IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

VNIVERSITAT DE VALÈNCIA

Do current data prefer a nonminimally coupled inflaton?

Héctor Ramírez

IFIC - University of Valencia

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From the Planck Scale to the Electroweak Scale

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L. Boubekeur, E. Giusarma, O. Mena and HR,

arXiv:1502.05193 [astro-ph.CO].

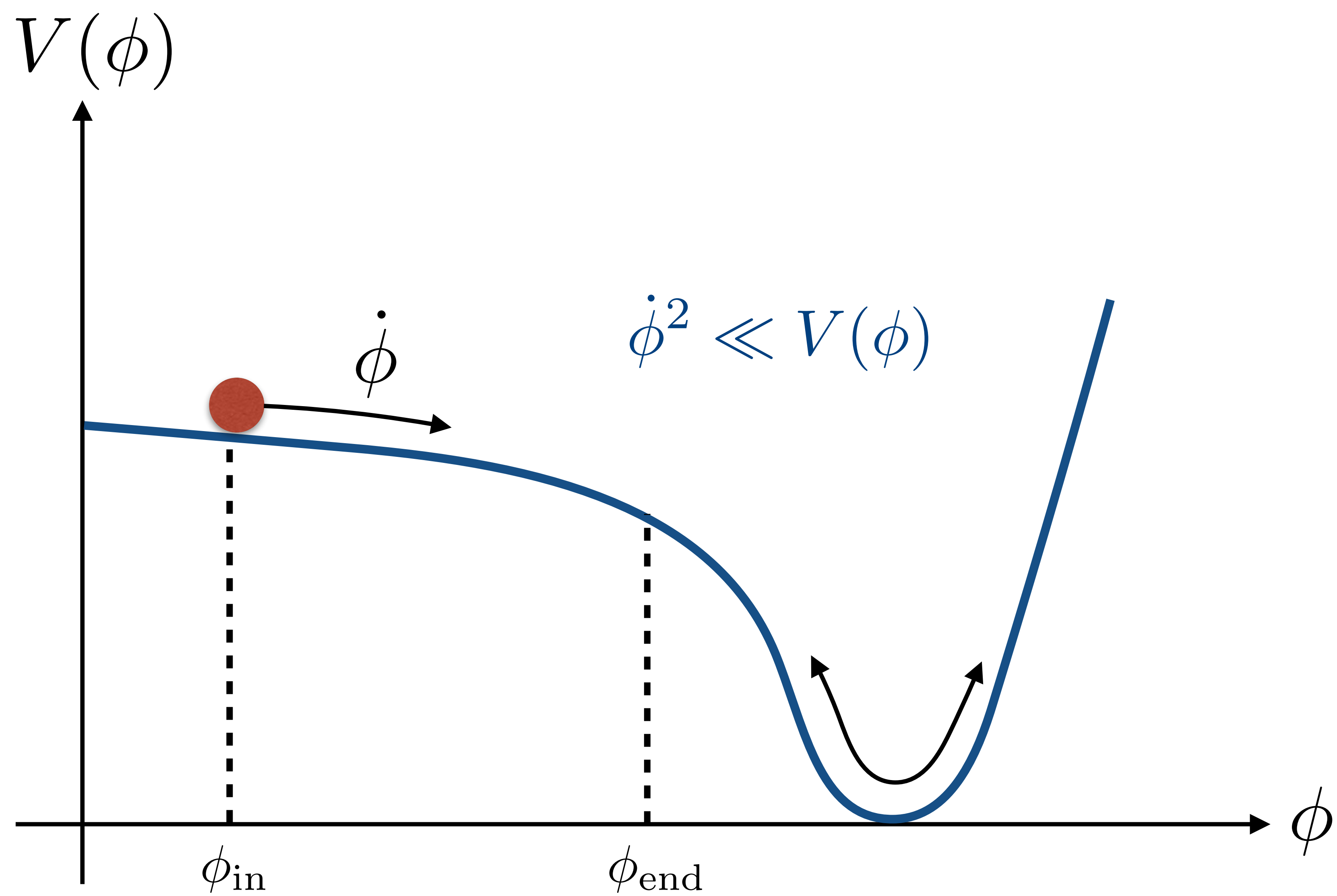
Phys. Rev. D 91 (2015) 103004.

Outline

1. Single-field slow-roll inflation: generalities and status.
2. Motivation.
3. The model.
4. Results.
5. Future constraints.
6. Conclusions.

Simplest picture: Single-field slow-roll inflation

A. Linde '82



$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{M_{\mathrm{pl}}^2}{2}\mathcal{R} - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - U(\phi)\right]$$

Minimal coupling

The observables

$$\Delta_s^2(k) \equiv \frac{k^3}{2\pi^2} P_\zeta(k) = \frac{1}{8\pi^2} \frac{H^2}{\epsilon}\bigg|_{k=aH}$$

Primordial scalar power spectrum

$$\Delta_t^2(k) = \frac{2}{\pi^2} \frac{H^2}{M_{\rm pl}^2}\bigg|_{k=aH}$$

Primordial tensor power spectrum

Tensor-to-scalar ratio

$$\boxed{r \equiv \frac{\Delta_t^2}{\Delta_s^2} = 16\epsilon}$$

Primordial tilt

$$\boxed{n_s - 1 \equiv \frac{d \ln \Delta_s^2}{d \ln k} = -2\epsilon - \eta}$$

And others: $n_t \equiv \dfrac{d \ln \Delta_t^2}{d \ln k}$, $\alpha_s \equiv \dfrac{d\, n_s}{d \ln k}$, $\beta_s \equiv \dfrac{d\, \alpha_s}{d \ln k}$, ...

Single field Slow-Roll inflation

- Single-field SR inflation is favoured:

Observables	Prediction	Exp. Value	
Fluctuations Amplitude	$\Delta_s^2 = \frac{H_\star^2}{8\pi^2 M_{\rm pl}^2 \epsilon_\star}$	2.2×10^{-9}	OK
Tensor-to-scalar ratio	$r = 16\epsilon_\star$	$r < 0.11$ (95% CL)	×
Tilt	$n_s = 1 + 2\eta_\star - 6\epsilon_\star$	$n_s = 0.9655 \pm 0.0062$	OK
Non-Gaussianity	$\sim$ Gaussian. $[O(\epsilon,\eta)]$	Compatible with 0.	OK
Isocurvature	No	$\lesssim$ few %	OK

- Alternatives are less elegant† and are in bad shape: too much non-Gaussianity, isocurvature modes, etc.

†**elegant**: (of a scientific theory or solution to a problem) pleasingly ingenious and simple: *the grand unified theory is compact and elegant in mathematical terms*. The Oxford dictionary.

Minimally coupled Chaotic inflation:

$$\boxed{V(\phi) = \frac{1}{2}m^2\phi^2}$$

- $\epsilon(\phi) = \eta(\phi) = 2\left(\frac{M_{\rm pl}}{\phi}\right)^2 \longleftrightarrow \phi_{\rm end} = \sqrt{2}M_{\rm pl}$
- $N = \int_{\phi_{\rm cmb}}^{\sqrt{2}M_{\rm pl}} \frac{\phi}{2M_{\rm pl}^2}{\rm d}\phi = -60 \longleftrightarrow \phi_{\rm cmb} \sim 15M_{\rm pl}$
- $r = 16\epsilon_\star \simeq 0.13$
- $n_s = 1 - 2\epsilon_\star - \eta_\star \simeq 0.96$

Super-Planckian values!

