

Inverse non-metricity in $f(Q)$ gravity: cosmology and observational constraints

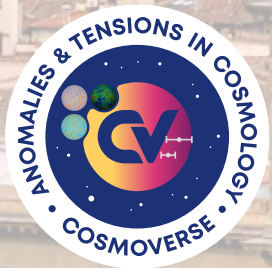
Simão Marques Nunes

Luís Atayde

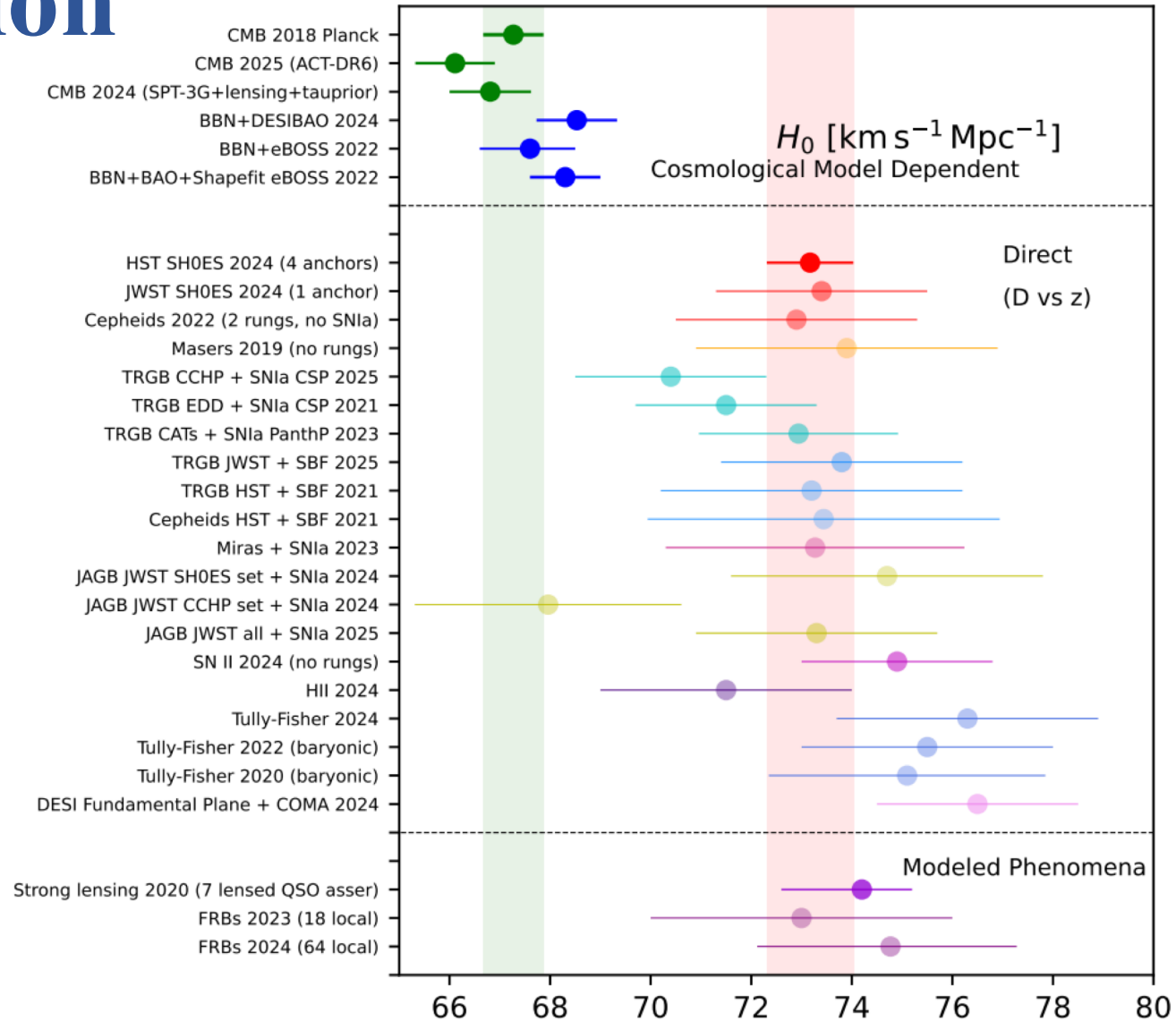
Noemi Frusciante



GGI workshop: Exploring New Frontiers in Cosmology – Week 1
Student Talks

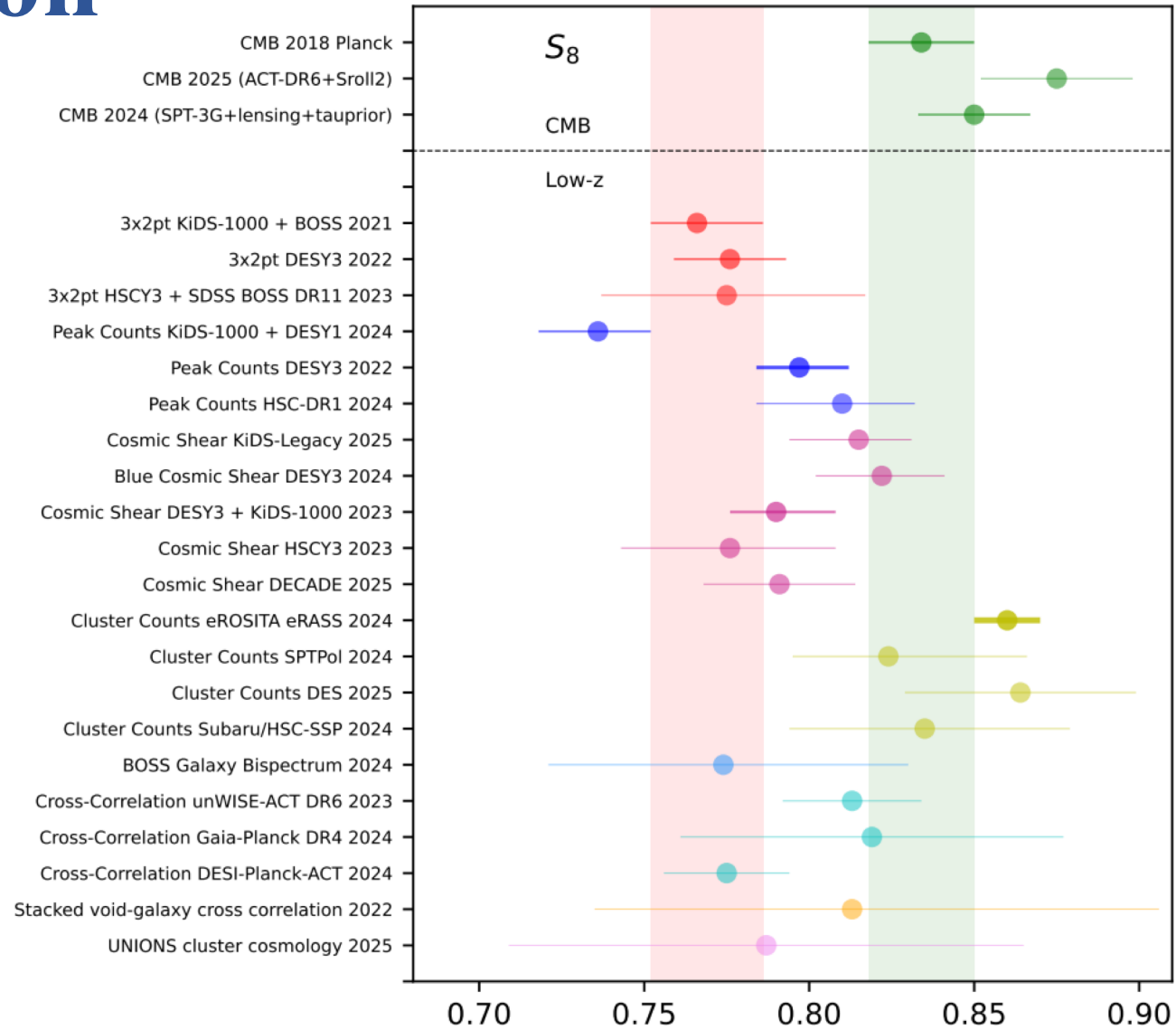


H_0 tension



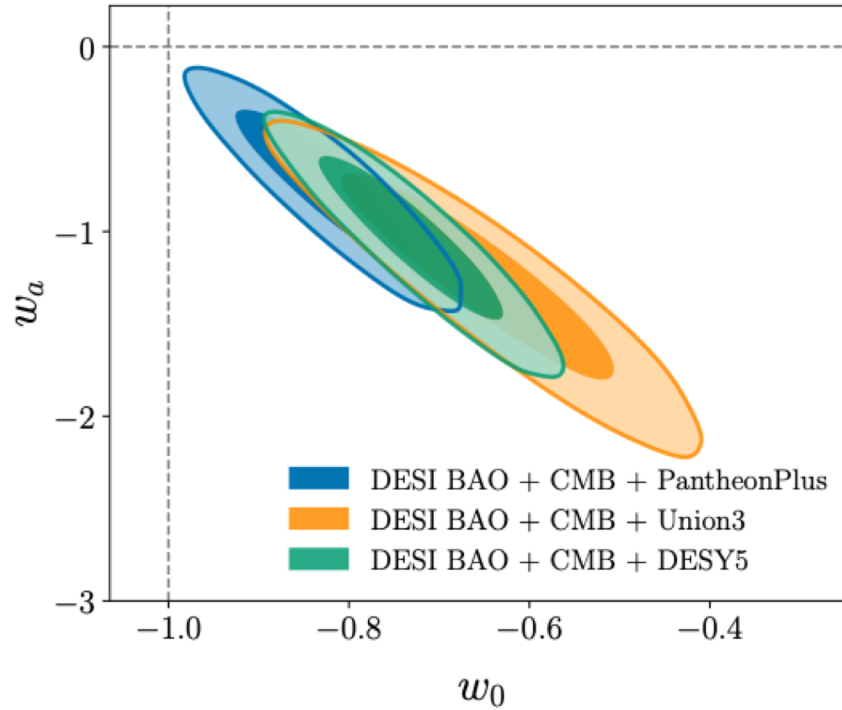
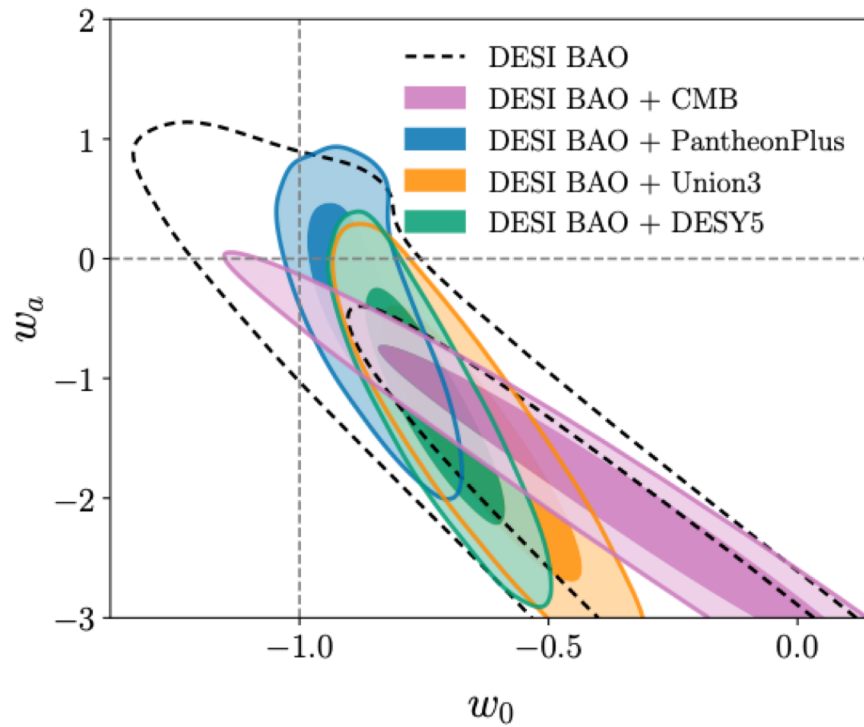
CosmoVerse White Paper 2025

