Galileon Gravity

The observational status after Planck

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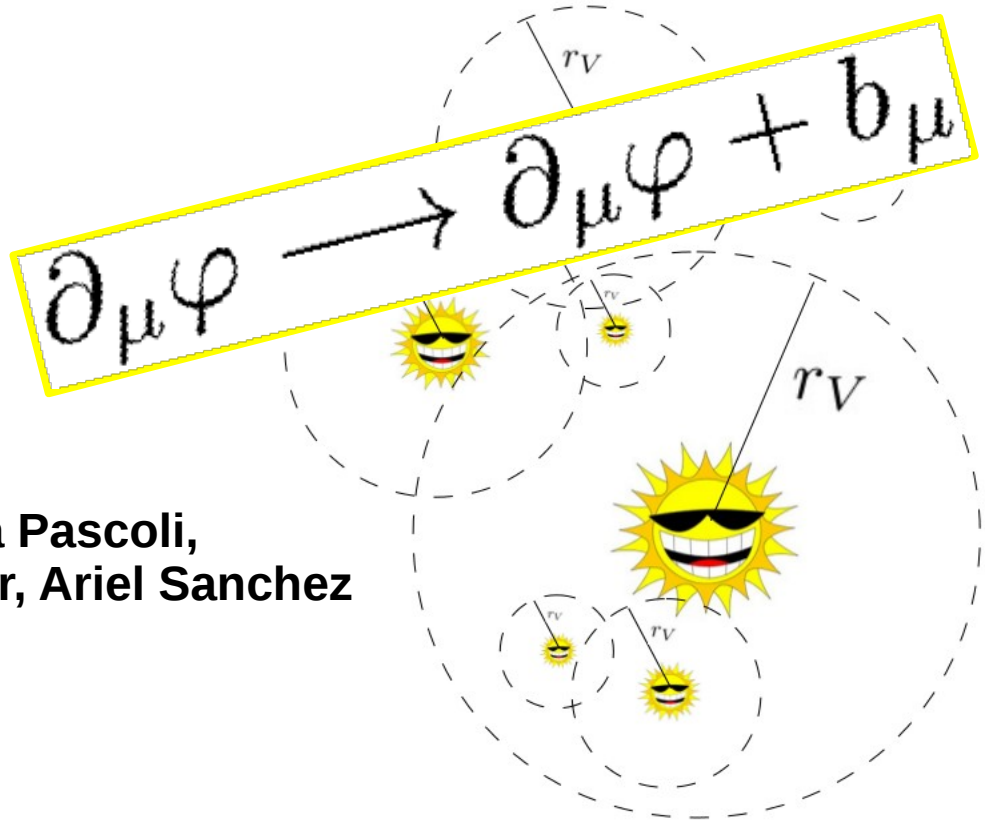

with Baojiu Li, Carlton Baugh, Silvia Pascoli, Wojciech Hellwing, Lucas Lombriser, Ariel Sanchez

FCT Fundação para a Ciência e a Tecnologia
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IP3

2nd Azores School on Observational Cosmology

June 3rd 2014, Angra do Heroísmo, Ilha Terceira, Portugal

The Galileon Model

Nicolis et al (2009) → 500+ citations; Deffayet et al (2009) → 250+ citations

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} - \frac{1}{2}\sum_{i=1}^{5} c_i\mathcal{L}_i - \mathcal{L}_m\right] \qquad M^3 \equiv M_{\rm Pl}H_0^2$$

$$\mathcal{L}_1 = M^3\varphi,$$
$$\mathcal{L}_2 = \nabla_\mu\varphi\nabla^\mu\varphi,$$
$$\mathcal{L}_3 = 2\Box\varphi\nabla_\mu\varphi\nabla^\mu\varphi/M^3,$$

$$\partial_\mu\varphi \longrightarrow \partial_\mu\varphi + b_\mu$$

Galilean invariance in Minkowski space.