Motivation

- It is usually assumed that a term of the form $\xi \mathcal{R} \phi^2$ vanishes.

- Since the inflaton is coupled to light degrees of freedom (during reheating),

$$\mathcal{L}_{\text{reheating}} \simeq \lambda \phi^2/4! + y_\psi \phi \bar{\psi} \psi + \lambda_\chi \chi^2 \phi^2 + \ldots$$

the RGE of ξ is nontrivial. One can make it vanish at some scale, but it will be nonzero at some point because of its running:

$$\beta_\xi = \frac{\xi - \frac{1}{6}}{(4\pi)^2} \left[\lambda + \lambda_\xi + 4 y_\psi^2 + \ldots \right]$$

- What about nonminimally scenarios?:

- D. S. Salopek, J. R. Bond and J. M. Bardeen, PRD 40, 1753 (1989).
- T. Futamase and K. i. Maeda, PRD 39 (1989) 399.
- R. Fakir and W. G. Unruh, PRD 41, 1783 (1990).
- D. I. Kaiser, PRD 52, 4295 (1995), [astro-ph/9408044].
- E. Komatsu and T. Futamase, PRD 59, 064029 (1999).
- M. P. Hertzberg, JHEP 1011, 023 (2010).
- N. Okada, M. U. Rehman and Q. Shafi,. PRD 82 (2010) 043502.
- A. Linde, M. Noorbala and A. Westphal, JCAP 1103, 013 (2011).
- D. I. Kaiser and E. I. Sfakianakis, PRL 112 (2014) 1, 011302.
- T. Chiba and K. Kohri, PTEP 2015, no. 2, 023E01.
- C. Pallis and Q. Shafi, JCAP 1503, no. 03, 023 (2015).
- S. Tsujikawa, J. Ohashi, S. Kuroyanagi and A. De Felice, PRD 88 (2013) 2, 023529.

Nonminimally coupled Chaotic inflation:

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{M_{\mathrm{pl}}^2}{2}\mathcal{R} + \frac{\xi}{2}\mathcal{R}\phi^2 - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - U(\phi)\right]$$

Performing a conformal (Weyl) transformation:

$$g_{\mu\nu}^{\mathrm{E}} = \Omega(\phi)g_{\mu\nu} \qquad \text{where} \qquad \Omega(\phi) \equiv 1 + \frac{\xi\phi^2}{M_{\mathrm{pl}}^2}$$

We recast the action in canonical form:

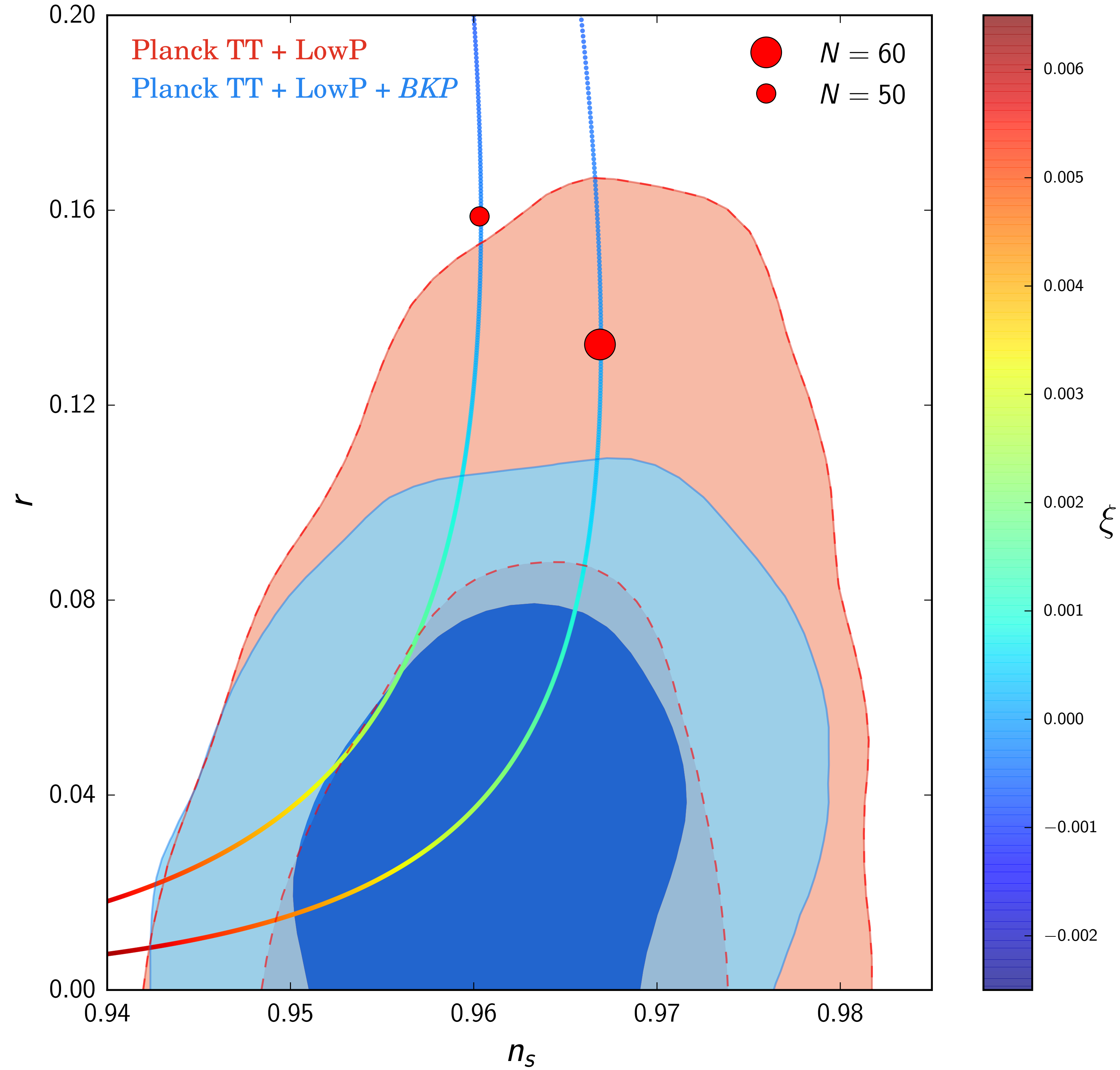
$$S = \int \mathrm{d}^4x\sqrt{-g_{\mathrm{E}}}\left[\frac{M_{\mathrm{pl}}^2}{2}\mathcal{R}_{\mathrm{E}} - \frac{1}{2}g_{\mathrm{E}}^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi - V[\phi(\varphi)]\right]$$

Where the potential is now:

$$V[\phi(\varphi)] = \frac{U(\phi)}{\Omega^2(\phi)} \longrightarrow U(\phi) = \frac{1}{2}m^2\phi^2$$

Results

- $\Lambda\mathrm{CDM}$ Cosmology + $\xi \neq 0$.
- Planck '15 TT measurements (BKP=BICEP2/KECK + Planck).
- We perform a MCMC analysis using COSMOMC.