S_8 tension



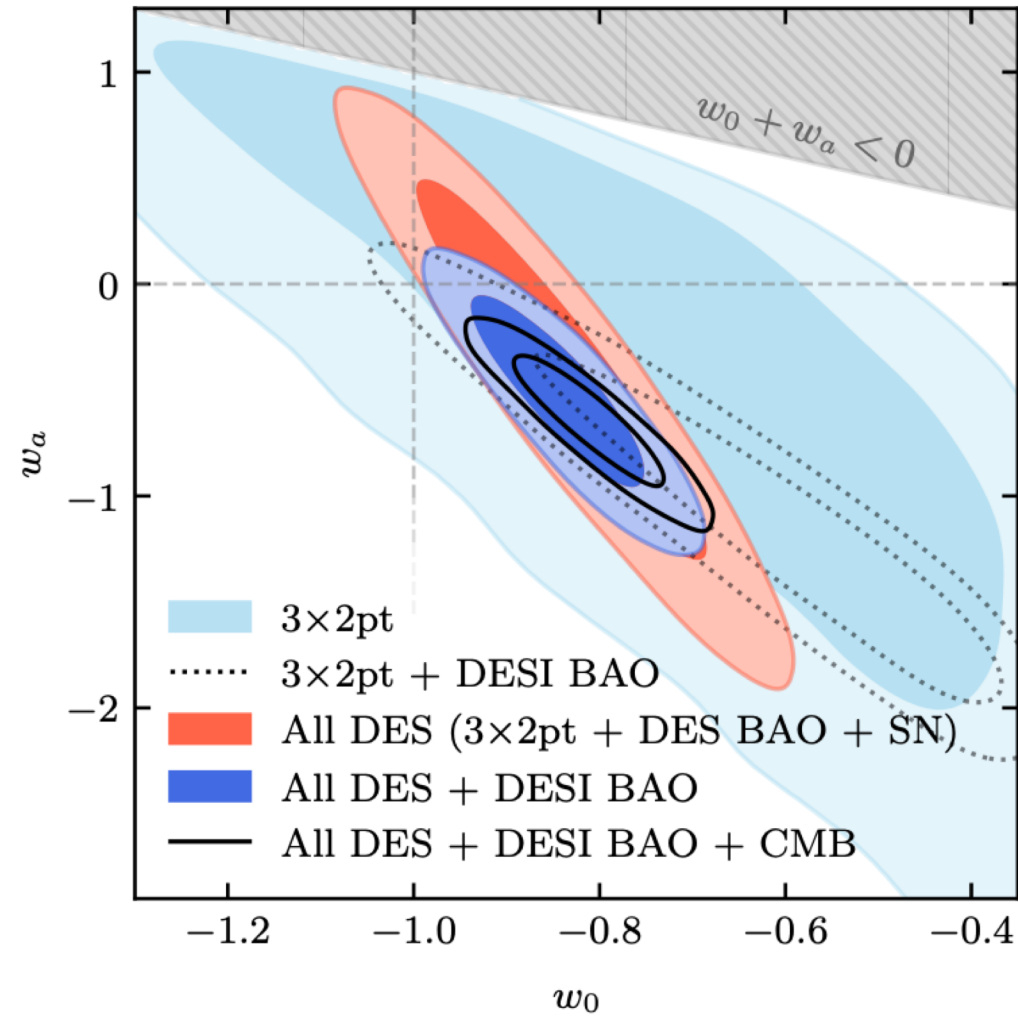
CosmoVerse White Paper 2025

Dynamical dark energy



DESI Collaboration Adame et al. 2024

Dynamical dark energy



DES Collaboration Abbott. et al 2026

Modified Gravity

Beyond metricity



Credit: Tiago B. Gonçalves

$f(Q)$ gravity

Action

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

with $\kappa^2 = 8\pi G_N/c^4$ and $Q_{\alpha\mu\nu} \equiv \nabla_\alpha g_{\mu\nu}$

