Relating Inflationary Predictions to the Moduli Mass

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StringPheno 2015
Madrid

In collaboration with
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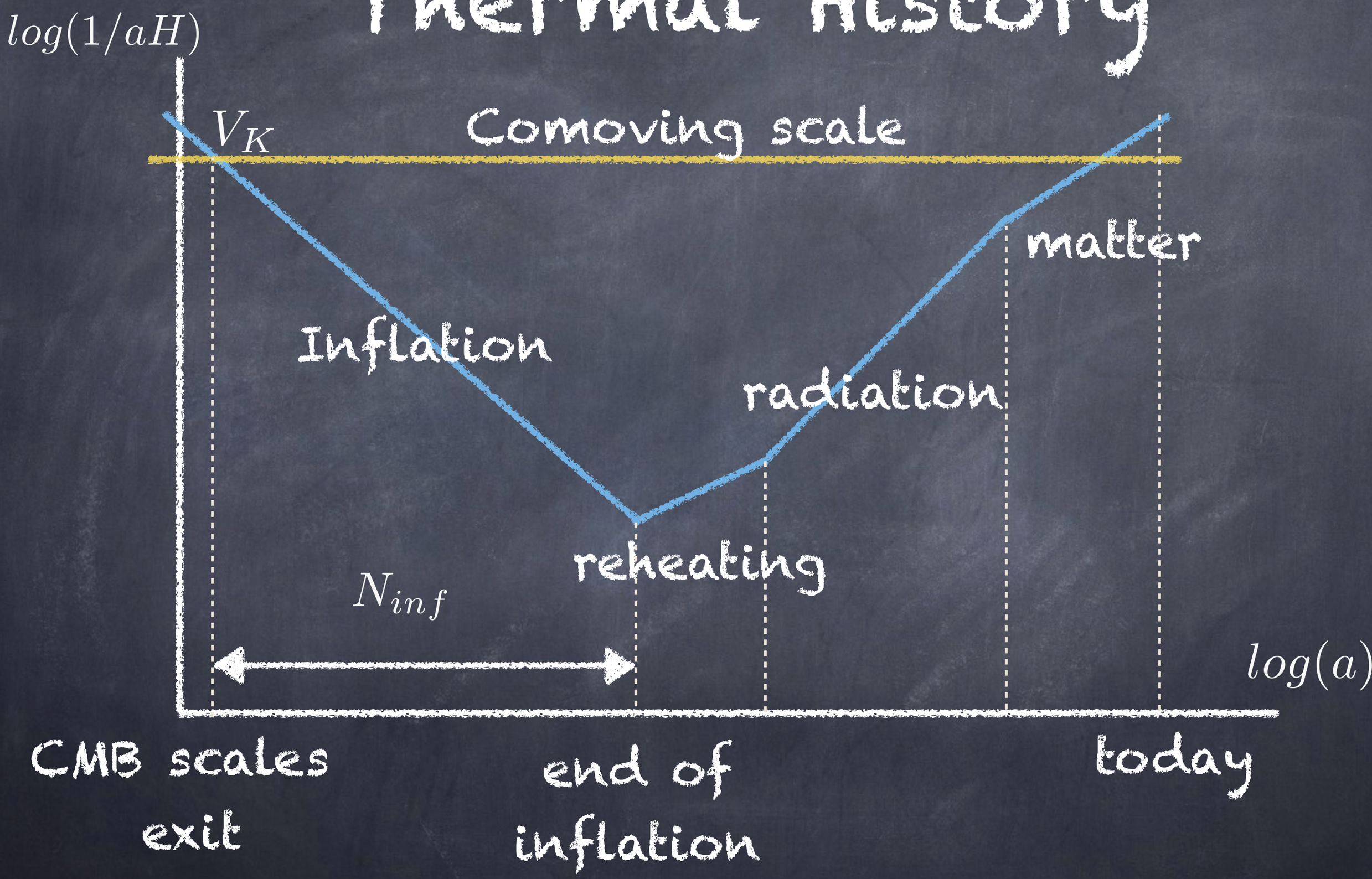
Phys.Rev. D91 (2015) 4, 043503

arXiv:1409.7037[hep-ph]

ongoing work with
Kumar Das (Saha Institute)
ANSHUMAN MAHARANA (HRI, Allahabad)
(hopefully in a week ..)

Thermal History



Consistency

V_k must be evolved to H_0

Any post inflationary evolution must be evolved to the present energy density

Consistency Condition

$$N_{inf} + \frac{1}{4}(1 - 3w_{rh})N_{rh} = 55 + \frac{1}{4}lnr + \frac{1}{4}ln(\rho_k/\rho_{end})$$

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Equivalent

$$N_* \approx 71.21 - \ln\left(\frac{k_*}{a_0 H_0}\right) + \frac{1}{4}\ln\left(\frac{V_{\rm hor}}{M_{\rm pl}^4}\right) + \frac{1}{4}\ln\left(\frac{V_{\rm hor}}{\rho_{\rm end}}\right)$$
$$+ \frac{1 - 3w_{\rm int}}{12(1 + w_{\rm int})}\ln\left(\frac{\rho_{\rm th}}{\rho_{\rm end}}\right),$$

PLANCK paper

Making predictions ..

$$N_{inf} + \frac{1}{4}(1 - 3w_{rh})N_{rh} = 55 + \frac{1}{4}lnr + \frac{1}{4}ln(\rho_k/\rho_{end})$$

$$N_{inf} = 55 \pm 5$$

Making predictions ..