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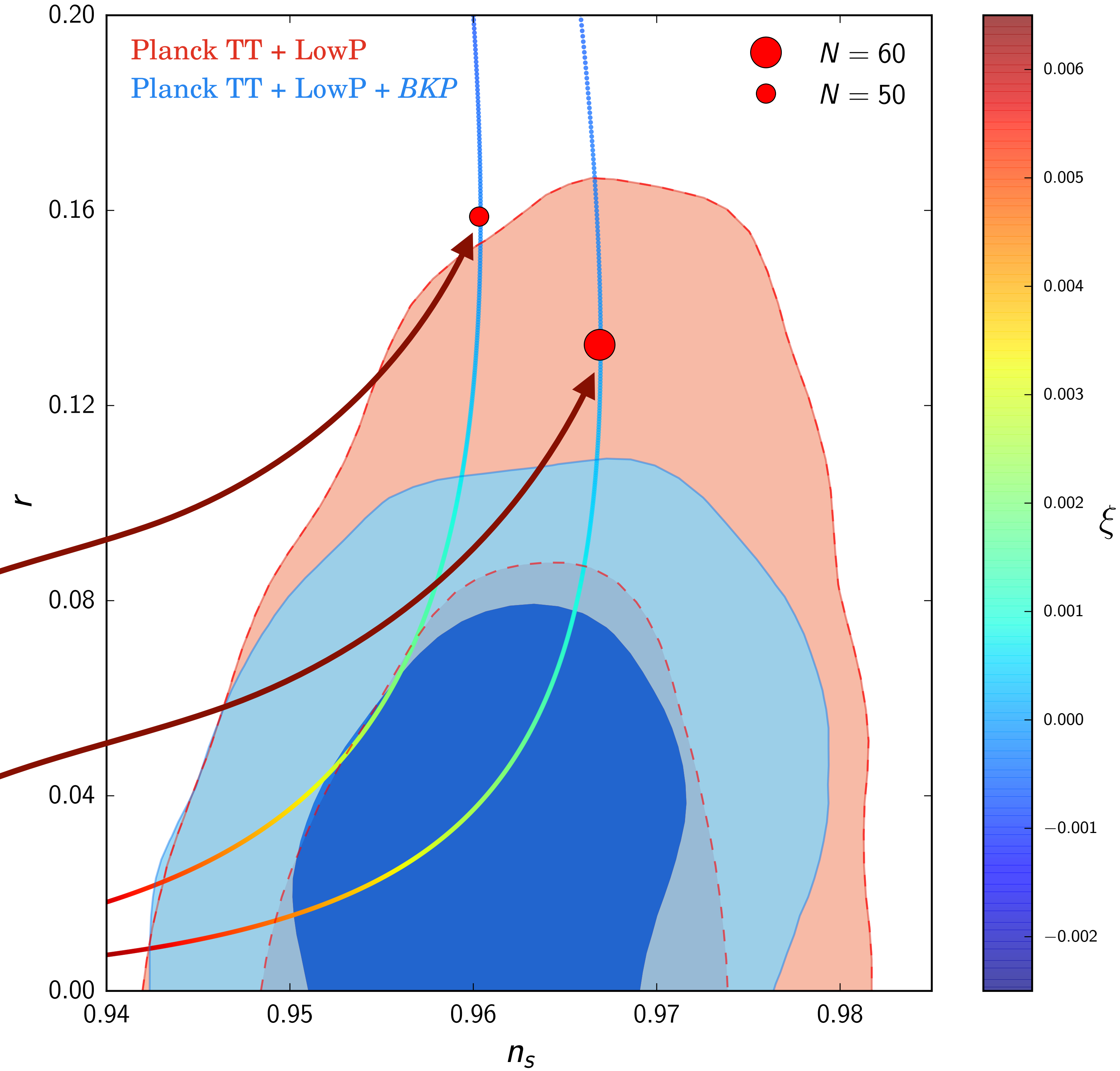
Ruled out at more than 99% C.L.

Disfavoured at 95% C.L.



Results

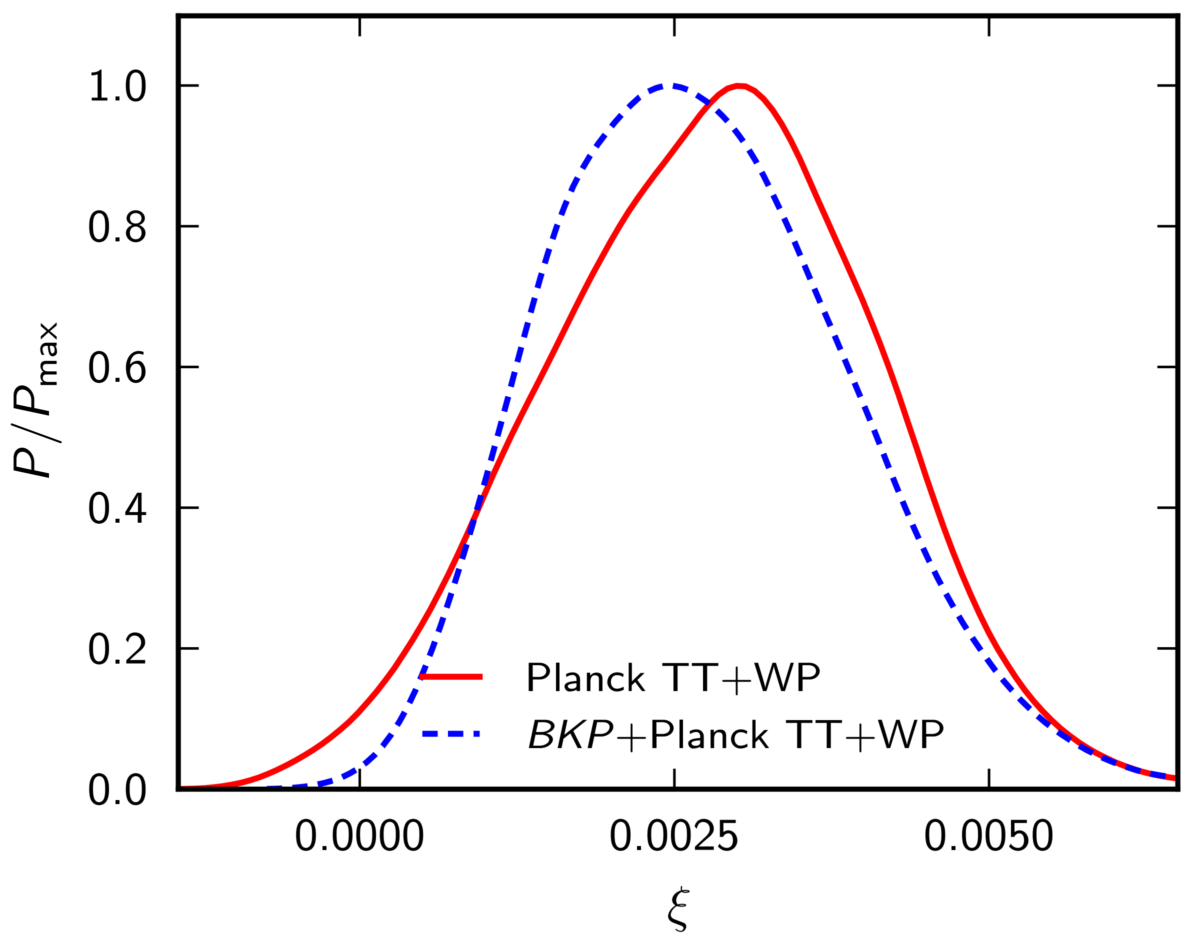
95% C.L. constraints:

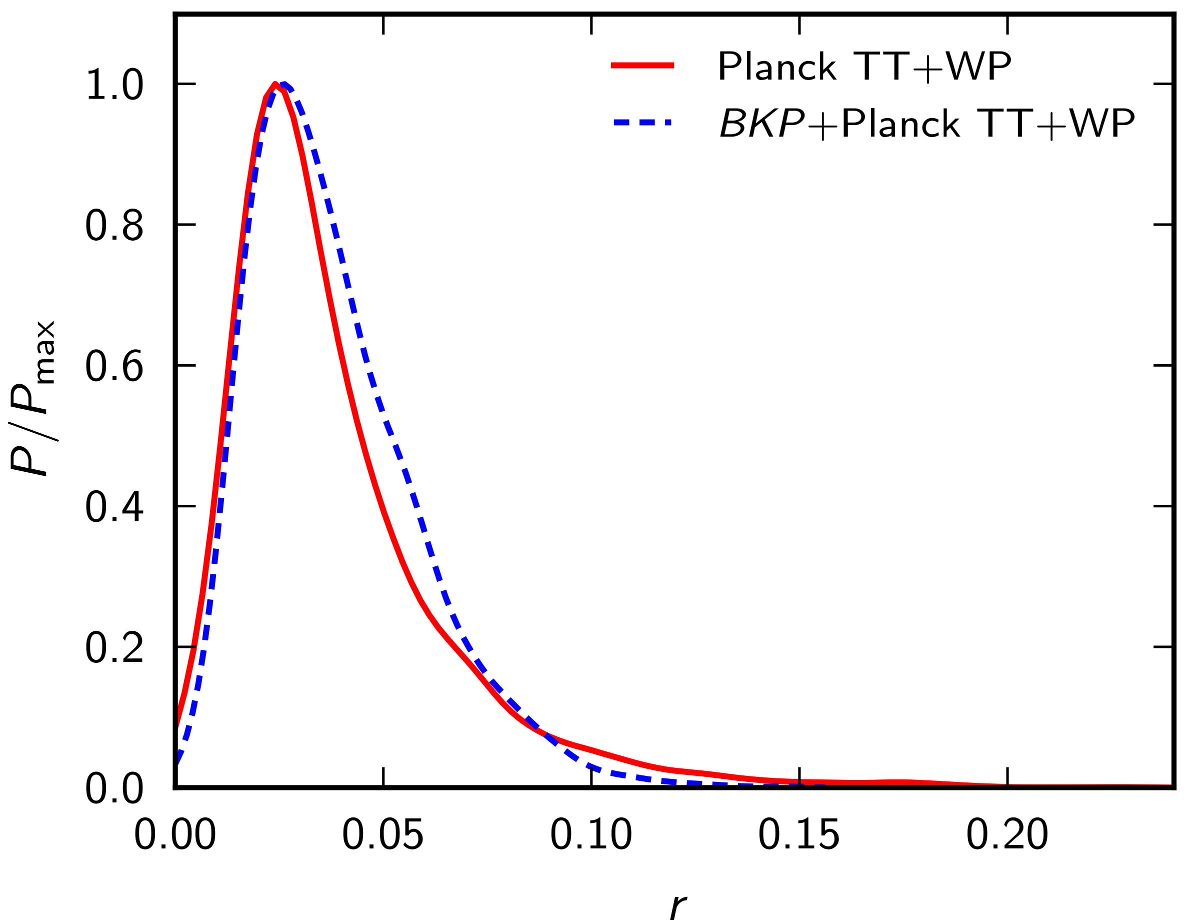
	Planck TT+WP		BK+Planck TT+WP	
N	60	50	60	50
ξ	$0.0028^{+0.0023}_{-0.0025}$	$0.0024^{+0.0023}_{-0.0023}$	$0.0027^{+0.0023}_{-0.0022}$	$0.0027^{+0.0020}_{-0.0019}$
n_s	$0.958^{+0.010}_{-0.011}$	$0.954^{+0.007}_{-0.009}$	$0.958^{+0.009}_{-0.011}$	$0.953^{+0.007}_{-0.009}$
r	$0.038^{+0.051}_{-0.031}$	$0.063^{+0.056}_{-0.048}$	$0.038^{+0.039}_{-0.030}$	$0.053^{+0.038}_{-0.037}$
$\alpha \equiv \mathrm{d}n_s/\mathrm{d}\ln k$	$-0.0005^{+0.0001}_{-0.0001}$	$-0.0007^{+0.0001}_{-0.0001}$	$-0.0005^{+0.0001}_{-0.0001}$	$-0.0007^{+0.0001}_{-0.0001}$

- A nonvanishing coupling is preferred in this context.
- A nonvanishing r is also favoured.

Results

One-dimensional posterior probability distributions.