Selected $f(Q)$ form

$$f(Q) = Q + \frac{M^4}{Q}$$

with $M^4 = 12 \Omega_Q^0 H_0^4$

J. Beltrán Jiménez et al. 2020

Neutrino bounds

Massive neutrinos imprint distinctive signatures in the CMB and in late-time LSS that can partially overlap with, and therefore be degenerate with, the effect induced by MG.

Because several MG scenarios can alter the expansion history and the growth/lensing sector in ways that partially mimic (or compensate) neutrino mass effects, the inferred bounds on Σm_ν are model dependent.

$$\Lambda\text{CDM} + \Sigma m_\nu \longrightarrow \Sigma m_\nu \lesssim 0.12 \text{ eV (95\% C.L.)} \quad \textit{Planck 2018 CMB + BAO}$$

N. Aghanim et al. (Planck) 2020

$$\Lambda\text{CDM} + \Sigma m_\nu \longrightarrow \Sigma m_\nu \lesssim 0.14 \text{ eV (95\% C.L.)} \quad \textit{DESY6 3x2pt with CMB and DESI DR2 BAO, DES SNIa and SPT clusters}$$

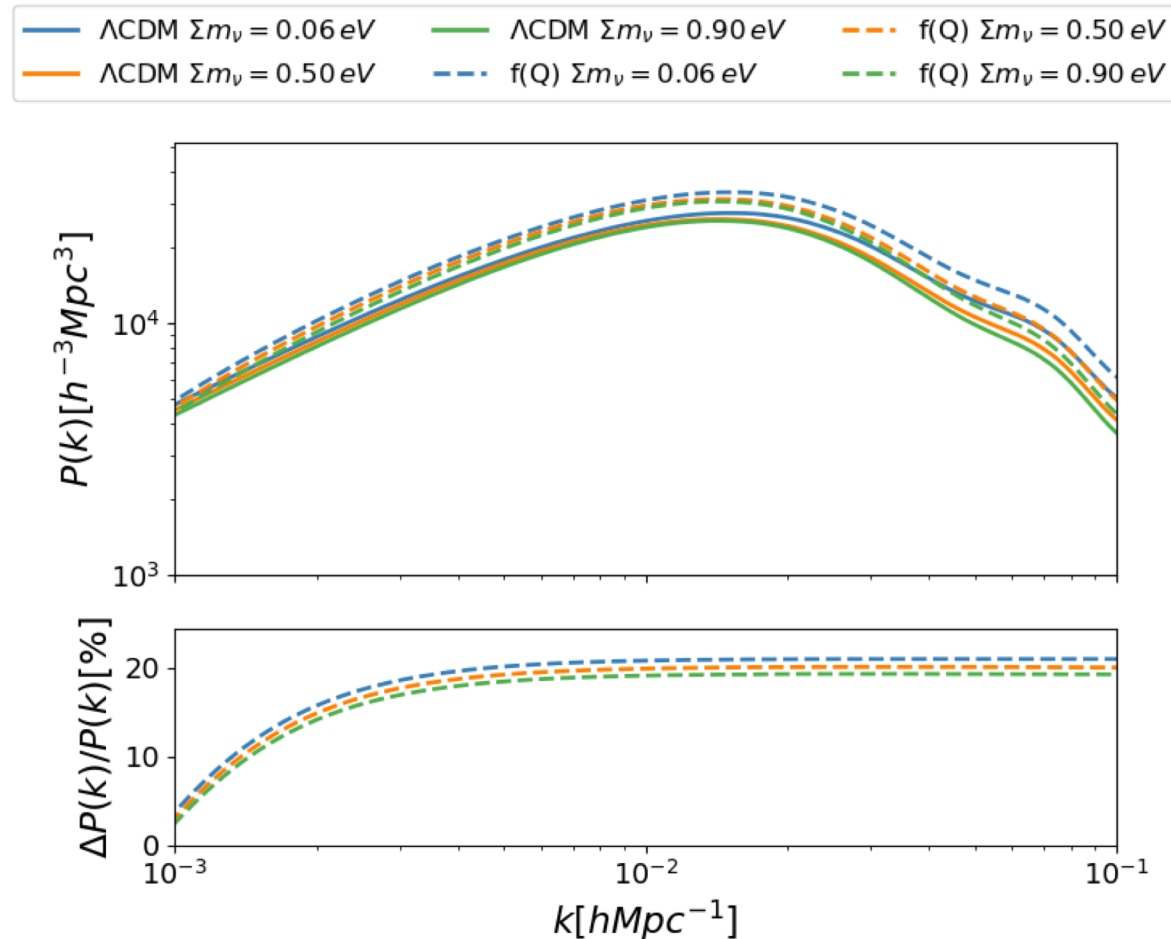
T. M. C. Abbott et al. (DES) 2026

$$f(Q) \text{ gravity}^* \longrightarrow \Sigma m_\nu < 0.277 \text{ eV (95\% C.L.)} \quad \text{CMB, BAO, RSD and SNIa}$$

