Erratum: Constraints on deviations from ΛCDM within Horndeski gravity

This content has been downloaded from IOPscience. Please scroll down to see the full text.

JCAP06(2016)E01
(http://iopscience.iop.org/1475-7516/2016/06/E01)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 163.1.203.59
This content was downloaded on 11/08/2017 at 14:48

Please note that terms and conditions apply.

You may also be interested in:

Cosmological perturbations in mimetic Horndeski gravity
Frederico Arroja, Nicola Bartolo, Purnendu Karmakar et al.

The two faces of mimetic Horndeski gravity: disformal transformations and Lagrange multiplier
Frederico Arroja, Nicola Bartolo, Purnendu Karmakar et al.

Constraints on deviations from CDM within Horndeski gravity
Emilio Bellini, Antonio J. Cuesta, Raul Jimenez et al.

Signatures of Horndeski gravity on the dark matter bispectrum
Emilio Bellini, Raul Jimenez and Licia Verde

The effective two-dimensional phase space of cosmological scalar fields
David C. Edwards

Attracted to de Sitter: cosmology of the linear Horndeski models
Prado Martin-Moruno, Nelson J. Nunes and Francisco S.N. Lobo

Disformal invariance of curvature perturbation
Hayato Motohashi and Jonathan White

Exploring gravitational theories beyond Horndeski
Jérôme Gleyzes, David Langlois, Federico Piazza et al.

Degenerate higher derivative theories beyond Horndeski: evading the Ostrogradski instability
David Langlois and Karim Noui
Erratum: Constraints on deviations from $\Lambda$CDM within Horndeski gravity

Emilio Bellini, Antonio J. Cuesta, Raul Jimenez and Licia Verde

Erratum to: JCAP02(2016)053

ArXiv ePrint: 1509.07816

doi:10.1088/1475-7516/2016/06/E01
In the paper “Constraints on deviations from ΛCDM within Horndeski gravity” some of the runs were done with standard numerical precision. However we have realised that with increased numerical precision some of the results change quantitatively but not qualitatively. The conclusions of the paper are unchanged. Here we report the plots and results for runs performed with increased precision. We include some discussion only when there are changes with respect to the published paper, indicating the relative section.

To understand why we need an increased precision, it is important to note that in general Dark Energy/Modified gravity models the additional degree of freedom may have a non-trivial dynamics. Indeed, we noticed that the perturbations of the scalar field can have rapid oscillations that potentially affect the observable properties of the universe. These rapid oscillations occur especially on large-scales, i.e. on scales that crossed the cosmological horizon only recently, and they have a timescale that is shorter than any other cosmological timescale. The precision parameters used in the standard CLASS (the ones we used in the previous version of the paper) have been tuned to correctly integrate the evolution of the perturbations assuming the usual timescales of a ΛCDM universe. Then, the general idea of this improvement is to modify the precision parameters that regulate the integration step of the perturbations, together with some other parameter that increases the accuracy of the results on large scales. For completeness, we report the list of all the parameters we modified together with the new value we gave (default values are reported in parenthesis):

- **perturb_sampling_stepsize** = 0.05 (0.10). Factor multiplied by the smallest timescale of the universe to get the integration step;

- **start_small_k_at_tau_c_over_tau_h** = 1e-4 (0.0015). Factor that ensures that the largest wavelengths start being sampled when the universe is sufficiently opaque. Decrease to start earlier in time;

- **start_large_k_at_tau_h_over_tau_k** = 1e-4 (0.07). Factor that ensures that the largest wavelengths start being sampled when the mode is sufficiently outside the Hubble scale. Decrease to start earlier in time;

- **l_logstep** = 1.045 (1.12). Maximum spacing of values of ℓ over which Bessel and transfer functions are sampled (so, spacing becomes linear instead of logarithmic at some point);

- **l_linstep** = 50 (40). Factor for logarithmic spacing of values of ℓ over which Bessel and transfer functions are sampled.

We also checked that a further improvement of these precision parameter does not affect the final result. For future works, we recommend the users of **hi_class** to use the new precision parameters and not the default ones implemented in CLASS. In the public release of **hi_class** [1] the default precision parameters have been modified to match this improved version.

