DBI Galileon inflation in the light of Planck 2015

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FCT

Outlines

- Inflation and Planck 2015
- Status of DBI inflation
- Motivations for DBI Galileon inflation
- Discussion on various limits of DBIG
- Results

Constraints on inflation

Spectral index Vs tensor scalar ratio

The current bounds $n_s = 0.968 \pm 0.006$ and $r < 0.09$ at 95% CL constrain many inflationary scenarios.

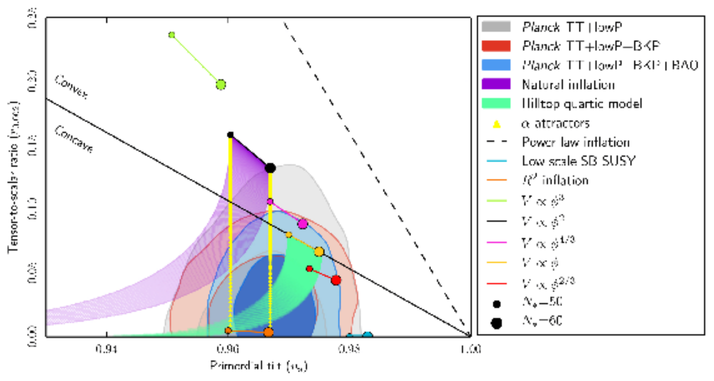


Figure : $n_s - r$ Planck

- The Planck results indicate that we live in a spatially flat universe, $\Omega_k = 0.000 \pm 0.0025$,
- The perturbation spectrum imprinted in the CMB is Gaussian to a high degree, imposing severe constraints on the bispectrum amplitudes: $f_{NL}^{loc} = 0.8 \pm 5.0$, $f_{NL}^{eq} = -4 \pm 43$ and $f_{NL}^{ortho} = -26 \pm 21$ at the 68% confidence level.
- Small running $dn_s/d\ln k = -0.003 \pm 0.007$

1. All these so far not evidently deviated from single field inflation.
2. The fact that Starobinsky and Higgs inflationary models are consistent with data indicates the micro-physics of inflation should therefore be described by an EFT.

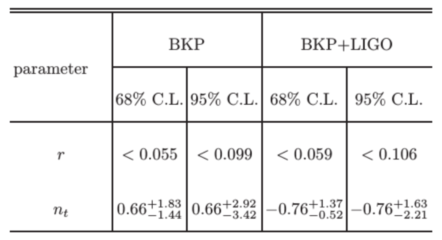
The new data gives us a wonderful opportunity to construct and validate viable and generic inflatioinary models from UV-completion theories such as SUGRA and string theory.

Inflationary model building

- The prediction of starobinsky model with $r = 0.0033$ is well consistent with the data and it has become a sweet spot of present day inflationary cosmology.
- It is important to build models with $r \sim \mathcal{O}\left(10^{-3}\right)$ maintaining $f_{NL} \sim \mathcal{O}(1)$ as the future experiments as the post-Planck sattellites CMBPol,COrE, Prism and LiteBIRD and many other ground based experiments such as Keck/BICEP3 etc are expected to reach sensitivity to detect $r \sim 2 \times 10^{-3}$ Creminelli et al (2015).
- $r \sim \mathcal{O}\left(10^{-3}\right)$ maintaining $f_{NL} \sim \mathcal{O}(1)$ is rather a difficult task for non-canonical models, perhaps models built with features of modified gravity, string theory and SUGRA might be best candidates ,Jerome Martin (2015).
- In the context of inflationary models the commonly heard word is ' generic ' which should mean how well the model consistent with UV-completion theory rather than how small is the parameter space.

Status of tensor tilt

- Tensor tilt is one of the crucial parameter to validate inflation. Especially a detection of red tilt can confirm standard inflationary paradigm. Alternatives to inflation such as Ekpyrotic and String gas cosmology predict a blue tensor tilt.
- Although we have not yet detected B-modes, the phenomenological and statistical evidence of BKP , BKP+LIGO find no evidence for blue tensor tilt. Huang and Wang (2015)



parameter	BKP		BKP+LIGO	
	68% C.L.	95% C.L.	68% C.L.	95% C.L.
r	< 0.055	< 0.099	< 0.059	< 0.106
n_t	$0.66^{+1.83}_{-1.44}$	$0.66^{+2.92}_{-3.42}$	$-0.76^{+1.37}_{-0.52}$	$-0.76^{+1.63}_{-2.21}$

Figure : The 68% and 95% limits for the parameters r and n_t from the BKP only and BKP+LIGO datasets.