L. Atayde and N. Frusciante (2023)

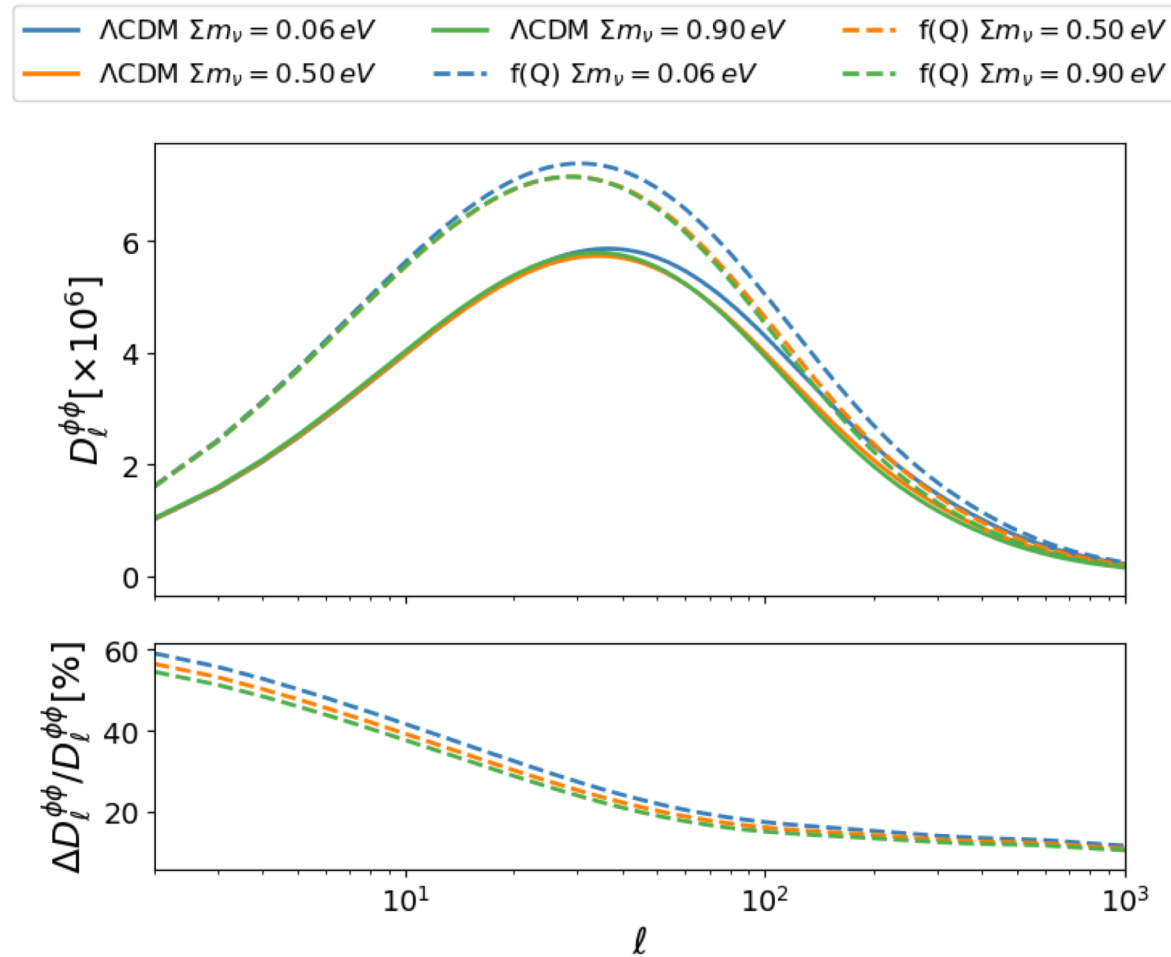
Effects on cosmological power spectra

Matter power spectra



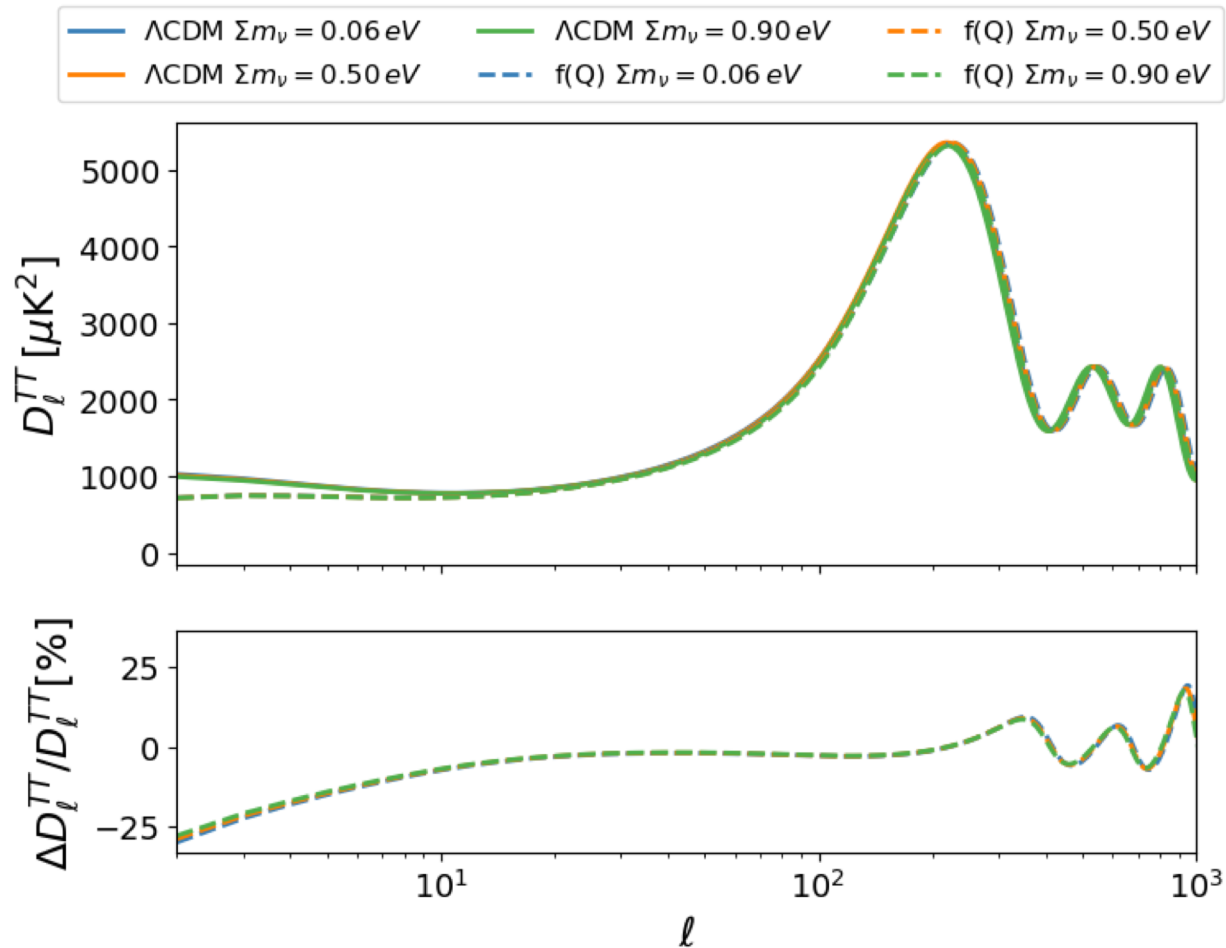
Effects on cosmological power spectra

Lensing angular power spectra

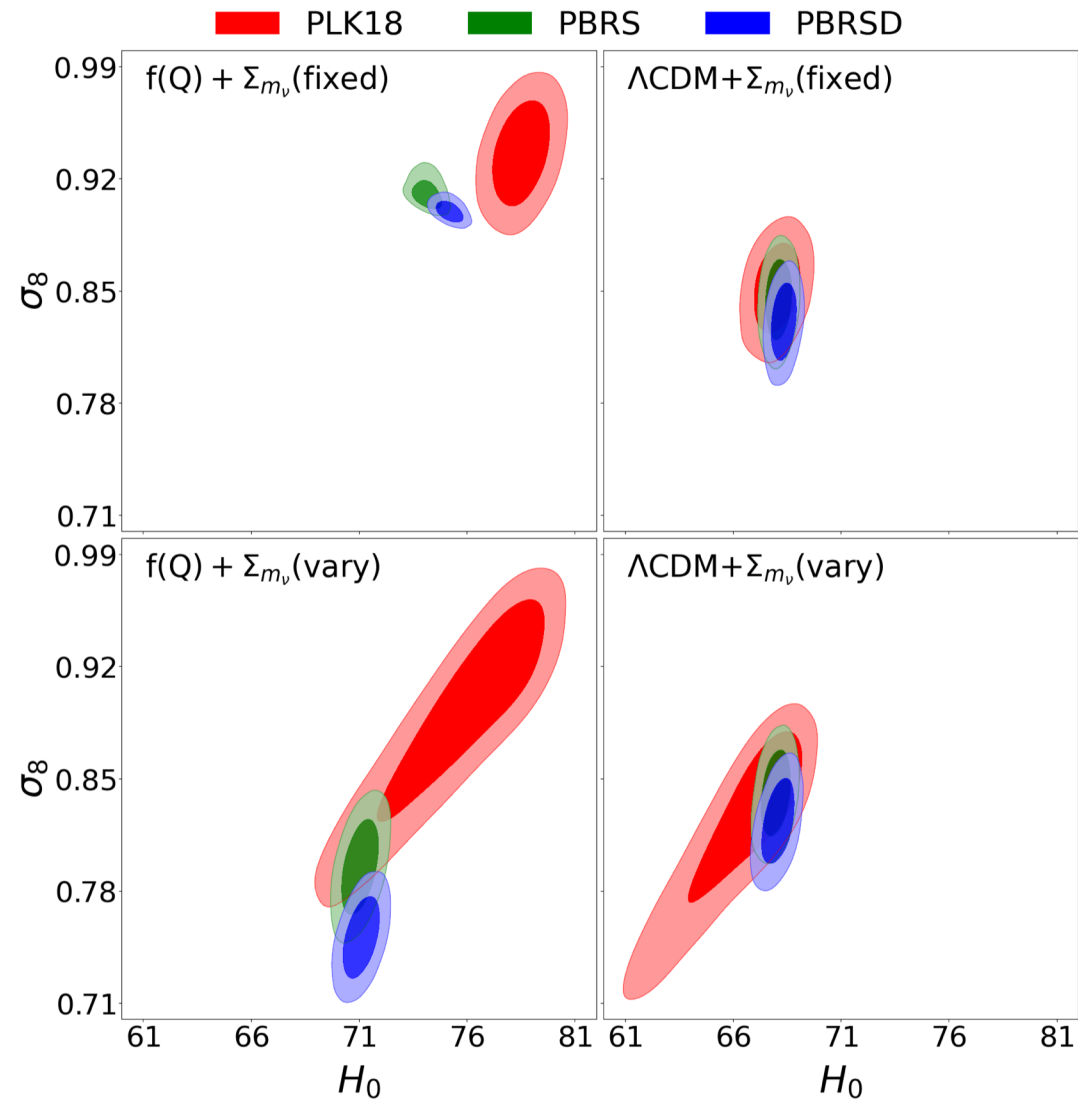


Effects on cosmological power spectra

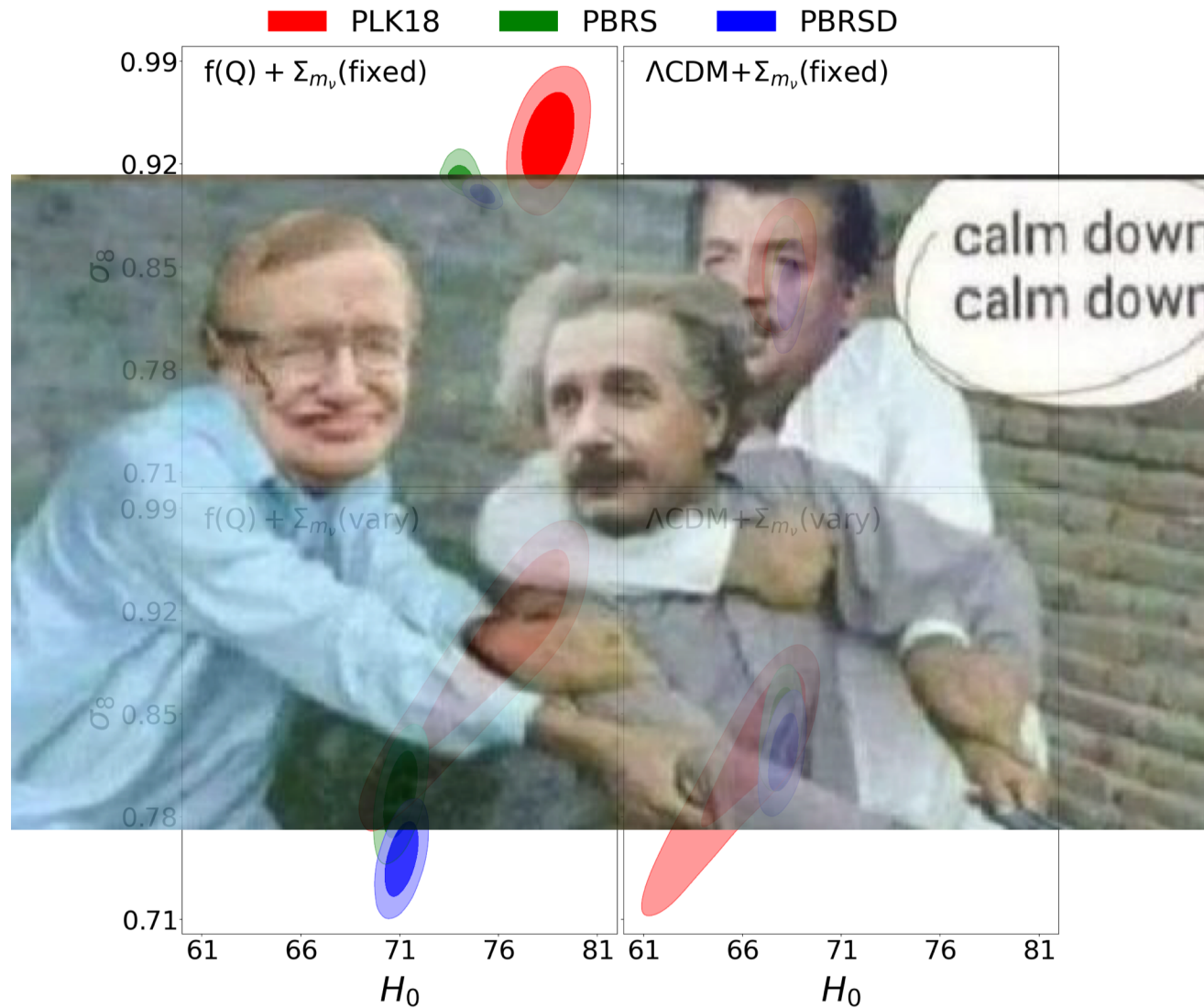
CMB TT angular power spectra



Cosmological constraints



Cosmological constraints



Cosmological constraints

Vary Σm_ν

DATASET	n_s	H_0	Ω_m^0	σ_8^0	Σm_ν
Λ CDM					
PLK18	0.97 ± 0.01	$66.6^{+2.9}_{-4.1}$	$0.325^{+0.054}_{-0.038}$	$0.823^{+0.064}_{-0.080}$	< 0.622
PBRS	0.970 ± 0.008	$67.97^{+0.87}_{-0.91}$	0.306 ± 0.011	0.839 ± 0.035	< 0.219
PBRSD	$0.973^{+0.010}_{-0.0093}$	$68.08^{+0.93}_{-1.0}$	$0.304^{+0.012}_{-0.011}$	$0.822^{+0.035}_{-0.034}$	< 0.277
$f(Q)$ -inverse power					
PLK18	0.97 ± 0.01	$75.9^{+4.1}_{-5.3}$	$0.251^{+0.047}_{-0.035}$	$0.893^{+0.075}_{-0.092}$	< 0.686
PBRS	0.9681 ± 0.0095	$71.1^{+1.2}_{-1.11}$	0.294 ± 0.011	0.795 ± 0.038	0.71 ± 0.19
PBRSD	$0.9695^{+0.0091}_{-0.0086}$	71.1 ± 1.1	0.292 ± 0.011	0.751 ± 0.033	$0.77^{+0.18}_{-0.17}$

Cosmological constraints

Statistics	PLK18	PBRS	PBRSD
$\Delta\chi^2 = \chi^2_{f(Q)} - \chi^2_{\Lambda\text{CDM}}$	-3.96	84.48	124.98
