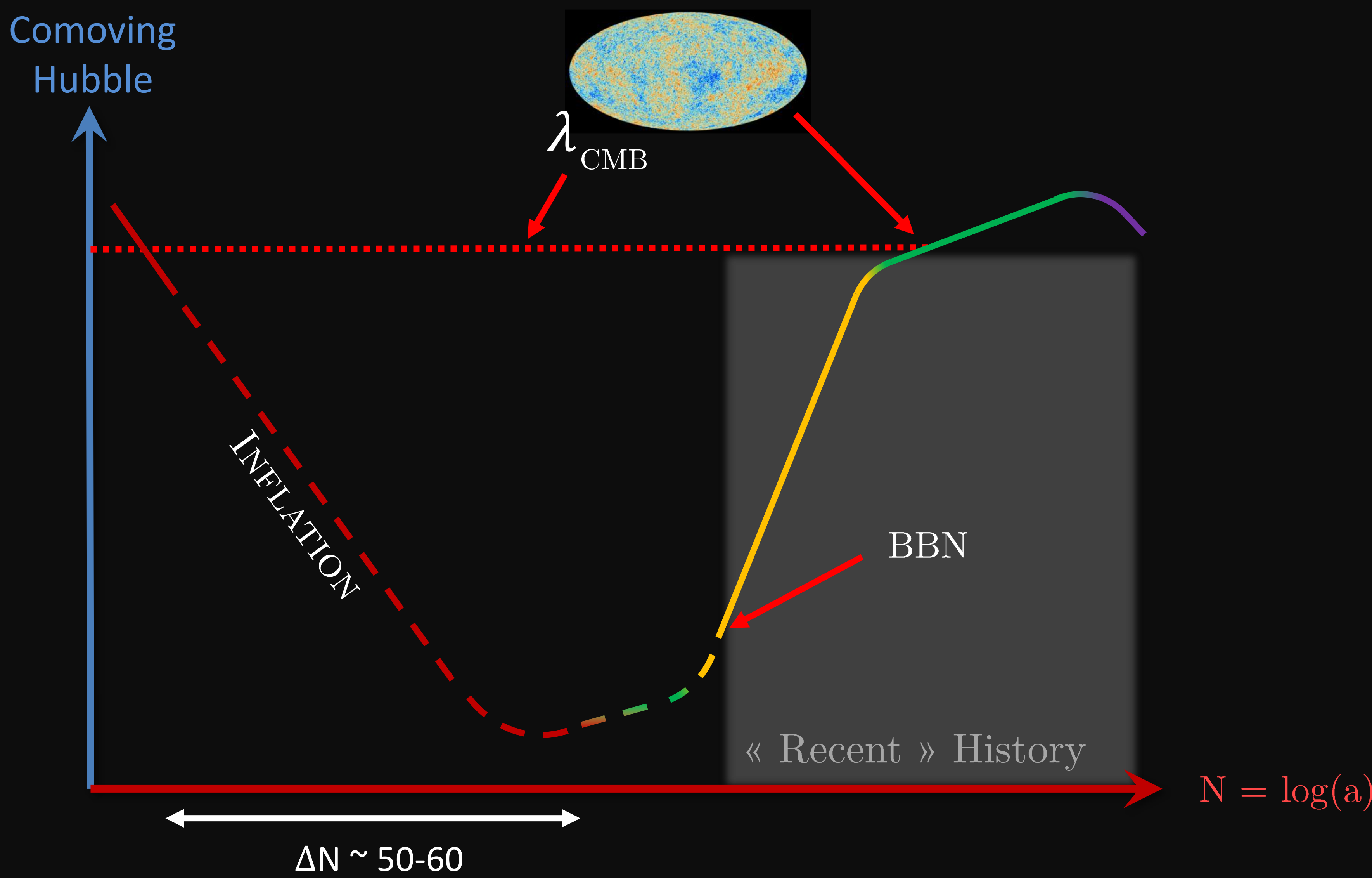
Astroparticle Symposium 2025 – Institut Pascal

Lucien HEURTIER

Is Inflation on the Run?

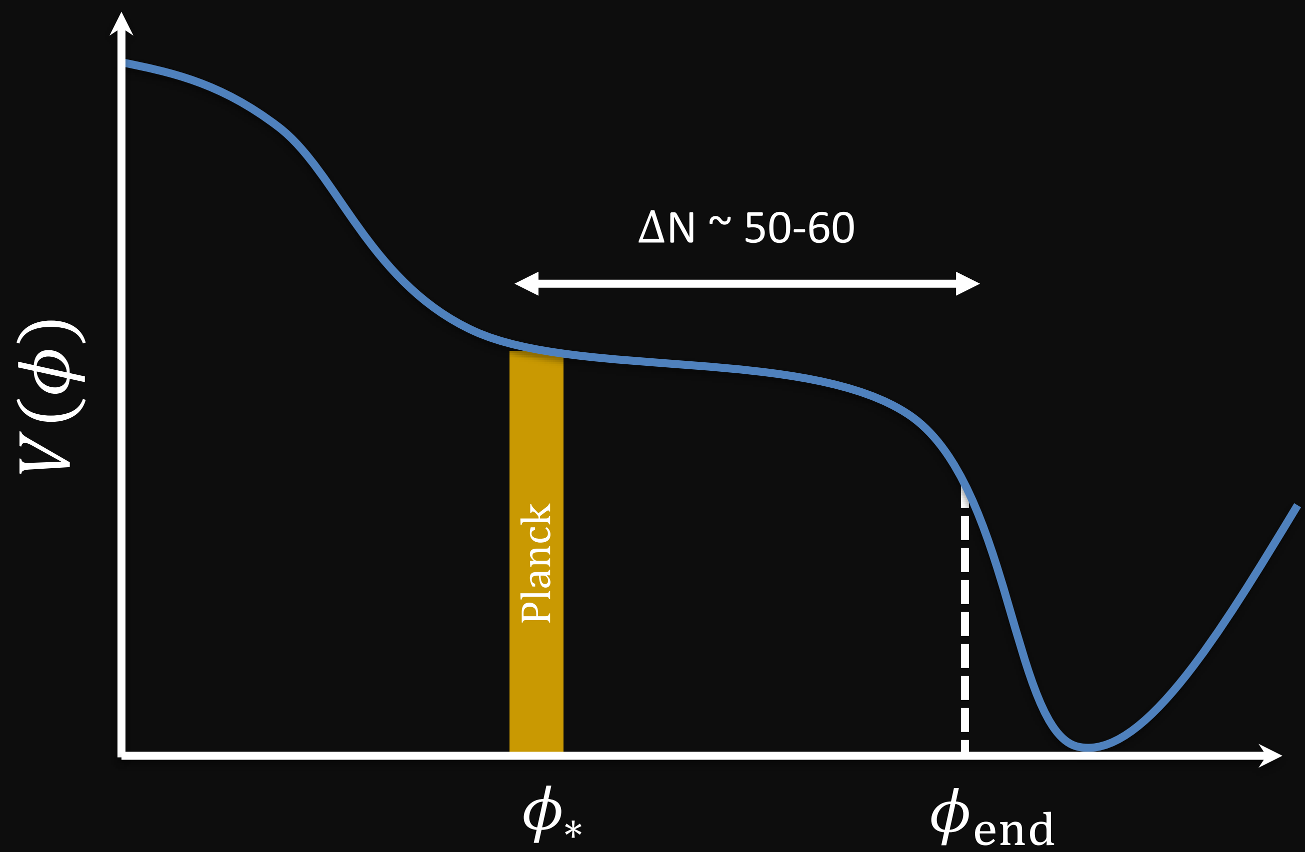
ArXiv:2511.01612 – M. Fairbairn, LH, M.O. Olea-Romacho
ArXiv:2511.05296 – J. Alexandre, LH, S. Pla

