$f(Q)$-gravity and neutrino physics

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RESEARCH TOPIC

Within the $f(Q)$-gravity framework we perform a phenomenological study of the cosmological observables in light of the degeneracy between neutrinos physics and the modified gravity parameter and we identify specific patterns which allow to break such degeneracy. We also provide separately constraints on the total mass of the neutrinos, Σm_ν, and on the effective number of neutrino species, $N_{\rm eff}$, using cosmic microwave background (CMB), baryon acoustic oscillation (BAO), redshift space distortion (RSD), supernovae (SNIa), galaxy clustering (GC) and weak gravitational lensing (WL) measurements. We find that all combinations of data we consider, prefer a stronger gravitational interaction than ΛCDM. Finally, we consider the χ^2 and deviance information criterion statistics and find the $f(Q)+\Sigma m_\nu$ model to be statistically supported by data over the standard scenario. On the contrary $f(Q)+N_{\rm eff}$ is supported by CMB+BAO+RSD+SNIa but a moderate evidence against it is found with GC and WL data.

MOTIVATION

- Understand the true nature of the cosmic acceleration;
- Test the degeneracy between modified gravity and neutrino physics;
- Constrain the properties of neutrinos for $f(Q)$-gravity.

THE MODEL

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

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

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 L_m being the matter action.

We specialise to

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

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

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

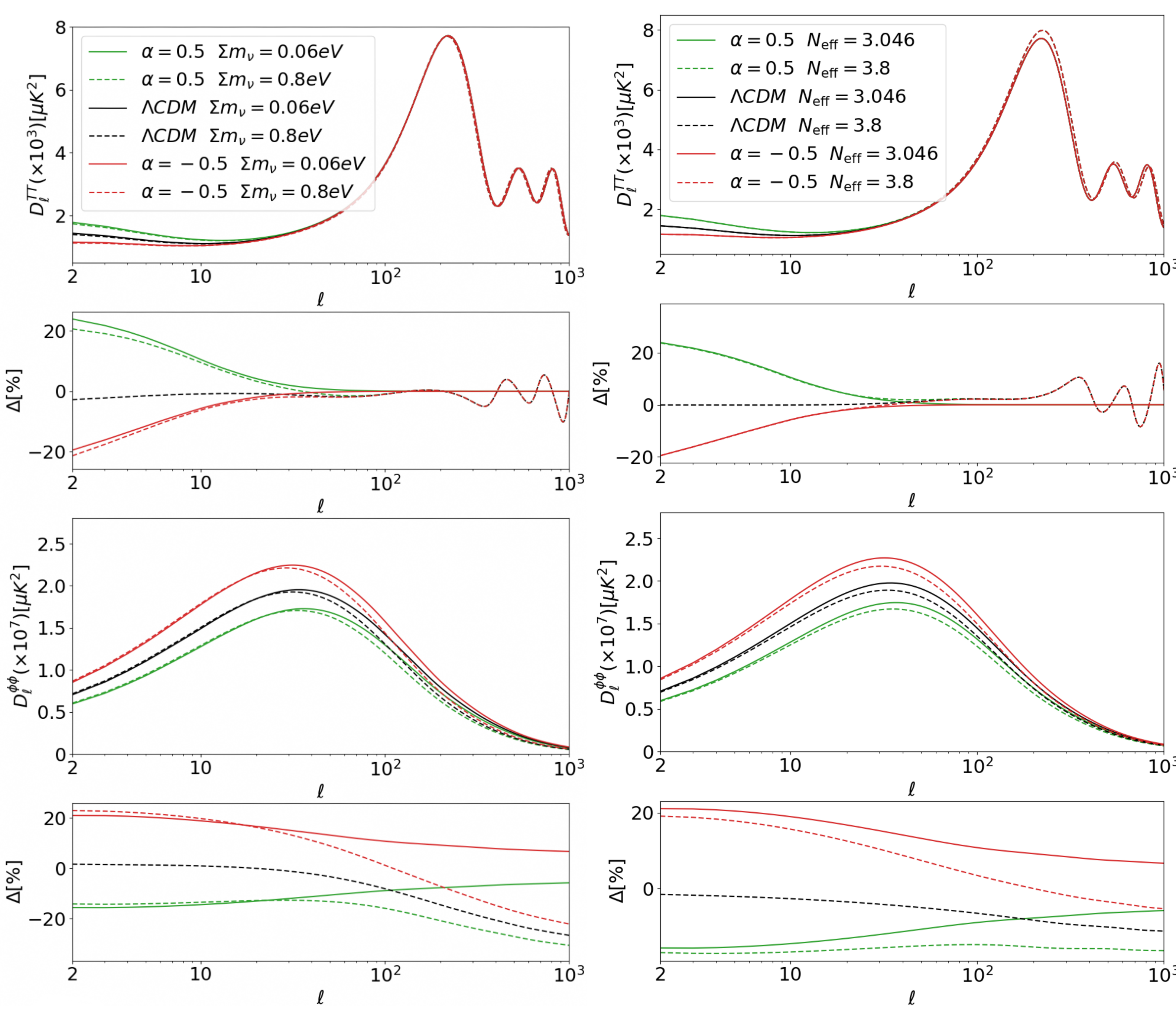
where $\delta_m \equiv \delta\rho_m/\rho_m$ is the density contrast and Ψ is the gravitational potential.
The f_Q modifies the strength of the gravitational interaction towards an e *ective gravitational coupling*:

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

with $f_Q \equiv df/dQ$.

