Constraints on modified gravity from future SZ surveys

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Outline

- Modified gravity vs LambdaCDM
- Modified gravity f(R) model
- Phenomenology of f(R) model
- Observational constraints

Accelerating Universe

ΛCDM:

General Relativity + Dark Energy

Growth of Structure

- Galaxy cluster Abundances
- Weak Lensing
- Velocity Field

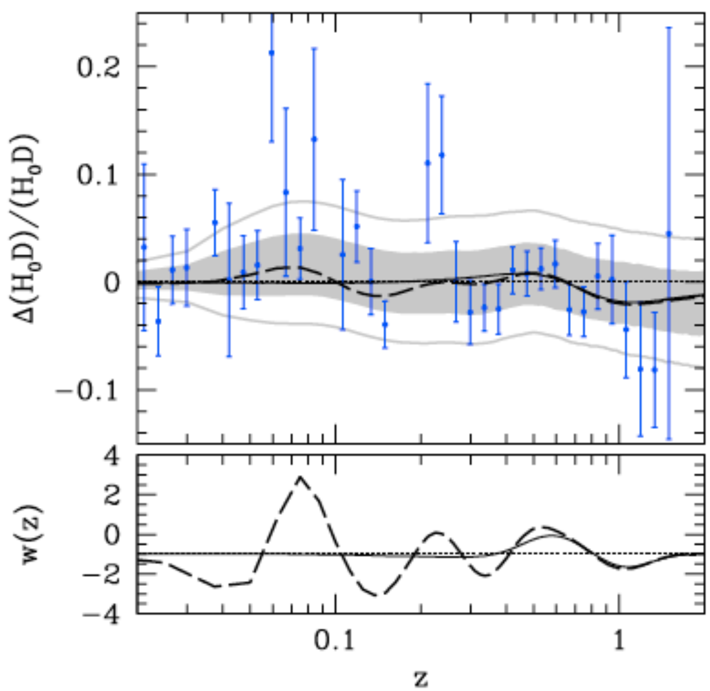
Expansion History

- Baryon Acoustic Oscillations (BAO)
- Cosmic Microwave Background (CMB)
- Supernovae (SN)

Challenge to General Relativity + Dark energy ?

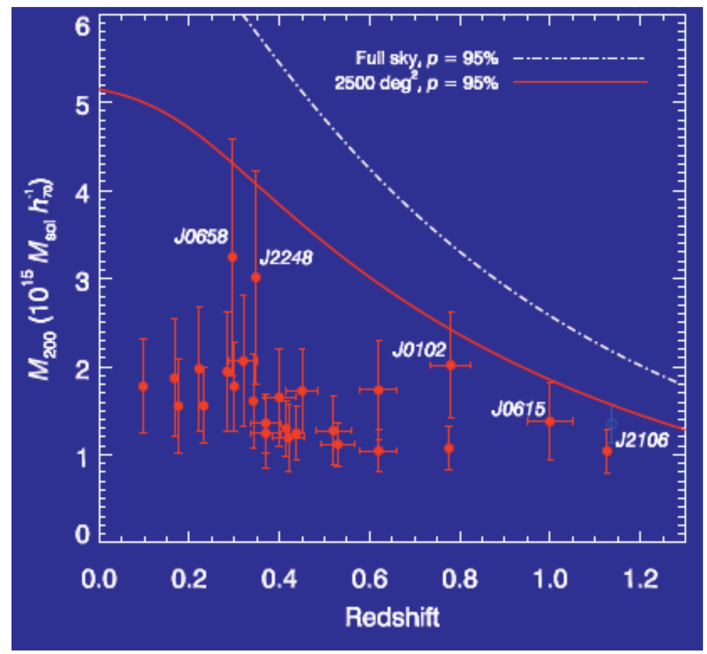
Excess of high redshift/ high mass clusters abundances provide argument for alternatives theory

Enhanced growth



Mortonson, Hu, Huterer (2009)

Pink Elephant



Mortonson, Hu, Huterer (2009)

What should be changed ?