Inflation in a sketch



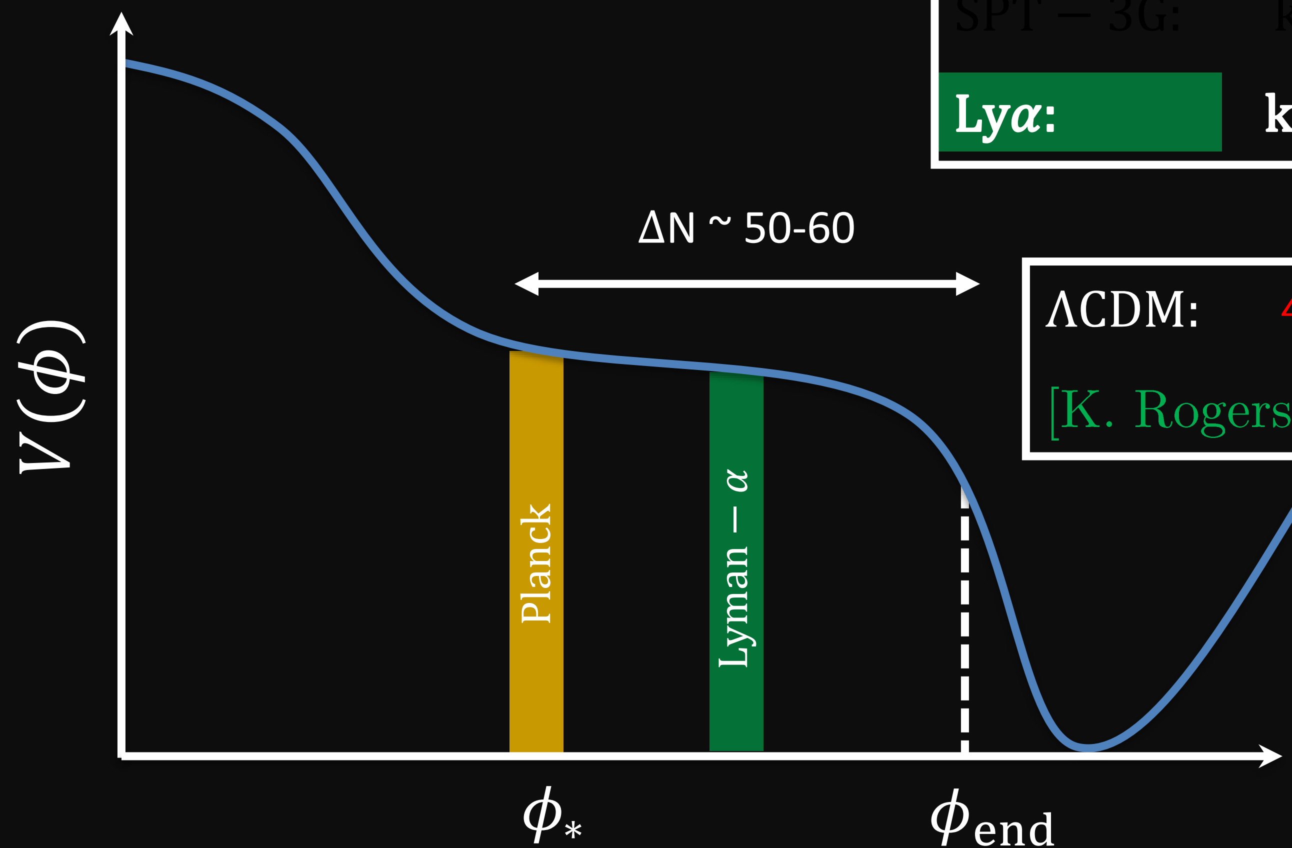
Inflation Model Building

Planck: $k \sim 0.05\ \mathrm{Mpc}^{-1}$



Constraints Across Scales

Planck:	$k \sim 0.05\ \mathrm{Mpc}^{-1}$
ACT:	$k \lesssim 0.6\ \mathrm{Mpc}^{-1}$
SPT − 3G:	$k \lesssim 0.7\ \mathrm{Mpc}^{-1}$
Lyα:	$k \sim 0.2 - 2.5\ \mathrm{Mpc}^{-1}$



ΛCDM: 4.9σ tension

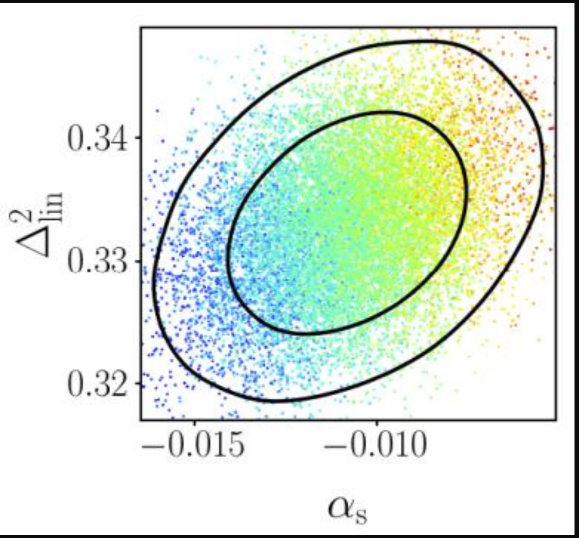
[K. Rogers & V. Poulin, 2023]

ΛCDM:

$$\ln \Delta^2_{\mathcal{R}}(k) \equiv \ln A_s + (n_s - 1) \ln \left(\frac{k}{k_\star} \right)$$

$\Lambda\mathrm{CDM} + \alpha_s$:

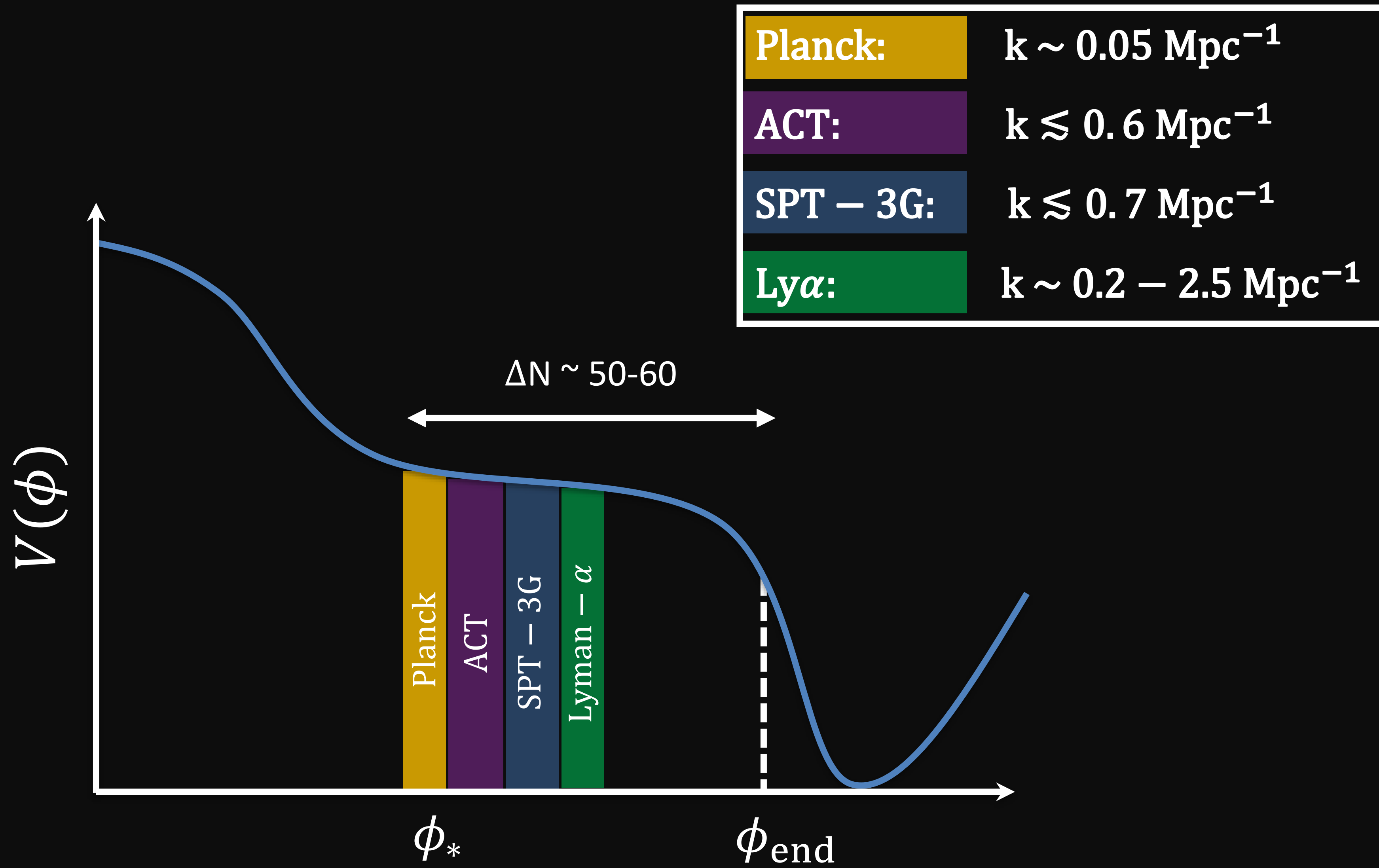
$$\ln \Delta^2_{\mathcal{R}}(k) \equiv \ln A_s + (n_s - 1) \ln \left(\frac{k}{k_\star} \right) + \frac{\alpha_s}{2} \ln \left(\frac{k}{k_\star} \right)^2 + \dots$$



