Unified Model for Inflation and Dark Energy

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*E.Massó & GZ, **JCAP0602:012,2006** (astro-ph/0602166)*

Introduction

- Standard Model (SM) is not the ultimate theory
- New symmetries are supposed to exist
- Global symmetries are expected to be explicitly broken by quantum gravity, apart from SSB
- For very small explicit breaking, the resulting PGB is a Dark Energy (DE) candidate
- Consider these effects in inflationary models and obtain a unified model for **Inflation** and **DE**

The Model

- $U(1)$ - global symmetry with SSB at scale f
- Complex scalar field charged under $U(1)$

$$\psi(x) = \phi(x)\, e^{i\theta(x)/f}$$

- $U(1)$ - symmetric potential for ψ

$$V_1(\psi) = \tfrac{1}{4}\lambda(|\psi|^2 - f^2)^2$$

- New real scalar field $\chi(x)$ interacting with $\psi(x)$

$$V_2(\psi,\chi) = \tfrac{1}{2} m_\chi^2 \chi^2 + \left(\Lambda^2 - \frac{\alpha^2 |\psi|^2 \chi^2}{4\Lambda^2} \right)^2$$

The Model

- Small explicit $U(1)$ - breaking term

$$V_{\text{non-sym}}(\psi) = -g \frac{1}{M_P^{n-3}} |\psi|^n \left(\psi\, e^{-i\delta} + h.c.\right),\ n \geq 4$$

- After writing $\psi(x) = \phi(x)\, e^{i\theta(x)/f}$ and eliminating global phases, we get

$$V_{\text{non-sym}}(\phi,\theta) = -2g \frac{\phi^{n+1}}{M_P^{n-3}} \cos(\theta / f)$$

- This gives a small mass to θ and is related to DE, being negligible during inflation

The Model – Inflation

- Hybrid inflation type

$$V_{sym}(\phi,\chi) = \Lambda^4 + \tfrac{1}{2}(m_\chi^2 - \alpha^2\phi^2)\chi^2 + \tfrac{1}{4}\lambda(\phi^2 - f^2)^2 + \ldots$$

- After $U(1)$ SSB, $\phi \approx 0$ and χ is stable, but ϕ is not

$$M_\chi^2(\phi) \equiv \tfrac{1}{2}(m_\chi^2 - \alpha^2\phi^2) \approx \tfrac{1}{2}m_\chi^2 > 0$$

$$m_\phi^2 = -\tfrac{1}{2}\lambda f^2 < 0$$

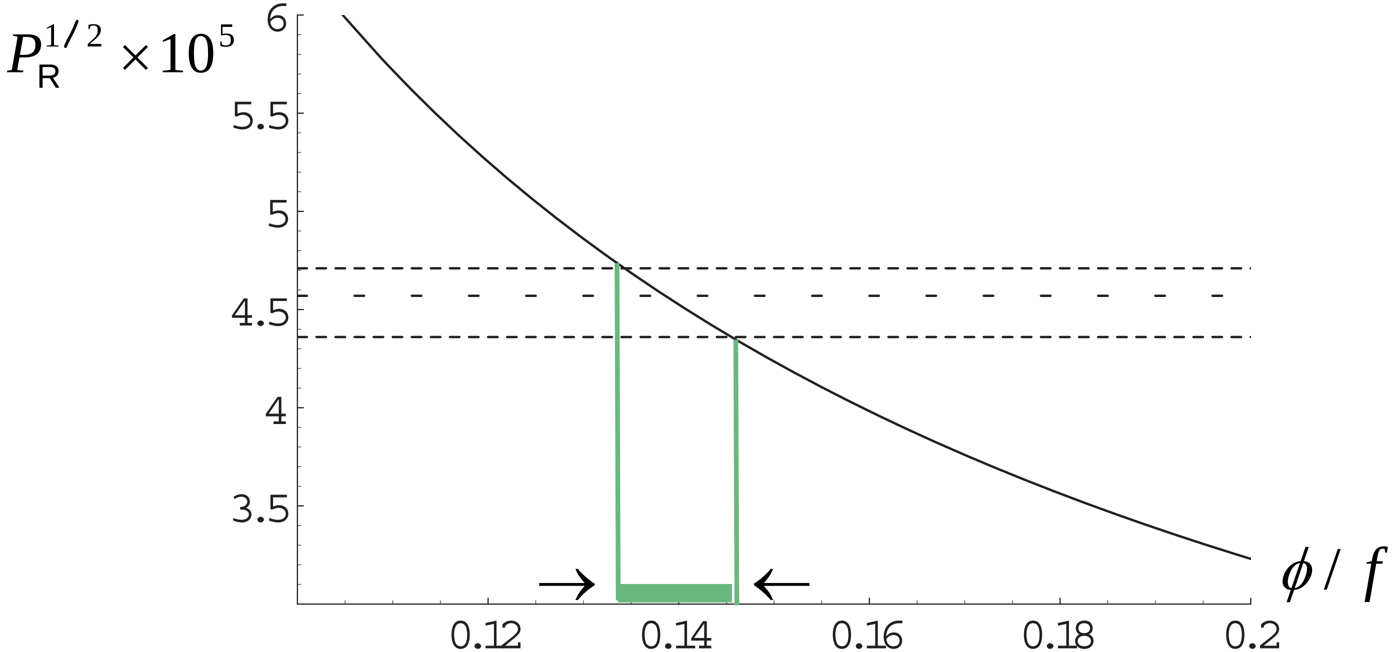
- When $\phi = \phi_{cr} = m_\chi / \alpha$ then χ becomes unstable and inflation ends

