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Potential-driven Galileon inflation

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Introduction

For the models of inflation driven by the potential energy of an inflaton field ϕ, the covariant Galileon Lagrangian $(\partial\phi)^2\Box\phi$ generally works to slow down the evolution of the field. On the other hand, if the Galileon self-interaction is dominant relative to the standard kinetic term, we show that there is no oscillatory regime of inflaton after the end of inflation. This is typically accompanied by the appearance of the negative propagation speed squared c_s^2 of a scalar mode, which leads to the instability of small-scale perturbations. For chaotic inflation and natural inflation we clarify the parameter space in which inflaton oscillates coherently during reheating. We also place observational constraints on the inflaton potentials from the information of the scalar spectral index n_s and the tensor-to-scalar ratio r .

Potential-driven inflation with Galileon term

We start with the following action

$$S=\int d^4x\sqrt{-g}\left[\frac{M_{\rm pl}^2}{2}R+X-V(\phi)-G_3(\phi,X)\Box\phi+\mathcal{L}_4+\mathcal{L}_5\right]$$

where

$$\mathcal{L}_4=G_4(\phi,X)R+G_{4,X}\left[(\Box\phi)^2-(\nabla_\mu\nabla_\nu\phi)(\nabla^\mu\nabla^\nu\phi)\right]$$

$$\mathcal{L}_5=G_5(\phi,X)G_{\mu\nu}(\nabla^\mu\nabla^\nu\phi)-\frac{1}{6}G_{5,X}\Big[(\Box\phi)^3-3(\Box\phi)(\nabla_\mu\nabla_\nu\phi)(\nabla^\mu\nabla^\nu\phi)+2(\nabla^\mu\nabla_\alpha\phi)(\nabla^\alpha\nabla_\beta\phi)(\nabla^\beta\nabla_\mu\phi)\Big]$$

For simplicity, we study the covariant Galileon theory in which only the G_3 term is present in the above action

$$G_3(\phi,X)=c_3\frac{X}{M^3}\,,G_4(\phi,X)=0\,,G_5(\phi,X)=0$$

$c_3\dot\phi>0$ to avoid ghosts

Slow-roll equations

$$3M_{\rm pl}^2H^2\simeq V\,,\quad 3H\dot\phi(1+\mathcal{A})+V_{,\phi}\simeq 0 \qquad \mathcal{A}=\frac{3\delta_3}{\delta_X}$$

Slow-roll parameter

$$\epsilon=-\frac{\dot H}{H^2}\simeq\frac{\epsilon_\phi}{1+\mathcal{A}} \qquad \epsilon_\phi=\frac{M_{\rm pl}^2}{2}\left(\frac{V_{,\phi}}{V}\right)^2$$

(for standard inflation)

In the limit $|\mathcal{A}|\gg 1$ ($|\delta_3|\gg\delta_X$)

$\epsilon\ll\epsilon_\phi$ — the evolution of ϕ slows down → Galileon inflation

In the limit $\mathcal{A}\to 0$ ($|\delta_3|\ll\delta_X$)

$\epsilon\simeq\epsilon_\phi$ → Standard inflation

slow-roll parameters

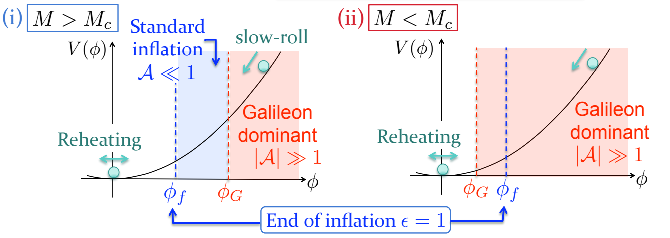
$$\delta_X=\frac{X}{M_{\rm pl}^2H^2}\,,\quad \delta_3=\frac{c_3\dot\phi X}{M_{\rm pl}^2M^3H}$$

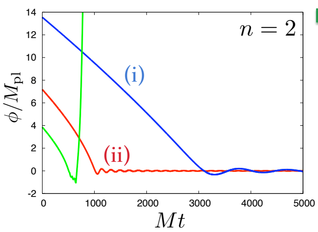
The transition from Galileon inflation to standard inflation can be quantified by the condition $\mathcal{A}(\phi_G)=1$.