tension $\sim 1\sigma$

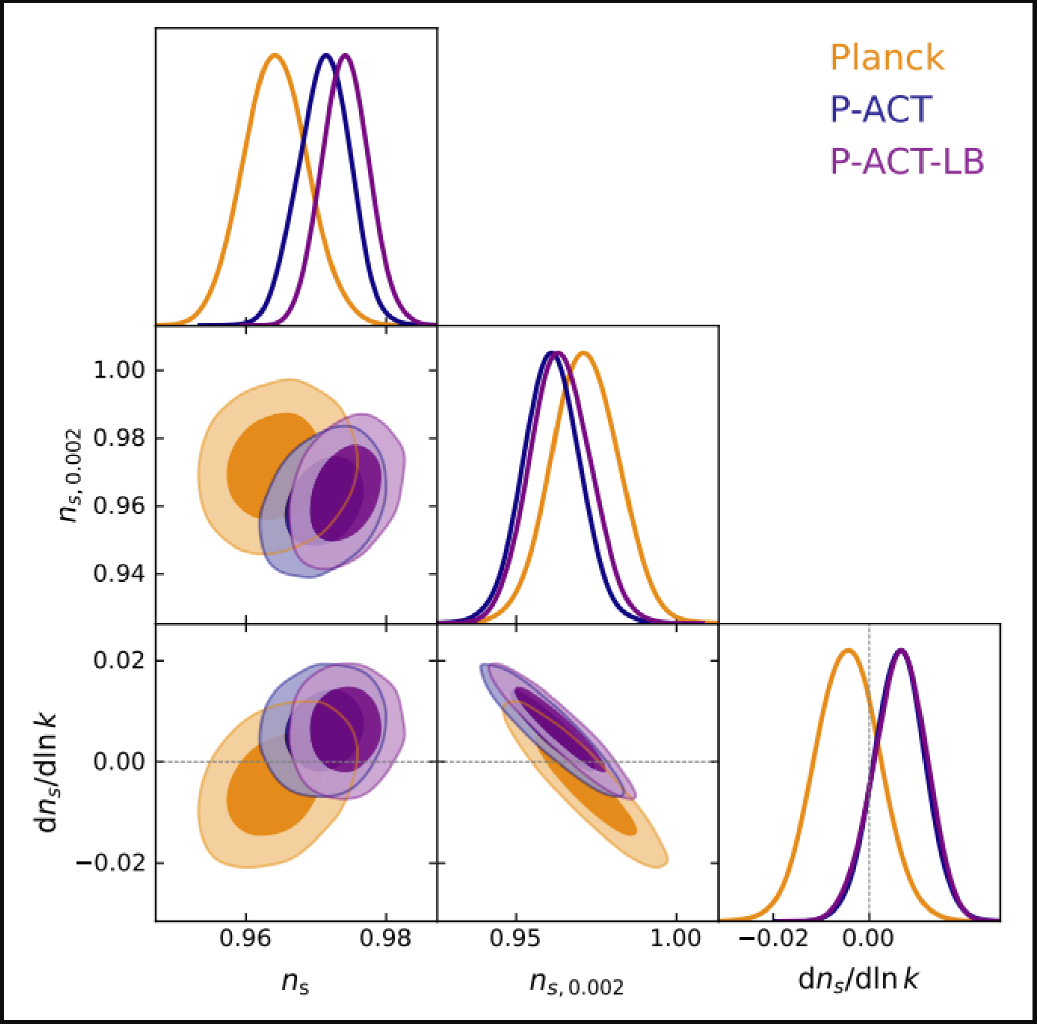
[K. Rogers & V. Poulin, 2023]

Constraints Across Scales



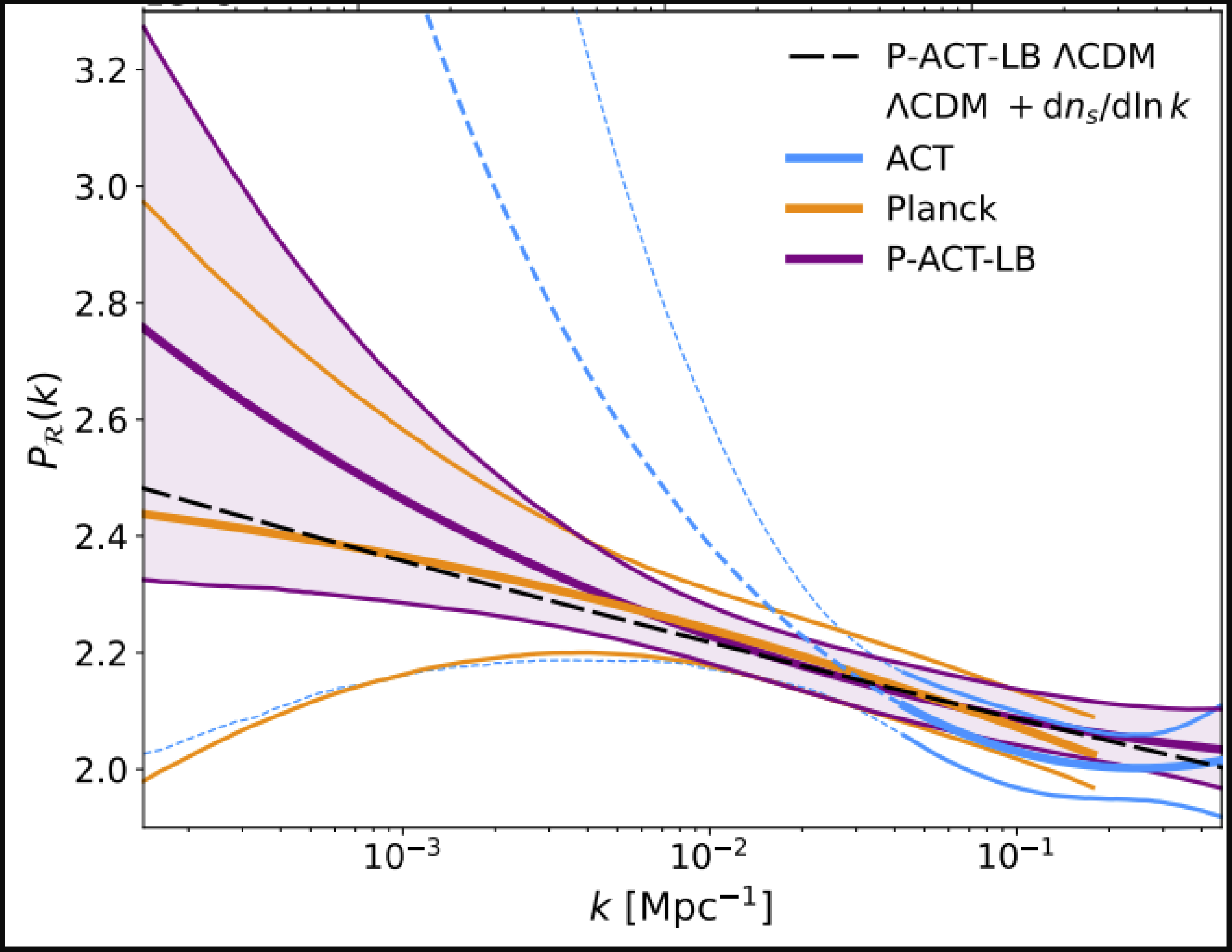
Spectral Index Running

ACT DR6, March 2025



Spectral Index Running

ACT DR6, March 2025



ΛCDM:

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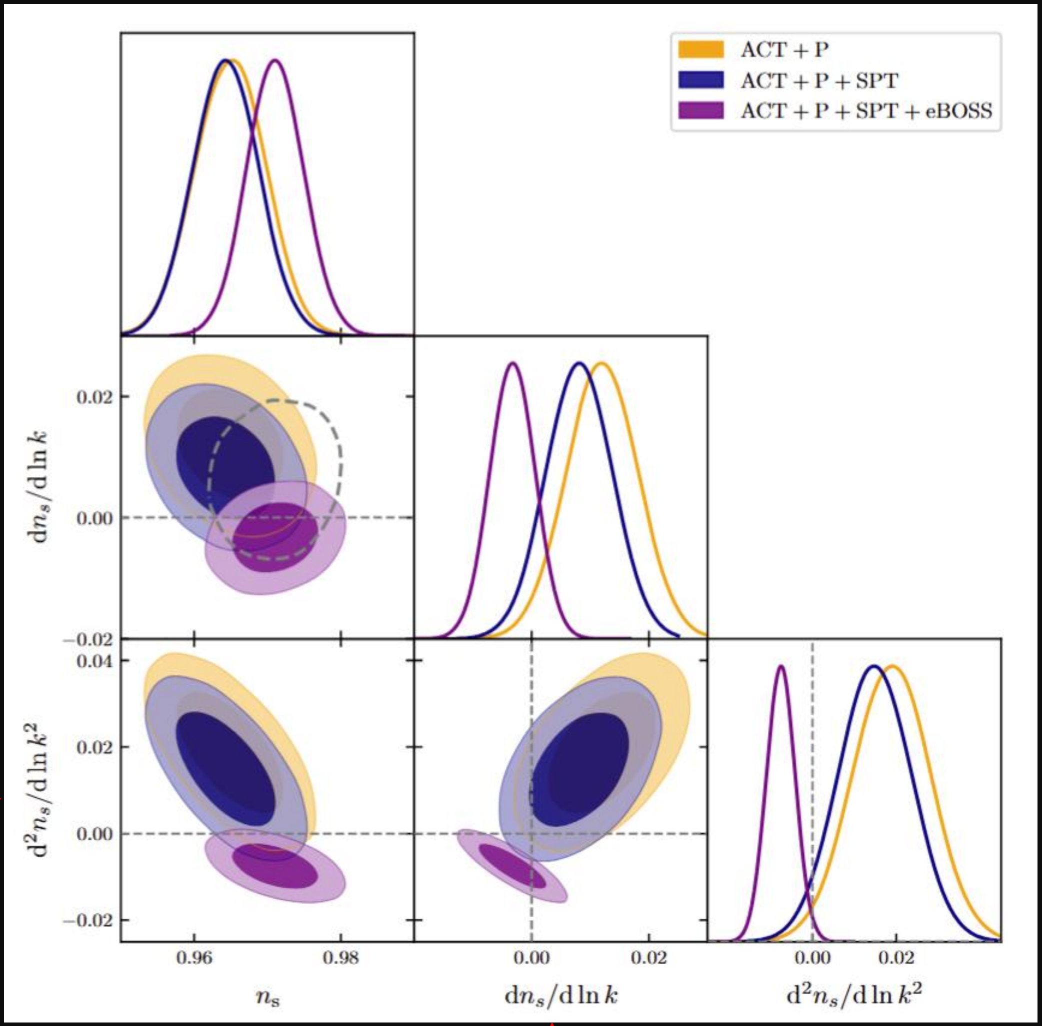
ΛCDM $+\alpha_s + \beta_s$:

$$\ln \Delta^2_{\mathcal{R}}(k) \equiv \ln A_s + (n_s - 1)\ln\left(\frac{k}{k_\star}\right) + \frac{\alpha_s}{2}\ln\left(\frac{k}{k_\star}\right)^2 + \frac{\beta_s}{6}\ln\left(\frac{k}{k_\star}\right)^3 + \dots$$

ΛCDM
$+\alpha_s + \beta_s$:



β_s

α_s

ArXiv:2511.01612 – M. Fairbairn, LH, M.O. Olea-Romacho

PIPE – Potential Inflation Posterior Emulator

gitlab.com/cosmoPipe/pipe-inflation

$$\log \mathcal{L}(A_s, n_s, \alpha_s, \beta_s) \longrightarrow \log \mathcal{L}(V_0, \ldots)$$

Power-law + Gaussian bump/dip

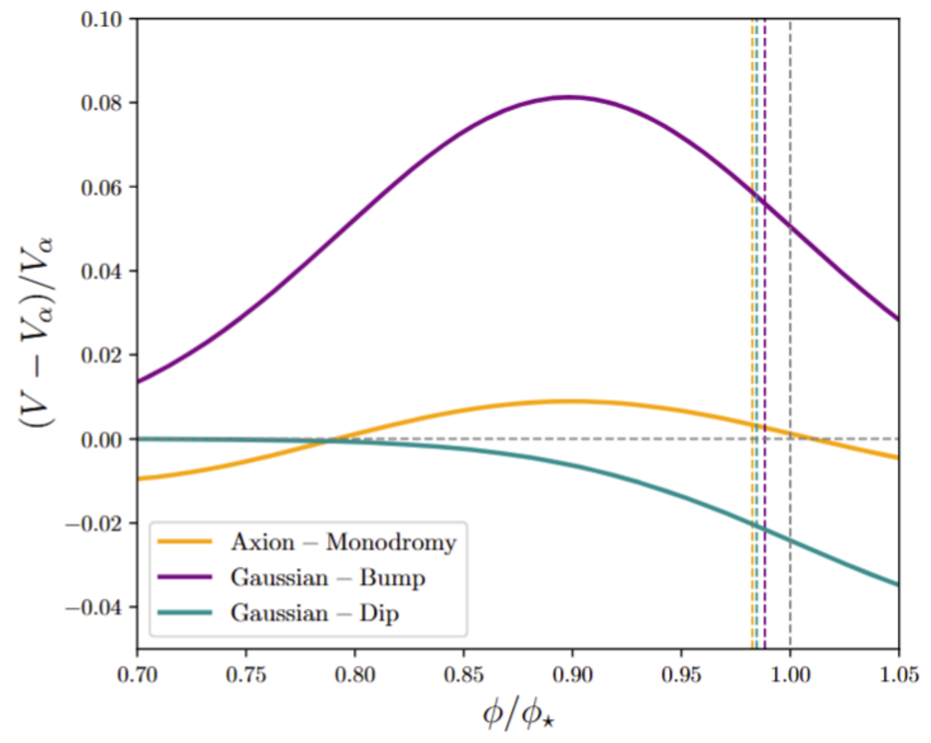
$$V = V_\alpha \left[1 \pm A \exp\left(-\frac{(\phi - \phi_0)^2}{2\sigma^2} \right) \right]$$

Axion Monodromy

$$V = V_0 \left[\left| \frac{\phi}{M_p} \right|^\alpha + A \cos\left(\gamma + \frac{M_p}{f} \left| \frac{\phi}{M_p} \right|^{1+p_f} \right) \right]$$

ArXiv:2511.01612 – M. Fairbairn, LH, M.O. Olea-Romacho

Dataset	Model	$\Delta\chi^2$	ΔAIC
ACT+P	Powerlaw+Bump	−7.27	−1.27
	Powerlaw+Dip	−7.27	−1.27
	Axion–Monodromy	−7.27	0.73
+SPT	Powerlaw+Bump	−5.52	0.48
	Powerlaw+Dip	−5.52	0.48
	Axion–Monodromy	−5.57	2.43
+eBOSS	Powerlaw+Bump	−107.09	−101.09
	Powerlaw+Dip	−107.09	−101.09
	Axion–Monodromy	−107.09	−99.09



Local feature
preferred by data at $> 10\sigma$

Power-law +
Gaussian bump/dip

$$V = V_\alpha \left[1 \pm A \exp\left(-\frac{(\phi - \phi_0)^2}{2\sigma^2}\right)\right]$$

Axion Monodromy

$$V = V_0 \left[\left|\frac{\phi}{M_p}\right|^{\alpha} + A \cos\left(\gamma + \frac{M_p}{f}\left|\frac{\phi}{M_p}\right|^{1+p_f}\right)\right]$$