- Einstein equation by General Relativity

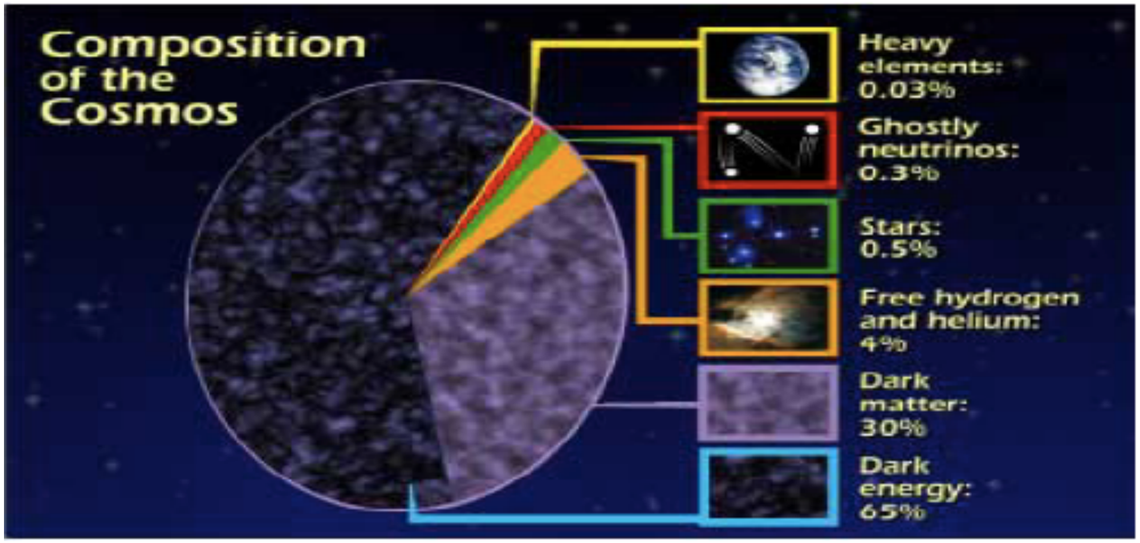
$$G_{\nu\mu} = 8\pi G T_{\nu\mu}$$

Modfied Gravity vs Dark Energy

- Einstein equation by General Relativity

New energy sources

$$G_{\nu\mu} = 8\pi G(T_{\nu\mu} + T_{\rm DE})$$



- Quintessence
- K-essence

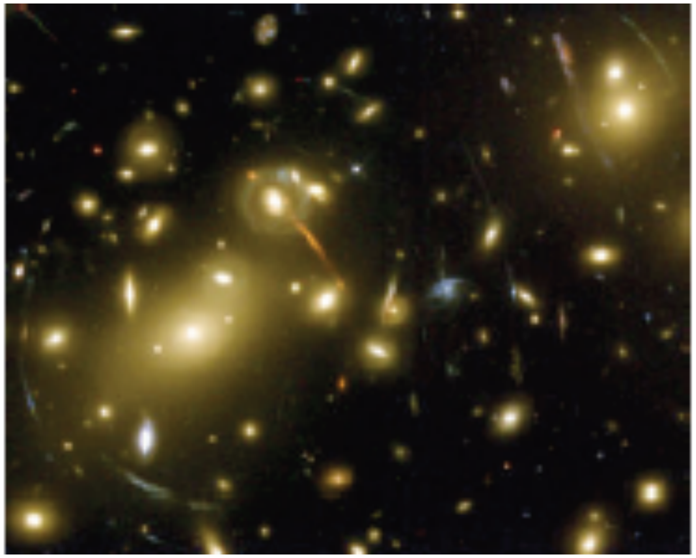
What should be changed ?

- Einstein equation by General Relativity

Modifications of Gravity

$$F(g_{\nu\mu}) + G_{\nu\mu} = 8\pi G T_{\nu\mu}$$

- DGP braneworld acceleration (Dvali et al. 00, Khoury & Weltman 04, etc….)
- f(R) modified action (Capzziello 02, Beans et. al. 05, Amendola et al. 08….)
- …….



Modfied Gravity vs Dark Energy

- Einstein equation by General Relativity

Modifications of Gravity

New energy sources

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- ....

- Quintessence
- K-essence
- DE

Both scenarios are lacking compelling models

Can only study illustrative toy models with generalized features

Good Modified Gravity Models ?

- Models are already constrained by data:
  - Linear regime: ***CMB, SN, ISW, BAO***
    - Model independent constraints, but limited constraining power
  - Non-linear regime: ***weak lensing, cluster abundance***
    - High S/N observables, but model dependent
- Looking for models which
  - Reduce gravity to GR in high density/curvature
  - Contains freedom to reproduce cosmological expansion history

Modified Action *f(R)* Model

- Modified action in *f(R)* gravity

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

- Effect:
  - Gravitation force on scales is enhanced below range (Compton length)
  - Chameleon mechanism: Compton length shrink in region with deep gravitational potential
- Our *f(R)* model:

$$f(R) = -16\pi G \rho_\Lambda - f_{R0} \frac{\bar{R}_o{}^2}{R} \propto \frac{1}{R}$$

