Testing Gravity using Cosmic Voids

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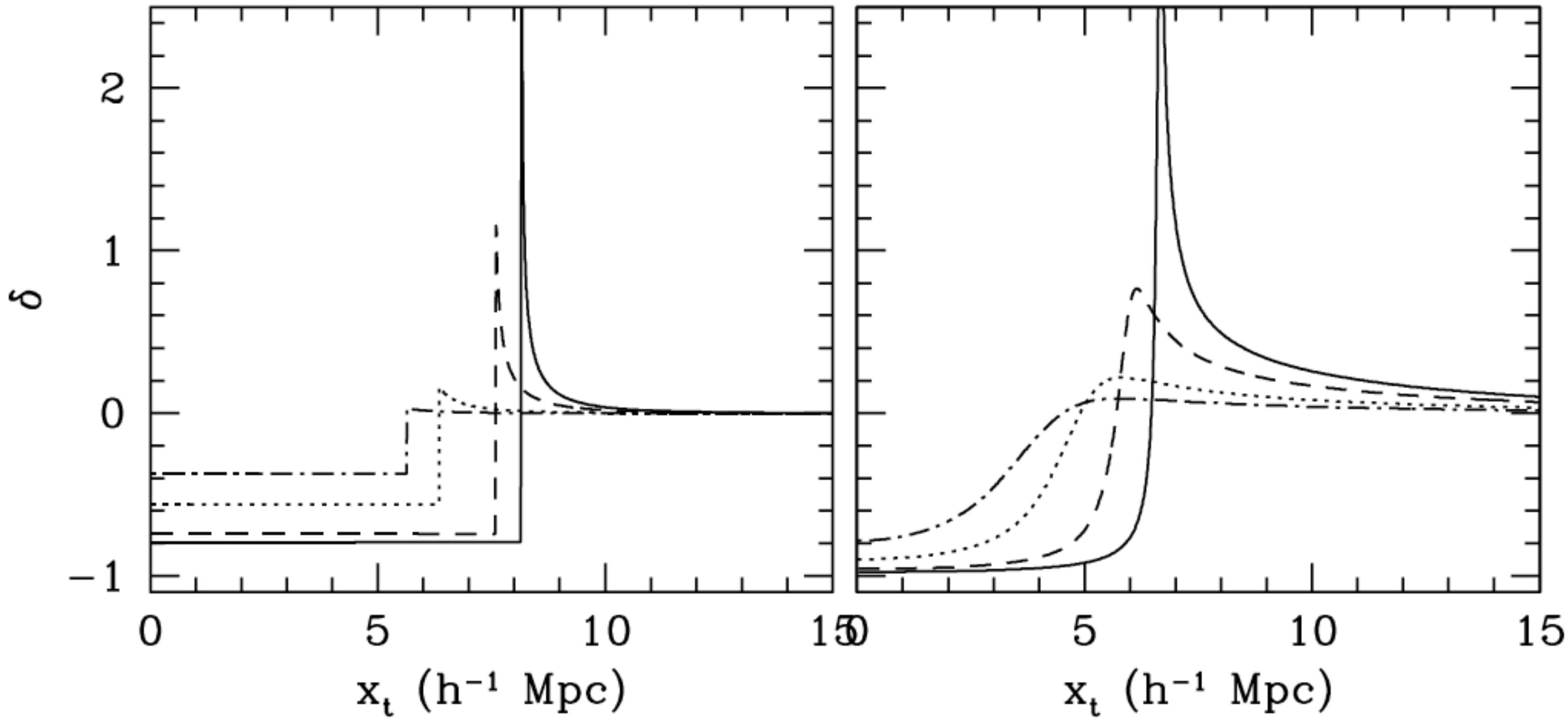
Theoretical and Observational Progress on Large-scale Structure of the Universe