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Inflation

Exact RG-Evolution

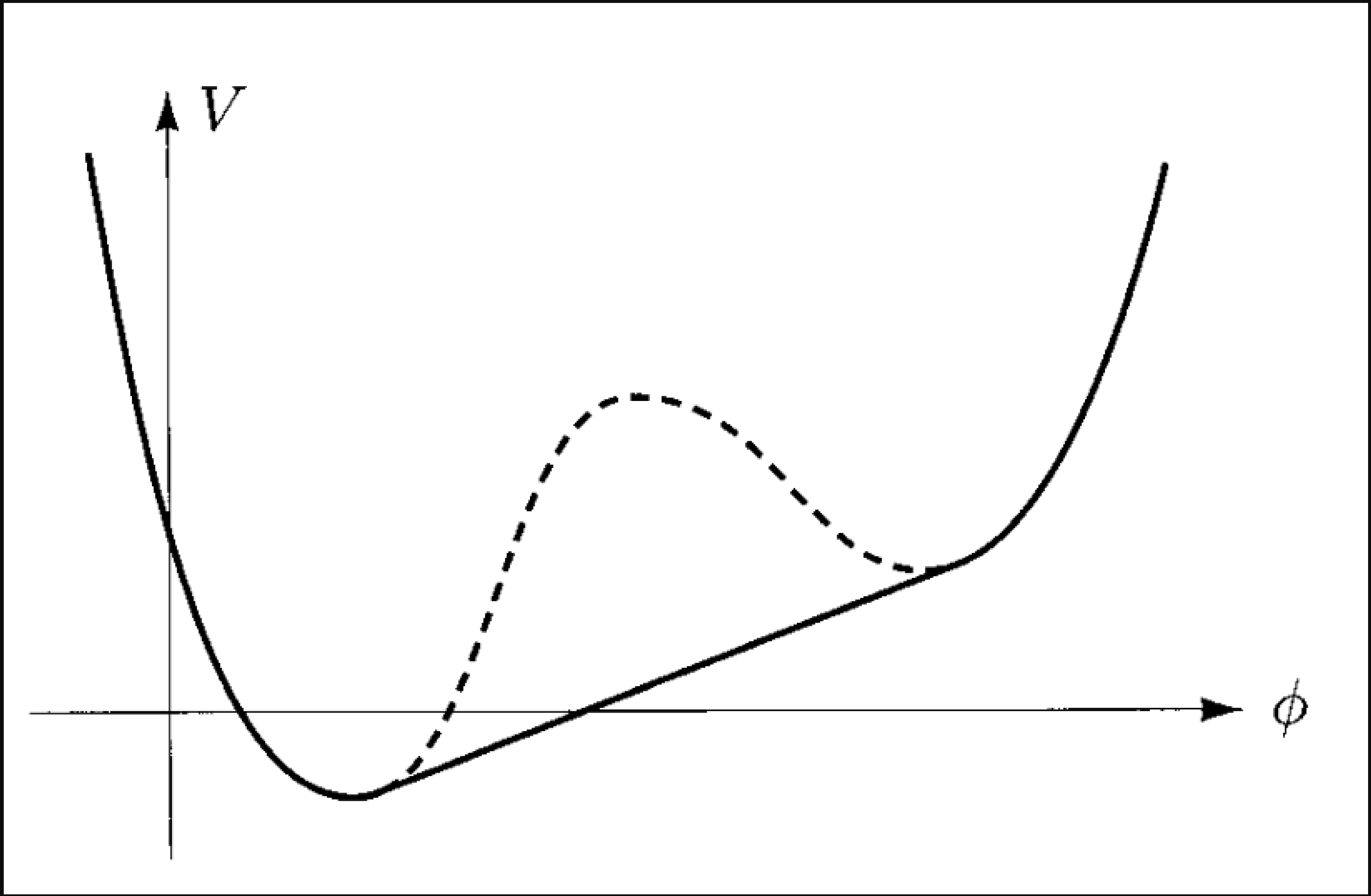
Effective Action

$$Z[J] = e^{-iE[J]} = \int \mathcal{D}\phi \exp\left[i \int d^4x \left(\mathcal{L}[\phi] + J\phi \right) \right].$$

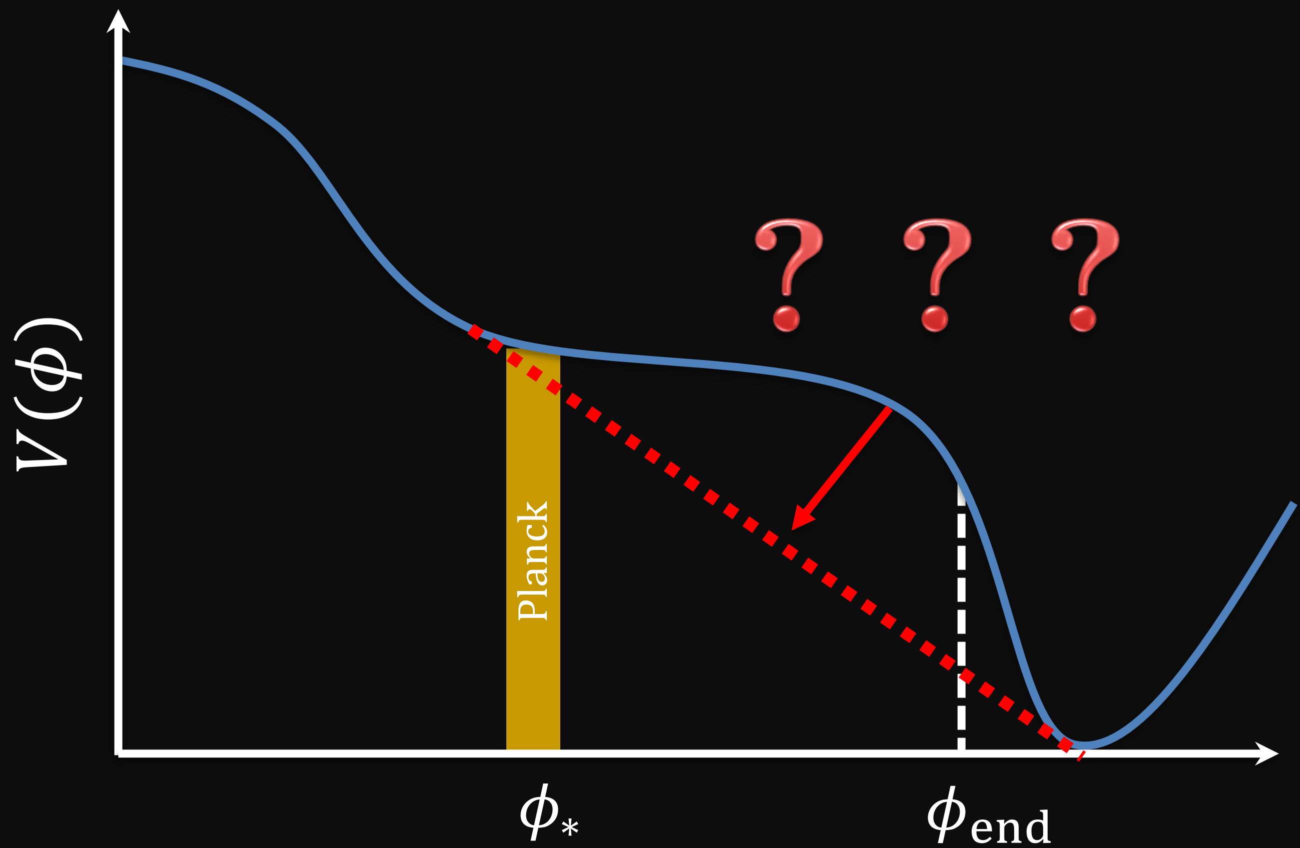
$$\Gamma[\phi_{\text{cl}}] \equiv -E[J] - \int d^4y\, J(y)\phi_{\text{cl}}(y).$$

$$\Gamma[\phi_{\text{cl}}] = -(VT) \cdot V_{\text{eff}}(\phi_{\text{cl}}).$$

Effective Action

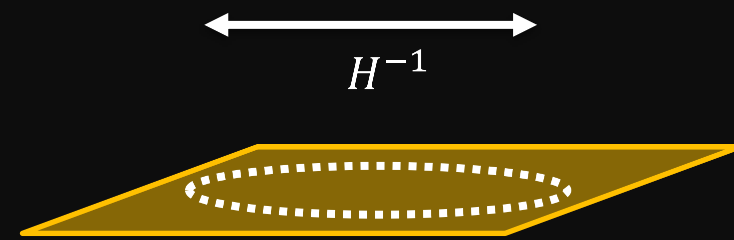


Effective Action



EFT of inflation

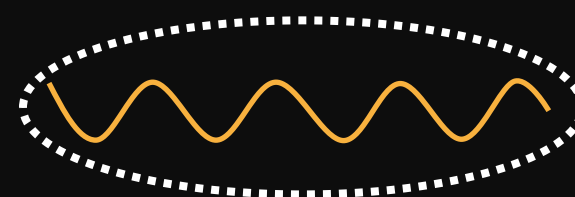
Homogeneous Background:



$=$

Quantum Perturbations

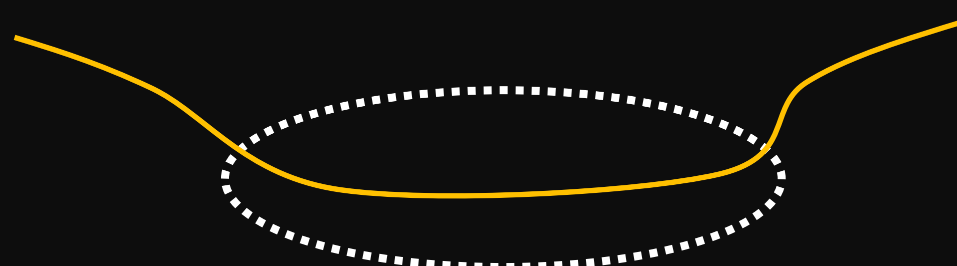
(integrated out)



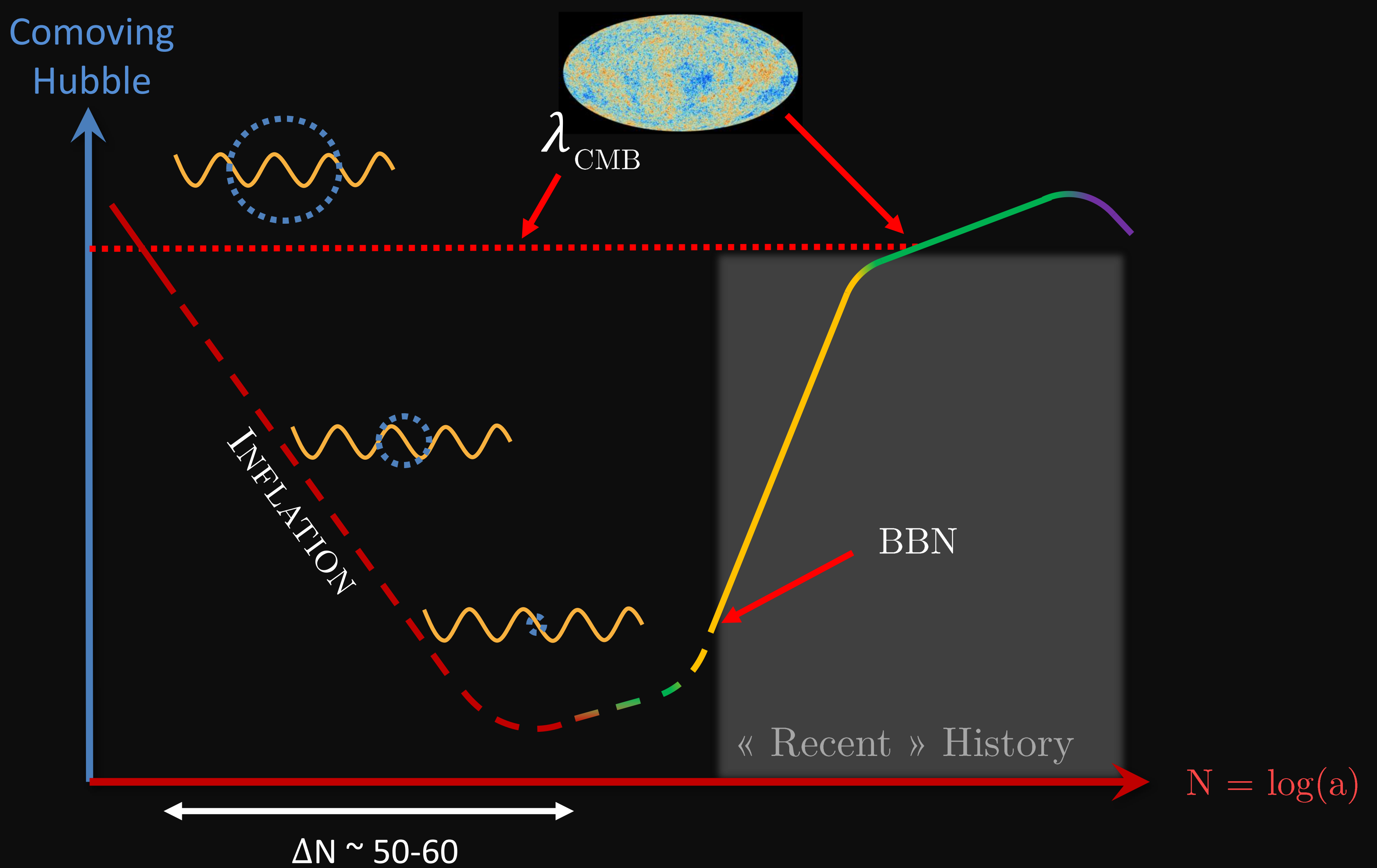
$+$

Classical Perturbations

(super-horizon)



EFT of inflation



RG running of inflation

Bare potential $\boxed{V(\phi)} \longrightarrow$ RG-Improved potential $\boxed{U(\phi)}$

Static field: $\boxed{\phi \sim \text{cst.}} \longrightarrow \boxed{H = H(\phi)} \longrightarrow \boxed{U = V_{RGI}(\phi)}$

Valid in the deep slow-roll era: See Wenqi Ke's talk !

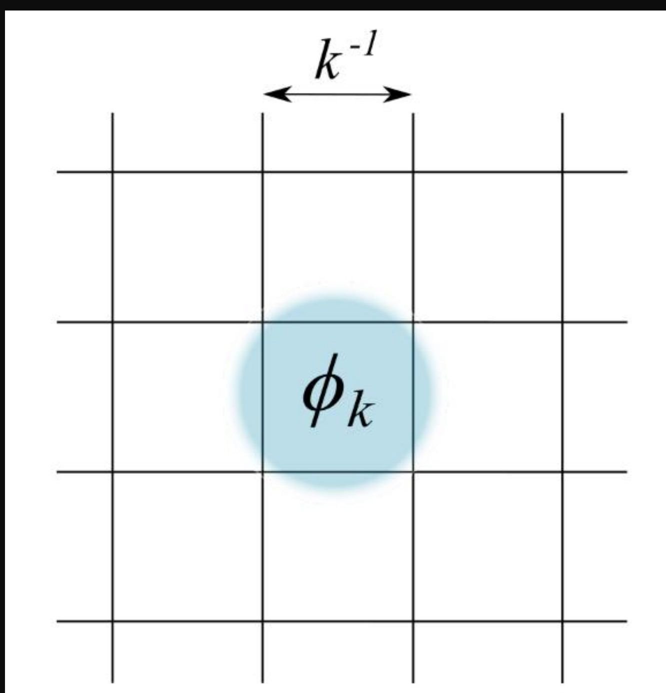
Rolling field: $\boxed{\phi(t), \dot{\phi}(t)} \longrightarrow \boxed{\phi(t), H(t)} \longrightarrow \boxed{U = U(\phi, H)}$

What about deviations from slow-roll ?

Exact Renormalisation Group

At every scale: coarse grain the theory.

- Short wavelengths are integrated out.
- Large wavelengths live in the effective field theory.



Litim, Wetterich, and many

$$\Delta S = \frac{1}{2}\Omega \sum_q R_k(q)\chi_a^*(q)\chi^a(q),$$

$$S_k = S \boxed{+ \Delta S} - \sum_q J_a^*(q)\,\chi^a(q).$$

$$W_k[J] = \ln Z_k[J] = \ln \int \mathcal{D}\chi \, \exp(-S_k[\chi, J]).$$

$$\tilde{\Gamma}_k[\varphi_k] + W_k[J] - \sum_q J_a^*(q)\varphi_k^a(q) = 0,$$

$$\Gamma_k = \tilde{\Gamma}_k \boxed{- \Delta S} = S.$$

Exact Renormalisation Group

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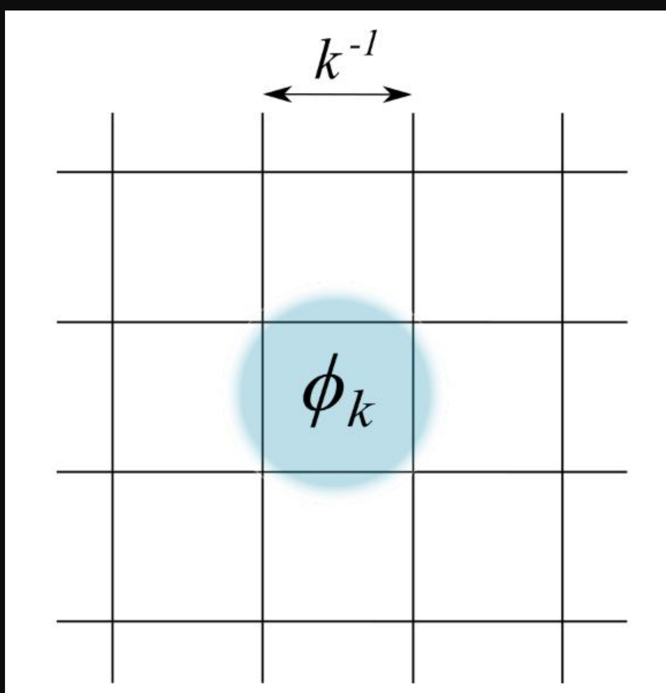
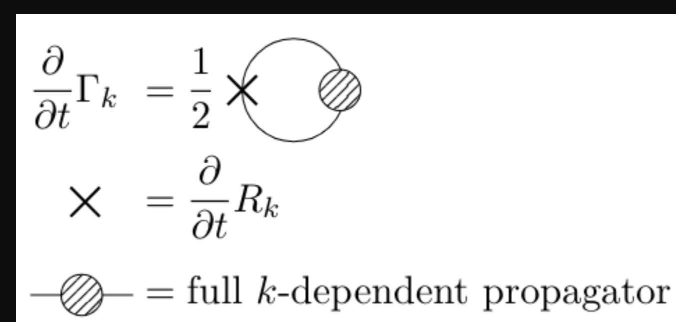
Litim, Wetterich, and many