Simulating Modified Gravity

- The f_R field equation:

$$\nabla^2 \delta f_R = \frac{a^2}{3}[\delta R(f_R) - 8\pi G \delta\rho_m]$$

- Modified Poisson equation:

$$\nabla^2 \Psi = 4\pi G a^2 \delta\rho_m - \frac{1}{2}\nabla^2 \delta f_R$$

- Matter falls in Newtonian potential, modification to gravity are completely contained in ψ
- The field is sourced by deviation from GR relation between curvature R and density ρ

Chameleon Effect

- To satisfy local test of gravity, e.g. Solar System Test
- Today value: $\lambda_{C0} \approx 32\sqrt{\frac{|f_{R0}|}{10^{-4}}} \approx 32\mathrm{Mpc}$
- The Compton length separates two regime:

$$\boxed{\lambda_c \gg \lambda}$$

$$\delta R \ll 8\pi G \delta\rho_m$$

- Curvature is small
- Dynamical potential is enhanced by 4/3

$$\boxed{\lambda_c \ll \lambda}$$

$$\delta R \approx 8\pi G \delta\rho_m$$

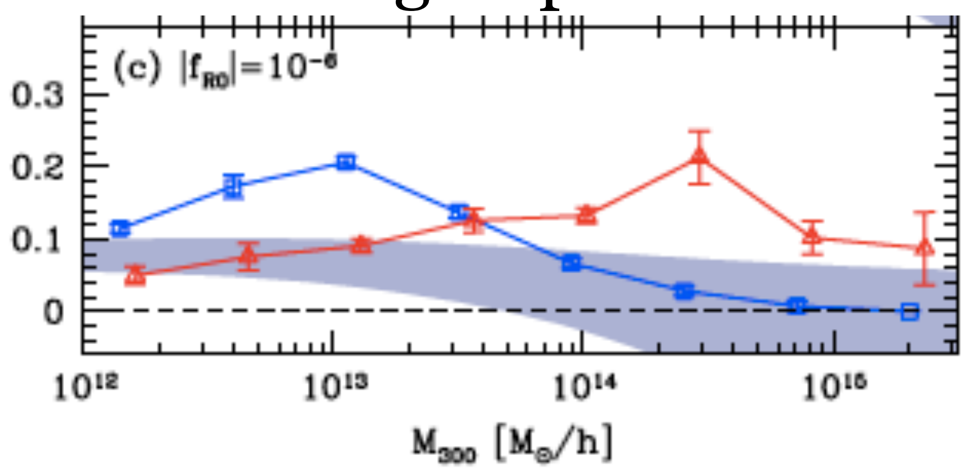
- Deep gravitational potential
- Chameleon operate and shut down the fR field

Forecast the uncertainty of f_{Ro}

- f_{Ro}: Control the strength and range of the force modification
- To satisfy solar system test, the background field should be comparable to gravitational potential

$$|f_{R0}| < |\Psi| \sim 10^{-6} - 10^{-5}$$

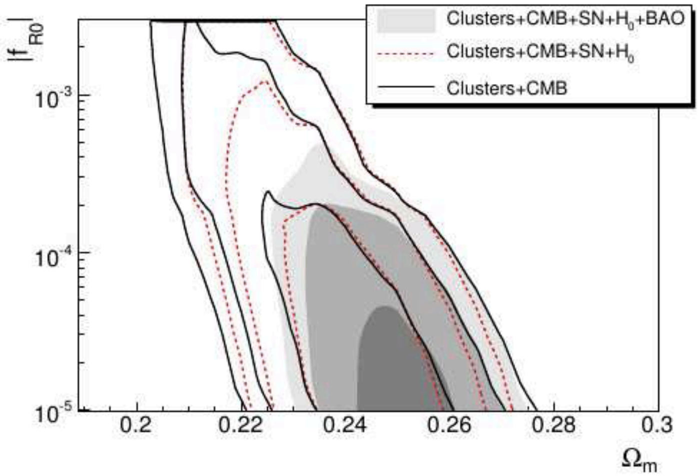
- Excess is max at group mass scale



Schmidt et. al. (2008)

Current Constraints

Schidmt et. al. (2008)



Local cluster abundance (*Chandra X-ray*) gives

$$|f_{R0}| < (1.3^{+1.7}_{-0.6}) \times 10^{-4}$$

at 95.8% C.L.

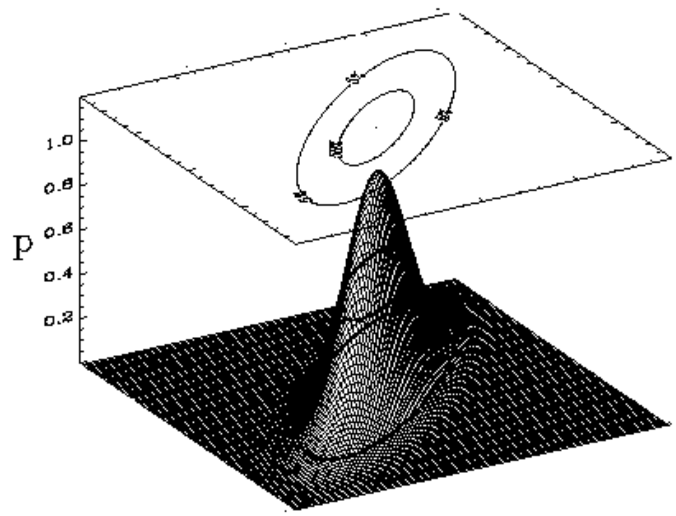
Can we do better ?