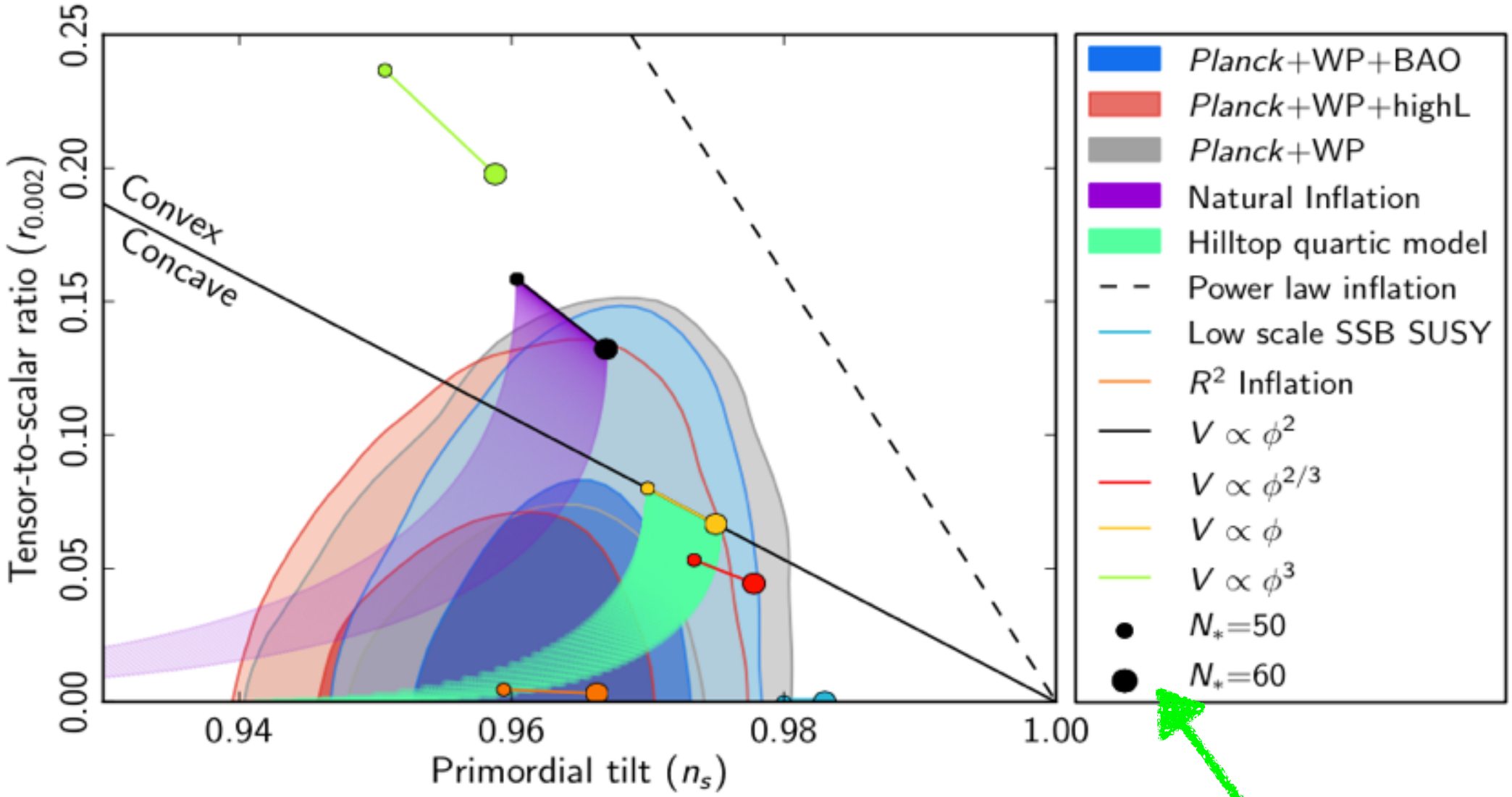
$$N_{inf} + \frac{1}{4}(1 - 3w_{rh})N_{rh} = 55 + \frac{1}{4}lnr + \frac{1}{4}ln(\rho_k/\rho_{end})$$

$$N_{inf} = 55 \pm 5$$

'Theoretical prior'

compute observables in terms of N_{inf} and see whether it fits data for N = 50-60!

$$V(\chi) = \frac{1}{2}m^2\chi^2 \qquad n_s - 1 = -\frac{2}{N_k} \qquad r = 8/N_K$$

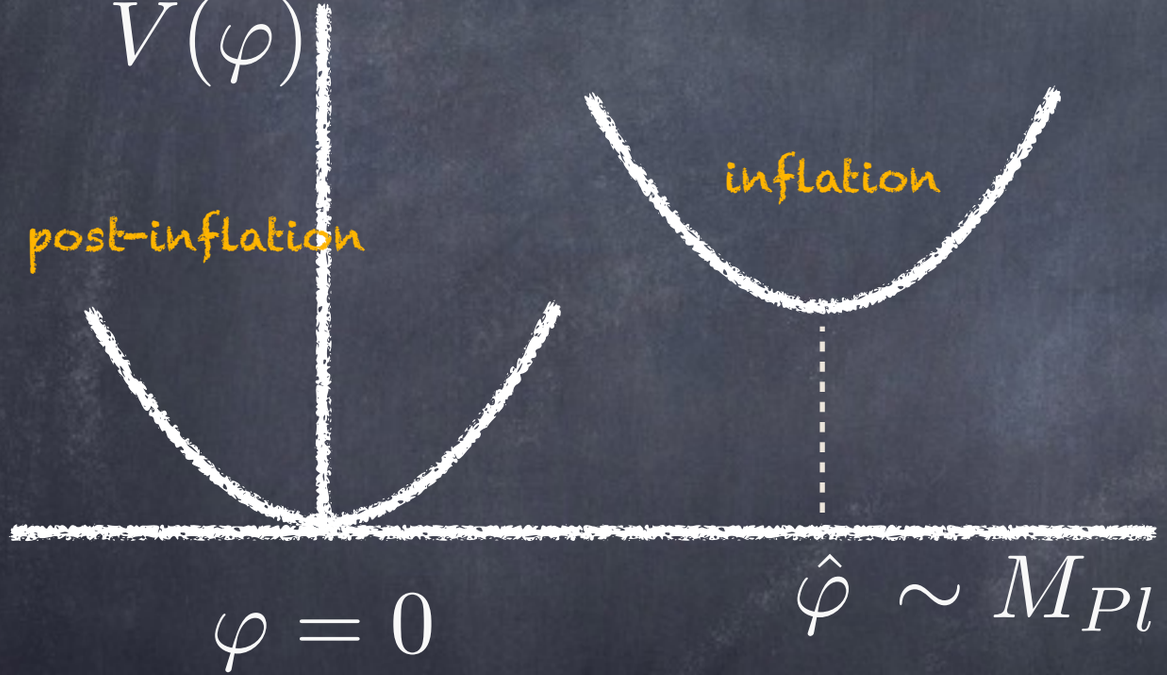


'Theoretical prior'