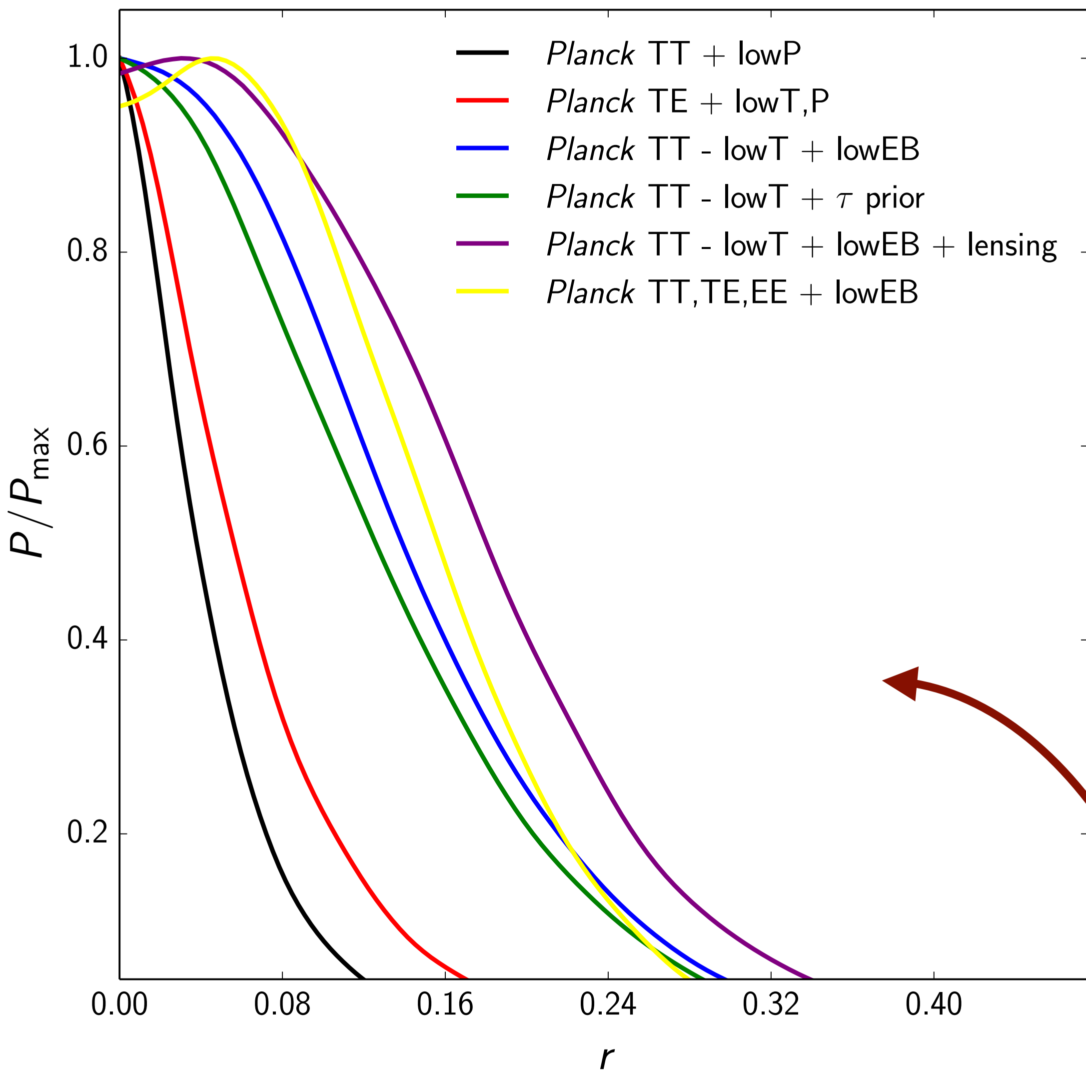


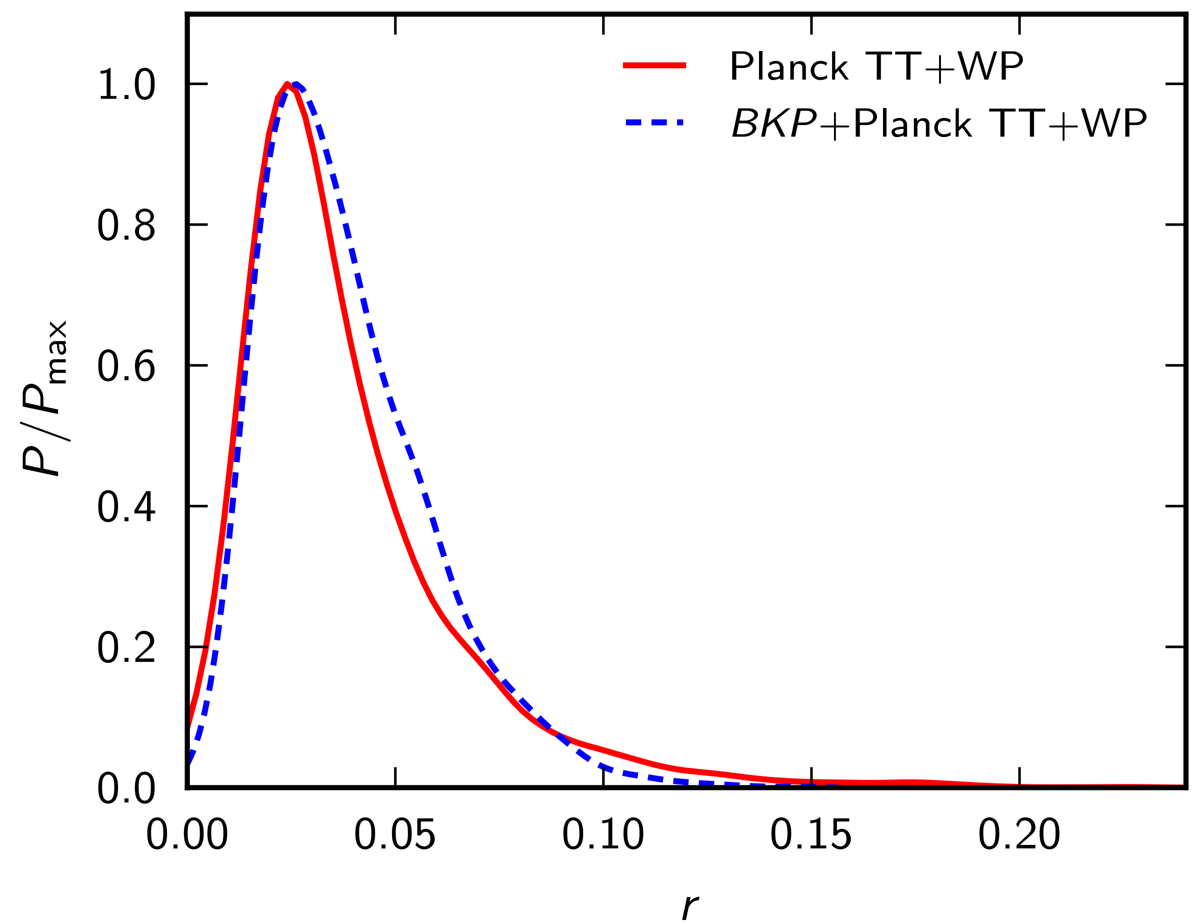


- Slight preference for nonzero ξ and r.

Results

One-dimensional posterior probability distributions.





Planck '15 ($\xi = 0$)

Results

We compare the χ^2-statistics for both models:

$$\Delta\chi^2 = \chi^2[\xi = 0] - \chi^2[\xi \neq 0]$$

Considering a distribution with one degree of freedom (ξ):

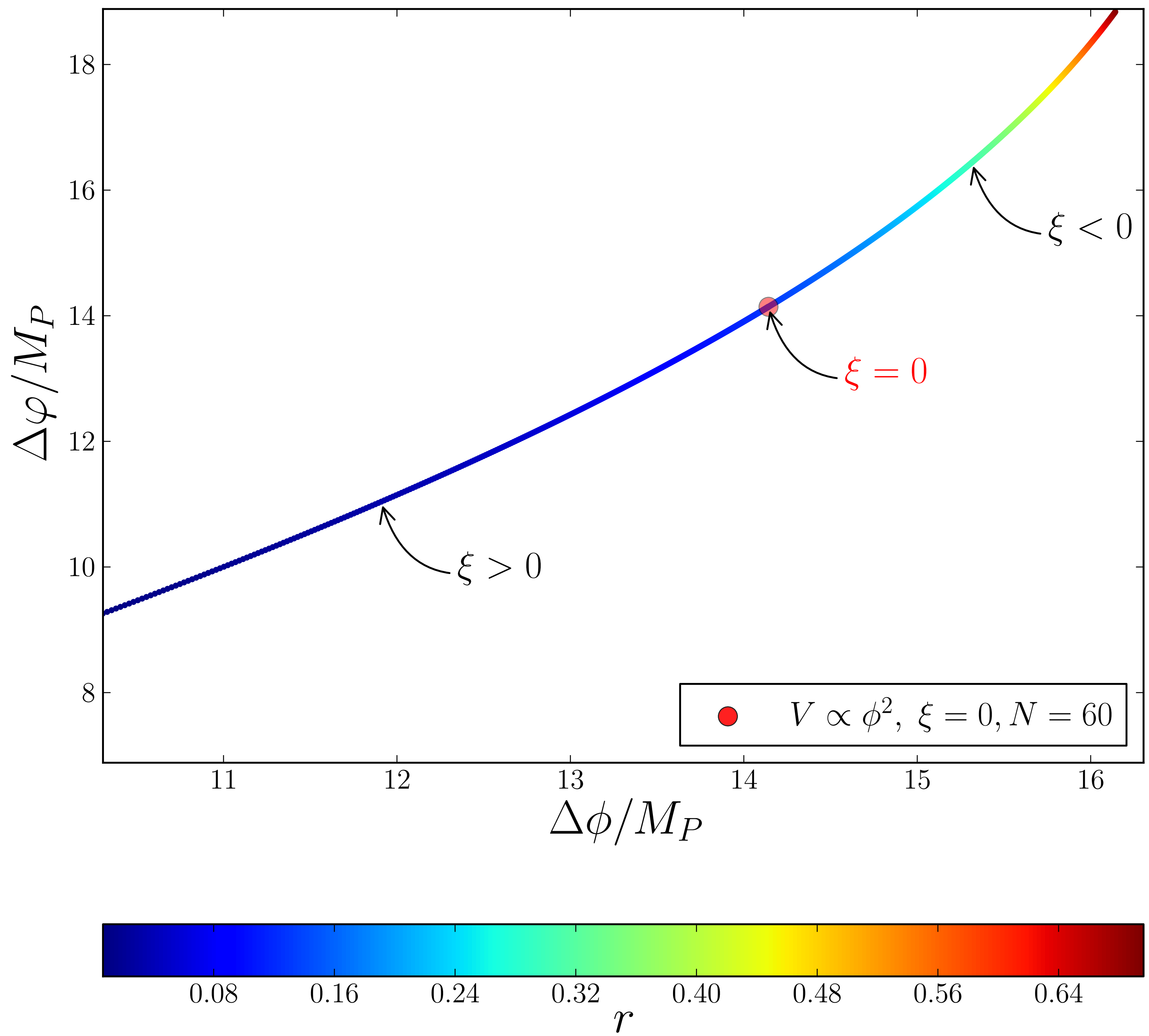
	Planck TT+WP	BK+Planck TT+WP
$\Delta\chi^2$	6	10
p-value	0.014	0.0016
Statistical Significance	Significant	Very significant