Parameters: cosmology + f_{Ro} + survey parameter
Observables:
Cluster abundance (dN/dz) + 3D power spectrum (P(k))

Goal: Push down the limits to f_{Ro}~10^{-6} or 10^{-7}

Fisher Matrix Forecast

- Predict the error of cosmological parameters in a given model from future experiments
- Project the 68% CL contour on the parameter plane centered on the fiducial values

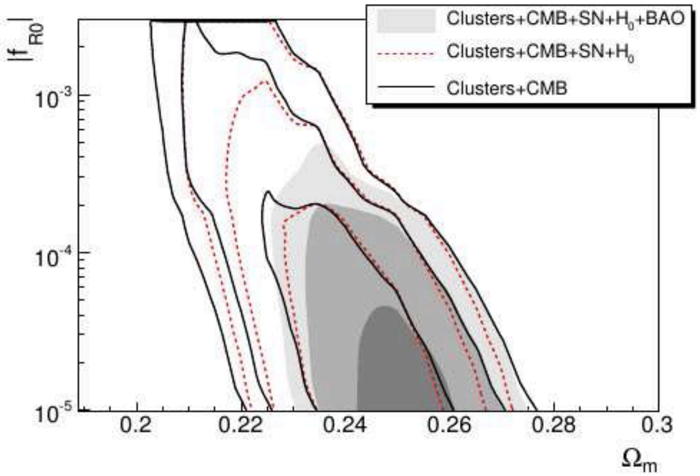


Fisher Matrix Forecast

Cosmological parameter (WMAP5)		
$\mathbf{n_s}$	Primordial spectral index	0.963
$\boldsymbol{\sigma_8}$	Normalization of P(k)	0.8
$\boldsymbol{\Omega_\Lambda}$	Dark Energy density	0.7
$\boldsymbol{\Omega_M h^2}$	Dark matter density	0.15
$\boldsymbol{\Omega_b h^2}$	Baryon density	0.023
***f(R)* parameter (fixed to ΛCDM)**		
λ_{Co}	Current compton length	0
Cluster Survey parameter		
$\mathbf{B_{mo}}$	Mass bias: Normalization	-0.15
$\boldsymbol{\alpha}$	Mass bias: slope	0
$\boldsymbol{\sigma_{mo}}$	Mass scatter: Normalization	0.1
$\boldsymbol{\beta}$	Mass scatter: slope	0

Current Constraints

Schidmt et. al. (2008)



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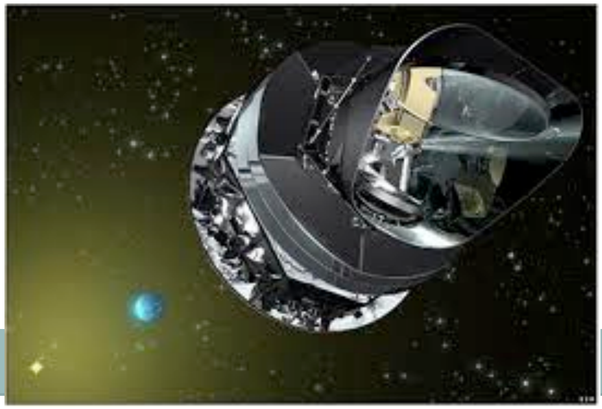
Future Constraints