**In section 3 discussion of table 5.** The MCMC procedure is not optimised to find the best fit model which maximises the likelihood, therefore there is an intrinsic error associated to these numbers which have been estimated to be ∼ 0.7 [2]. Compared to the ΛCDM model, we find that the improvement on the fitting of cosmological data due to the extra degrees of freedom provided by the Horndeski parameters is not significant in most of the cases. A possible exception is the inclusion of RSD where the improvement is log likelihood ≳ 4 but
at the “cost” of three extra degrees of freedom. This suggests that the deviations found in our datasets are still consistent with a fluctuation within the ΛCDM scenario, even though (remarkably) the posterior distributions of MG coefficients presented in table 4 are not always consistent with zero. We have checked that the effect of the RSD is not driven by the data point with the smallest error-bars (the BOSS measurement at z = 0.57; 8th entry in table 3).

In section 3 discussion about table 6. In table 6 we report the Bayes factor of the ΛCDM to MG models computed following [2]; we use a slightly modified version of the Jeffrey’s scale to interpret the evidence ratios. The Bayes factor favours the simpler, ΛCDM, model or does not decide between the two cases but in no case prefers the more complex model.
Table 5. Absolute value of the log likelihoods (i.e. $\chi^2/2$) at the best fit point from the individual data that comprises each dataset combination explored in our analysis. The column labelled Total displays the maximum likelihood value in the chain. The last column shows the difference in Log likelihood with respect to the $\Lambda$CDM model. Red (negative) numbers represent worst fit, positive (black) numbers better fit. Given the intrinsic uncertainty of the MCMC in determining the best likelihood value, the improvement in $\chi^2$ offered by the more complex model is in most cases not significant.

| Dataset combination | Evidence ratio $\ln \left( \frac{E_{\Lambda CDM}}{E_H} \right)$ | interpretation |
|---------------------|-------------------------------------------------|----------------|
| CMB                 | 1.48                                            | substantial   |
| CMB+BAO             | -0.21                                           | not significant|
| CMB+RSD             | 0.64                                            | not significant|
| CMB+PK              | 1.13                                            | substantial   |
| CMB+BAO+RSD+PK      | 0.09                                            | not significant|

Table 6. The Savage-Dickey Density Ratio for the $\Lambda$CDM + GR model with respect to the Modified Gravity models studied here. We have considered the case $c_K = 0$.

**In section 3 discussion about figure 4.** The revised constraints on the $c_T$ parameter turn out to be slightly more constraining, which has some implications for the toy model discussed in this section. Whereas the $n = 1/3$ value was marginally inside the 99.7% C.L. region, now this is no longer true, although by a small margin. This would imply that all three cases we studied for this toy model are put under pressure by current cosmological data.
Figure 2. CMB temperature power spectra, matter power spectra, and structure growth for ΛCDM and MG best fit models. From top to bottom, we show these quantities when we fit only the CMB, CMB+BAO, CMB+RSD, CMB+PK, and CMB+BAO+RSD+PK respectively. Vertical dashed lines correspond to the braiding scale $k_B(z = 0)$ for each particular model and dataset combination.
Figure 3. Constraints on $c_B$, $c_M$, $c_T$ and $M_2^*$ from the combination of CMB+BAO+RSD+PK datasets.

Table 7. Constraints on the coefficients $c_B$, $c_M$, and $c_T$ from different cosmological dataset combinations and for different values of $c_K$. Quoted limits are 99.73% CL. A hard prior on $c_T > -0.9$ is applied.
Figure 4. Correlations between the coefficients $c_B$, $c_M$, and $c_T$. Contours are shown for 68.3%, 95.4%, and 99.7% CL. The symbols correspond to different values for the parameters of the model of ref. [3, 4] as discussed in the text. The three points in the left two panels correspond to (from left to right) $n = 1/3$, $n = 2/3$, $n = 1$. In the right panel the three models overlap.

References

[1] M. Zumalacárregui, E. Bellini, I. Sawicki and J. Lesgourgues, *Horndeski in the cosmic linear anisotropy solving system*, arXiv:1605.06102 [SPIRE].

[2] L. Verde, S.M. Feeney, D.J. Mortlock and H.V. Peiris, *(Lack of) cosmological evidence for dark radiation after Planck*, *JCAP* 09 (2013) 013 [arXiv:1307.2904] [SPIRE].

[3] C. Deffayet, O. Pujolàs, I. Sawicki and A. Vikman, *Imperfect dark energy from kinetic gravity braiding*, *JCAP* 10 (2010) 026 [arXiv:1008.0048] [SPIRE].

[4] O. Pujolàs, I. Sawicki and A. Vikman, *The imperfect fluid behind kinetic gravity braiding*, *JHEP* 11 (2011) 156 [arXiv:1103.5360] [SPIRE].