DEGENERACY

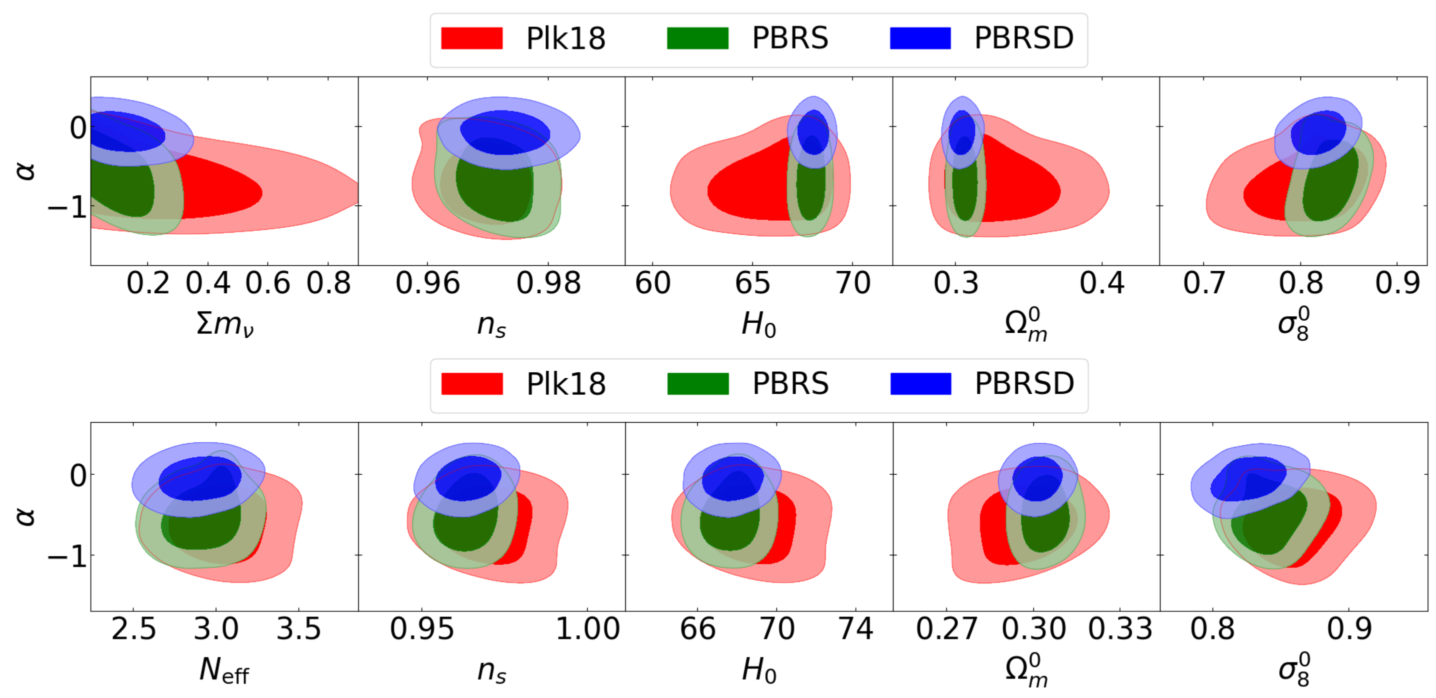
- There are degeneracy effects between α and Σm_ν, but we also have patterns that can allow us to break the degeneracies;
- The degeneracy between MG and $N_{\rm eff}$ is less relevant than the one identified for the case of Σm_ν.



COSMOLOGICAL CONSTRAINTS

We use the following combinations of DATA SETS for the MCMC analysis:
- PLK18 (PLK18);
- PLK18+BAO+RSD+SNIa (PBRS);
- PLK18+BAO+RSD+SNIa+DES-1Y (PBRSD).

Marginalised constraints at 68% (darker) and 95% (lighter) C.L. on the model parameter α and five cosmological parameters H_0, n_s, σ_8^0, Ω_m^0 as well as Σm_ν and N_{eff} according to each case.



Results:
- Cosmological parameters are consistent with the ΛCDM scenario;
- α is compatible among the datasets;
- The degeneracy with Neutrinos allow lower values of α, which 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):

$$\mathrm{DIC} := \chi^2_{\rm eff} + 2p_{\rm D}, \quad (5)$$

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

Then we compute the difference:

$$\Delta\mathrm{DIC} = \mathrm{DIC}_{\rm f(Q)} - \mathrm{DIC}_{\Lambda\rm CDM}\,, \quad (6)$$

which will indicate a preference for the $f(Q)$ model over the ΛCDM scenario if ΔDIC < 0.

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

Varying massive neutrinos			Varying $N_{\rm eff}$		
Data	$\Delta\chi^2$	ΔDIC	Data	$\Delta\chi^2$	ΔDIC
Plk18	-2.284	-6.547	Plk18	-5.282	-1.975
PBRS	-2.938	-3.987	PBRS	-3.204	-3.153
PBRSD	-2.470	0.732	PBRSD	-2.468	4.985

Results:
- Lower $\chi^2_{\rm eff}$ for the $f(Q)$ model $\Rightarrow$ $f(Q)$-gravity fits the data better than ΛCDM;
- The $f(Q)$ model is preferred over the ΛCDM for PLK18 and PBRS;
- For DES in the case of Varying $N_{\rm eff}$ 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.
- For the case varying massive neutrinos with DES there is No evidence in support or against $f(Q)$

CONCLUSION

- It exist degeneracy and the one between MG and Σm_ν is more relevant than the one present with N_{eff}
- 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; (except when DES is include and N_{eff} is varying)
- $f(Q)$-model is among the challenging candidates to the ΛCDM scenario.

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