Cosmological constraints on $f(Q)$-gravity

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RESEARCH TOPIC

We study observational constraints on the non-metricity $f(Q)$-gravity which reproduces an exact ΛCDM background expansion history while modifying the evolution of linear perturbations. To this purpose we use Cosmic Microwave Background (CMB) radiation, baryonic acoustic oscillations (BAO), redshift-space distortions (RSD), supernovae type Ia (SNIa), galaxy clustering (GC) and weak gravitational lensing (WL) measurements. We set stringent constraints on the parameter of the model controlling the modifications to the gravitational interaction at linear perturbation level. We find the model to be statistically preferred by data over the ΛCDM according to the χ^2 and deviance information criterion statistics for the combination with CMB, BAO, RSD and SNIa. This is mostly associated to a better fit to the low-ℓ tail of CMB temperature anisotropies.

MOTIVATION

- Understand the true nature of the cosmic acceleration;
- Test the standard cosmological model (ΛCDM)
- Test deviations from ΛCDM: Modified Gravity

THE MODEL

$f(Q)$-gravity is an extension of the Symmetric Teleparallel General Relativity, with action

$$S = \int d^4x\sqrt{-g}\left\{-\frac{1}{2\kappa^2}\left[Q + f(Q)\right] + \mathcal{L}_m(g_{\mu\nu}, \chi_i)\right\}, \qquad (1)$$

where g is the determinant of the metric $g_{\mu\nu}$, $\kappa^2 = 8\pi G_N$ with G_N being the Newtonian constant, Q is the non-metricity scalar and $\mathcal{L}_m$ being the matter action.

We specialise to

$$f(Q) = \alpha H_0\sqrt{Q} + 6H_0^2\Omega_\Lambda, \qquad (2)$$

where α is a dimensionless constant, H_0 is the present day value of the Hubble parameter and Ω_Λ is the energy density parameter of the cosmological constant.

Features:

- same background evolution as in ΛCDM;
- different dynamics for the perturbations: the Poisson equation in Fourier space reads

$$-k^2\Psi = 4\pi\frac{G_N}{1+f_Q}a^2\rho_m\delta_m\,, \qquad (3)$$

where $\delta_m \equiv \delta\rho_m/\rho_m$ is the density contrast and Ψ is the gravitational potential.

The f_Q modifies the strength of the gravitational interaction towards an *effective gravitational coupling*:

$$\mu = \frac{1}{1+f_Q}, \qquad (4)$$

with $f_Q \equiv df/dQ$.

COSMOLOGICAL CONSTRAINTS

We use the following DATA SETS for the MCMC analysis: CMB data from Planck 2018 (PLK18), BAO data from 6dF Galaxy Survey and SDSS (DR7), DR7 Main Galaxy Sample from the Sloan Digital Sky Survey (SDSS), combined BAO and RSD datasets from the SDSS DR12, SNIa from the Joint Light-curve Array (JLA) and GC and WL measurements from DES-1Y.

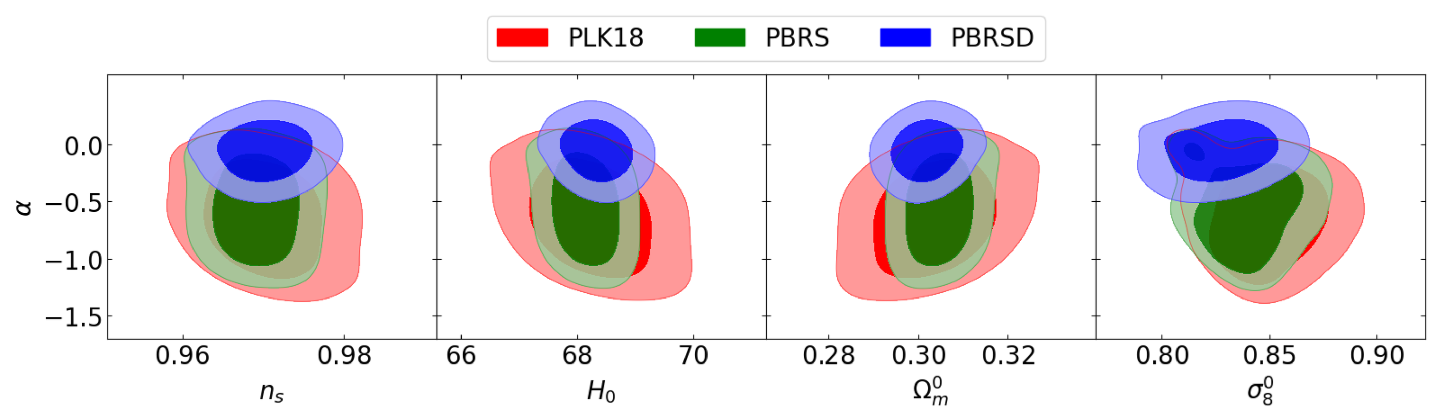
In these combinations:

