Approaching the Chameleon Regime in f(R) Gravity with Cluster Abundance Data

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F(R) GRAVITY 101

- Toy-model for Einstein-Hilbert action extensions

$$S_{EH} = \int \mathrm{d}^4x\sqrt{-g}\left[\frac{R+f(R)}{16\pi G}\right]$$

- Modified Friedmann equations $\mathcal{H}^2 = \frac{\kappa^2}{3}a^2(\rho+\rho_{\rm eff}) \;\rightarrow\; w_{\rm eff} = w_{\rm eff}(a, f_R)$

$$f_R \equiv \frac{\partial f}{\partial R} \qquad\qquad m_{f_R}^{-2} = \lambda_C^2 = 3f_{RR}$$

- f(R) models

Hu-Sawicki

$$\begin{cases} f(R) = -2\Lambda - \frac{f_{R0}}{n}\frac{\bar{R}_0^{n+1}}{R^n} \\ |f_{R0}| \ll 10^{-2} \end{cases} \Rightarrow \quad w_{\rm eff} \approx -1$$

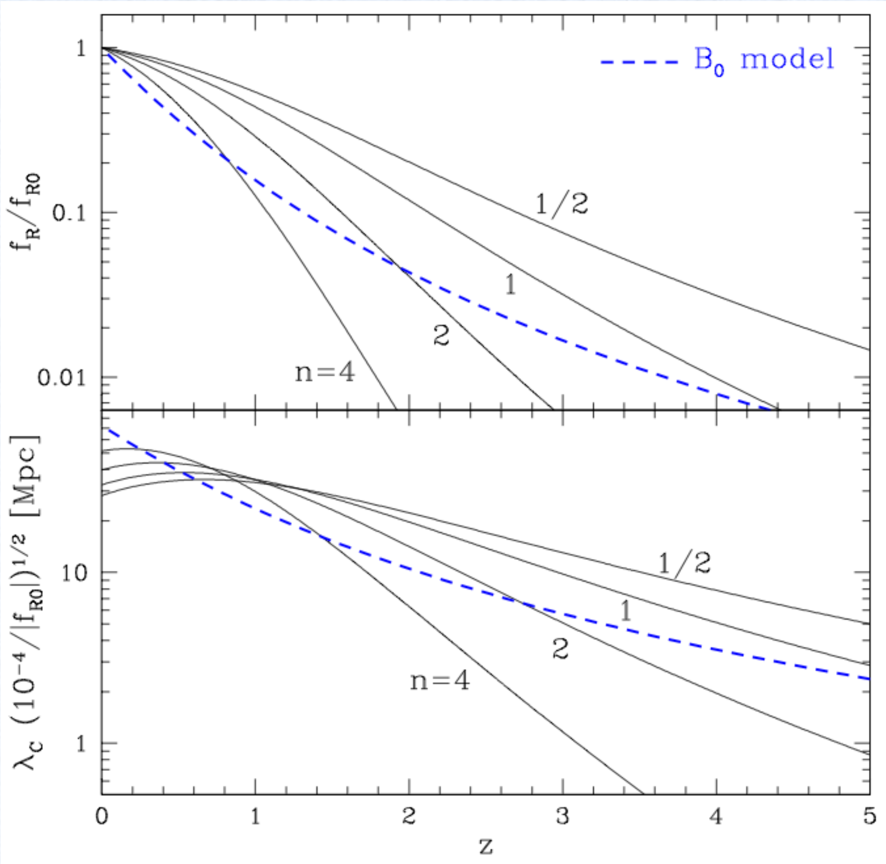
Hu and Sawicki (2007) (arXiv:0705.1158)

Designer

$$\begin{cases} w_{\rm eff} = -1 \Rightarrow \text{solve for } f(R) \\ B_0 \equiv \frac{f_{RR}}{1+f_R}\frac{\mathcal{H}\dot{R}}{\dot{\mathcal{H}}-\mathcal{H}^2}\Big|_0 \end{cases}$$

Song et al. (2006) (arXiv:0610532)

