NICPB KBFI

CONNECTING SCIENCES

Natural Metric-Affine Inflation

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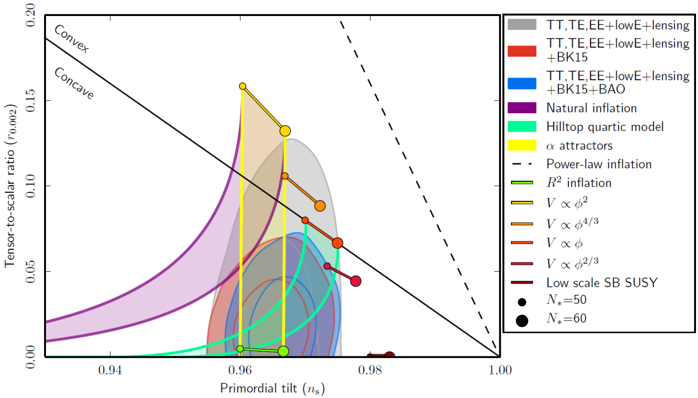
Quy Nhon, July 9th, 2024

based on
arXiv:2403.18004 (JCAP 06 (2024) 033)
with
A. Salvio (Univ. Rome Tor Vergata & INFN)

Euroopa Liit
Euroopa Sotsiaalfond
Eesti tuleviku heaks

• NI vs Planck 2018 data •



- NI became strongly disfavored after BICEP/Keck 2018 data
- several proposals to save it by modifying gravity:
  - $\xi[1 + cos(\phi)]R$ → OK only at 2σ (Ferreira et al. 1806.05511)
  - $\xi\phi^n R$ → OK only at 2σ (Bostan, 2209.02434; dos Santos et al., 2312.12286)
  - Palatini R^2 → OK! but $(\partial\phi)^4$ (Antoniadis et al., 1812.00847)
  - probably more?

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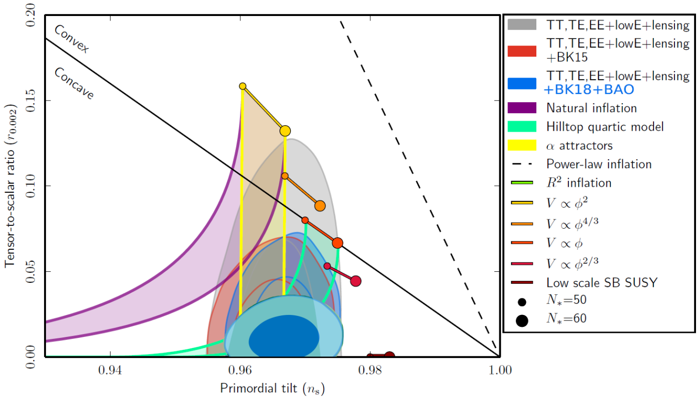

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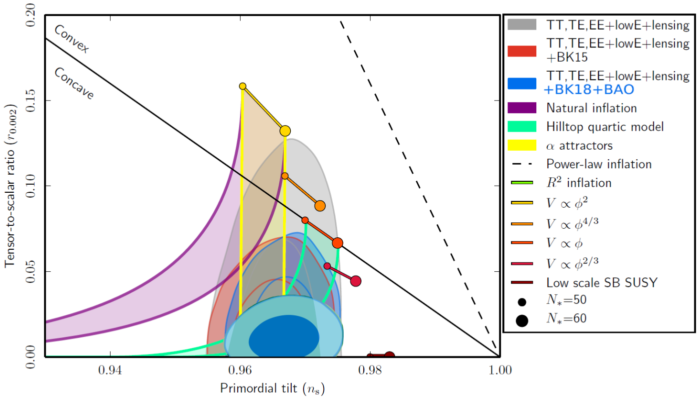

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• Gravity preliminaries •

The properties of torsion-free spacetime are essentially described by:

- the affine connection: $\mathcal{A}^{\lambda}_{\alpha\beta} \to$ parallel transport
- the metric tensor: $g_{\mu\nu} \to$ distance

The connection coefficients and metric tensor are fundamentally independent quantities. They exhibit no *a priori* known relationship. If they are to have any relationship, it must derive from