➡ The nonminimally coupled scenario is favoured (with respect to the minimal one) at 99% of confidence level.

Results

$$\left(\frac{\mathrm{d}\varphi}{\mathrm{d}\phi}\right)^2 = \frac{1}{\Omega} + \frac{3}{2}M_P^2\left(\frac{\Omega'}{\Omega}\right)^2$$

- The excursion of the nonminimally coupled inflaton is bit smaller but still super-Planckian.
- Large r correlates with large excursions as dictated by the Lyth bound.



Future constraints

- We can construct a combination of first order slow-roll observables:

$$n_s - 1 + \frac{r}{4} = -20\,\xi\,,$$

- This combination vanishes for $\xi = 0$, in the context of the chaotic scenario.

- Future observations from PIXIE, Euclid, COrE, and PRISM are targeting

$$\sigma_r = \sigma_{n_s - 1} = 10^{-3}$$

$$\Downarrow$$

$$\sigma_\xi \leq 10^{-4}$$

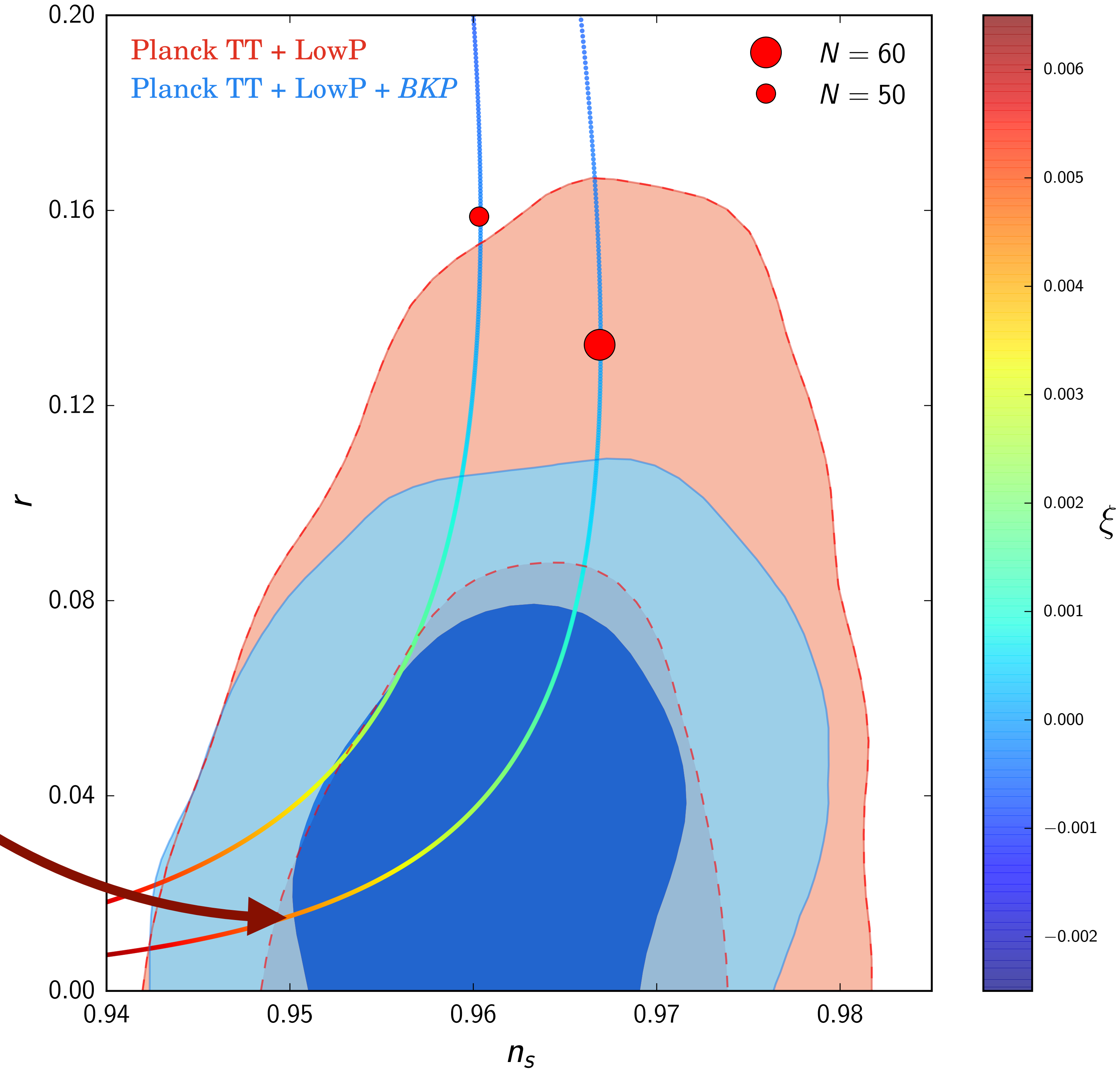
- Combined with future accurate measurements of n_s , this might rule-out this model due to its nontrivial correlation with r.