$\Delta\chi^2_{\Sigma m_\nu} = \chi^2_{f(Q)+\Sigma m_\nu} - \chi^2_{\Lambda\text{CDM}+\Sigma m_\nu}$	-2.47	33.64	45.22
$\Delta\chi^2 = \chi^2_{f(Q)+\Sigma m_\nu} - \chi^2_{f(Q)}$	0.55	-50.69	-79.71
$\Delta\text{DIC} = \text{DIC}_{f(Q)+\Sigma m_\nu} - \text{DIC}_{f(Q)}$	1.54	-50.85	-85.11

Conclusion

- We investigated the cosmology of an inverse nonmetricity model in symmetric teleparallel $f(Q)$ gravity. The model does not have extra parameters compared to Λ CDM.
- The model has several effects on cosmological spectra such as an enhanced matter and lensing power spectra and a suppressed ISW tail of the TT power spectra.
- By allowing the total neutrino mass Σm_ν to vary reveals an important degeneracy: neutrino free-streaming suppresses structure growth and can partially compensate the MG enhancement. This yields values closer to weak-lensing preferences, at the cost of preferring comparatively large neutrino masses.
- Despite its conceptual economy and parameter minimality, inverse $f(Q)$ gravity is highly sensitive to structure-growth and lensing measurements and it is generally not supported by data as a fully viable alternative to Λ CDM.
- Future data with improved control of late-time systematics and tighter neutrino-mass information will be particularly powerful in testing (or ruling out) this class of non-metricity models.