$$\mathcal{L}_4 = \nabla_\mu\varphi\nabla^\mu\varphi\left[2(\Box\varphi)^2 - 2(\nabla_\mu\nabla_\nu\varphi)(\nabla^\mu\nabla^\nu\varphi) - R\nabla_\mu\varphi\nabla^\mu\varphi/2\right]/M^6,$$

$$\mathcal{L}_5 = \nabla_\mu\varphi\nabla^\mu\varphi\left[(\Box\varphi)^3 - 3(\Box\varphi)(\nabla_\mu\nabla_\nu\varphi)(\nabla^\mu\nabla^\nu\varphi) + 2(\nabla_\mu\nabla^\nu\varphi)(\nabla_\nu\nabla^\rho\varphi)(\nabla_\rho\nabla^\mu\varphi) - 6(\nabla_\mu\varphi)(\nabla^\mu\nabla^\nu\varphi)(\nabla^\rho\varphi)G_{\nu\rho}\right]/M^9.$$

2nd order field equations of motion → **No ghosts.**

Nonlinear derivative couplings **modify and suppress gravity** in different regions.

Cubic $\{\mathcal{L}_2, \mathcal{L}_3\}$

Quartic $\{\mathcal{L}_2, \mathcal{L}_3, \mathcal{L}_4\}$

Quintic $\{\mathcal{L}_2, \mathcal{L}_3, \mathcal{L}_4, \mathcal{L}_5\}$

Planck + BAO constraints

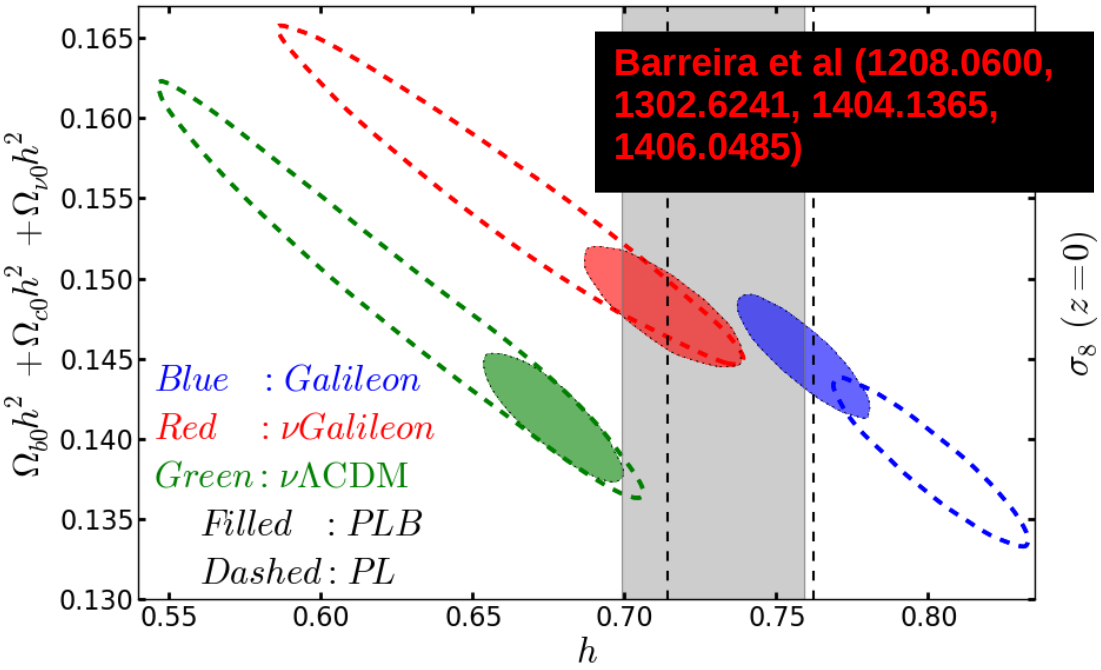
- ***"Modify CAMB and COSMOMC":***

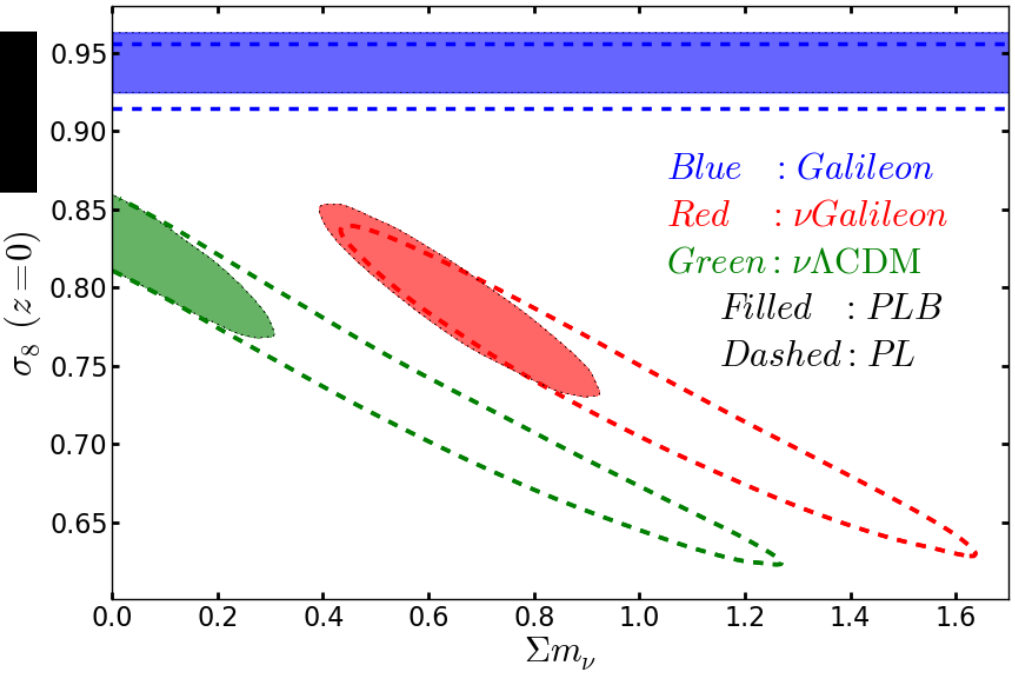
Standard cosmological parameters

$$\{\Omega_{b0}h^2, \Omega_{c0}h^2, h, \tau, n_s, A_s, \Sigma m_\nu\}$$

Galileon parameters (only two are independent)

$$\{c_2, c_3, c_4, c_5, \xi\}$$





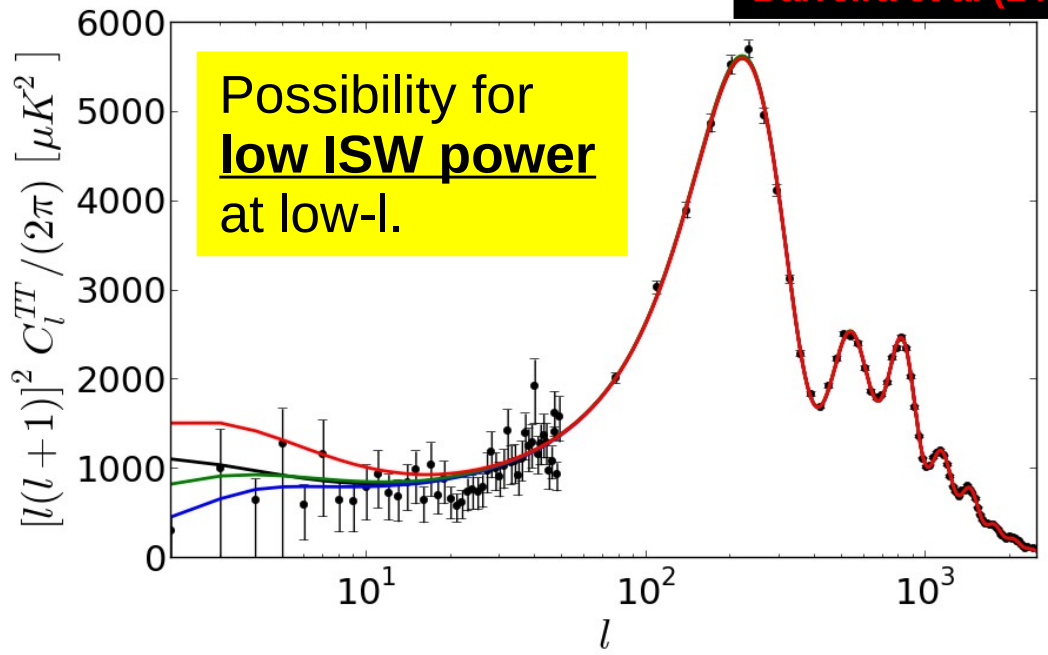
Strong evidence (>6 sigma) for **nonzero neutrino masses.**

Compatibility with local H0 determinations, unlike LCDM.