MODIFIED GROWTH

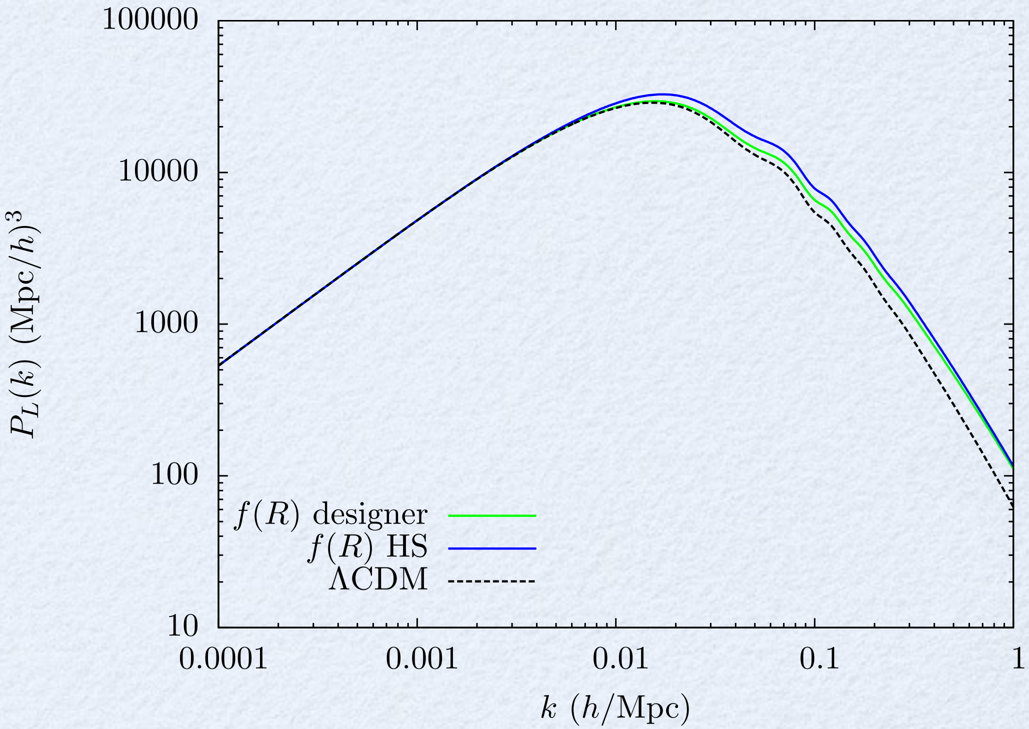


Ferraro et al. (2010) (arXiv:1011.0992)

- Modified growth equation

$$\Delta_m'' + \left[2 - \frac{3}{2}\Omega_m(a)\right]\Delta_m' - \frac{3}{2}\left[1 - g(a,k)\right]\Omega_m(a)\Delta_m = 0$$

$$g(a,k) \equiv -\frac{1}{3}\frac{k^2}{k^2 + m_{f_R}^2 a^2}$$



CLUSTER ABUNDANCE

- Sheth-Tormen mass function (arXiv:9901122)

$$\frac{dn}{d\ln M_v} = f(\nu)\frac{\bar{\rho}_m}{M_v}\frac{d\nu}{d\ln M_v} \qquad \nu \equiv \frac{\delta_c}{\sigma(M_v)}$$

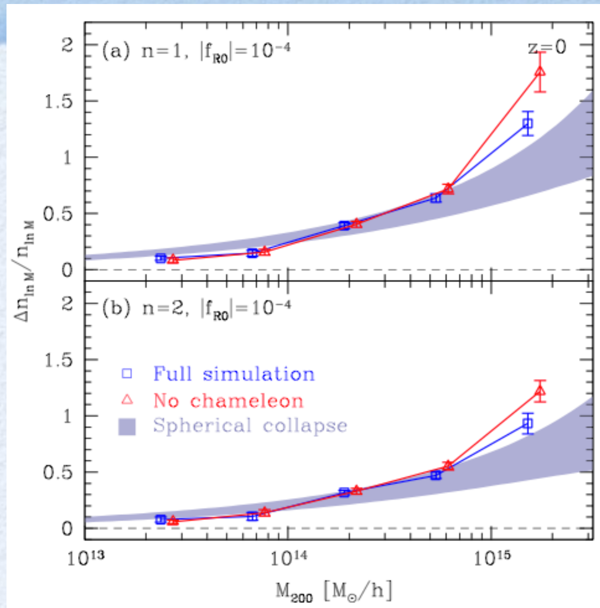
$$M = \frac{4}{3}\pi\bar{\rho}_m R^3 \qquad \sigma^2(R) = \int \frac{d^3k}{2\pi^3}|\tilde{W}(kR)|^2 P_L(k)$$

$$\nu f(\nu) = A\sqrt{\frac{2}{\pi}a\nu^2}\left[1+(a\nu^2)^{-p}\right]\exp[-a\nu^2/2]$$