Thank you

Extra Slides

$f(Q)$ gravity

The function $f(Q)$ is an arbitrary function of the non-metricity scalar Q .

$$Q = -Q_{\alpha\mu\nu}P^{\alpha\mu\nu}$$

Coincidence gauge: $\Gamma_{\mu\nu}^{\alpha} = 0$

The tensor $P_{\mu\nu}^{\alpha}$ is given by:

$$P_{\mu\nu}^{\alpha} = -\frac{1}{2}L_{\mu\nu}^{\alpha} + \frac{1}{4}(Q^{\alpha} - \tilde{Q}^{\alpha})g_{\mu\nu} - \frac{1}{4}\delta_{(\mu}^{\alpha}Q_{\nu)}$$

where

$$L_{\mu\nu}^{\alpha} = \frac{1}{2}(Q_{\mu\nu}^{\alpha} - Q_{(\mu\nu)\alpha}); \quad Q_{\alpha} = g^{\mu\nu}Q_{\alpha\mu\nu}; \quad \tilde{Q}^{\alpha} = g^{\mu\nu}Q_{\mu\alpha\nu}.$$

Friedmann equations

For FLRW metric: $Q = 6H^2$

$$3H^2 = \kappa^2(\rho + \rho_Q) \quad \dot{H} = -\frac{\kappa^2}{2}(\rho + p + \rho_Q + p_Q)$$

$f(Q)$ gravity

$$f(Q) = Q + \frac{M^4}{Q}$$

Pressure and density equations

$$p_Q = -\frac{M^4}{12\kappa^2 H^2} \left(3 - 2 \frac{\dot{H}}{H^2} \right)$$

$$\rho_Q = \frac{M^4}{4\kappa^2 H^2}$$

Poisson equation

$$-\frac{k^2}{a^2} \Psi = \frac{\kappa^2}{2} \mu(a) \rho_m \delta_m$$

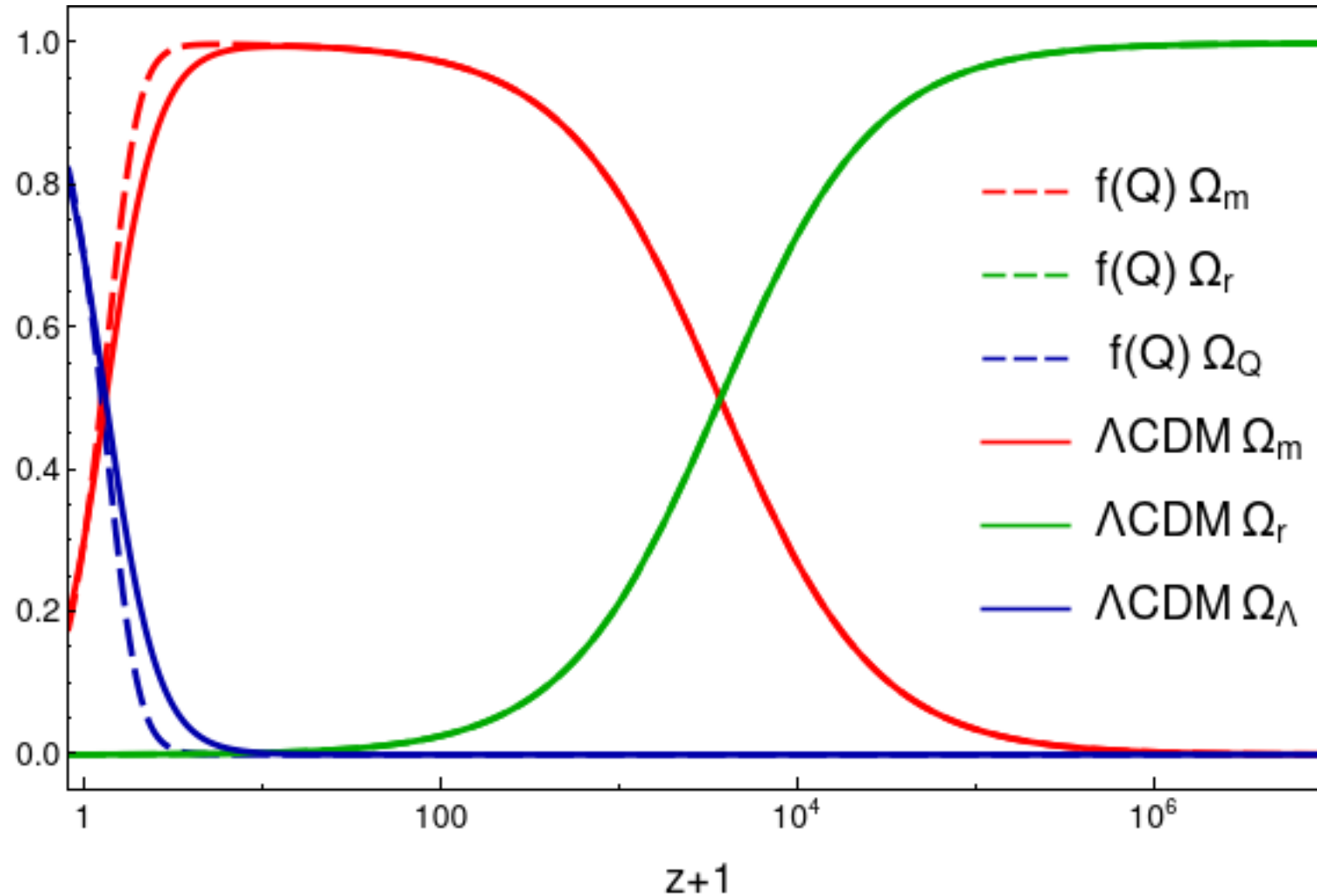
where

$$\mu(a) = \frac{1}{f_Q}$$

For the selected $f(Q)$ form

$$\mu(a) = \left[1 - \frac{\Omega_Q^0}{3} \left(\frac{H_0}{H(a)} \right)^4 \right]^{-1}$$