Consistency relation

We need to detect GW's to further screen out and validate inflationary models. A significant detection of tensor tilt n_t in post Planck experiments could play a vital role in inflationary cosmology.

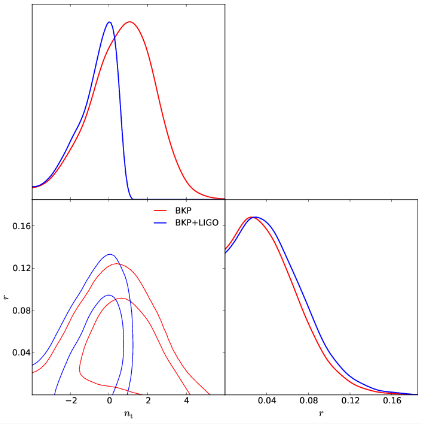


Figure : The marginalized contour plot and likelihood distributions of the parameters r and n_t from the BKP only (red) and BKP+LIGO (blue) datasets.

DBI inflation

- DBI inflation has been an attractive model in String cosmology , Silverstein and Tong (2004).
- DBI is a natural non-canonical model from String theory. And it has the potential for smaller tensor scalar ratio and large Non-gaussianity

$$\underset{\downarrow}{r} = 16\epsilon \underset{\downarrow}{c_s} \qquad f_{NL} \sim \frac{1}{c_s^2}$$

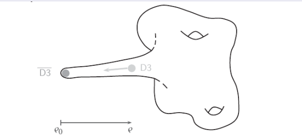


Figure : A Calabi–Yau space with a warped throat region. The dot on the left denotes a D3-brane sitting at the tip of the throat. The dot to the right with the arrow is a mobile D3-brane in the throat. It is attracted by the D3-brane.

DBI->DBI Galileon

- DBI inflation is consistent with the current planck data although speed of sound is constrained to be $c_s > 0.087$.
- Due to NG constraints, the lower bound on tensor scalar ratio in DBI model is given by $r > 0.01$, Baumann and McAllister (2006).
- de Rham and Tolley (2010) proposed a very interesting extension of the DBI action which generalizes and unifies single field DBI and the modified gravity model called the Galileon (DBIG).
- Multifield DBI Galileon inflation has been studied in literature by its potential to generate large Orthogonal NG. S.Renaux-Petel et al (2011), Koyama et al (2014).
- DBI Galileon model has also been embedded in SUGRA , Sayantan choudhury et al (2013).

DBIG model

$$S = \int d^4x \left[\frac{m_p^2}{2} \sqrt{-g} R[g] + \frac{\tilde{m}^2}{2} \sqrt{-\gamma} R[\gamma] + \sqrt{-g} \mathcal{L}_{brane} \right]$$

Einstein-Hilbert + Induced gravity + DBI action

where m_p is reduced planck mass $\left(m_p = 2.24 \times 10^{18} \mathrm{Gev}\right)$ and $\tilde{m}$ is a parameter associated with induced gravity. And

$$\mathcal{L}_{brane} = -\frac{1}{f(\varphi)} \left(\sqrt{\mathcal{D}} - 1 \right) - V(\varphi)$$

Where

$$\mathcal{D} \equiv \det\left(\delta^\mu_\nu + f \partial_\mu \varphi \partial_\nu \varphi\right)$$

The induced metric is

$$\gamma_{\mu\nu} = f^{-1/2} \left(g_{\mu\nu} + f \partial_\mu \varphi \partial_\nu \varphi \right)$$

From now on f and φ are rescaled warp factor and scalar field,

$$f = \frac{h}{T_3}, \quad \varphi = \sqrt{T_3} \rho \tag{1}$$

DBIG model

The modified Friedmann equations for the action are given by

$$3H^2\left(m_P^2+\frac{\tilde{m}^2}{c_{\mathcal{D}}^3}\left(1-\frac{\epsilon_f}{2}-\frac{\epsilon_f^2}{16}\right)\right)=\frac{1}{f}\left(\frac{1}{c_{\mathcal{D}}}-1\right)+V$$