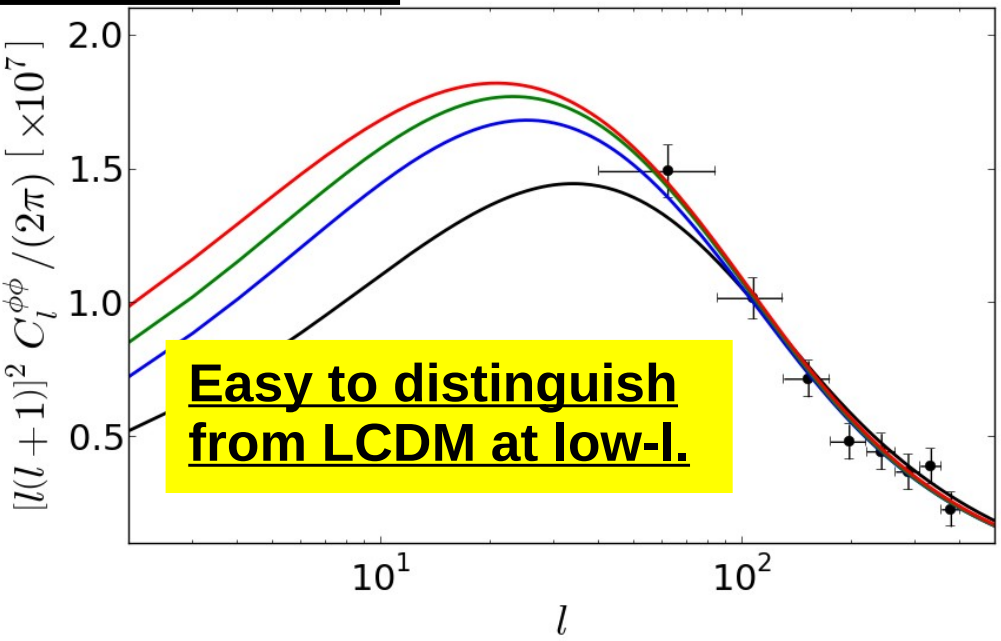
Low clustering amplitude, despite enhanced gravity.

LSS: linear regime

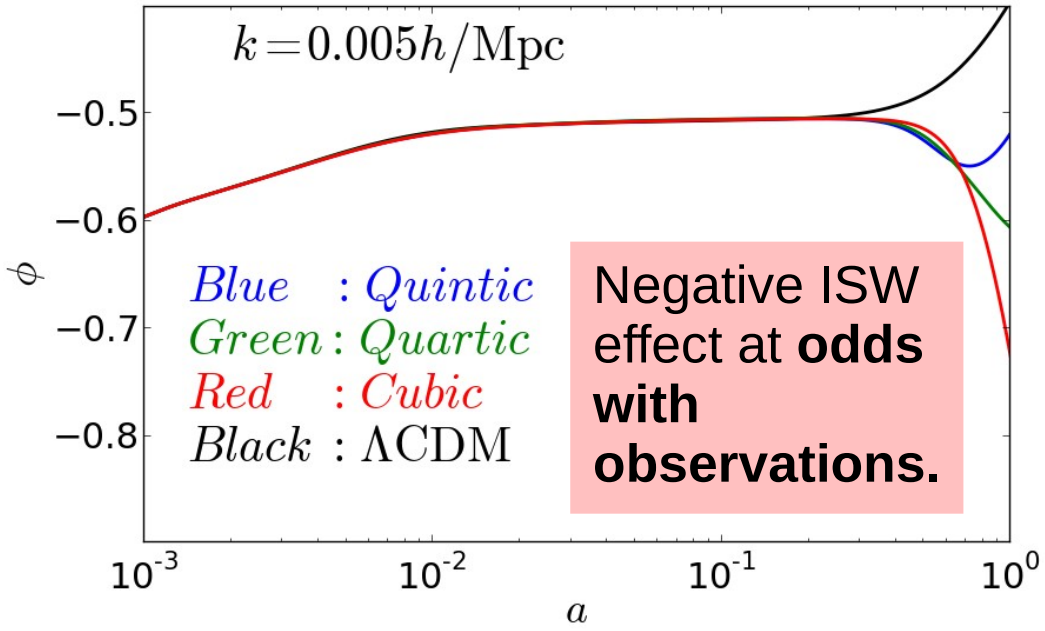
Barreira et al (1406.0485) :: arXiv Today