Munich, 23.07.2015

Spherical expansion

Sheth & van de Weygaert, 2004

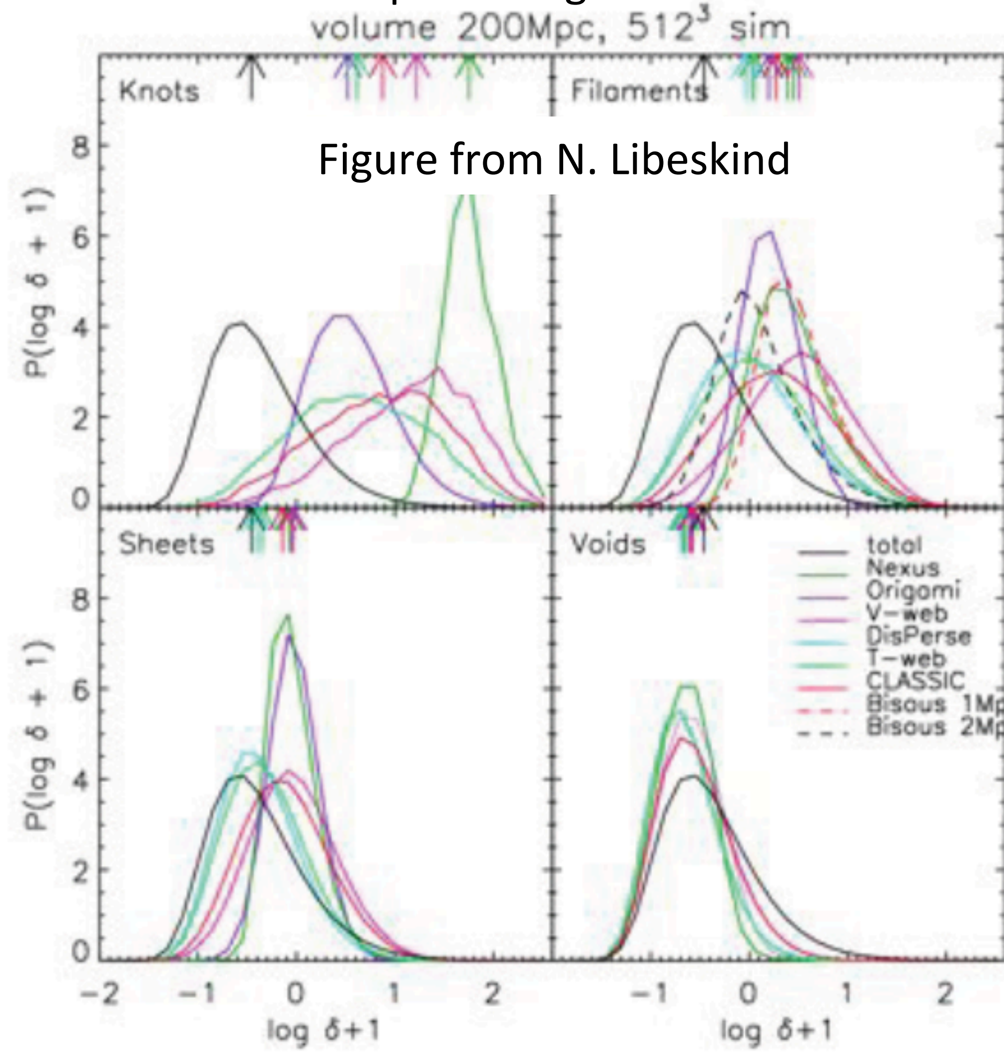


In LCDM, shell-crossing occurs at $\delta = -0.8$

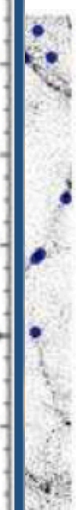
$R_f/R_{int} \sim 1.7$

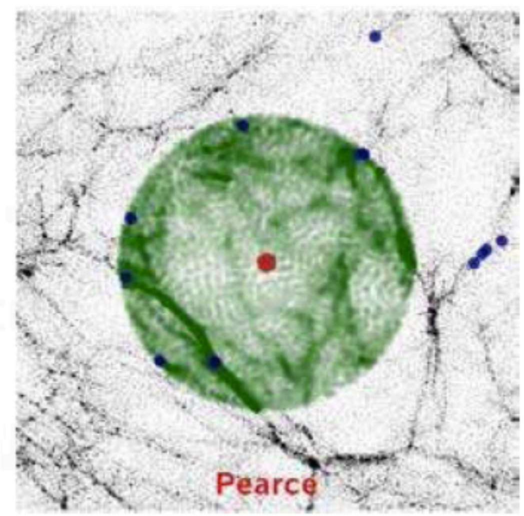
Voids in Simulations

From the workshop “Tracing the Cosmic Web”