Evolution of Ω

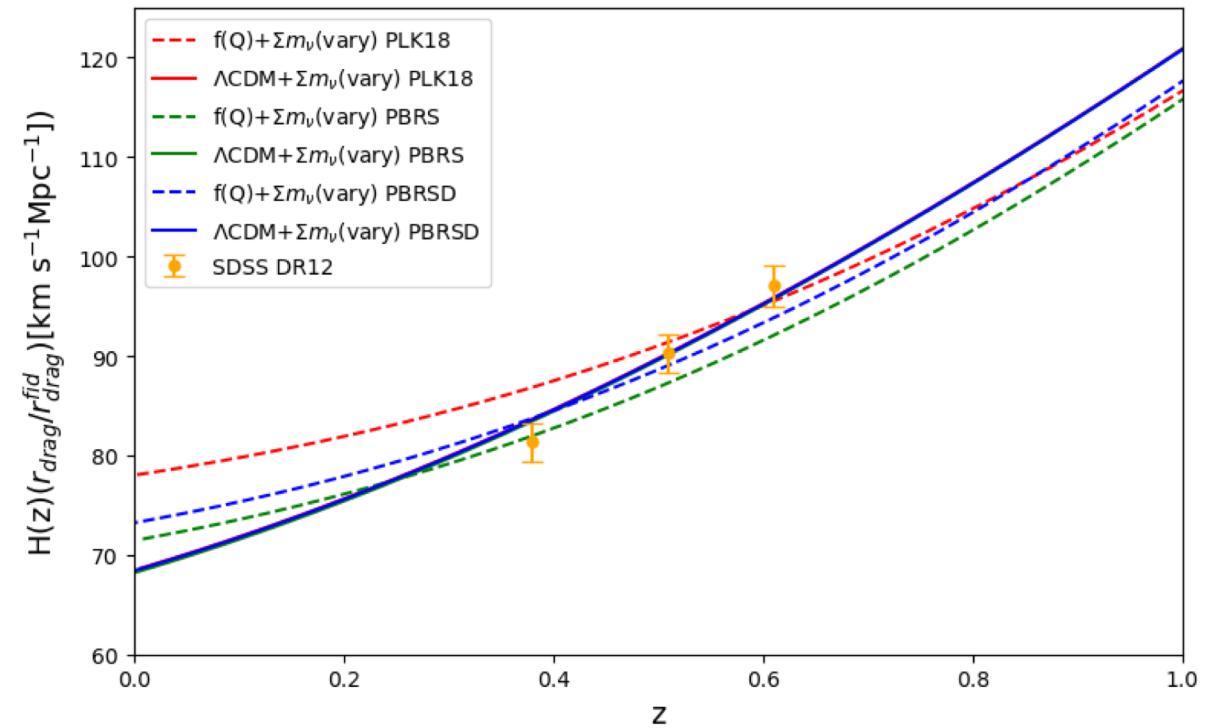
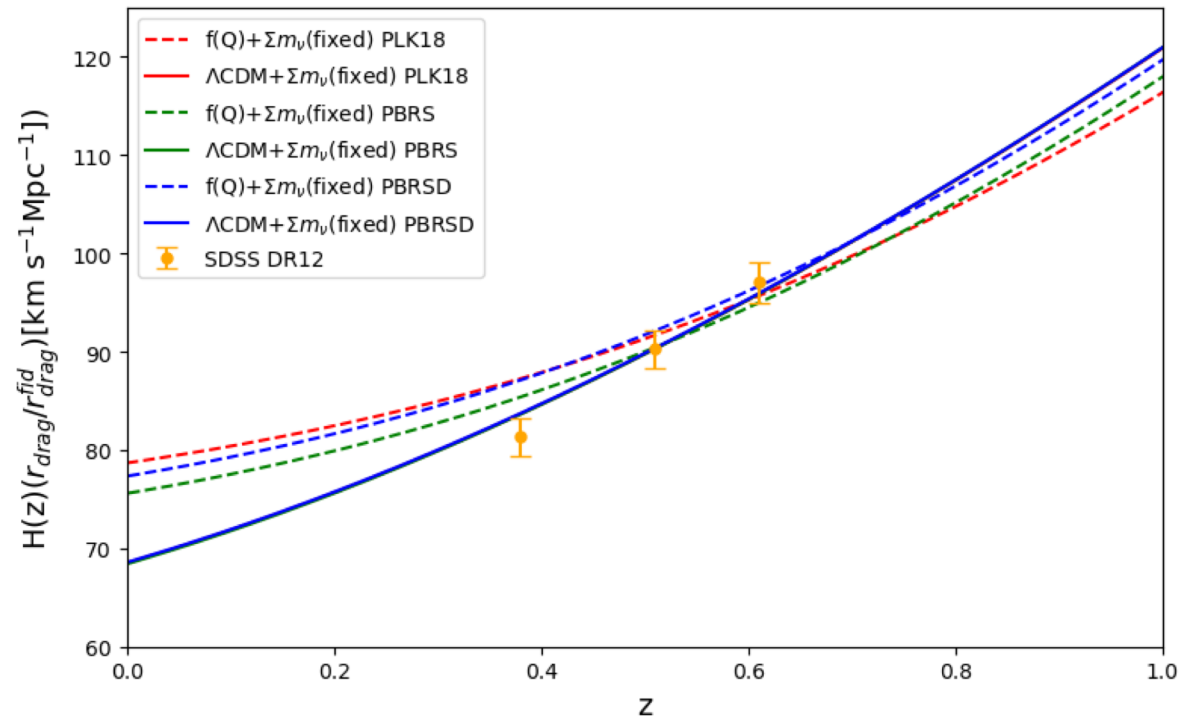


Cosmological constraints

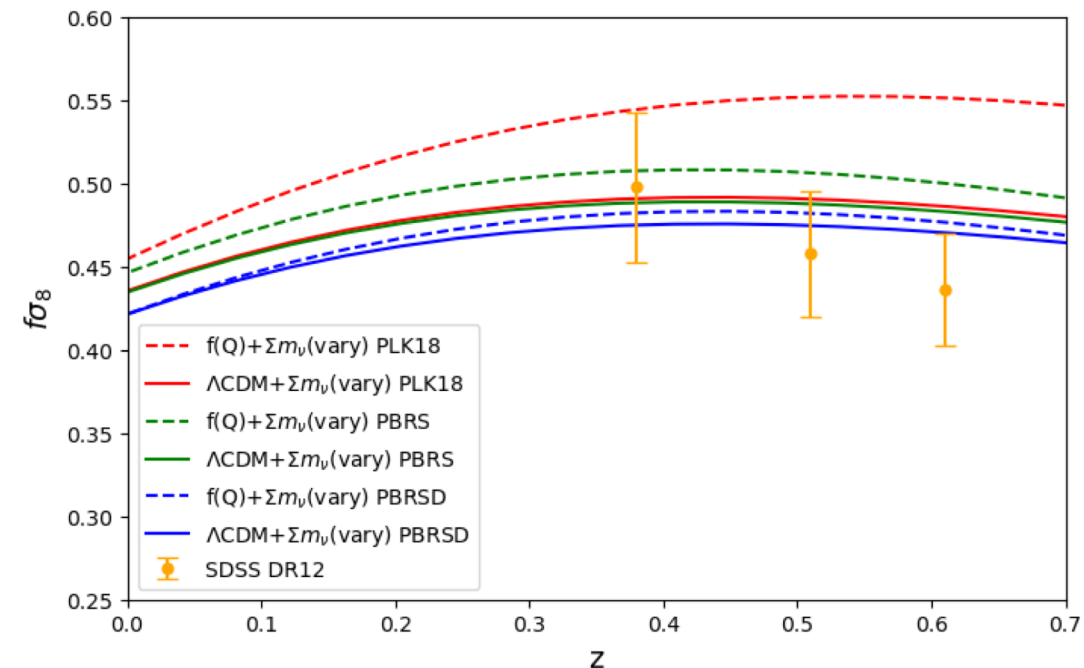
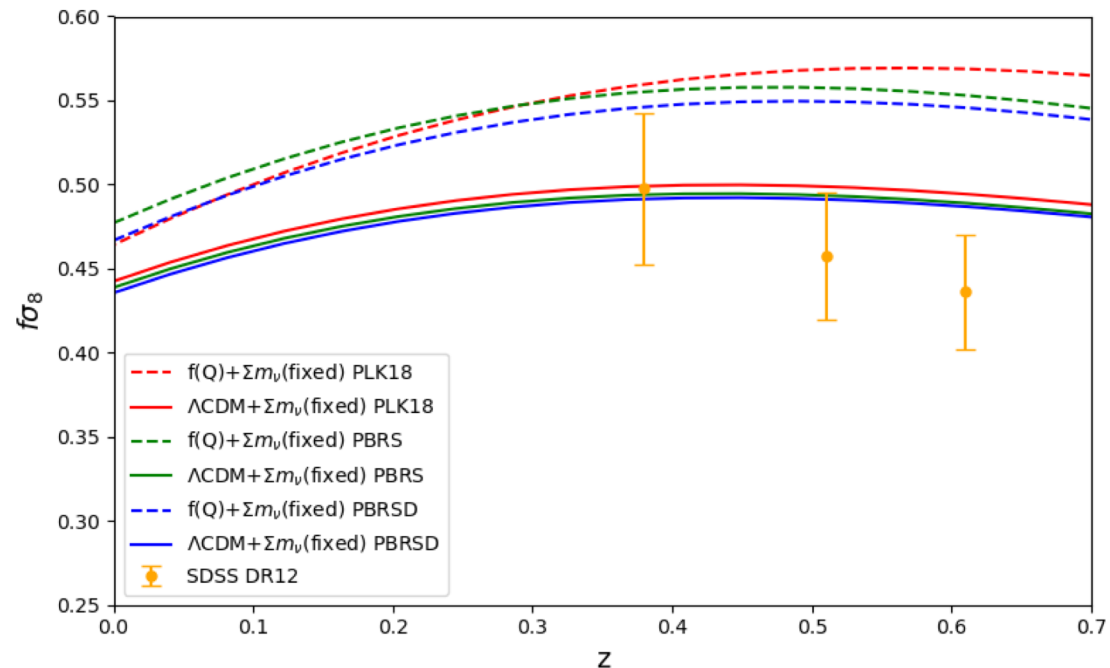
Fixed Σm_ν