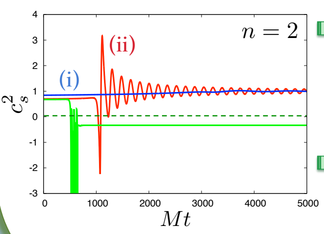
Results

Background analysis for $V(\phi)=(\lambda/n)\phi^n$ with Galileon term $X\Box\phi/M$

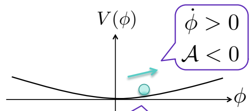
We have the critical mass $M_c=2^{-n/3}n^{(n-1)/3}M_{\rm pl}^{(n-1)/3}\lambda^{1/3}$







During the oscillating stage of inflaton



$$\mathcal{A}=-3\frac{H\dot\phi}{M^3}$$

$$(1+2\mathcal{A})\ddot\phi\simeq -V_{,\phi}$$

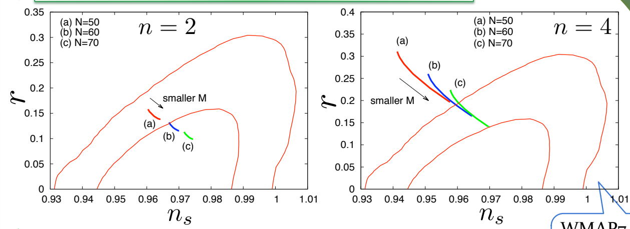
If $(1+2\mathcal{A})<0$, ϕ diverges.
This can be happened for smaller M.

This is typically accompanied by the appearance of the negative propagation speed squared c_s^2 of a scalar mode, which leads to the instability of small-scale perturbations.

We find that the inflaton oscillations occur under the conditions

$M>2.5\times10^{-4}M_{\rm pl}$ (for $n=2$)
$M>9.5\times10^{-5}M_{\rm pl}$ (for $n=4$) (※1)

Observational constraints for $V(\phi)=(\lambda/n)\phi^n$



WMAP7, BAO, and HST

For smaller M, r gets smaller whereas n_s increases.

The quartic potential can be compatible with the current observations in the presence of the Galileon term. The model is within the 2σ contour for $M<7.7\times10^{-4}M_{\rm pl}$ (※2) with 60 e-foldings.

In terms of the parameter λ the conditions (※1) and (※2) translate into $3.4\times10^{-13}<\lambda<3.1\times10^{-10}$ (for $n=4$).

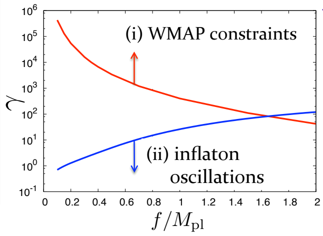
viable parameter space of λ

Natural inflation $V(\phi)=\Lambda^4[1+\cos(\phi/f)]$

In standard natural inflation

$f\gtrsim 3.5M_{\rm pl}$ for the consistency with the WMAP constraints.
However, $f>M_{\rm pl}$ is not generally realized in particle physics.

In the presence of the Galileon term $X\Box\phi/M$



where $\gamma=\Lambda^4/(M^3M_{\rm pl})$

For the compatibility of two constraints we require that f is bounded to be $f>1.7M_{\rm pl}$.
Hence the problem of the super-Planckian values of f in standard inflation is not improved significantly.

Conclusion

We have studied the viability of potential-driven Galileon inflation. The Galileon self-interactions generally lead to the slow down for the evolution of the field, which allows the possibility to accommodate steep inflaton potentials. The dominance of the Galileon self-interactions relative to the standard kinetic term X can modify the dynamics of reheating after inflation. In order to clarify this issue, we numerically solved the background equations for chaotic inflation and natural inflation. We found that, depending on the couplings G_i ($i=3,4,5$) and their associated mass scales M, there is no oscillatory regime of inflaton. Moreover the dominance of the Galileon terms generally gives rise to the negative scalar propagation speed squared c_s^2 during reheating, which leads to the instability of small-scale density perturbations.