Future constraints

In this scenario,

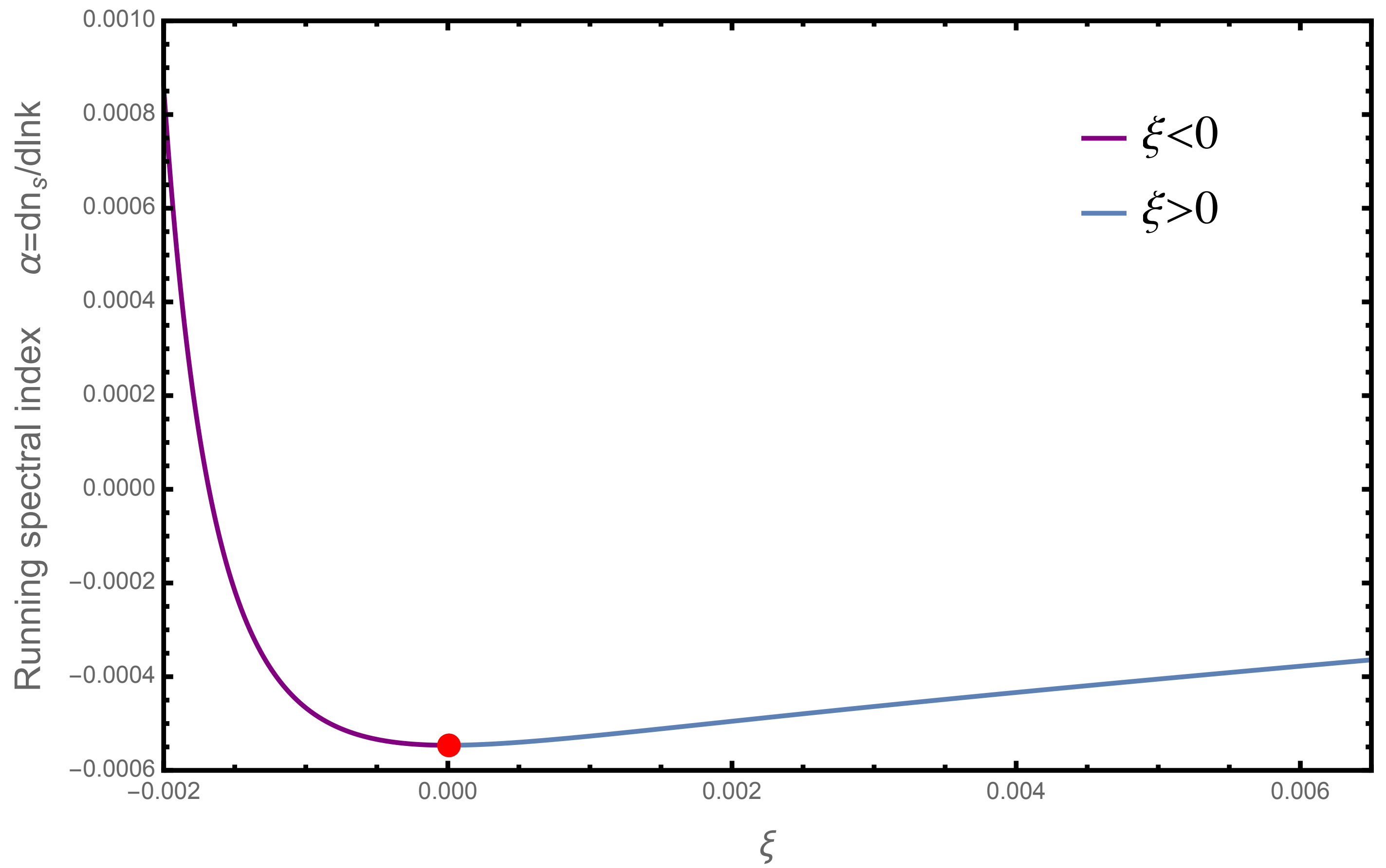
$n_s < 0.96$ for $r < 0.03$

is potentially falsifiable.



Future constraints

- Negative coupling gives significant running (and higher r).
- The running is a good discriminator.
- Future constraints might falsify this model.



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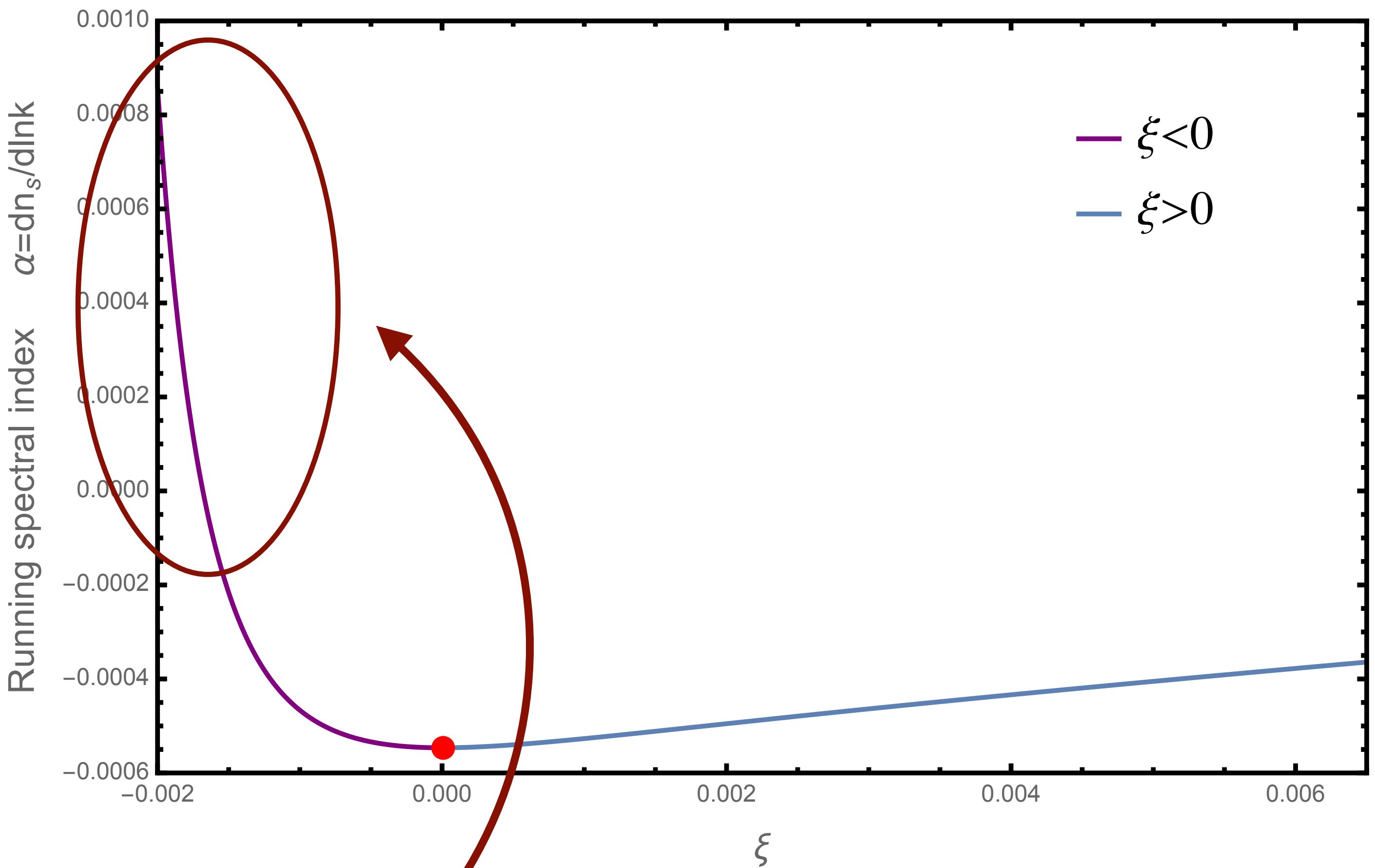