- additional constraints (metric formalism $\mathcal{A}_{\mu}{}^{\rho}{}_{\sigma} = \Gamma_{\mu}{}^{\rho}{}_{\sigma}$)
- EoM for $\mathcal{A}$ & g (Palatini formalism)
  - minimal theories $\Rightarrow \mathcal{A}_{\mu}{}^{\rho}{}_{\sigma} = \Gamma_{\mu}{}^{\rho}{}_{\sigma}$
    $\Rightarrow$ metric $\sim$ Palatini
  - non-minimal theories $\Rightarrow \mathcal{A}_{\mu}{}^{\rho}{}_{\sigma} \neq \Gamma_{\mu}{}^{\rho}{}_{\sigma}$
    $\Rightarrow$ metric $\neq$ Palatini (e.g. Koivisto & Kurki-Suonio: 0509422)

• Palatini NI action •

$$S_{\rm NI} = \int d^4x \sqrt{-g_J}\left[\alpha(\phi)\mathcal{R}_J - \frac{\partial_\mu\phi\,\partial^\mu\phi}{2} - V(\phi)\right]$$

$$V(\phi) = \Lambda^4\left[1+\cos\left(\frac{\phi}{f}\right)\right]$$

$$\alpha(\phi) = \frac{M_P^2}{2}\left[1+\xi\left(1+\cos\left(\frac{\phi}{f}\right)\right)\right] > 0$$

- notation: $\begin{cases} \mathcal{R} \to \text{curvature from generic } \mathcal{A}_{\mu\ \sigma}^{\ \rho} \\ R \to \text{curvature from Levi-Civita } \Gamma_{\mu\ \sigma}^{\ \rho} \end{cases}$

- Einstein frame: $g^E_{\mu\nu} = F(\phi) g^J_{\mu\nu}$, $F \equiv \frac{2\alpha}{M_P^2}$

  N.B. Palatini $\Rightarrow \mathcal{R}_J = F\, R_E$

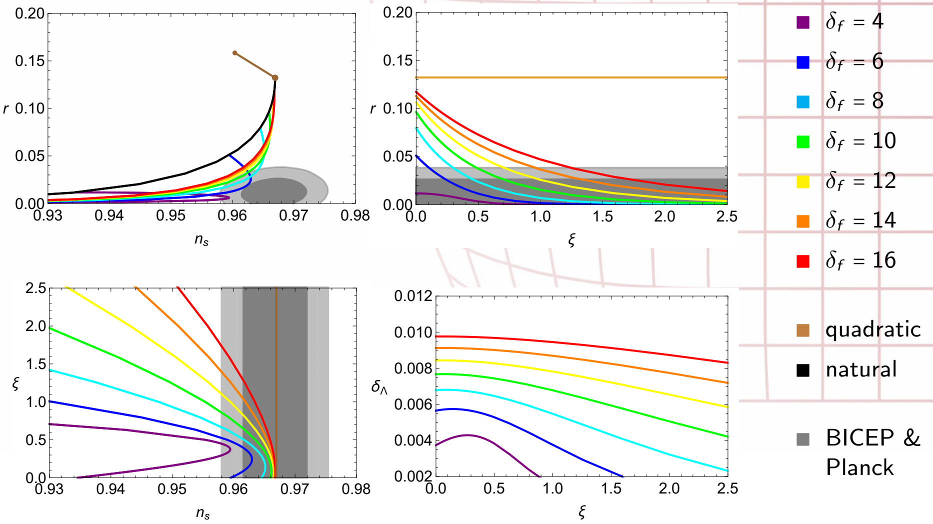
$$S_{\rm NI} = \int d^4x \sqrt{-g_E}\left[\frac{M_P^2}{2} R_E - \frac{\partial_\mu\chi\,\partial^\mu\chi}{2} - U(\chi)\right]$$

$$\frac{d\chi}{d\phi} = \sqrt{\frac{1}{F(\phi)}} = \sqrt{\frac{M_P^2}{2\alpha(\phi)}} \qquad \leftarrow \text{no } \frac{3}{2}\left(\frac{F'}{F}\right)^2 \text{ like in metric}$$

$$U(\chi) = \frac{V(\phi(\chi))}{F^2(\phi(\chi))}$$

• Palatini results •

$N_e = 60 \qquad \delta_f = f/M_P \qquad \delta_\Lambda = \Lambda/M_P$



• Palatini → Metric-Affine •

- any way to get better results?
- YES! allow for torsion → MAG

but in a way that new dof's are not generated!