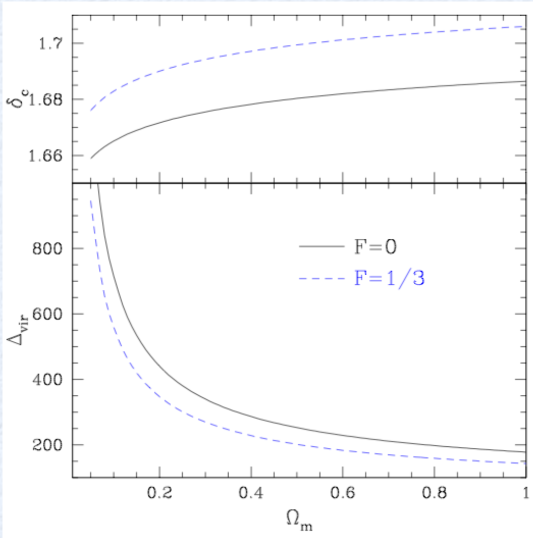
- Tinker mass function (arXiv:0803.2706)

$$\frac{dn}{d\ln M} = f(\sigma)\frac{\bar{\rho}_m}{M}\frac{d\ln\sigma^{-1}}{d\ln M}$$

$$f(\sigma) = A\left[\left(\frac{\sigma}{b}\right)^{-a}+1\right]\exp[-c/\sigma^2]$$



Ferraro et al. (2010) (arXiv:1011.0992)

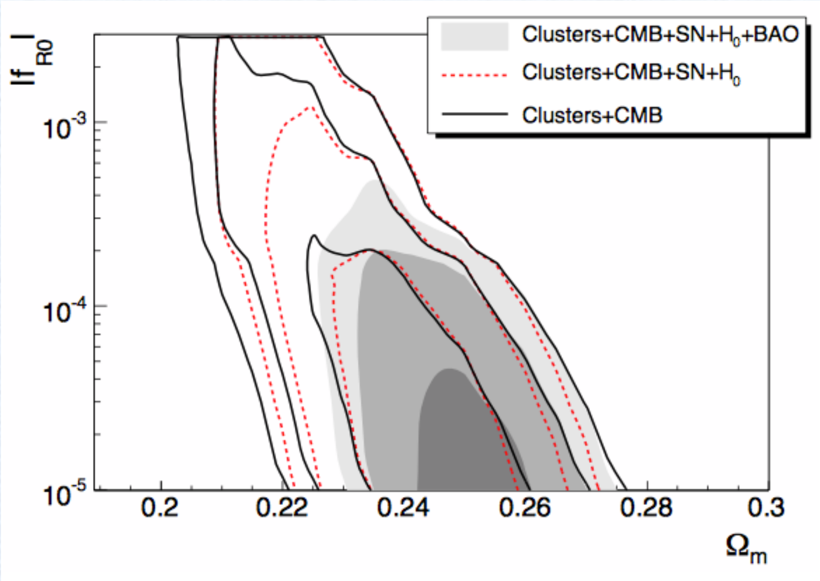


Schmidt et al. (2009a) (arXiv:0812.0545)

Large Field Constraints: Current Status

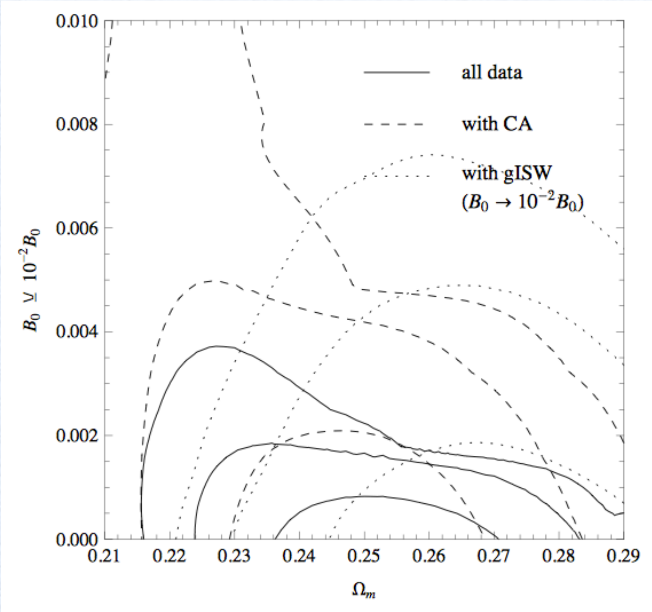
Schmidt et al. (2009b) (arXiv:0908.2457)