How does making predictions change for modular cosmology?

Modular Cosmology

- moduli: light scalar fields with Planck suppressed interactions

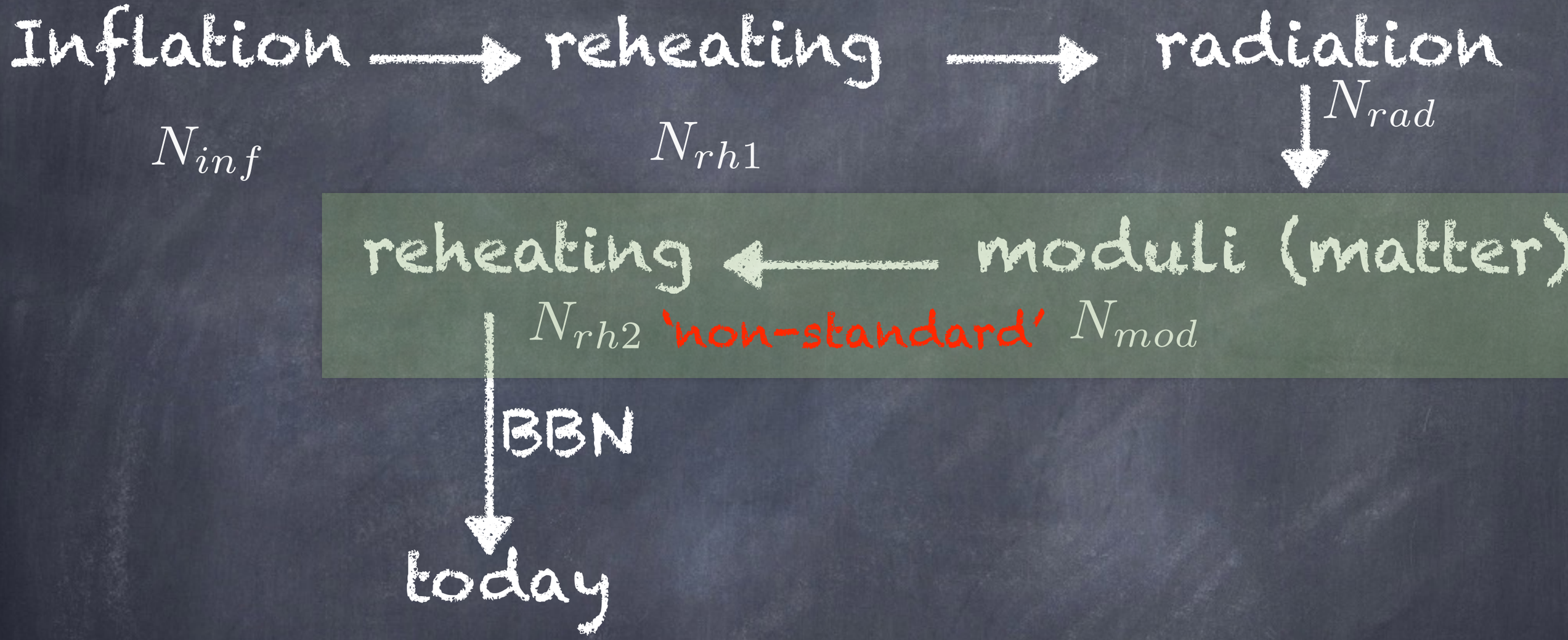


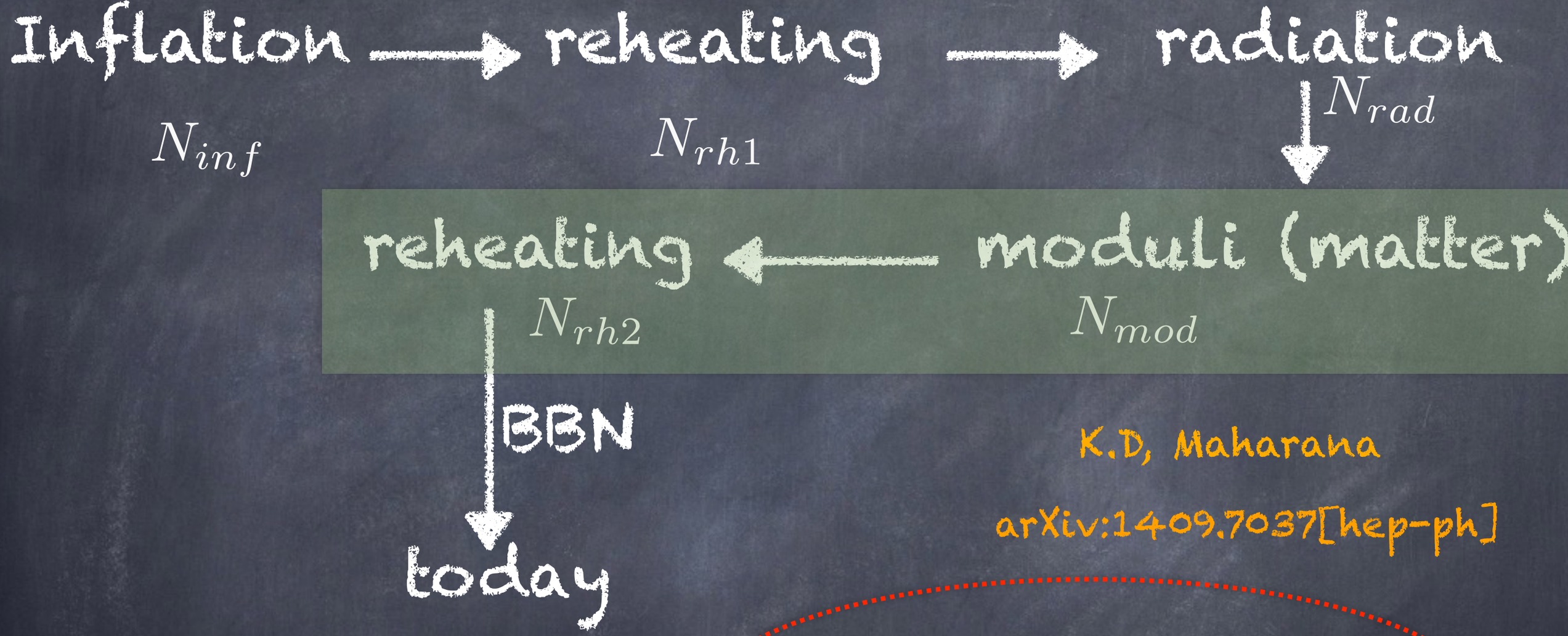
Goncharov, Linde, Vysotsky 1984; Dine, Fischler, Nemeschansky 1984; Coughlan, Holman, Ramond, Ross 1984; Linde 1996.

$$m_\varphi < H_{inf}$$

$$Y = \hat{\varphi}/M_{Pl} \sim 1$$

Dine, Randall, Thomas (1995)


Inflation
reheating
radiation
N_{inf}
N_{rh1}
N_{rad}
reheating
moduli (matter)
N_{rh2} 'non-standard' N_{mod}
BBN
today



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$$N_{inf} + \frac{1}{4}(1-3w_{rh1})N_{rh1} + \frac{1}{4}N_{mod} + \frac{1}{4}(1-3w_{rh2})N_{rh2}$$