- $\mathcal{A}^{\lambda}_{\alpha\beta} \neq \mathcal{A}^{\lambda}_{\beta\alpha}$

$$\mathcal{F}_{\mu\nu}{}^{\rho}{}_{\sigma} \equiv \partial_\mu \mathcal{A}_\nu{}^\rho{}_\sigma - \partial_\nu \mathcal{A}_\mu{}^\rho{}_\sigma + \mathcal{A}_\mu{}^\rho{}_\lambda \mathcal{A}_\nu{}^\lambda{}_\sigma - \mathcal{A}_\nu{}^\rho{}_\lambda \mathcal{A}_\mu{}^\lambda{}_\sigma$$

Holst inv. → $\tilde{\mathcal{R}} \equiv \frac{1}{\sqrt{-g}}\epsilon^{\mu\nu\rho\sigma}\mathcal{F}_{\mu\nu\rho\sigma}$

cf. $\mathcal{R} \equiv \mathcal{F}_{\mu\nu}{}^{\mu\nu}$

where $\epsilon^{\mu\nu\rho\sigma}$ is the totally antisymmetric Levi-Civita symbol with $\epsilon^{0123} = 1$

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• MAG NI action •

$$S_{\mathrm{NI}} = \int d^4x\sqrt{-g_J}\left[\alpha(\phi)\mathcal{R}_J + \beta(\phi)\tilde{\mathcal{R}}_J - \frac{\partial_\mu\phi\,\partial^\mu\phi}{2} - V(\phi)\right]$$

$$V(\phi) = \Lambda^4\left[1+\cos\left(\frac{\phi}{f}\right)\right] \qquad \alpha(\phi) = \frac{M_P^2}{2}\left[1+\xi\left(1+\cos\left(\frac{\phi}{f}\right)\right)\right] > 0$$

$$\beta(\phi) = \beta_0 + \frac{M_P^2}{2}\tilde{\xi}\left(\cos\left(\frac{\phi}{f}\right)+1\right) \qquad \frac{M_P^2}{4\beta_0} \to \text{Barbero-Irmizzi par.}$$

- it is possible to integrate out the $\tilde{R}$ term
- performing all the computations ...

$$S_{\mathrm{NI}} = \int d^4x\sqrt{-g}\left[\alpha\mathcal{R}_J - \left[1+\frac{12(\alpha'\beta+\alpha\beta')^2}{\alpha(\alpha^2+4\beta^2)}\right]\frac{\partial_\mu\phi\,\partial^\mu\phi}{2} - V\right]$$

- allowing torsion changes the inflaton kinetic term

• MAG NI action •

Einstein frame:

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$$S_{\rm NI} = \int d^4x \sqrt{-g_E}\left[\frac{M_P^2}{2} R_E - \frac{\partial_\mu \chi \partial^\mu \chi}{2} - U(\chi)\right]$$

$$\frac{d\chi}{d\phi} = M_P \sqrt{\frac{1}{2\alpha}\left[1 + \frac{12(\alpha'\beta + \alpha\beta')^2}{\alpha(\alpha^2 + 4\beta^2)}\right]}$$

← new term from $\beta\tilde{R}$

$$U(\chi) = \frac{V(\phi(\chi))}{F^2(\phi(\chi))}$$

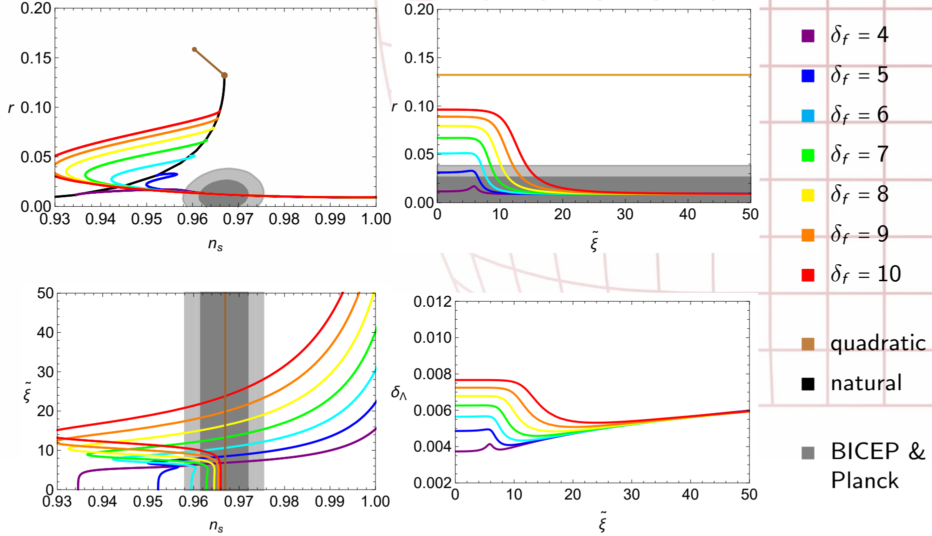
← same as before

N.B.

