{\rm max}$	$\mathbf{0.964}\vert_{\rm max}$	$\mathbf{0.0036}\vert_{\rm min}$	Non-th
2	10^9	10^8	10^8	10^3	$10^2\vert_{\rm min}$	$52\vert_{\rm max}$	$\mathbf{0.964}\vert_{\rm max}$	$\mathbf{0.0036}\vert_{\rm min}$	Th
3	10^8	10^7	10^7	10^5	$10^8\vert_{\rm min}$	$48\vert_{\rm max}$	$\mathbf{0.961}\vert_{\rm max}$	$\mathbf{0.0042}\vert_{\rm min}$	Non-th
4	10^5	10^5	10^5	10^3	1	54	**0.965**	**0.0034**	Th

An example: Starobinsky R2 inflation



Conclusion

- We cannot exclude or verify SUSY by (ns, r) precision measurements.
- Nevertheless we can support the presence of BSM physics by ruling out the “BSM-desert” hypothesis for a particular inflation model.
- Hence precision cosmology can offer us complementary constrains to the parameter space of SUSY.