$$= 55.43 + \frac{1}{4}ln\ r + \frac{1}{4}ln(\frac{\rho_k}{\rho_{end}})$$

Implications: I

Central value of e-folding shifts

$$N_{inf} = 55 \pm 5$$

$$N_{inf} = \left(55 - \frac{N_{mod}}{4}\right) \pm 5$$

$$\Gamma_{mod} \sim \frac{m_\varphi^3}{16\pi M_{Pl}^2}$$

$$N_{inf} = \left(55 - \frac{1}{3} ln \left(\frac{\sqrt{16\pi} M_{pl} Y^2}{m_\varphi}\right)\right) \pm 5$$

$$N_{inf} = \left(55 - \frac{1}{3} ln \left(\frac{\sqrt{16\pi} M_{pl} Y^2}{m_\varphi} \right) \right) \pm 5$$

Central value of e folding shifts

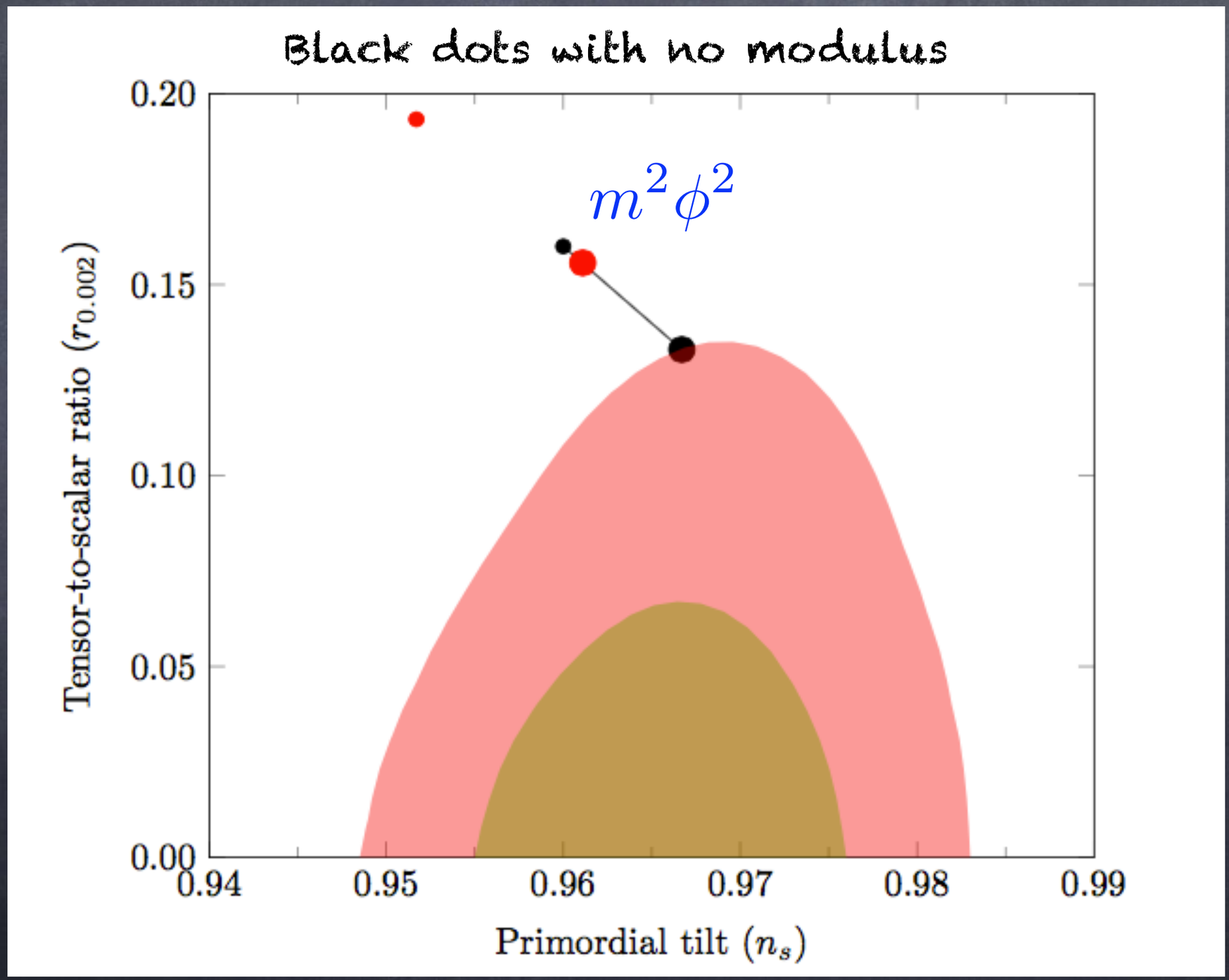
For $m_\varphi \sim 10^3$ TeV : $N_{inf} = 41 \quad - \quad 51$