South Pole Telescope (SPT, SPTpol)
148, 218, 277 GHz

Atacama Cosmology Telescope Polarization survey (ACTpol)
150 GHz

Planck Satellite
30-857 GHz



Future Constraints

18μK/arcmin²
Ω~2500 sq degrees
1000 clusters

4μK/arcmin²
Ω~625 sq degrees
5000 clusters

20μK/arcmin²
Ω~4000 sq degrees
1000 clusters

1μK/arcmin²
Ω~30,000 sq degrees
2500 clusters

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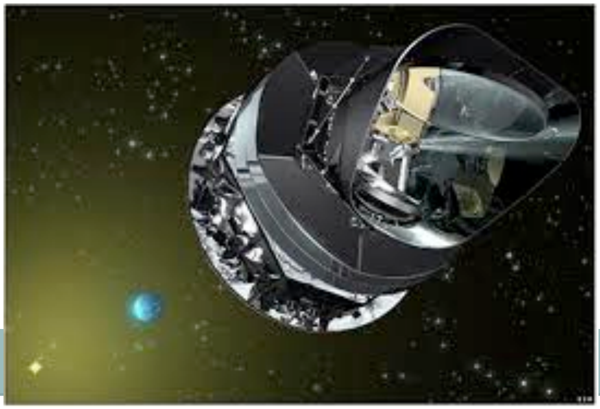
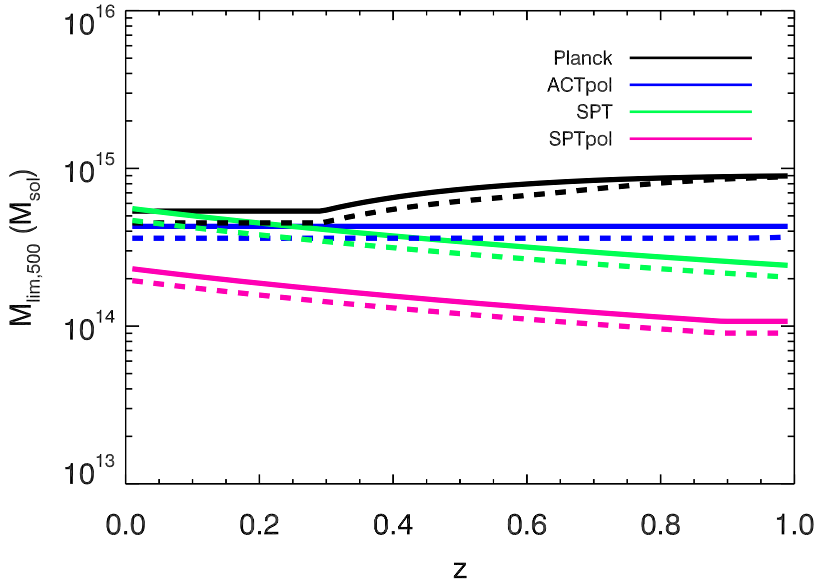
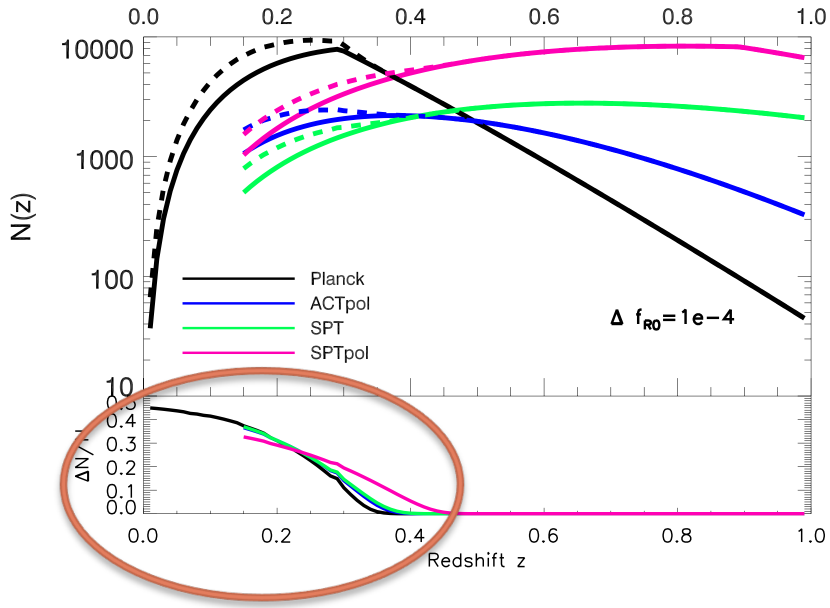


Selection and dN/dz





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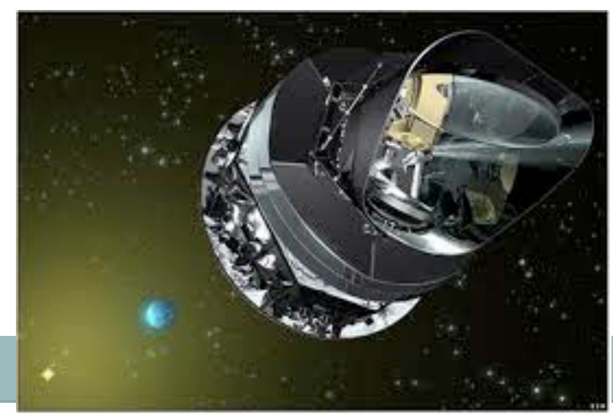