The Model – Inflation

- Conditions for inflation
  - – Vacuum energy dominance: $\Lambda^4 \geq \frac{1}{4}\lambda f^4$
  - – Slow-roll of the inflaton: $\varepsilon = \frac{M_P^2}{16\pi}\left(\frac{V'}{V}\right)^2 << 1$ $\quad |\eta| = \left|\frac{M_P^2}{8\pi}\frac{V''}{V}\right| << 1$
  - – Sufficient e-folds of inflation: $N(\phi) = \frac{8\pi}{M_P^2}\int_{\phi_e}^{\phi}\frac{V}{V'}d\phi \approx 60$
  - – Sudden end of inflation: $\left|\Delta M_\chi^2\right|_{\phi=\phi_c} > H^2$
  - – Predictions consistent with observations: $P_{\mathrm{R}}^{1/2},\ n_s,\ r \ldots$
- <u>Results</u>: $f \leq M_P$ $\quad 6\times 10^{-14} \leq \lambda \leq 1.7\times 10^{-12}$

The Model – Inflation

Amplitude of curvature perturbations vs. *Inflaton field*

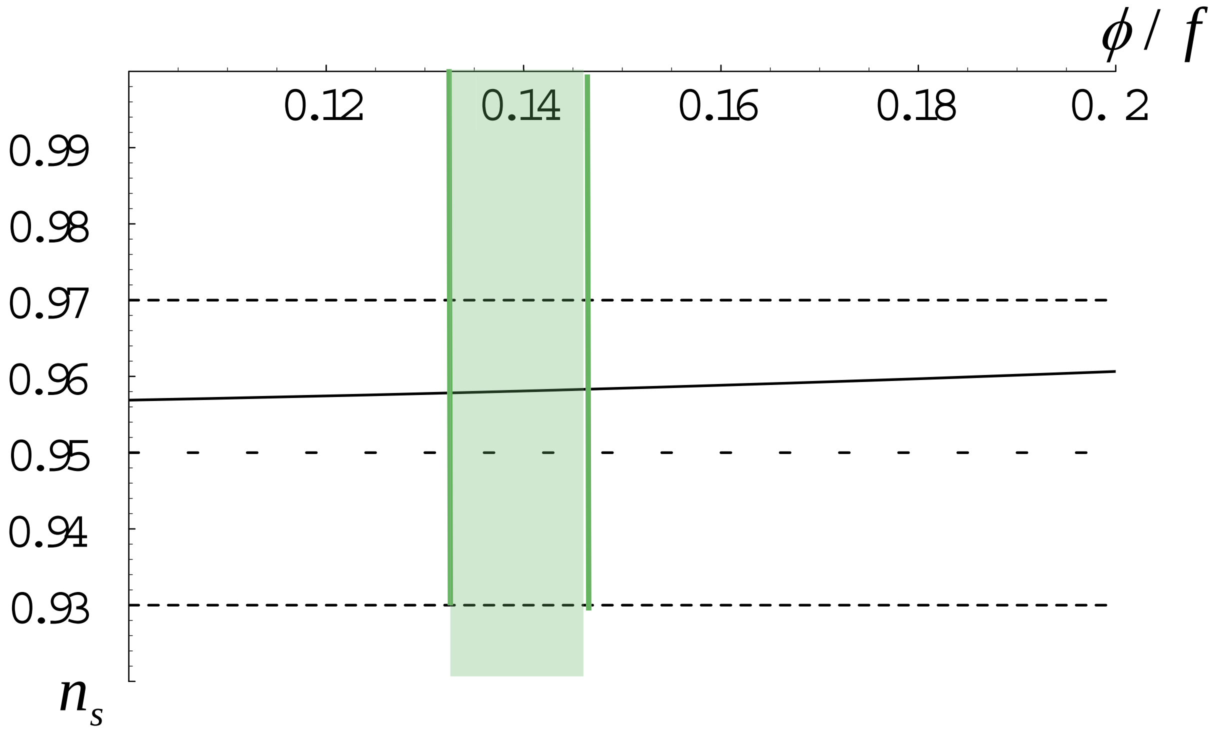


Parameter values: $f = 5\times10^{18}\,\mathrm{GeV}; \quad \lambda = 5\times10^{-14}; \quad \alpha = 10^{-4}$

$\Lambda = 4.5\times10^{15}\,\mathrm{GeV}; \quad m_\chi = 2.5\times10^{14}\,\mathrm{GeV}$