For $m_\varphi \sim 10^6$ TeV : $N_{inf} = 43 \quad - \quad 53$

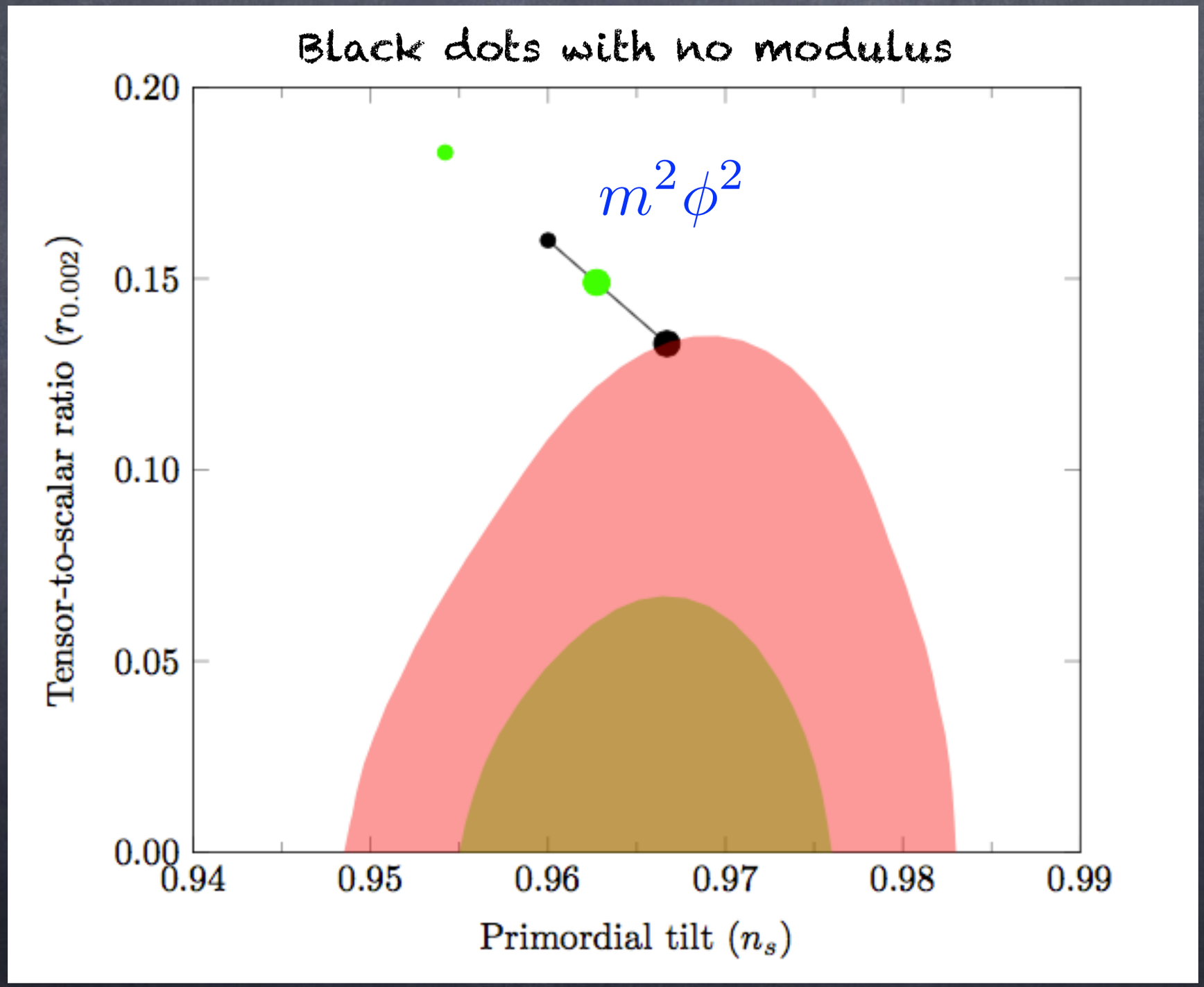
(used to be 50 - 60)

(Y ~ 0.1 assumed)