Effects of Modified Gravity

- Dark Matter Halo Mass function

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

  - Abundances of clusters

$$\boxed{N_{l,m} = \Delta\Omega\Delta z \frac{d^2V}{dzd\Omega} \int_{M^{ob}_{l,m}}^{M^{ob}_{l,m+1}} dM^{ob} \int_0^\infty dM n_{\ln M_v}(M,z) p(M^{ob} \parallel M)}$$

- Dark Matter Halo Bias and Power Spectrum

$$b_L(M) = 1 + \frac{a\nu^2 - 1}{\delta_c} + \frac{2p}{\delta_c[1 + (a\nu^2)^p]} \qquad P_{\text{lin}} = Ak^{n-1}$$

  - Spatial cluster clusters

$$\boxed{P(k,z) = b(z)^2 P_{\text{lin}}(k)}$$

Cluster Abundances

- Larger background field
  - ➔ More enhancement in abundance in most massive halos
- Small background field
  - ➔ Chameleon operate
  - ➔ Departure from ΛCDM is small
  - ➔ Abundance of clusters is not a good probe

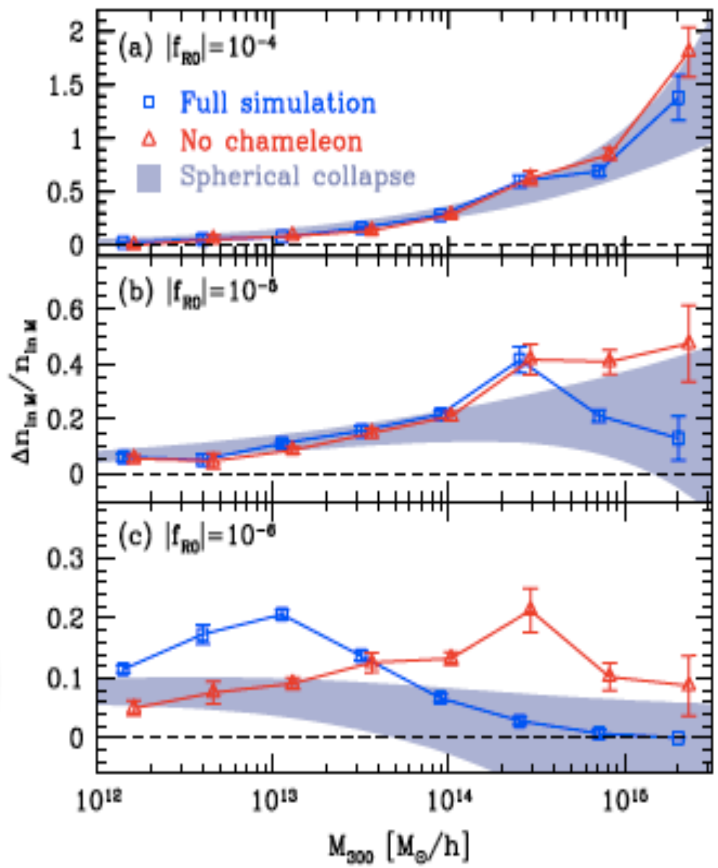
Smaller f_{Ro}

↓

Deviations shift to lower mass

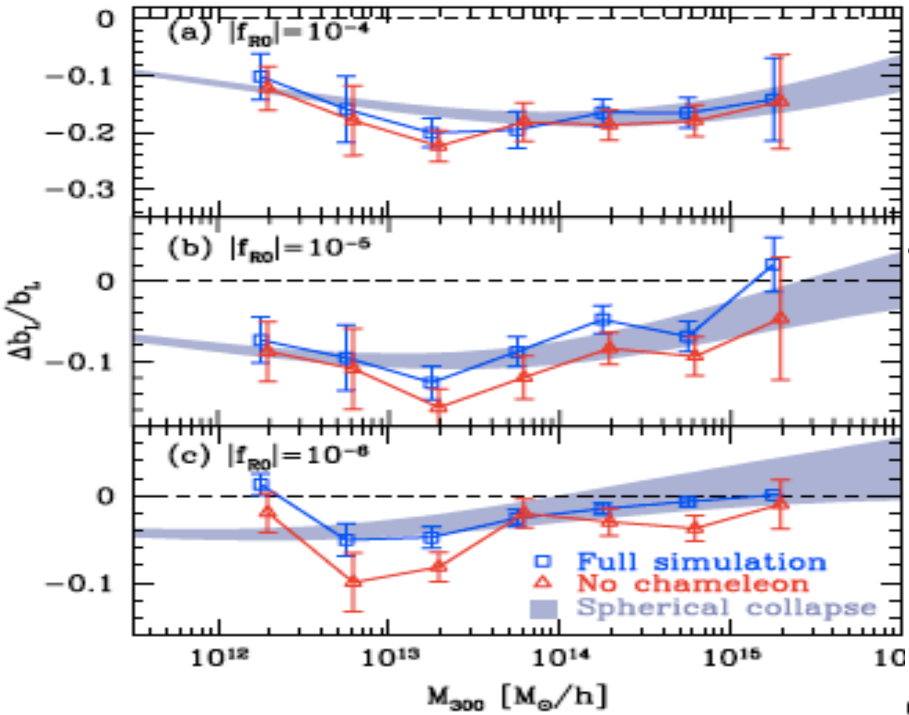
Schmidt et. al. (2008)