DATASET	n_s	H_0	Ω_m^0	σ_8^0
Λ CDM				
PLK18	0.97 ± 0.01	68.0 ± 1.4	0.31 ± 0.02	0.85 ± 0.04
PBRS	$0.970^{+0.008}_{-0.007}$	68.1 ± 0.8	0.30 ± 0.01	$0.843^{+0.032}_{-0.037}$
PBRSD	0.970 ± 0.008	$68.17^{+0.77}_{-0.78}$	$0.304^{+0.010}_{-0.0098}$	$0.839^{+0.030}_{-0.033}$
$f(Q)$ -inverse power				
PLK18	0.97 ± 0.01	78.5 ± 1.7	$0.230^{+0.015}_{-0.014}$	$0.935^{+0.041}_{-0.040}$
PBRS	0.950 ± 0.007	74.18 ± 0.86	$0.2703^{+0.0089}_{-0.0087}$	$0.912^{+0.024}_{-0.014}$
PBRSD	0.954 ± 0.003	75.21 ± 0.41	0.2596 ± 0.0040	$0.9008^{+0.0031}_{-0.0061}$

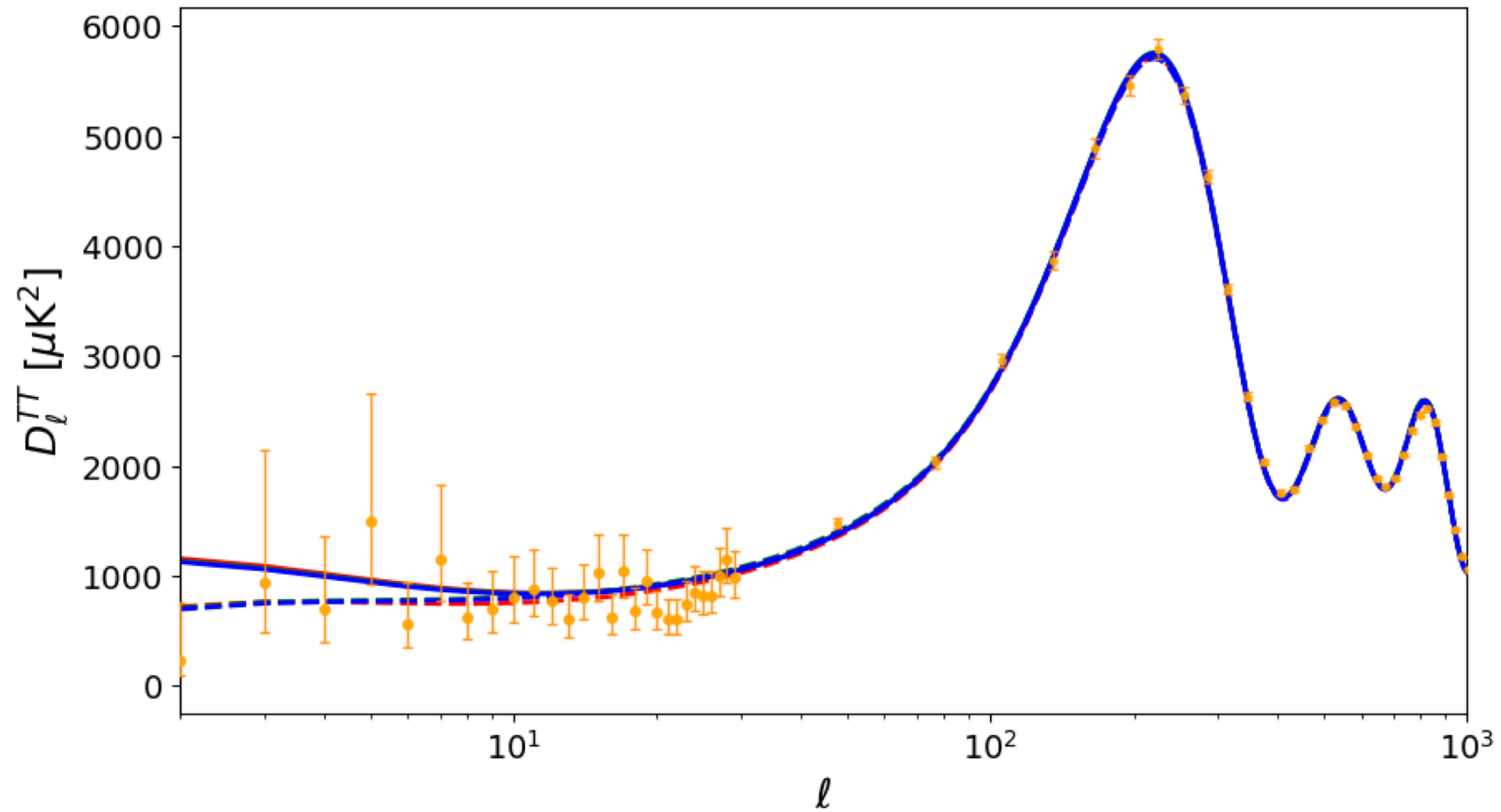
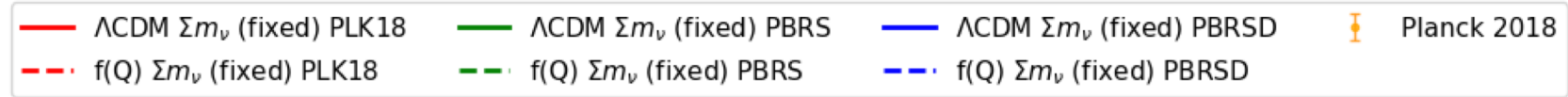
Cosmological constraints



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