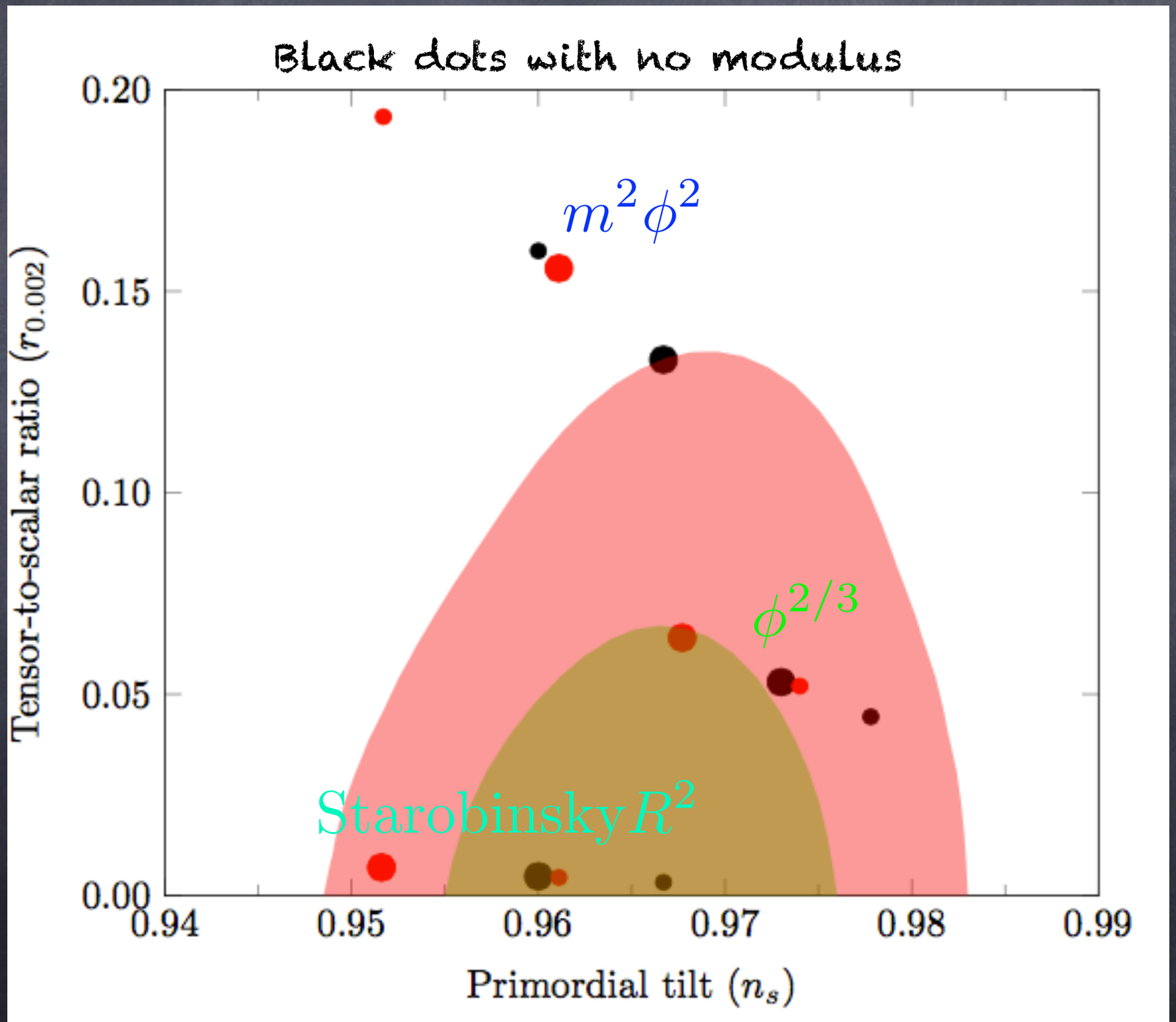
10^3 Tev Modulus



10^6 Tev Modulus



10^3 Tev Modulus



Implications: II

$$\frac{1}{6}ln(\frac{16\pi M_{Pl}^2 Y^4}{m_\varphi^2}) + \frac{1}{4}(1-3w_{rh1})N_{re1} + \frac{1}{4}(1-3w_{rh2})N_{re2}$$

positive definite

$$= 55.43 - N_{inf} + \frac{1}{4}ln\ r + \frac{1}{4}ln(\frac{\rho_k}{\rho_{end}})$$

analytical/numerical understanding of reheating: $w_{re} < 1/3$

Constraint on Modulus mass

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 \; e^{-3\left(55.43 - N_k + \frac{1}{4}\ln(\frac{\rho_{\rm k}}{\rho_{\rm end}}) + \frac{1}{4}\ln r\right)}$$

- take $Y = 0.01$, then for $N = 50$

$$m_\varphi > 10^6 - 10^8 \; TeV$$

much stronger than BBN bound

($T_{reheat} > MeV$ $\quad$ $m_\varphi > 30 \; TeV$)

- Large SUSY breaking scale ... ?