$$-m_P^2\dot{H}+\frac{\tilde{m}^2H^2}{c_{\mathcal{D}}}\left[\epsilon+g_1\left(\epsilon_{\mathcal{D}},\epsilon_f,\eta_f\right)+\frac{3}{2}\left(\frac{1}{c_{\mathcal{D}}^2}-1\right)g_2\left(\epsilon_f\right)\right]=\frac{\dot{\varphi}^2}{2c_{\mathcal{D}}},$$

$$c_{\mathcal{D}}^2\equiv 1-f\dot{\varphi}^2\,,$$

Where the slow roll parameters are

$$\epsilon\equiv-\frac{\dot{H}}{H^2}\quad,\quad\eta\equiv\frac{d\ln\epsilon}{d\ln a}\quad,\quad\epsilon_{\mathcal{D}}\equiv\frac{d\ln c_{\mathcal{D}}}{d\ln a}$$

$$\eta_{\mathcal{D}}\equiv\frac{d\ln\epsilon_{\mathcal{D}}}{d\ln a}\quad\epsilon_f\equiv\frac{d\ln f}{d\ln a}\quad,\quad\eta_f\equiv\frac{d\ln\epsilon_f}{d\ln a}.$$

Studying DBIG in various limits

- DBIG $\longrightarrow$ DBI as$\tilde{m} \rightarrow 0$: In this limit we revisit the constraints on parameter space of DBI inflation.
- DBIG $\longrightarrow$ Galileon as $m_p \longrightarrow 0$ (i.e, switching off Einstein gravity): Taking this limit is not generic but it help us to understand the effects of induced gravity.
- Intermediate case: This case contains both the features of induced gravity and DBI. $c_{\mathcal{D}}, f = constant$
- DBIG with constantly varying speed of sound $\eta_{\mathcal{D}} = 0$
- DBIG with constantly varying warp factor $\eta_f = 0$: It is interesting to study motion of D3 brane in the varying warped geometries.
- Studying the model with varying warp factor and varying speed of sound is theoretically more generic but it is complicated. We leave this case for future studies.

Approach

- The parameter space of DBIG inflation is $(c_{\mathcal{D}}, \tilde{m}, f)$ and the free parameters are $(\epsilon_{\mathcal{D}}, \eta_{\mathcal{D}}, \epsilon_f, \eta_f)$.
- We numerically constrain the parameter space using background equations wrt the latest CMB bounds on $n_s = 0.968 \pm 0.006$ and $r < 0.09$, and power spectrum at pivot scale $\mathcal{P}_{\zeta_*} = 2.2 \times 10^{-9}$.
- Within the constrained parameter space $(c_{\mathcal{D}*}, \tilde{m}, f_*)$ we compute the tensor tilt n_t to all orders in slowroll parameters. Therefore these values of n_t can serve as the test of this model for future experiments.
- From the numerical results we predict No blue tensor tilt in this model but the consistency relation is violated from standard one $r \simeq -8n_t$.
- We also compute the energy scale of inflation Λ and mass of inflation m_φ.

Power spectra

- Perturbations in most general single field (Generalized G-inflation) inflationary models has been studied by Kobayashi et al (2011).
- We compute all the inflationary parameters to the full order in slow roll parameters.

The power spectrum of scalar perturbations is

$$\mathcal{P}_\zeta = \frac{\gamma_s}{2} \frac{\mathcal{G}_{s*}^{1/2}}{\mathcal{F}_{s*}^{3/2}} \frac{H_*^2}{4\pi^2} \quad , \quad \gamma_s \equiv 2^{2\nu_s - 3} \frac{\Gamma(\nu_s)^2}{\Gamma(3/2)^2} \left(1 - \epsilon_* + \frac{g_{s*}}{2} - \frac{f_{s*}}{2}\right)^2 .$$

The spectral index (n_s) is given by

$$n_s - 1 = 3 - 2\nu_s$$

For DBIG $\mathcal{F}_s \equiv \mathcal{F}_s(\epsilon, c_{\mathcal{D}}, \tilde{m}, \epsilon_{\mathcal{D}})$, $\mathcal{G}_s \equiv \mathcal{G}_s(\epsilon, c_{\mathcal{D}}, \tilde{m}, \epsilon_{\mathcal{D}})$ and $f_s \equiv \frac{d \ln \mathcal{F}_s}{d \ln a}$ $\quad g_s \equiv \frac{d \ln \mathcal{G}_s}{d \ln a}$.