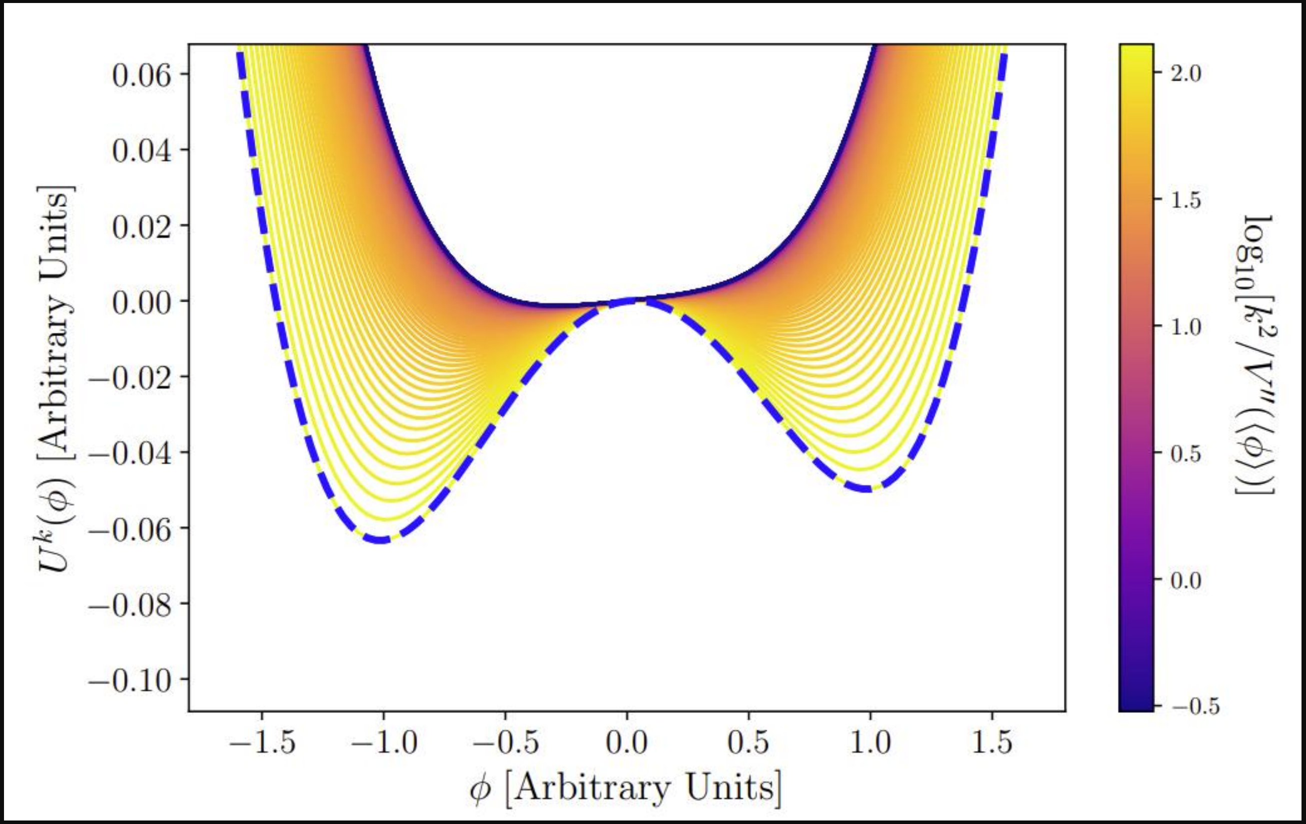
$$\frac{\partial}{\partial t}\Gamma_k[\varphi] = \frac{1}{2}\,\mathrm{Tr}\Big[\big(\Gamma_k^{(2)}[\varphi] + R_k\big)^{-1}\partial_t R_k\Big].$$

$$\lim_{k\to 0} R_k(q) = 0$$

$$\lim_{k\to 0} \Gamma_k[\varphi] = \Gamma[\varphi],$$



Exact Renormalisation Group



S. Abel, LH, JHEP 08 (2025) 198

Exact Renormalisation Group

4D-Euclidean space $\longrightarrow$ 3+1 FLRW problem

$$\frac{\delta\Gamma_k}{\delta k(t)} = \frac{\sqrt{-g(t)}}{2}\int\frac{d^3p}{(2\pi)^3}\int\frac{d^3q}{(2\pi)^3}\delta(\vec{p}+\vec{q})$$
$$\int dt'\delta(t-t')\ \mathcal{O}(t,t',\vec{p},\vec{q})\ \partial_k C_k(p)\ , \qquad (5)$$

where

$$\mathcal{O}(t,t',\vec{p},\vec{q}) =$$
$$\left[\sqrt{|g|}(C_k(p)-i\varepsilon)\delta(\vec{p}+\vec{q})\delta(t-t') - \frac{\delta^2\Gamma_k}{\delta\varphi_b(t,\vec{p})\delta\varphi_b(t',\vec{q})}\right]^{-1}, \qquad (6)$$

ArXiv:2511.05296 – J. Alexandre, LH, S. Pla

Exact Renormalisation Group

4D-Euclidean space $\longrightarrow$ 3+1 FLRW problem

+ Local Potential Approximation

$$\Gamma_k[\phi] = \int dt\sqrt{-g}\int d^3x\left(-\frac{g^{\mu\nu}}{2}\partial_\mu\phi\partial_\nu\phi - U_k(\phi)\right)$$

+ Top-Hat Regulator

$$\partial_\kappa U_\kappa(\phi) = \frac{aT^{-1}}{6\pi^2}\mathcal{D}_E^{-1}\left(a^{-1}\kappa^4\right)\ , \tag{9}$$

where

$$\mathcal{D}_E = -\frac{d^2}{dt^2} - 3H\frac{d}{dt} + \kappa^2 + \partial_\phi^2 U_\kappa(\phi)\ , \tag{10}$$

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Exact Renormalisation Group

4D-Euclidean space $\longrightarrow$ 3+1 FLRW problem

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$$\Gamma_k[\phi] = \int dt\sqrt{-g}\int d^3x\left(-\frac{g^{\mu\nu}}{2}\partial_\mu\phi\partial_\nu\phi - U_k(\phi)\right)$$

+ Top-Hat Regulator

$$\ddot{F} + H\dot{F} + (\partial_\phi^2 U - H^2 - \dot{H})F = \frac{H_0 H^4}{6\pi^2}\ ,$$

where $F \equiv \partial_H U$

ArXiv:2511.05296 – J. Alexandre, LH, S. Pla

Exact Renormalisation Group

4D-Euclidean space $\longrightarrow$ 3+1 FLRW problem

$U = U(\phi, H)$ $\longrightarrow$ Modifed Friedmann Equations

$$\ddot{\phi} + 3H\dot{\phi} + \partial_\phi U = 0 \ , \tag{13}$$

$$3M_p^2 H^2 = \frac{1}{2}(\dot{\phi})^2 + U - HF \ , \tag{14}$$

$$M_p^2\left(2\frac{\ddot{a}}{a} + H^2\right) + \frac{1}{2}(\dot{\phi})^2 - U + HF + \frac{\dot{F}}{3} = 0 \ . \tag{15}$$

[redacted]