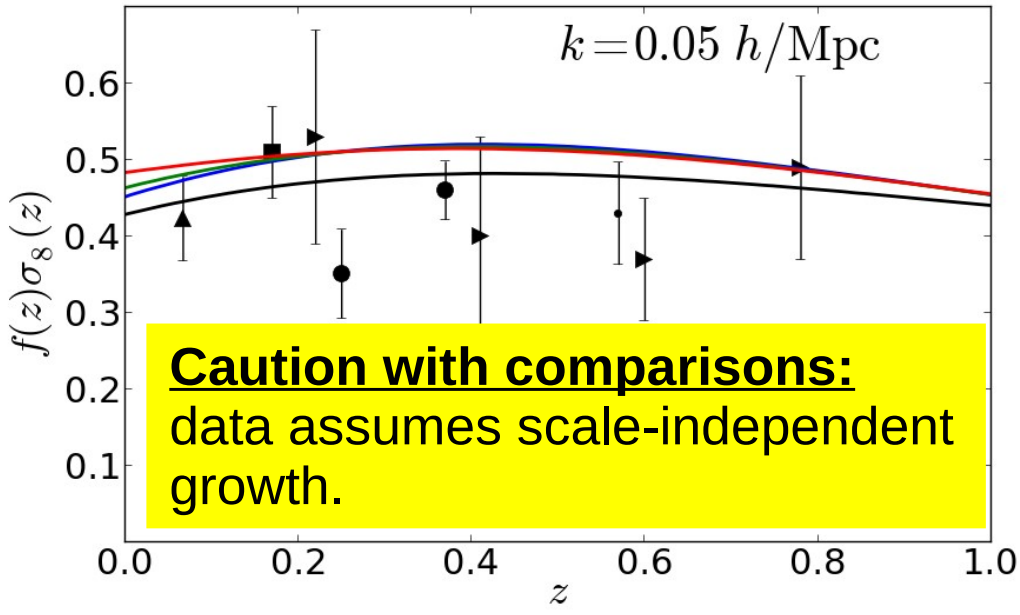
Possibility for **low ISW power** at low-l.



Easy to distinguish from LCDM at low-l.



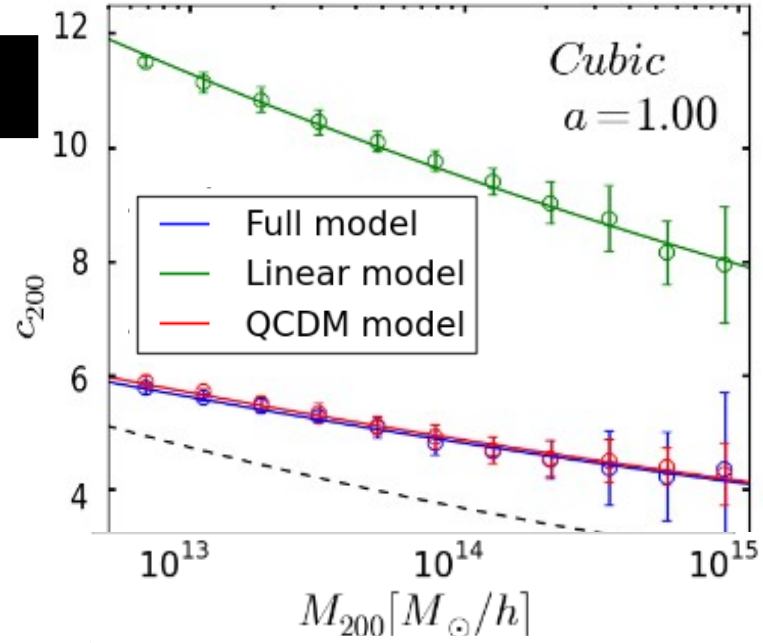
Negative ISW effect at **odds with observations.**