- PLK18 (PLK18);
- PLK18+BAO+RSD+SNIa (PBRS);
- PLK18+BAO+RSD+SNIa+DES-1Y (PBRSD).

Marginalised constraints on cosmological and model parameters at 95% C.L. for the ΛCDM and $f(Q)$ models.

Model	α	n_s	H_0	Ω_m^0	σ_8^0
ΛCDM (PLK18)	-	0.97 ± 0.01	68.0 ± 1.4	0.31 ± 0.02	0.85 ± 0.04
ΛCDM (PBRS)	-	$0.970^{+0.008}_{-0.007}$	68.1 ± 0.80	0.30 ± 0.01	$0.843^{+0.032}_{-0.037}$
ΛCDM (PBRSD)	-	0.970 ± 0.008	$68.33^{+0.76}_{-0.77}$	$0.302^{+0.010}_{-0.0097}$	0.829 ± 0.031
$f(Q)$ (PLK18)	$-0.64^{+0.64}_{-0.60}$	0.97 ± 0.01	$68.3^{+1.5}_{-1.4}$	0.304 ± 0.019	$0.848^{+0.038}_{-0.037}$
$f(Q)$ (PBRS)	$-0.56^{+0.58}_{-0.57}$	$0.968^{+0.007}_{-0.008}$	$68.14^{+0.79}_{-0.84}$	$0.305^{+0.011}_{-0.010}$	$0.839^{+0.032}_{-0.031}$
$f(Q)$ (PBRSD)	$-0.05^{+0.34}_{-0.36}$	$0.970^{+0.008}_{-0.007}$	68.35 ± 0.80	0.302 ± 0.010	0.828 ± 0.032

Marginalised constraints at 68% (darker) and 95% (lighter) C.L. on the model parameter α and four cosmological parameters H_0, n_s, σ_8^0 and Ω_m^0.



Results:

- Cosmological parameters are consistent with the ΛCDM scenario;
- α is compatible among the datasets;
- Negative values of α are preferred because they suppress the large-scale temperature anisotropies accommodating better the CMB data.

MODEL SELECTION ANALYSIS

In order to quantify the preference of the $f(Q)$ model over the ΛCDM we computed the Deviance Information Criterion (DIC):

$$\text{DIC} := \chi^2_{\text{eff}} + 2p_{\text{D}}, \qquad (5)$$

where χ^2_{eff} is the value of the effective χ^2 corresponding to the maximum likelihood and $p_{\text{D}} = \overline{\chi}^2_{\text{eff}} - \chi^2_{\text{eff}}$, with the bar being the average of the posterior distribution.

Then we compute the difference:

$$\Delta\text{DIC} = \text{DIC}_{\text{f(Q)}} - \text{DIC}_{\Lambda\text{CDM}}\,, \qquad (6)$$

which will indicate a preference for the $f(Q)$ model over the ΛCDM scenario if $\Delta\text{DIC} < 0$.

Results for the $\Delta\chi^2_{\text{eff}}$ and ΔDIC:

Data	$\Delta\chi^2_{\text{eff}}$	ΔDIC
PLK18	-3.3820	-4.4739
PBRS	-2.9040	-3.1317
PBRSD	-2.3040	4.8203

Results:

- Lower χ^2_{eff} for the $f(Q)$ model $\rightarrow$ $f(Q)$-gravity fits the data better than ΛCDM;
- The fQ model is preferred over the ΛCDM for PLK18 and PBRS;
- For DES the DIC prefers the ΛCDM because DES data leads to a larger mean value for α in order to have a lower σ_8^0, thus degrading the better fit to the low-ℓ tail of the TT power spectrum.

CONCLUSION

- The $f(Q)$ model can fit better the data compared to ΛCDM (lower χ^2):
  - ability of the model to lower the ISW tail;
- The DIC favors the $f(Q)$-model over ΛCDM;
- $f(Q)$-model is among the challenging candidates to the ΛCDM scenario.

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