ArXiv:2511.05296 – J. Alexandre, LH, S. Pla

Exact Renormalisation Group

4D-Euclidean space $\longrightarrow$ 3+1 FLRW problem

Set of Equations

$$F'' = \frac{H_0 H^2}{6\pi^2} - \left(1 + \frac{H'}{H}\right) F' - \left(\frac{\partial_\phi^2 U}{H^2} - \frac{H'}{H} - 1\right) F\,,$$

$$\phi'' = -\left(3 + \frac{H'}{H}\right)\phi' - \frac{\partial_\phi U}{H^2}\,,$$

$$H' = -\frac{H}{2M_p^2}\left((\phi')^2 + \frac{F'}{3H}\right)\,. \tag{17}$$

ArXiv:2511.05296 – J. Alexandre, LH, S. Pla

Exact Renormalisation Group

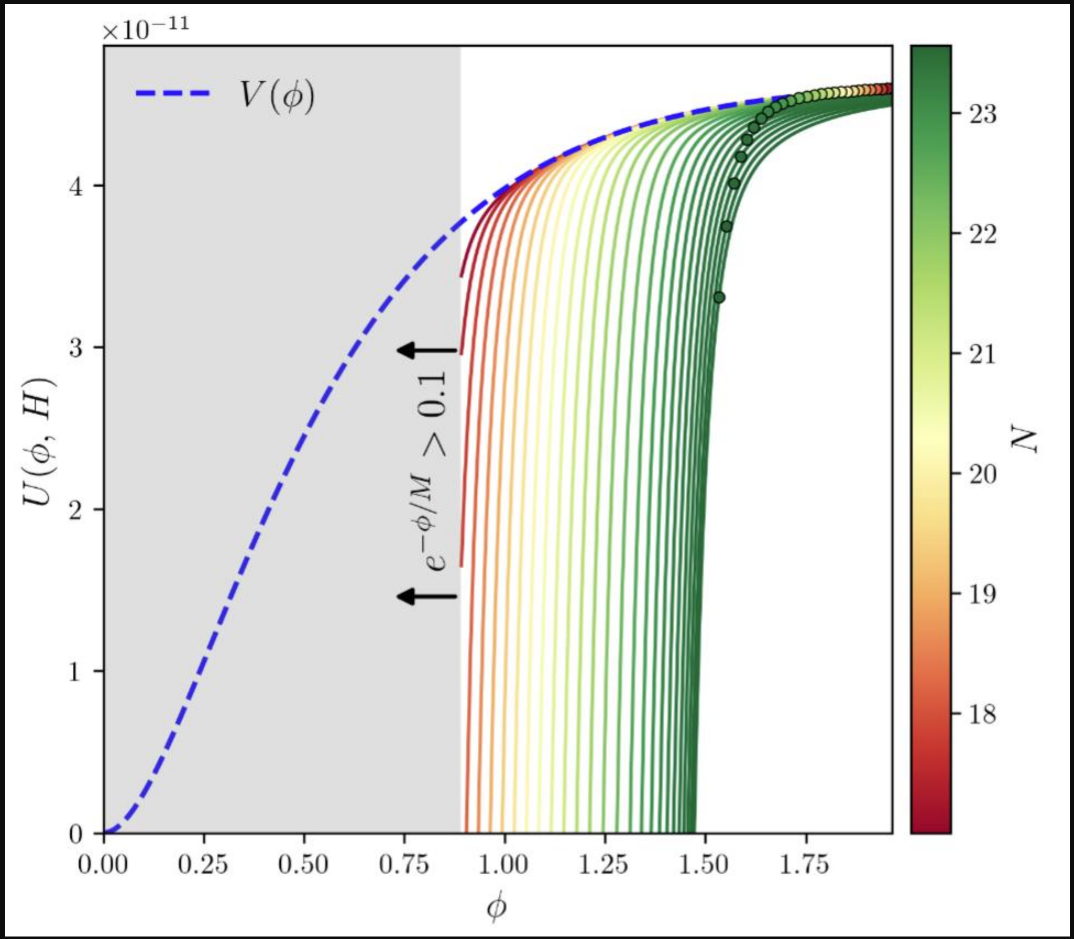
E-models

$$U(\phi, H_0) = V(\phi) = V_0 \left(1 - e^{\sqrt{\frac{2}{3\alpha}}\frac{\phi}{M_p}}\right)^2 .$$

$$U_H(\phi) = \sum_{n=0}^{\infty} U_n(H)\, e^{-n\phi/M}$$

$$F = \sum_{n=0}^{\infty} F_n\, e^{-n\phi/M} \,, \quad \text{with} \quad F_n = \frac{dU_n}{dH}$$

$$\begin{aligned} F_n'' = \delta_{n,0}\frac{H_0 H^2}{6\pi^2} - F_n'\left[-2n\frac{\phi'}{M} + \left(1 + \frac{H'}{H}\right)\right] \\ + F_n\left[n\frac{\phi''}{M} - \left(n\frac{\phi'}{M}\right)^2 + \left(1 + \frac{H'}{H}\right)\left(1 + n\frac{\phi'}{M}\right)\right] \\ - \frac{1}{H^2 M^2}\left(\sum_{l=0}^{n} l^2 U_l F_{n-l}\right) , \qquad n \geqslant 0. \end{aligned} \tag{26}$$



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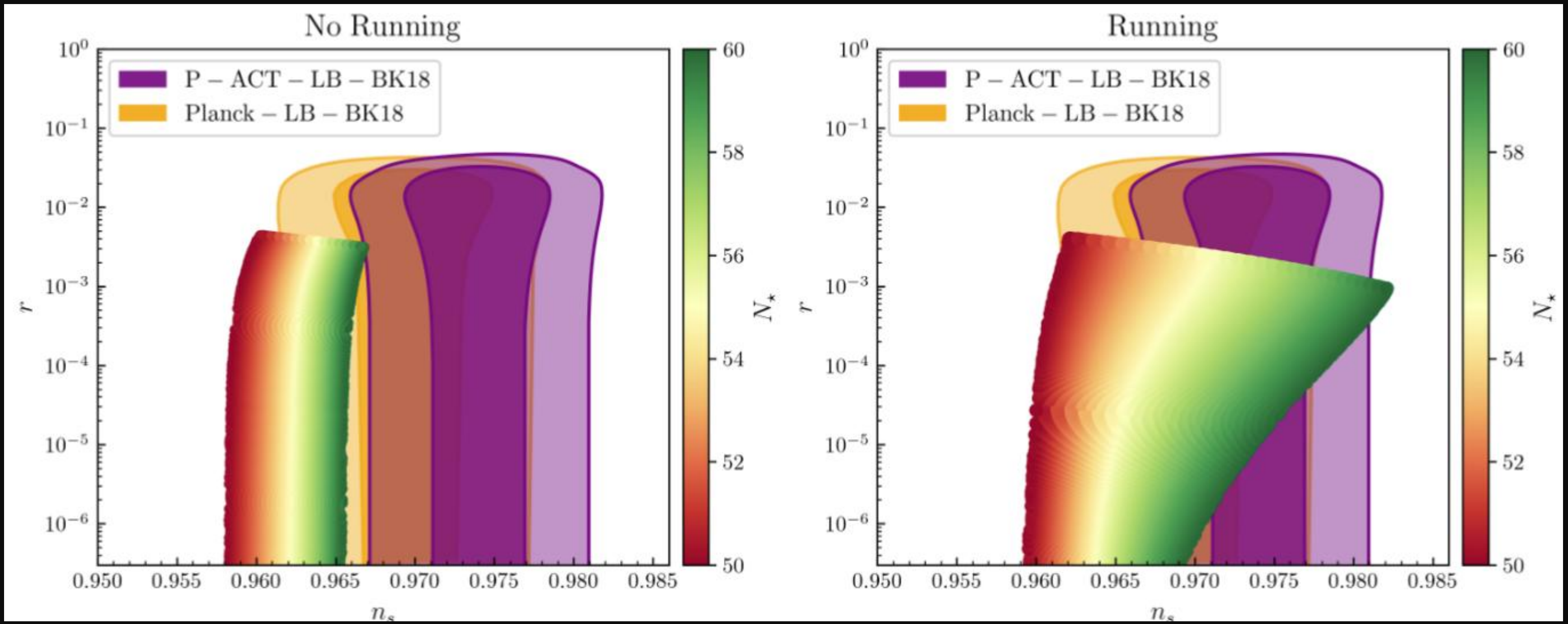
Exact Renormalisation Group



Effect on Observables:

Reduced number of e-folds $\longrightarrow$ Shift to larger n_s

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Thank you for your attention!