r comparison project





Spherical overdensity

3

Voids in observations

- SDSS voids from

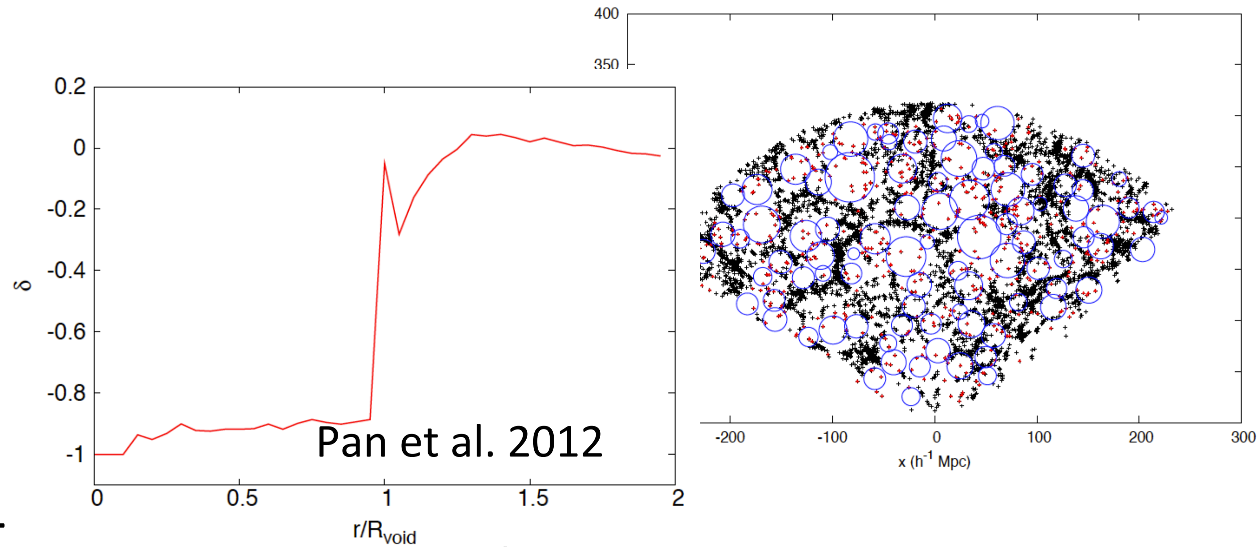
Pan et al. 2012

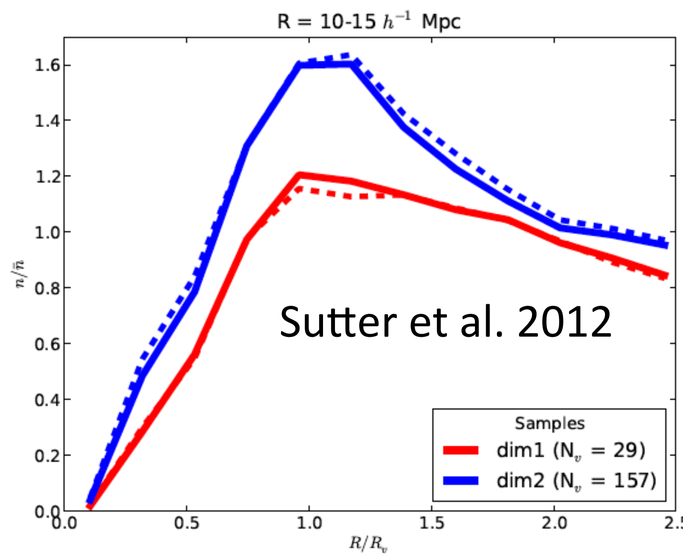
Sutter et al. 2012

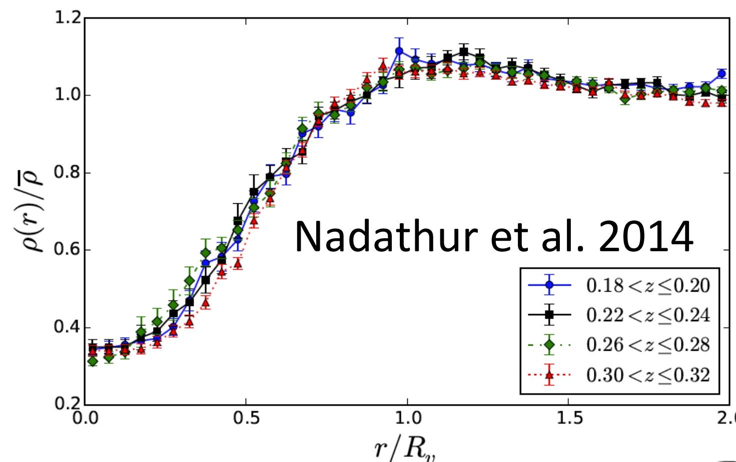
Cai et al. 2014

Nadathur et al. 2014

...