K.D, Maharana

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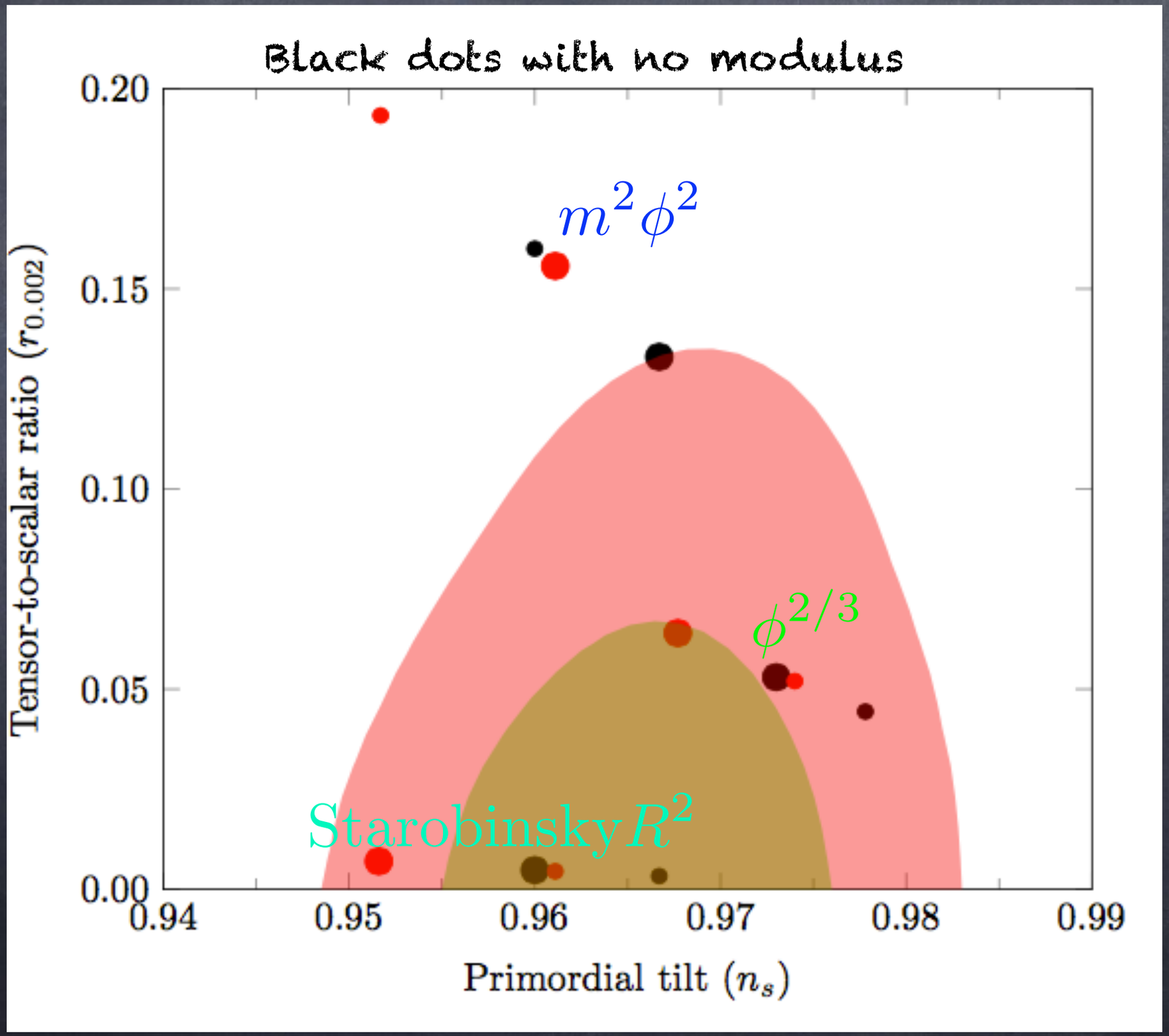
Conclusions

- modulus dominated cosmology is a generic feature of string/sugra motivated scenario

$$N_{inf} = \left(55 - \frac{1}{3} ln \left(\frac{\sqrt{16\pi} M_{pl} Y^2}{m_\varphi} \right) \right) \pm 5$$

10^3 Tev Modulus



Conclusions

- modulus dominated cosmology is a generic feature of string/sugra motivated scenario

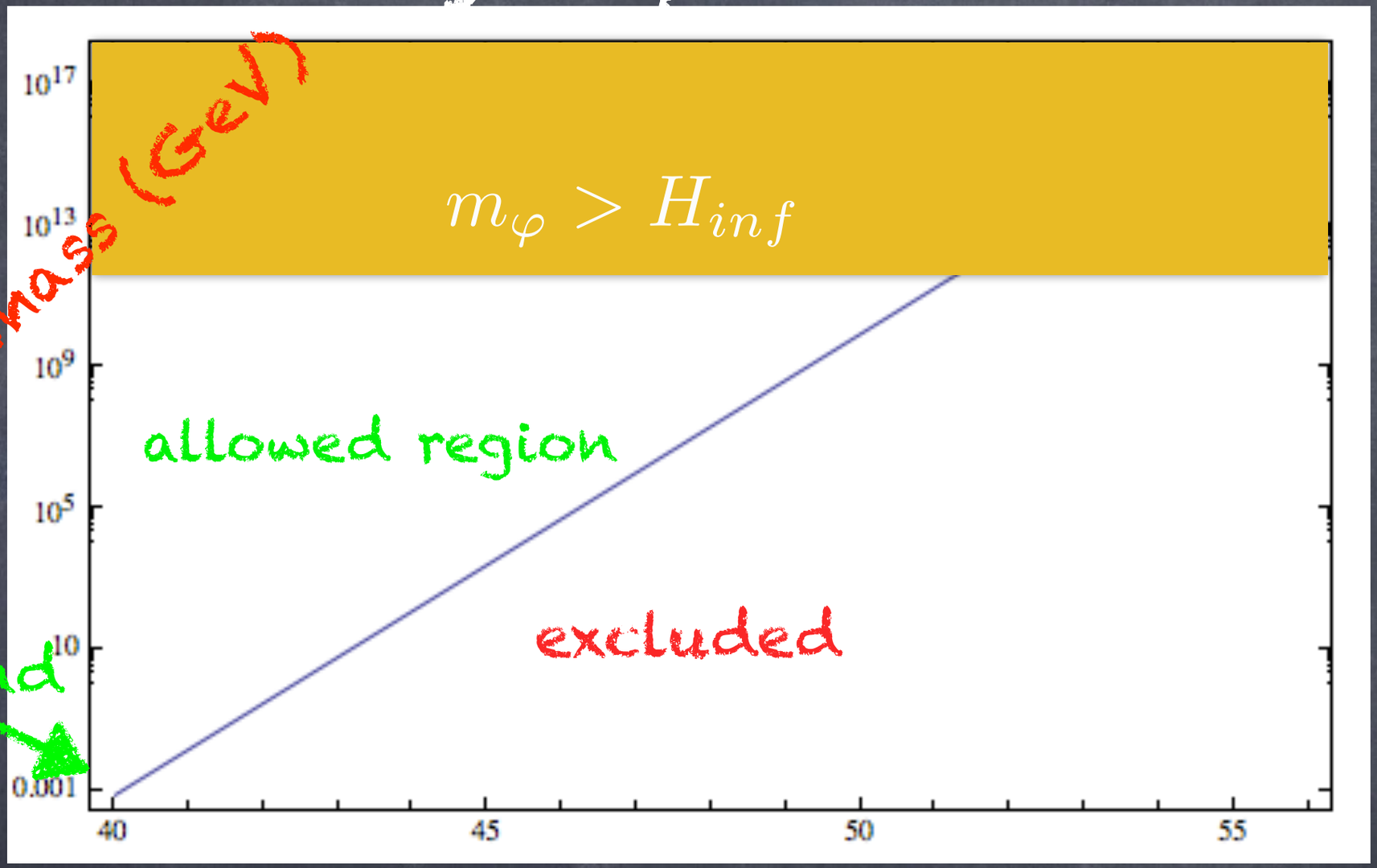
$$N_{inf} = \left(55 - \frac{1}{3} ln \left(\frac{\sqrt{16\pi} M_{pl} Y^2}{m_\varphi} \right) \right) \pm 5$$