- $\beta < 0$ allowed
- symmetry: $\beta \to -\beta$ $\Rightarrow$ $\tilde{\xi} > 0,\ \beta_0 \gtreqless 0$

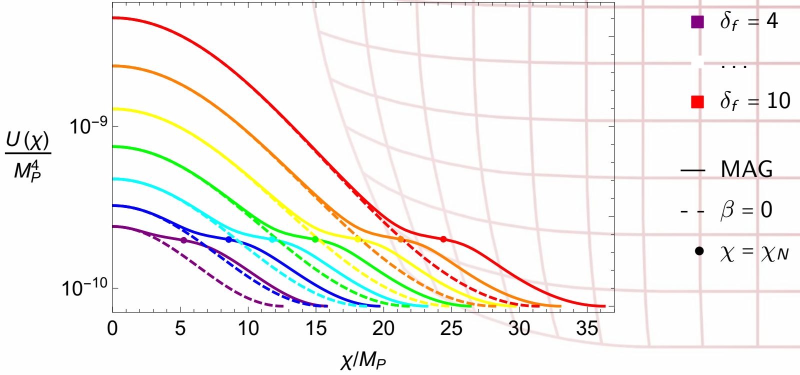
$\xi = 0$ & $\tilde{\xi} > 0$ & $\beta_0 < 0$

$\xi = 0 \quad \beta_0 = -6M_P^2 \quad N_e = 60 \quad \delta_f = f/M_P \quad \delta_\Lambda = \Lambda/M_P$



• $\xi = 0$ & $\tilde{\xi} > 0$ & $\beta_0 < 0$ •

$\xi = 0 \quad \beta_0 = -6M_P^2 \quad N_e = 60 \quad n_s \simeq 0.97 \quad \delta_f = f/M_P \quad \delta_\Lambda = \Lambda/M_P$



• inflection point inflation!!!

$\xi = 0$ & $\tilde{\xi} > 0$ & $\beta_0 < 0$

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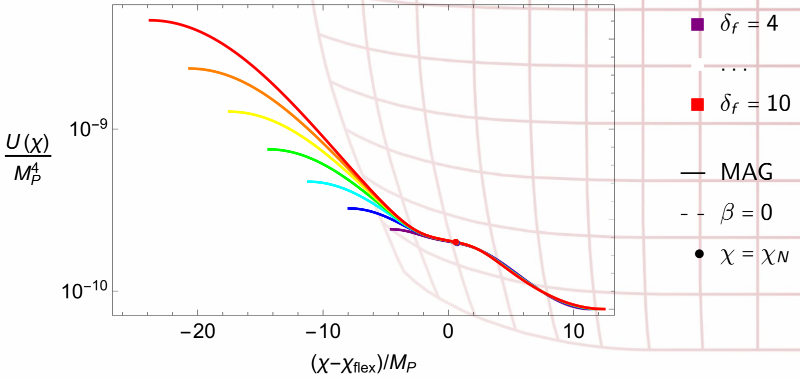
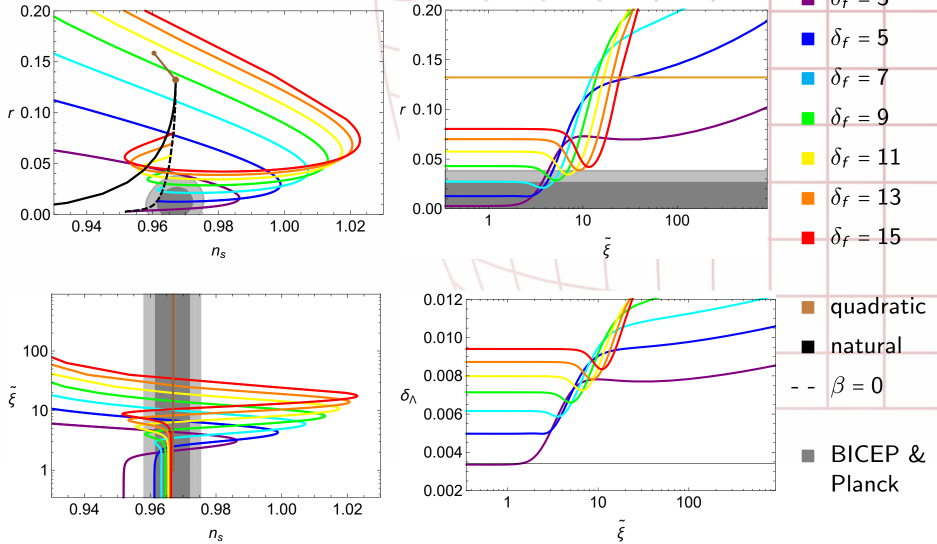