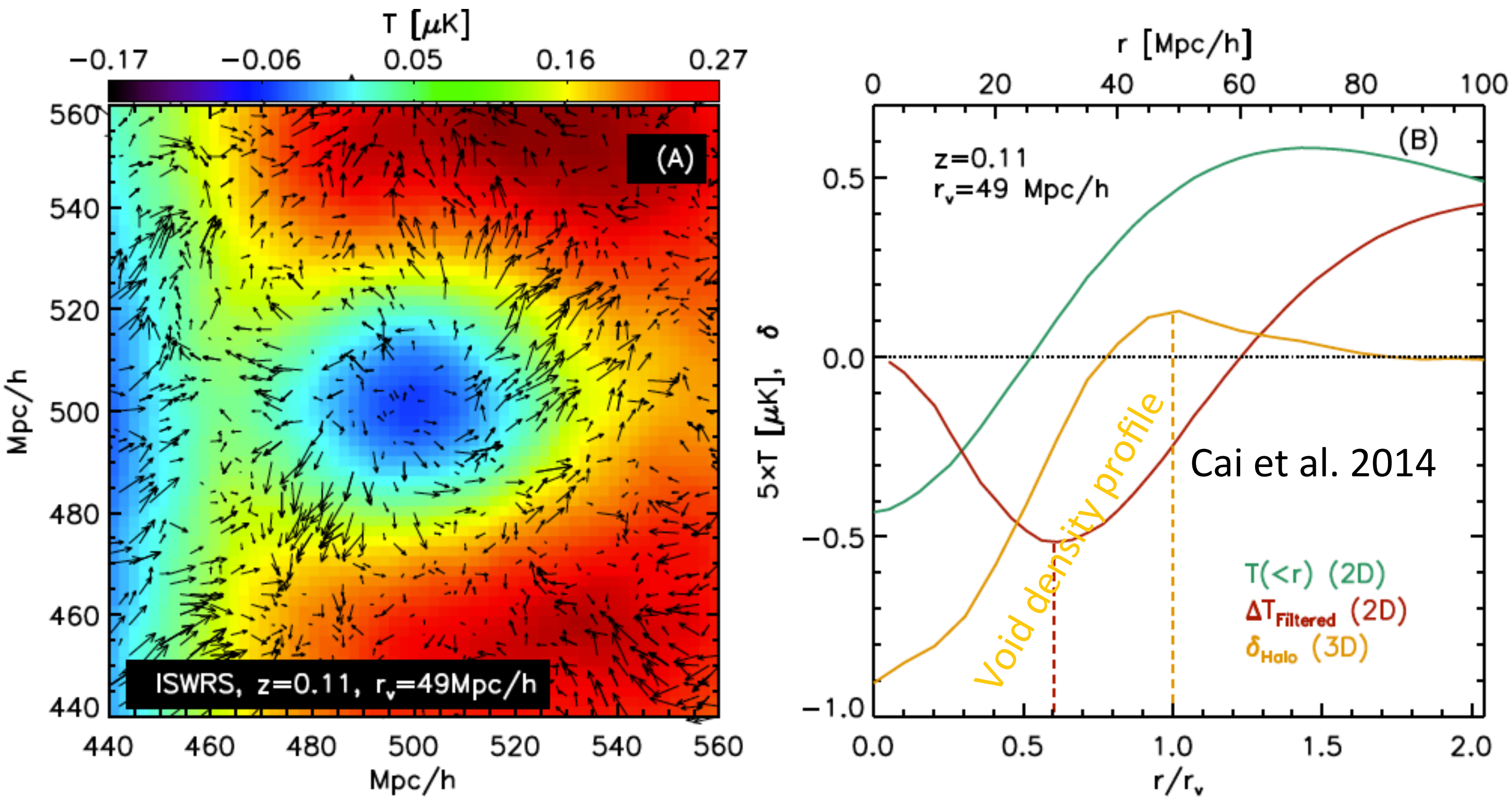






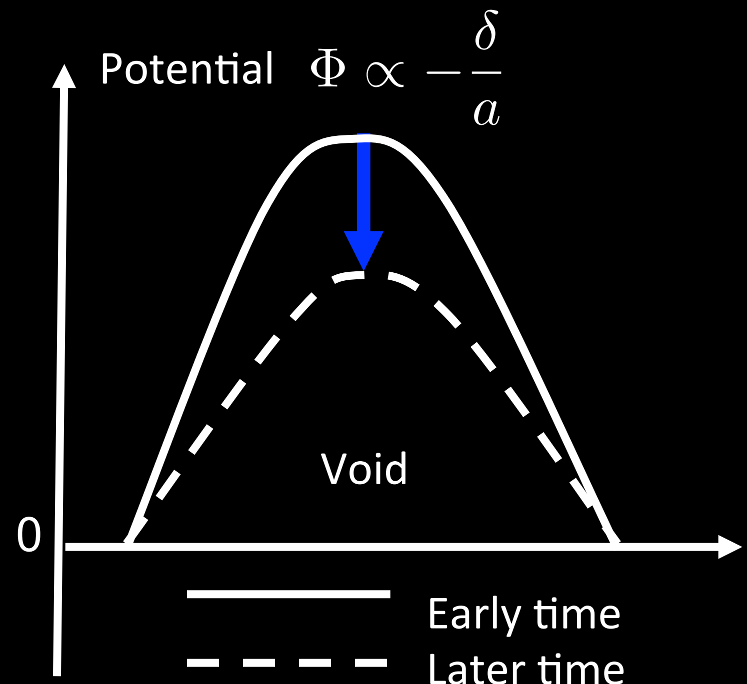
Y. Cai

ISW with voids

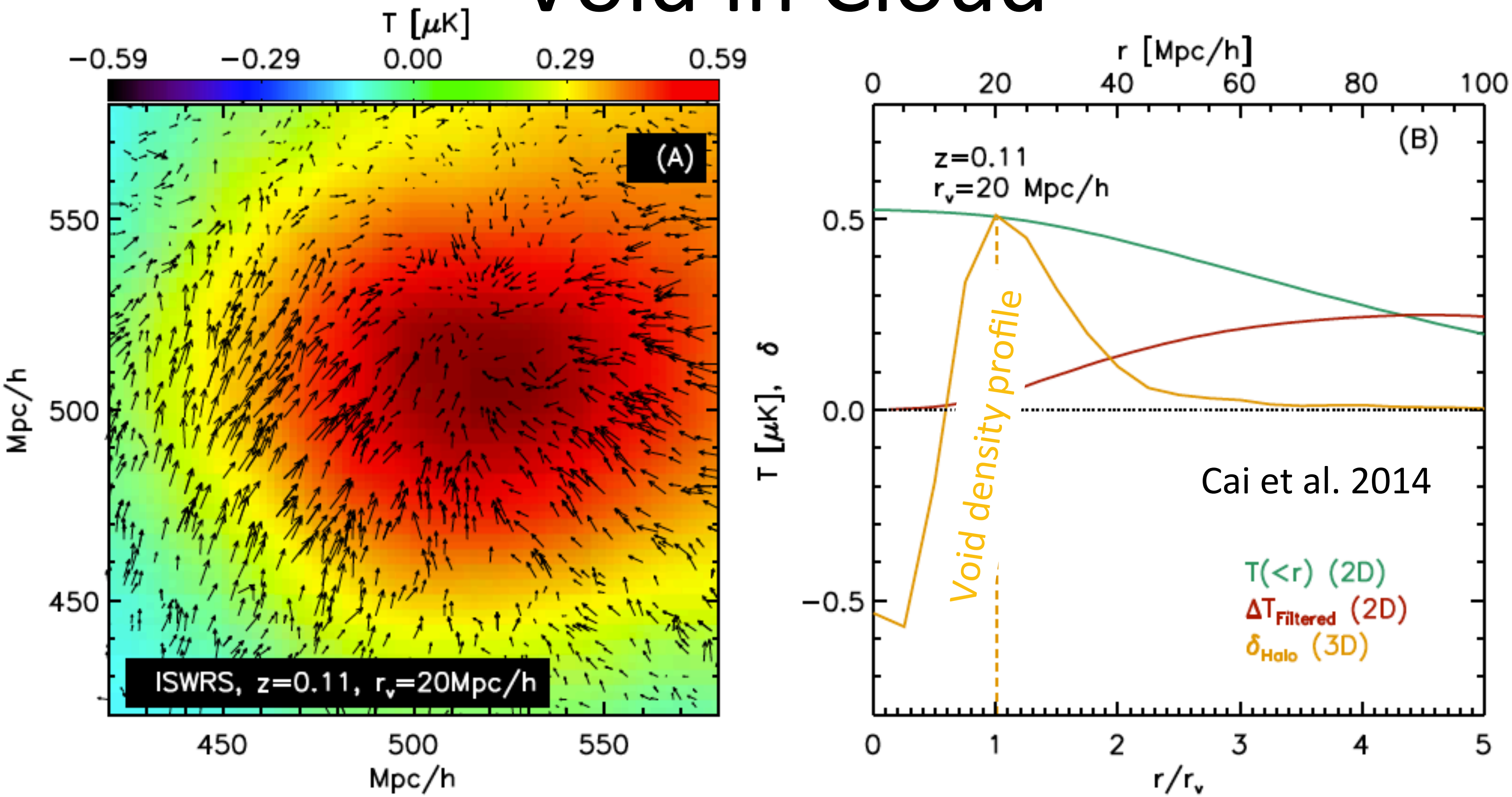


ISW stacking using simulated SDSS DR7 voids

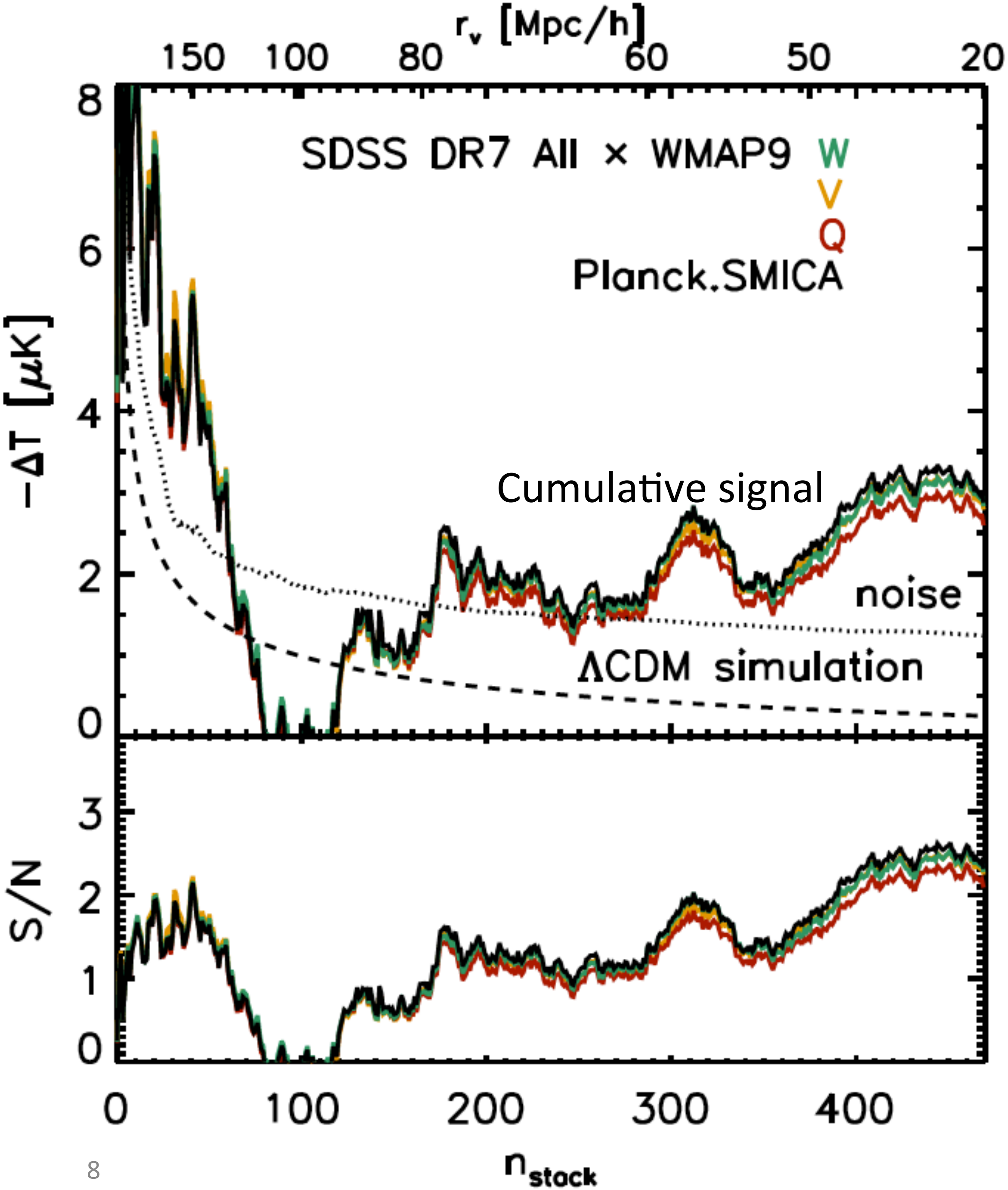
The optimal top-hat filter size is NOT the void radius, but 0.6 of void radius


Potential $\Phi \propto -\frac{\delta}{a}$
0
Void
Early time
Later time

Void in Cloud



- Small voids are more likely to reside in overdense environment;
- Stacking void-in-clouds yield an ISW hot spot, rather than a cold spot!