- Independent constraint on modulus mass derived using precision CMB data

- typically for N ~ 50 and PLANCK central value of spectral index $m_\varphi > 10^6 - 10^8 \; TeV$

Thank You

Simplicity: Neglect 'r' and energy density dependent term



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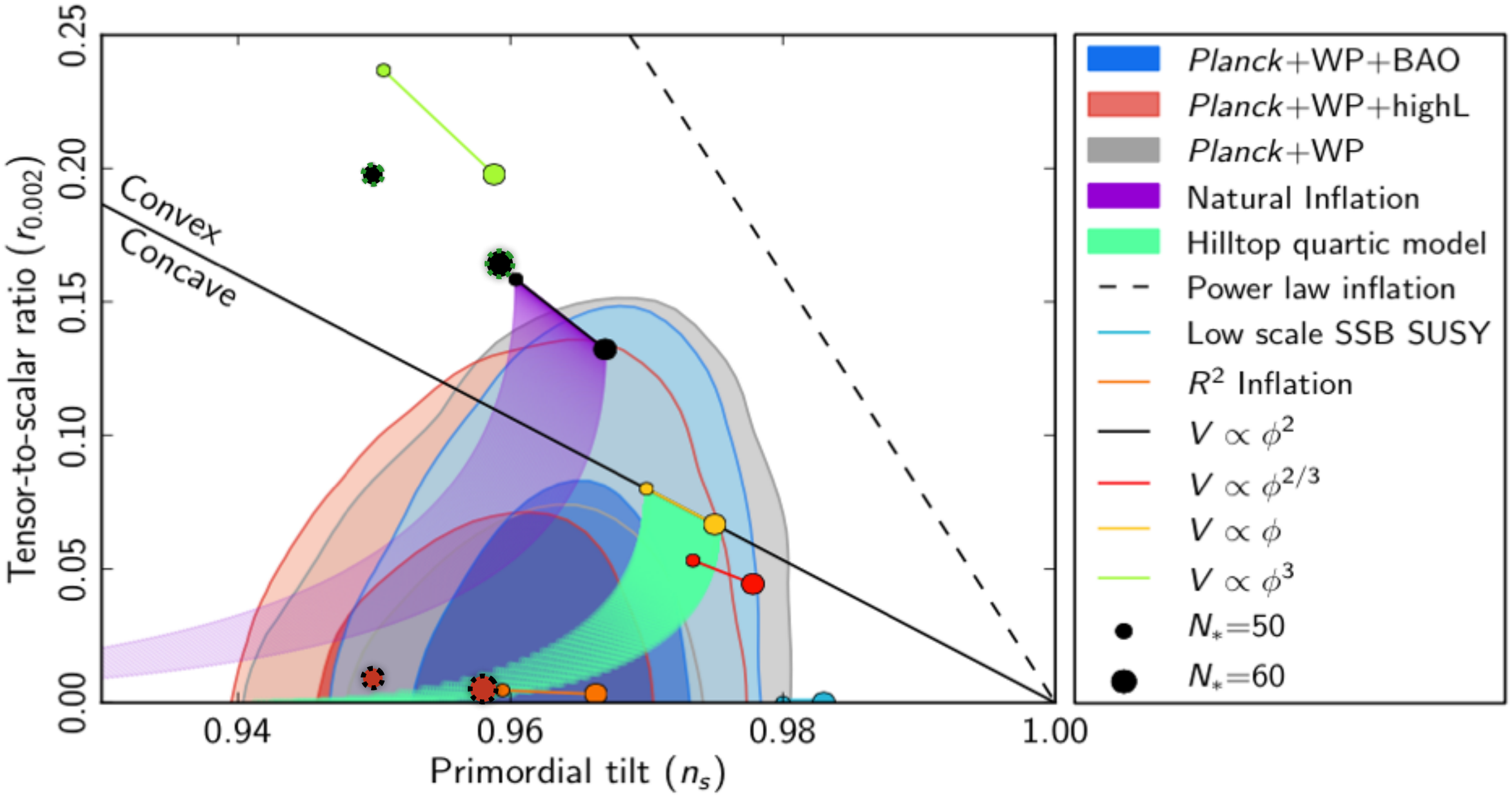
Tensor-to-scalar ratio ($r_{0.002}$)
0.25
0.20
0.15
0.10
0.05
0.00
Convex
Concave
0.94
0.96
0.98
1.00
Primordial tilt (n_s)
Planck+WP+BAO
Planck+WP+highL
Planck+WP
Natural Inflation
Hilltop quartic model
Power law inflation
Low scale SSB SUSY
R^2 Inflation
$V \propto \phi^2$
$V \propto \phi^{2/3}$
$V \propto \phi$
$V \propto \phi^3$
N_*=50
N_*=60