- inflection point inflation!!!

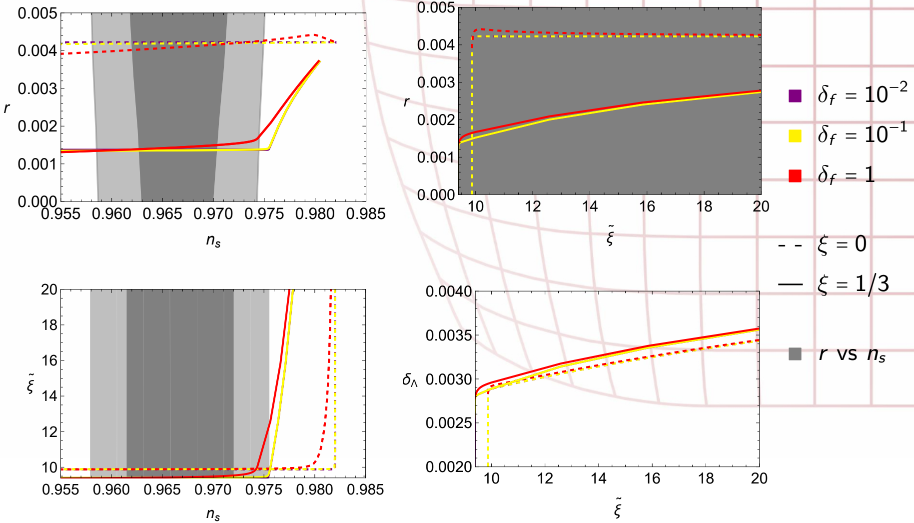
$\xi > 0$ & $\tilde{\xi} > 0$

$\xi = 1/3 \quad \beta_0 = -2M_P^2 \quad N_e = 60 \quad \delta_f = f/M_P \quad \delta_\Lambda = \Lambda/M_P$



• $\xi > 0$ & $\tilde{\xi} > 0$: low $f \lesssim M_P$ •

$\beta_0 = -10 M_P^2$ $N_e = 60$ $\delta_f = f/M_P$ $\delta_\Lambda = \Lambda/M_P$



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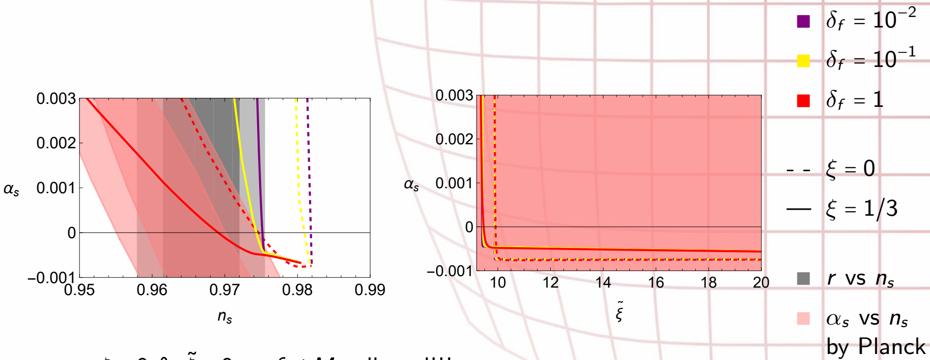

- $\xi > 0$ & $\tilde{\xi} > 0 \Rightarrow f \lesssim M_P$ allowed!!!

• Summary & Conclusions •

- NI strongly disfavored after Planck+BICEP 2018 data

- introducing a non-minimal coupling to gravity
  - compatible at 2σ in the Palatini formulation

- allowing for torsion (i.e. $\tilde{\mathcal{R}}$) (MAG formalism)
  - compatible at 1σ with data
  - allows also for subPlanckian f!!!

Grazie! - Thank you! - Aitäh!