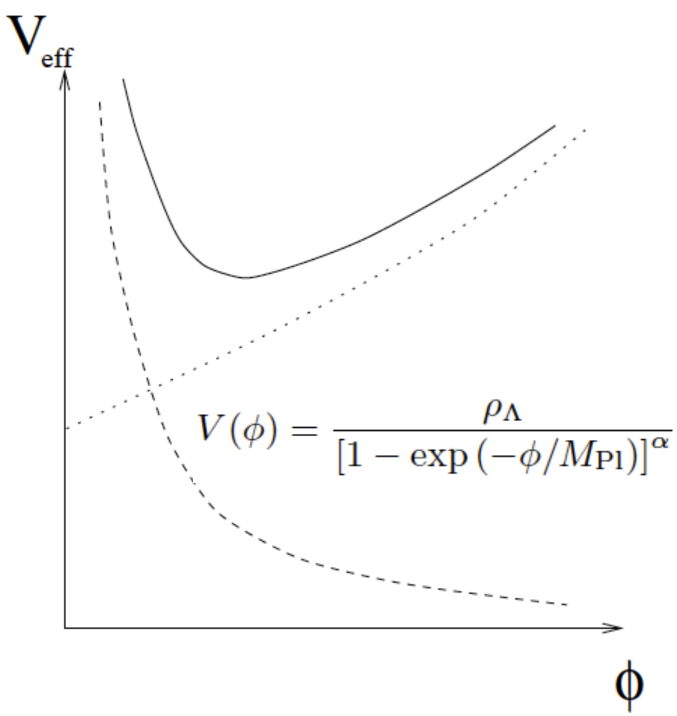
- 1521 voids at 0<z<0.44 from SDSS DR7 galaxy sample
- Clean off 2/3 voids that are likely to be void-in-cloud or noise

2.2σ

Cai et al. 20

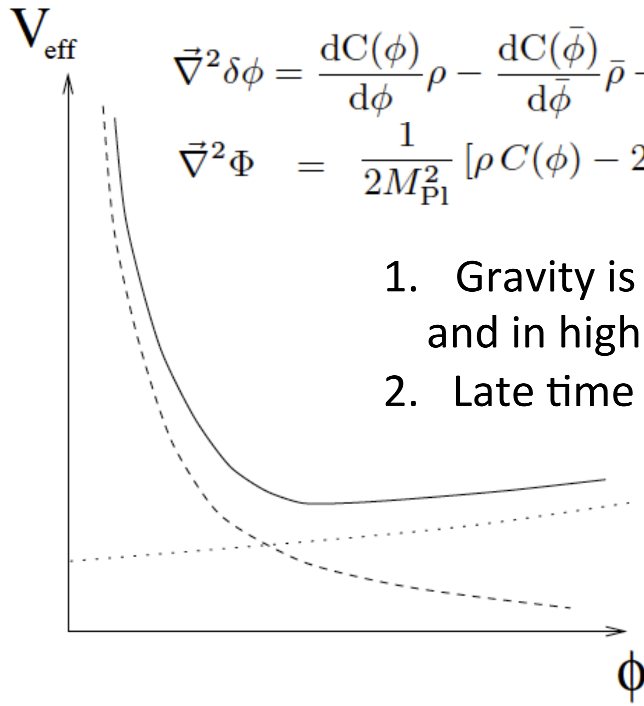
Chameleon model

(Khoury & Weltman 2004)



Large ρ
Small ϕ_{min}
GR, no 5th force

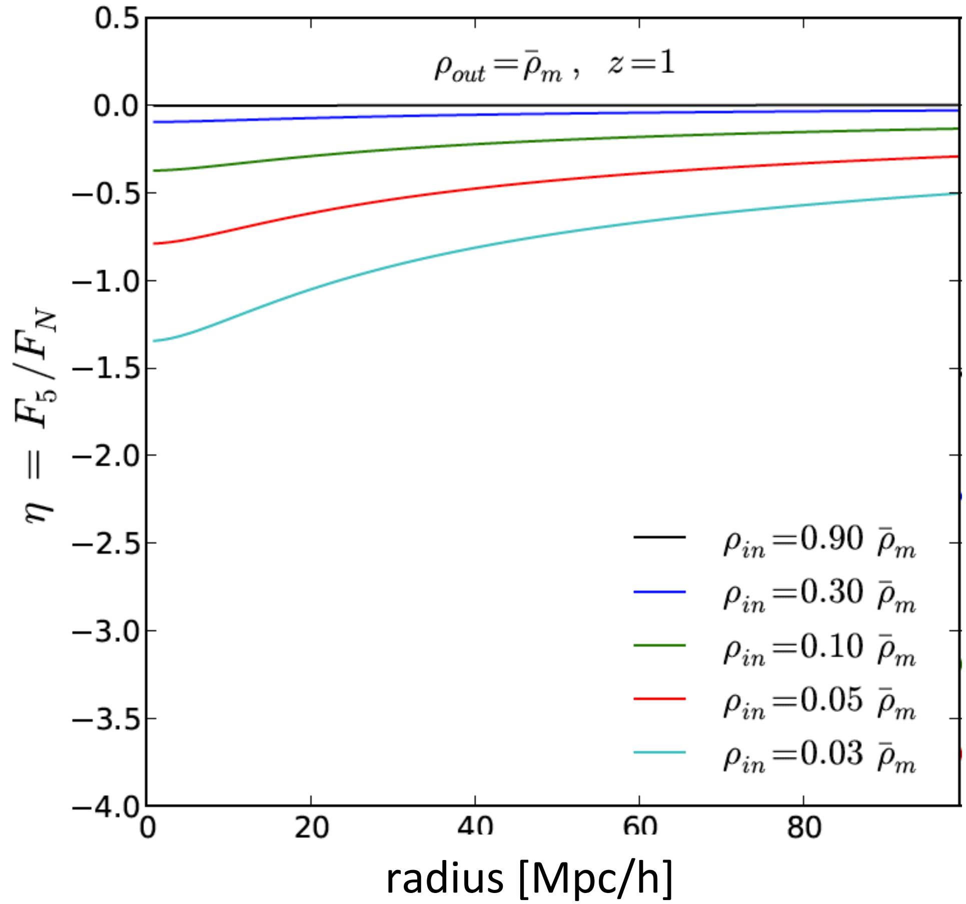
$$\vec{\nabla}^2\delta\phi = \frac{dC(\phi)}{d\phi}\rho - \frac{dC(\bar\phi)}{d\bar\phi}\bar\rho + \frac{dV(\phi)}{d\phi} - \frac{dV(\bar\phi)}{d\bar\phi},$$
$$\vec{\nabla}^2\Phi = \frac{1}{2M_{Pl}^2}[\rho C(\phi) - 2V(\phi)]$$