1. Enhancements calculated at z=0
2. Effective σ_8 (not full likelihood calculation)
3. Cluster sample z = 0 - 0.15
4. $\{A_s, \Omega_m, f_{R0}\}$



Lombriser et al. (2011) (arXiv:1003.3009)

1. Tinker HMF → overestimation for $|f_{R0}|$ → 10^{-4}
2. ΛCDM Tinker parameters used for f(R)
3. Cluster sample z = 0.18



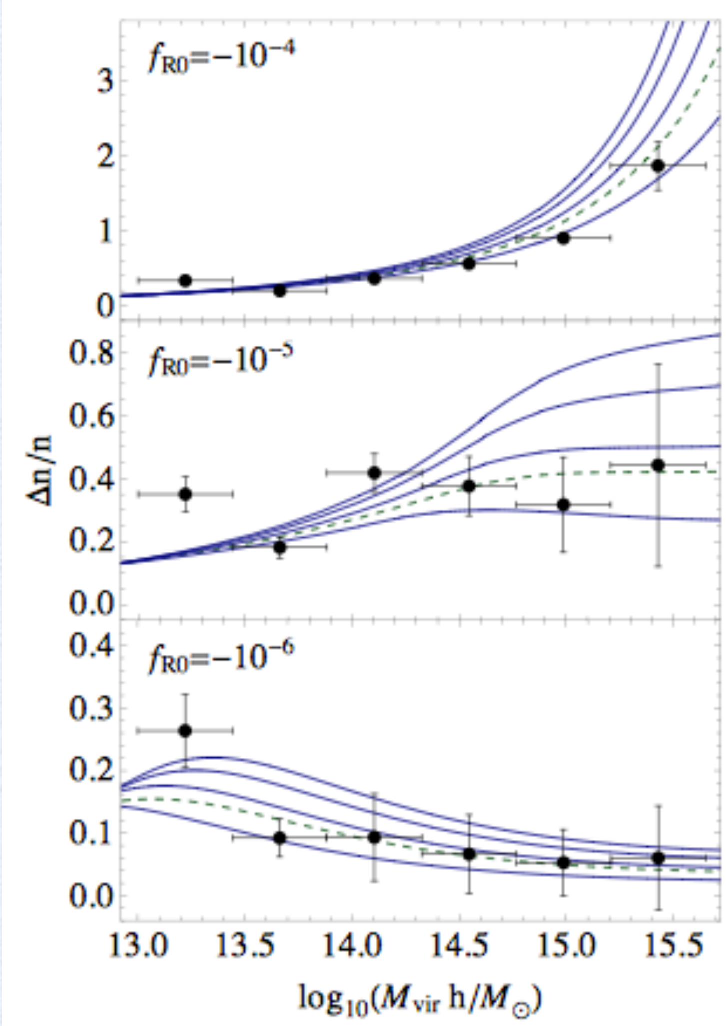
OUTLOOK

1. Improve constraints on f(R) with a more robust analysis (Cataneo et al., in prep.)

- Refined analysis using WL mass calibration (Mantz et al., in prep.; von der Linden et al., arXiv: 1208.0597; Kelly et al., arXiv:1208.0602; Applegate et al., arXiv:1208.0605)
- Cluster sample z = 0 - 0.5 (Allen et al., arXiv: 0706.0033; Mantz et al., arXiv:0909.3098; Mantz et al., arXiv:0909.3099)
- Allow uncertainties in HMF (departure from universality) (Mantz et al., arXiv:0909.3098)
- Full redshift dependence

$$\frac{\mathrm{d}n}{\mathrm{d}\ln M_\Delta} \equiv \left(\frac{n_{\mathrm{MG}}^{(\mathrm{ST})}}{n_{\mathrm{GR}}^{(\mathrm{ST})}}\right)_\Delta n_\Delta^{(\mathrm{Tinker})}$$

2. Use HMF consistently including the suppression of gravity modifications



Lombriser et al. (2013) (arXiv:1312.1292)