Large field



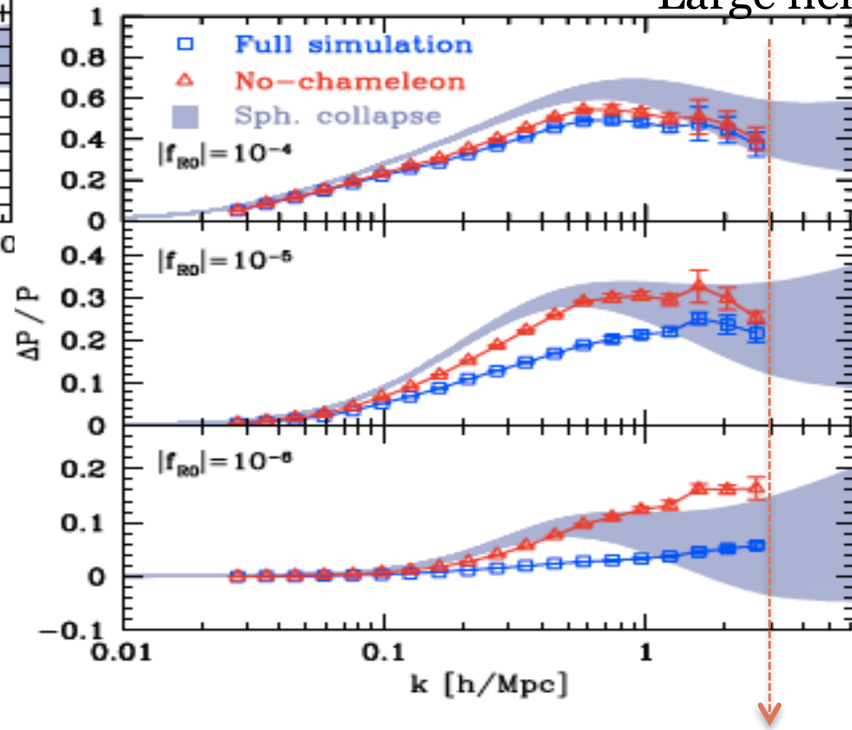
Small field

Spatial Clustering Schmidt et. al. (2008)