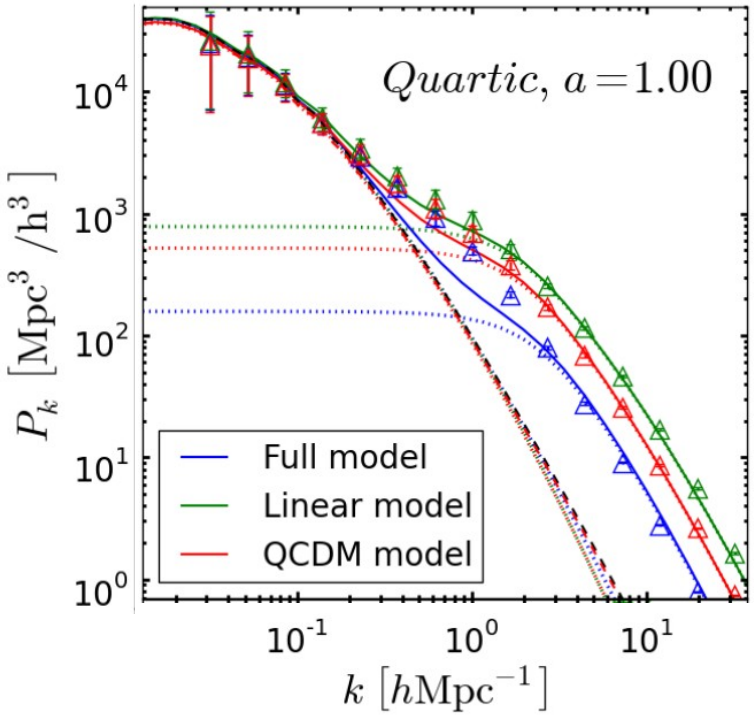
Caution with comparisons: data assumes scale-independent growth.

LSS: Nonlinear regime

Barreira et al (1306.3219, 1401.1497)



In the Cubic model, **Vainshtein mechanism suppresses essentially all modifications to gravity** on small scales.



Weakening of gravity on small scales in the Quartic model.

Li et al (1308.3491) ; Barreira et al (1308.3699, 1401.1497)

Explicit couplings to curvature

$$\mathcal{L}_4 \sim R\nabla_\mu\varphi\nabla^\mu\varphi$$

$$\mathcal{L}_5 \sim \nabla_\mu\varphi\nabla^\mu\nabla^\nu\varphi\nabla^\rho\varphi G_{\nu\rho}$$

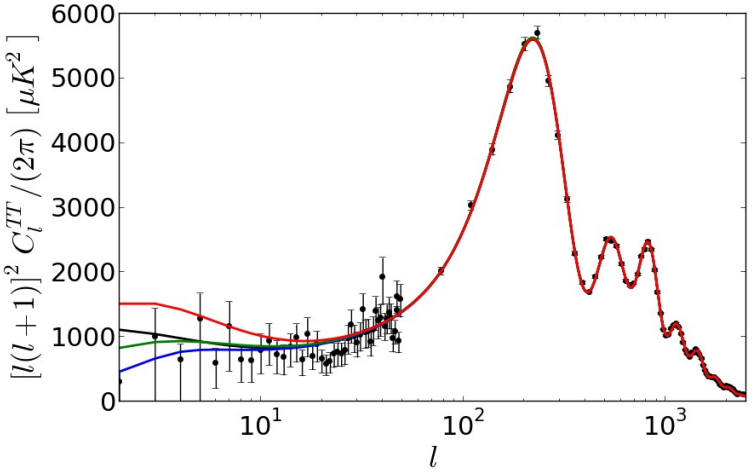
Vainshtein effect leaves behind these modifications to gravity. **Trouble with Solar System tests.**

Summary

Planck + BAO data

- The Galileon model fits the data very well with massive neutrinos.

Barreira et al (1208.0600, 1302.6241, 1404.1365, 1406.0485)



Explicit couplings to curvature

- May render the Cubic model as the only branch that passes Solar System tests.

Barreira et al (1306.3219, 1308.3699, 1401.1497)
Li et al (1308.3491)

$$\mathcal{L}_4 \sim R\nabla_\mu\varphi\nabla^\mu\varphi$$

$$\mathcal{L}_5 \sim \nabla_\mu\varphi\nabla^\mu\nabla^\nu\varphi\nabla^\rho\varphi G_{\nu\rho}$$

Negative ISW in the Cubic model

- This is at odds with the current observational suggestion of a positive ISW effect.

Barreira et al (1208.0600, 1406.0485)