1. Gravity is the same as GR at high-z and in high density region
2. Late time acceleration like LCDM

Small ρ
Large ϕ_{min}
5th force

The repulsive 5^{th} force in void



Ratio of 5^{th} force VS. Newtonian force

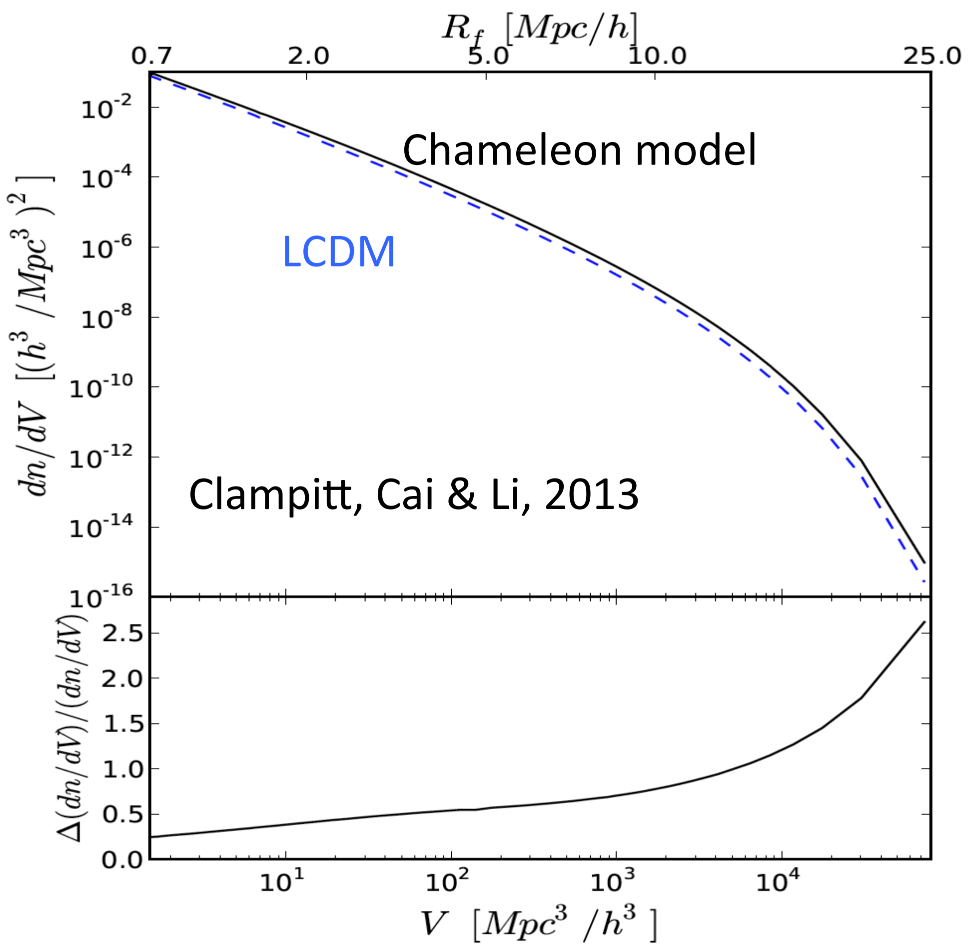
- The 5^{th} force is repulsive in voids
- Its amplitudes is unbound in principle
- Emptier voids have larger $|F_5/F_N|$

$$F_5 = \gamma \frac{\mathrm{d}\,(\phi/M_{\mathrm{Pl}})}{\mathrm{d}\chi}\Big|_{\chi=r}$$

Clampitt, Cai & Li, 2013

- The repulsive force drives voids in MG to grow larger and expand faster

Void abundance



- Void abundance is more sensitive to gravity than the case of halos

f(R) simulations

models	$L_{\rm box}$	number of particles
ΛCDM, F6, F5, F4	$1.5h^{-1}$Gpc	1024^3
ΛCDM, F6, F5, F4	$1.0h^{-1}$Gpc	1024^3
ΛCDM	$250h^{-1}$Mpc	1024^3

F6, F5 and F4 are labels of the Hu-Sawicki f(R) models for $|f_{R0}| = 10^{-6}, 10^{-5}, 10^{-4}$