Power spectra

The power spectrum of tensor perturbations is,

$$\mathcal{P}_t = 8\gamma_t \frac{\mathcal{G}_{t*}^{1/2}}{\mathcal{F}_{t*}^{3/2}} \frac{H_*^2}{4\pi^2} \quad , \quad \gamma_t \equiv 2^{2\nu_t - 3} \frac{\Gamma(\nu_t)^2}{\Gamma(3/2)^2} \left(1 - \epsilon_* + \frac{g_{t*}}{2} - \frac{f_{t*}}{2}\right)^2 .$$

The tensor tilt (n_t) is given by

$$n_t = 3 - 2\nu_t$$

Where$\mathcal{F}_t \equiv \mathcal{F}_t\left(c_{\mathcal{D}}, \tilde{m}\right)$, $\mathcal{G}_t \equiv \mathcal{G}_t\left(c_{\mathcal{D}}, \tilde{m}\right)$ and $f_t \equiv \frac{d \ln \mathcal{F}_t}{d \ln a} \quad g_t \equiv \frac{d \ln \mathcal{G}_t}{d \ln a}$.
The tensor scalar ratio is

$$r \equiv \frac{\mathcal{P}_t}{\mathcal{P}_\zeta} = 16 \frac{\gamma_t}{\gamma_s} \left(\frac{\mathcal{G}_t}{\mathcal{F}_t}\right)^{1/2} \left(\frac{\mathcal{F}_s}{\mathcal{F}_t}\right)^{3/2}$$

Results

Inflation	r	n_t	m_φ (TeV)	f/m_p^4
DBI limit	$(0.01, 0.1)$	$(-0.049, -0.038)$	1.46×10^9	$(0.07, 0.5) \times 10^{12}$
Galileon limit	$(0.13, 0.15)$	$(-0.05, -0.03)$	$m_\varphi^2 < 0$	$\sim 10^8$
Intermediate	$(0.0095, 0.06)$	$(-0.07, -0.04)$	$m_\varphi^2 < 0$	$(0.2, 1.1) \times 10^9$
Varying $c_\mathcal{D}$	$(0.023, 0.033)$	-0.05	$m_\varphi^2 < 0$	$(1.2, 1.5) \times 10^9$
Varying f	$(0.0037, 0.0087)$	$(-0.068, -0.027)$	$(2, 8.2) \times 10^7$	$(0.54, 1.37) \times 10^7$

Table : Summary of inflationary observables in single field DBI galileon model for No. of efoldings $N_e = 60$.

Conclusion

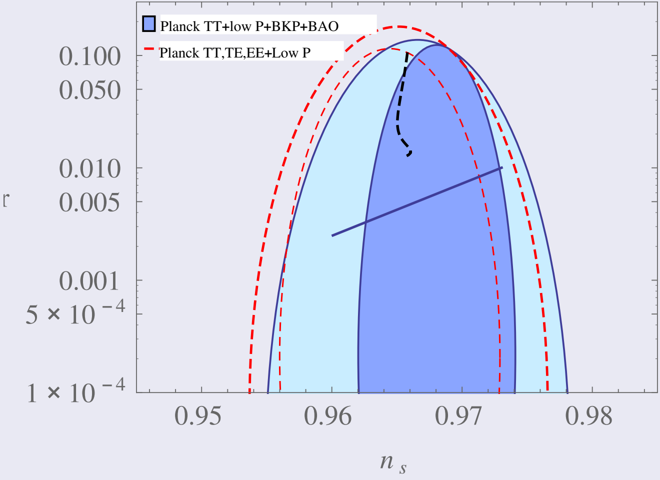


Figure : Predictions of DBIG ($n_s - r$) for constant warp factor (dotted line) and varying warp factor cases (full line).

Conclusions

- In all the cases, we restricted the speed of sound $c_{\mathcal{D}} \lesssim 1$ to avoid large Non-gaussianities. Therefore we attain inflation with $r \sim \mathcal{O}\left(10^{-3}\right)$ with $f_{NL} \sim \mathcal{O}(1)$.
- We predict tensor tilt of the model n_t and violation of standard consistency relation $(r \simeq -8n_t)$. This can serve as an experimental test of the model if future experiments detect gravitational waves.
- We obtain the constraints on warp factor to have the model observationally viable. The values of warp factor might be important in understanding warped geometries and also in string phenomenology.

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