The Model – Inflation

Spectral index vs. *Inflaton field*



Parameter values: $f = 5\times10^{18}\,\text{GeV};\quad \lambda = 5\times10^{-14};\quad \alpha = 10^{-4}$

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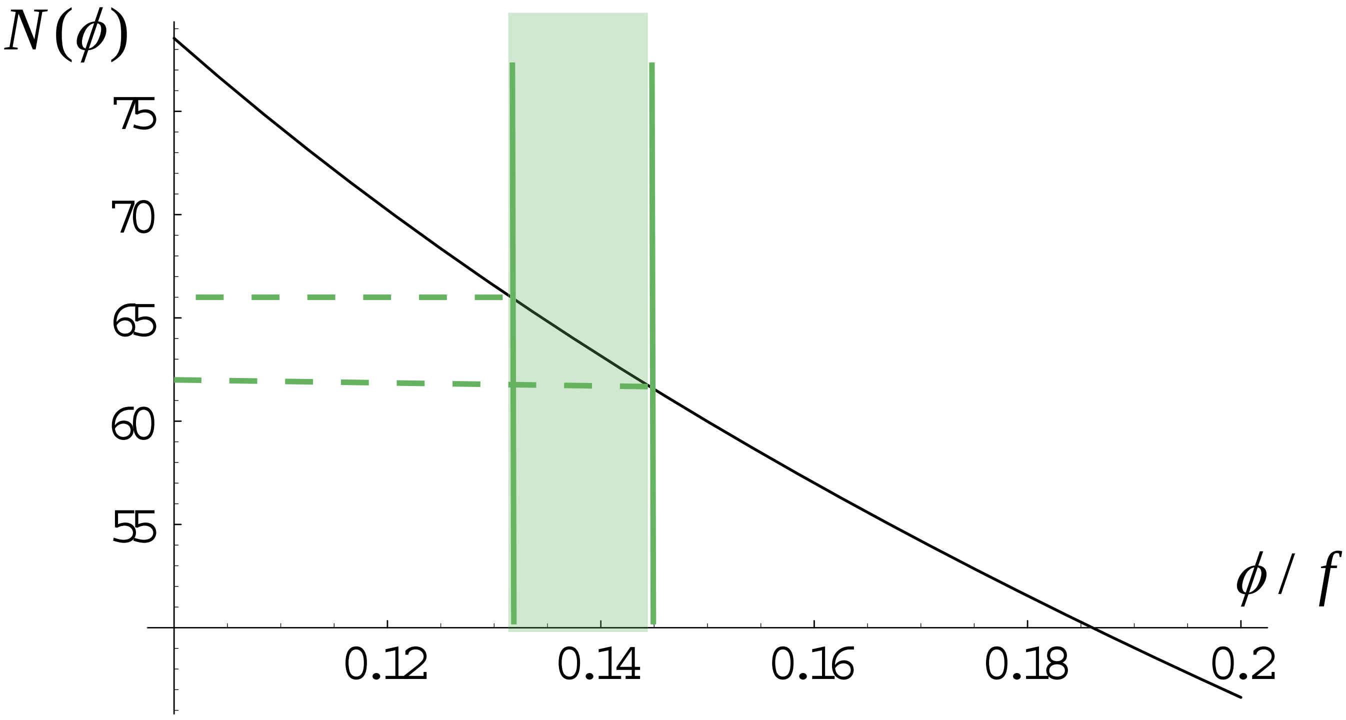
The Model – Inflation

Number of e-folds *vs.* *Inflaton field*



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The Model – Dark Energy

- θ- field has a potential given by $V_{non-sym}(\psi)$

$$V(\theta) = -g\left(\frac{f}{M_P}\right)^{n-1} M_P \theta^2 = \tfrac{1}{2} m_\theta^2 \theta^2$$

- Requirements in order to be a DE candidate
  1. slowly varying field in a potential: $m_\theta < 3H_0$
  2. energy density comparable to the critical: $\rho_\theta \approx \rho_{c0}$
- <u>Results</u>: $f \geq \tfrac{1}{6} M_P$ - independent of n

  $g < 10^{-119}$ - for the lowest $n = 4$

Discussions and Conclusions

- The SSB scale f must be at Planck scale

$$\frac{1}{6} M_P \leq f \leq M_P$$

- Small values for λ- coupling

$$\lambda \approx 10^{-12} - 10^{-13}$$

- Extremely small values for g - coupling

$$g \leq 10^{-119}$$

- Such small values are not unexpected, *e.g.*

R.Kallosh, A.D.Linde, D.A.Linde, L.Susskind, ***Phys.Rev.D52:912-935,1995***

Discussions and Conclusions

- **Summarize**:
- – new global $U(1)$ symmetry
- – complex scalar field $\psi(x)$ coupled to a real $\chi(x)$

$$\psi(x) = \phi(x)\, e^{i\theta(x)/f}$$

- – $\phi(x)$ is the inflaton field
- – $\theta(x)$ is the field describing DE
- – the energy density of $\theta(x)$ is due to a small explicit breaking of $U(1)$ at Planck scale