Compatible with Planck '15, but $r > 0.2$

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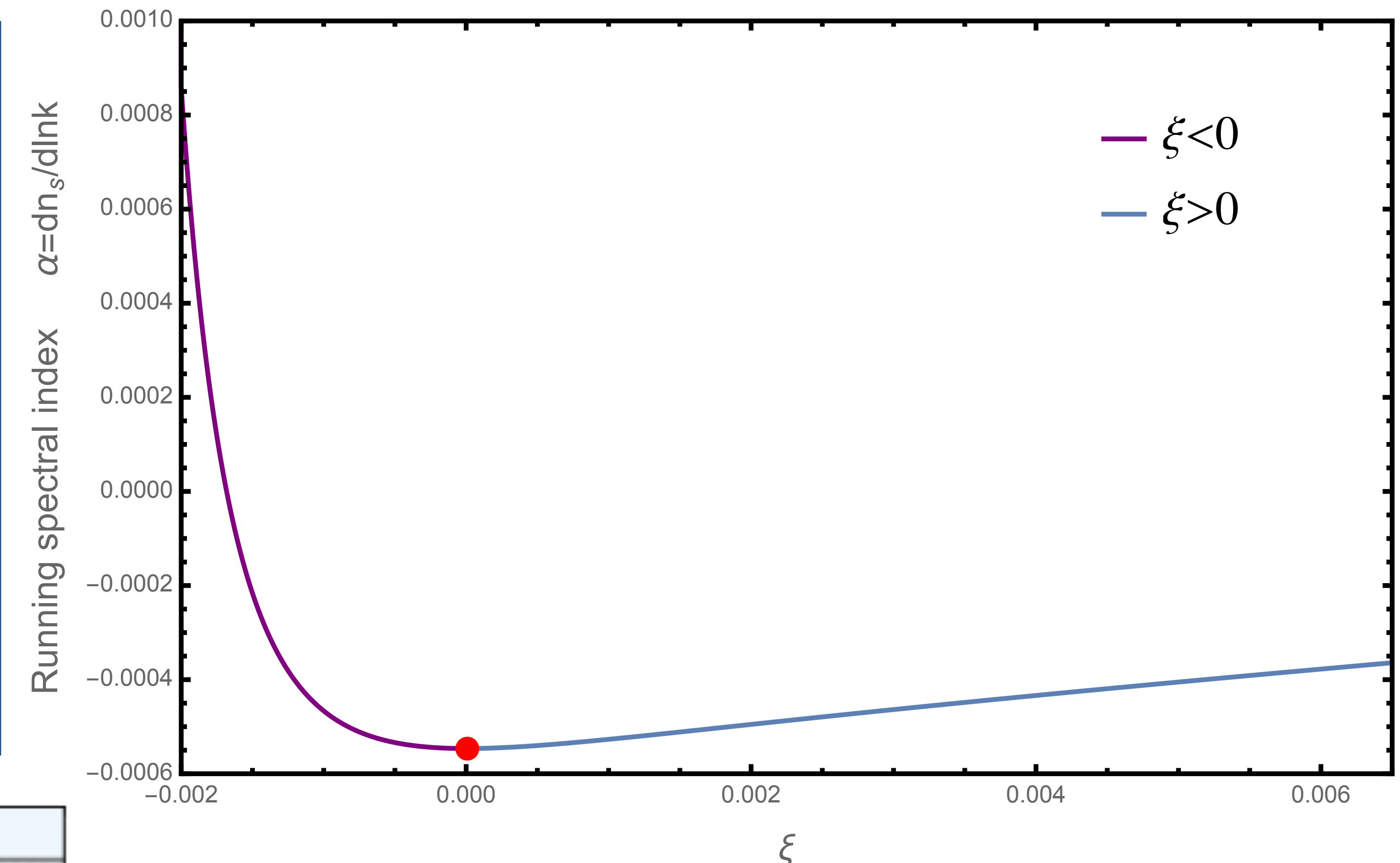

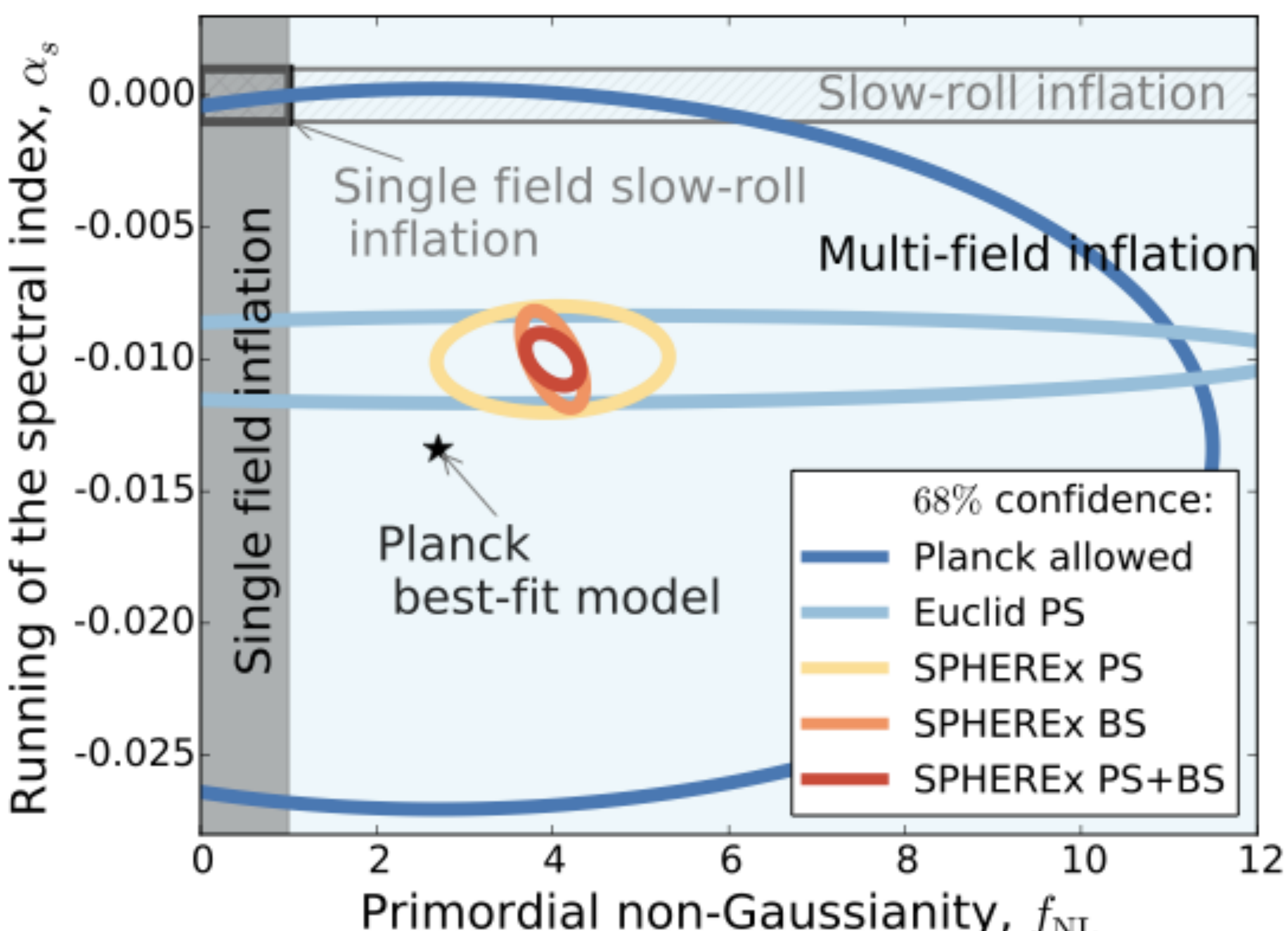

SPHEREx (Caltech)

(Spectrophotometer for the History of Universe, Epoch of Reionization and ices Explorer)

$$\sigma_{\alpha_s} \simeq 0.00065$$

O. Doré *et al.*, arXiv:1412.4872 [astro-ph.CO].

Conclusions

- The answer is YES!
    - Current data have a preference for a nonminimally coupled ϕ^2 scenario.
- With the introduction of a nonminimal coupling, the preferred value of r is nonzero.
- Next round of observations might rule-out this scenario
    - Better measurements of n_s and r by, *e.g.*, PIXIE, Euclid, COrE, and PRISM.
    - Better measurements of α_s by, *e.g.*, SPHEREx.
- More futuristic observations (like 21 cm Cosmology) will certainly answer this question.

Thank you!