○ Halos at a fixed mass are less rare and less highly biased

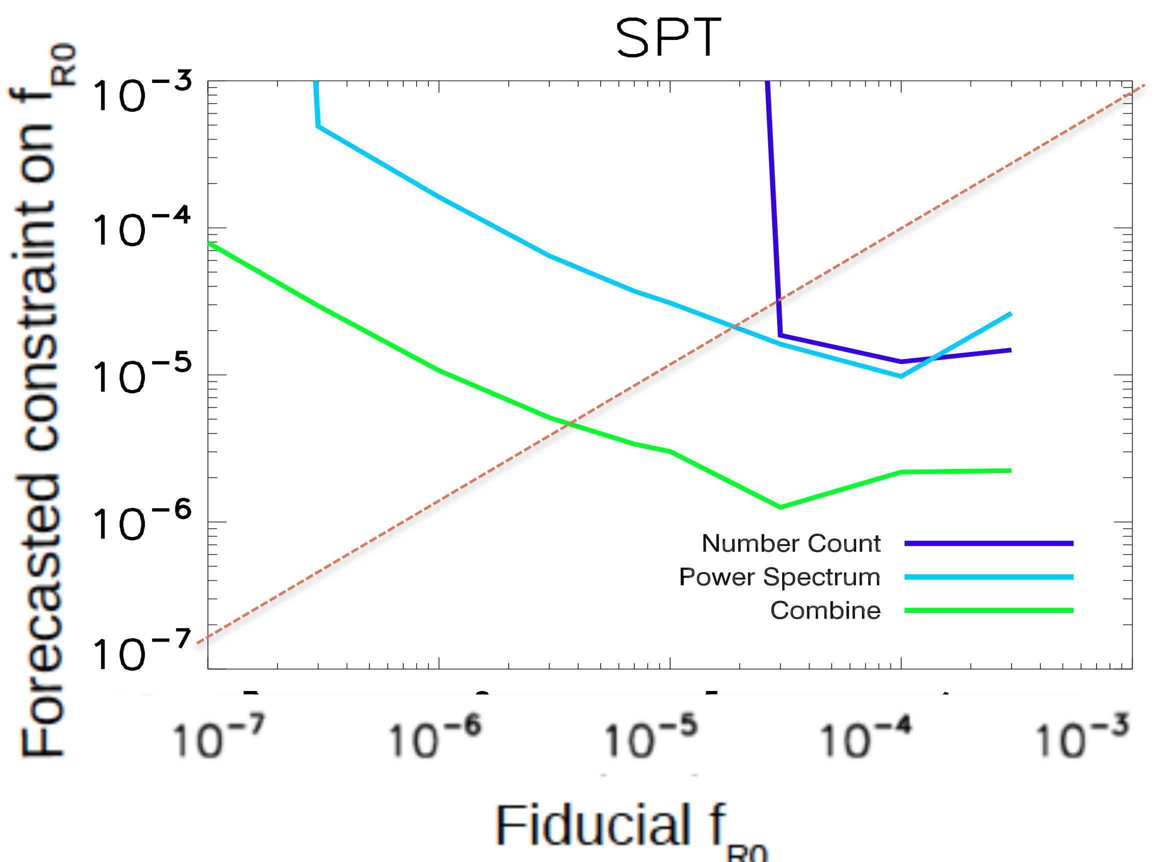
Large field



○ largely enhanced at cluster scale: k=0.1-1

Small field

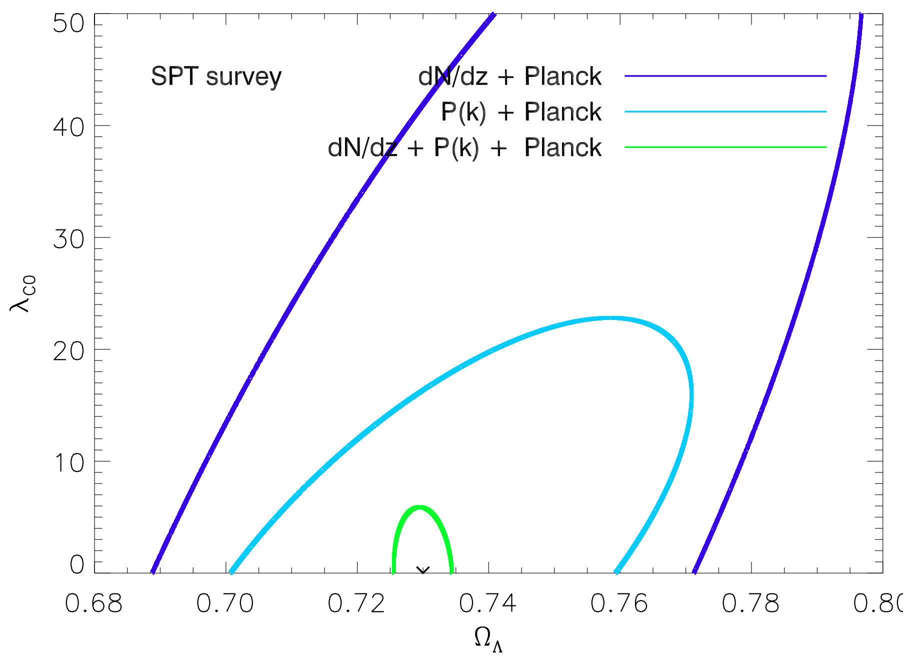
Marginalized 68%CL
Planck CMB Prior added
Combination dN/dz + P(k) breaks degeneracies with nuisance parameters



number count fails; power spectrum dominate the constraint

TABLE II: Marginalized errors on λ_{C0} and f_{R0}

Survey	$f_{R0}(10^{-6})$			λ_{C0} (Mpc/h)		
	dN/dz	$P(k)$	$dN/dz+P(k)$	dN/dz	$P(k)$	$dN/dz+P(k)$
			no			
Planck	∞	288.32	38.89	∞	40.29	14.76
ACTpol	∞	675.74	338.74	∞	61.10	43.60
SPT	∞	162.11	10.71	∞	30.01	7.75
SPTpol	∞	34.66	4.90	∞	13.94	5.20



Constraining power:

Good: ACTpol;

Better: Planck, SPT;

Best: SPTpol

Prefer lower flux-limited survey

Conclusion

- With latest N-body simulation of *f(R)* modified gravity, good constraints that push down to solar-system limit can be obtained
- Power spectrum overpower number count and give $\sigma_{fR0} \approx 10^{-6}$
- Higher sensitivity surveys, such as SPTpol, that include lower m clusters are more powerful to probe $|f_{R0}|$

THE END