Spherical voids are found with halos M > 10^13 M_sun/h, $\delta(r < r_v) < -0.8$

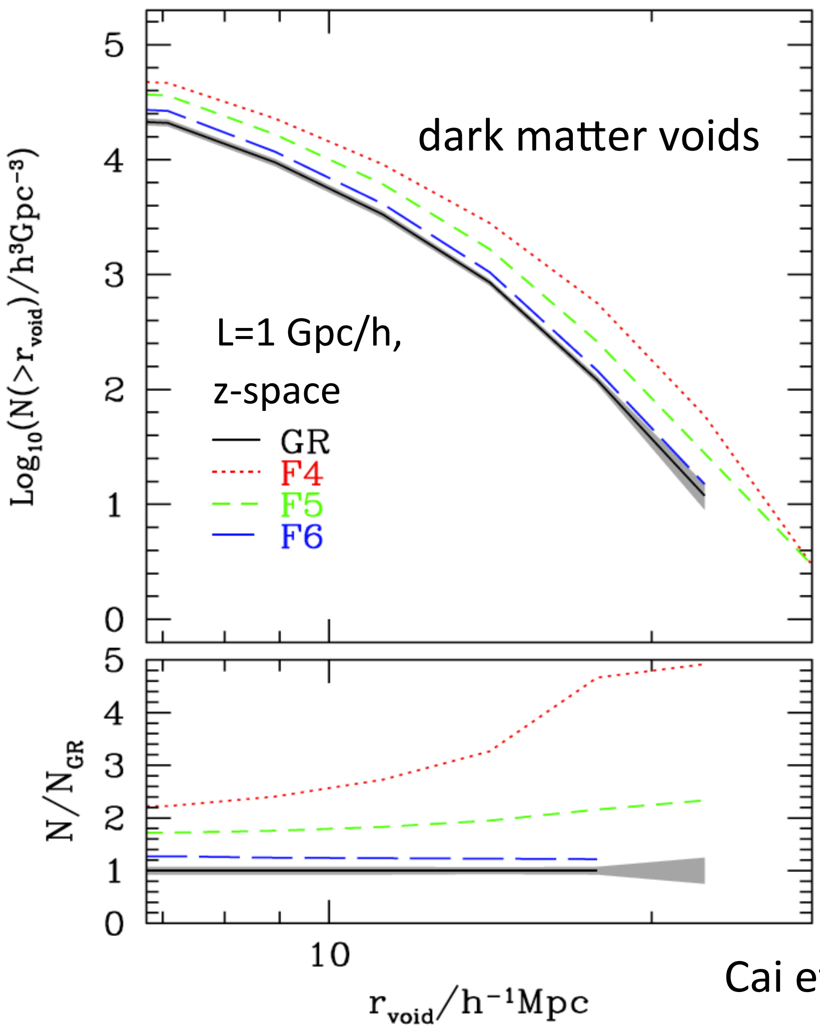
$$\nabla^2 \delta f_R = \frac{1}{3}\left[\delta R(f_R) - 8\pi G \delta\rho\right]$$

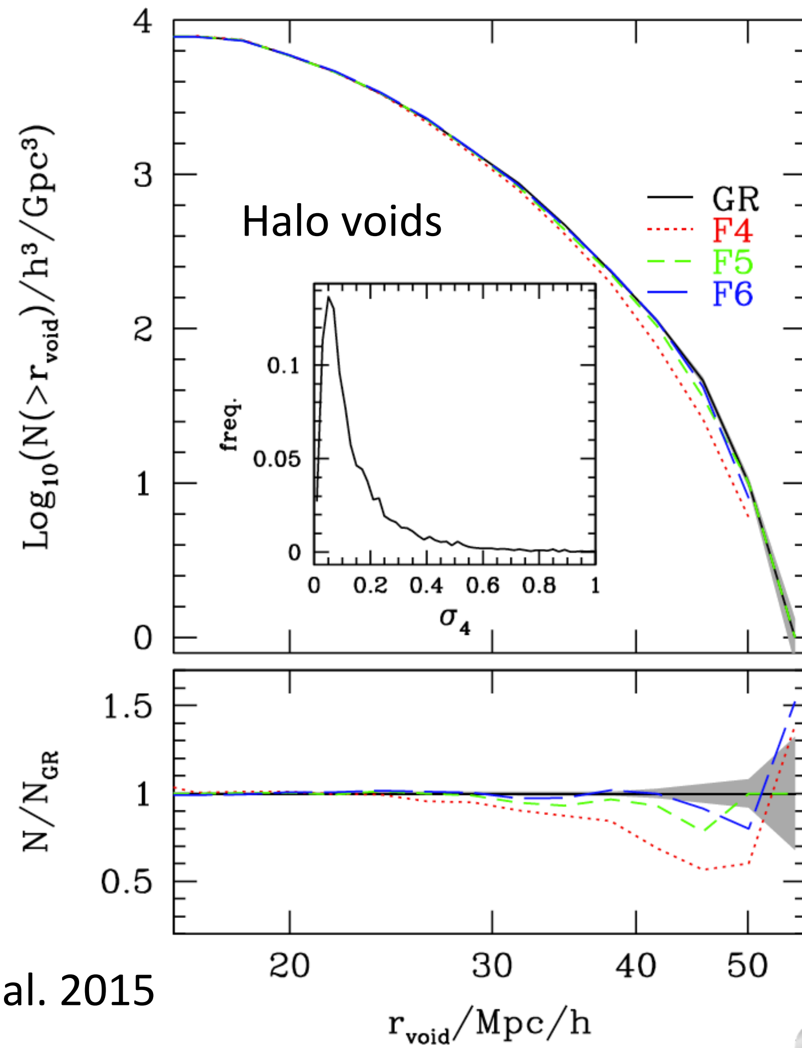
$$\nabla^2 \Psi = \frac{16\pi G}{3}\delta\rho - \frac{1}{6}\delta R(f_R)$$

Li et al. 2013

First order: $f(R) = -2\Lambda - f_{R0}\frac{\bar{R}_0^2}{R}.$

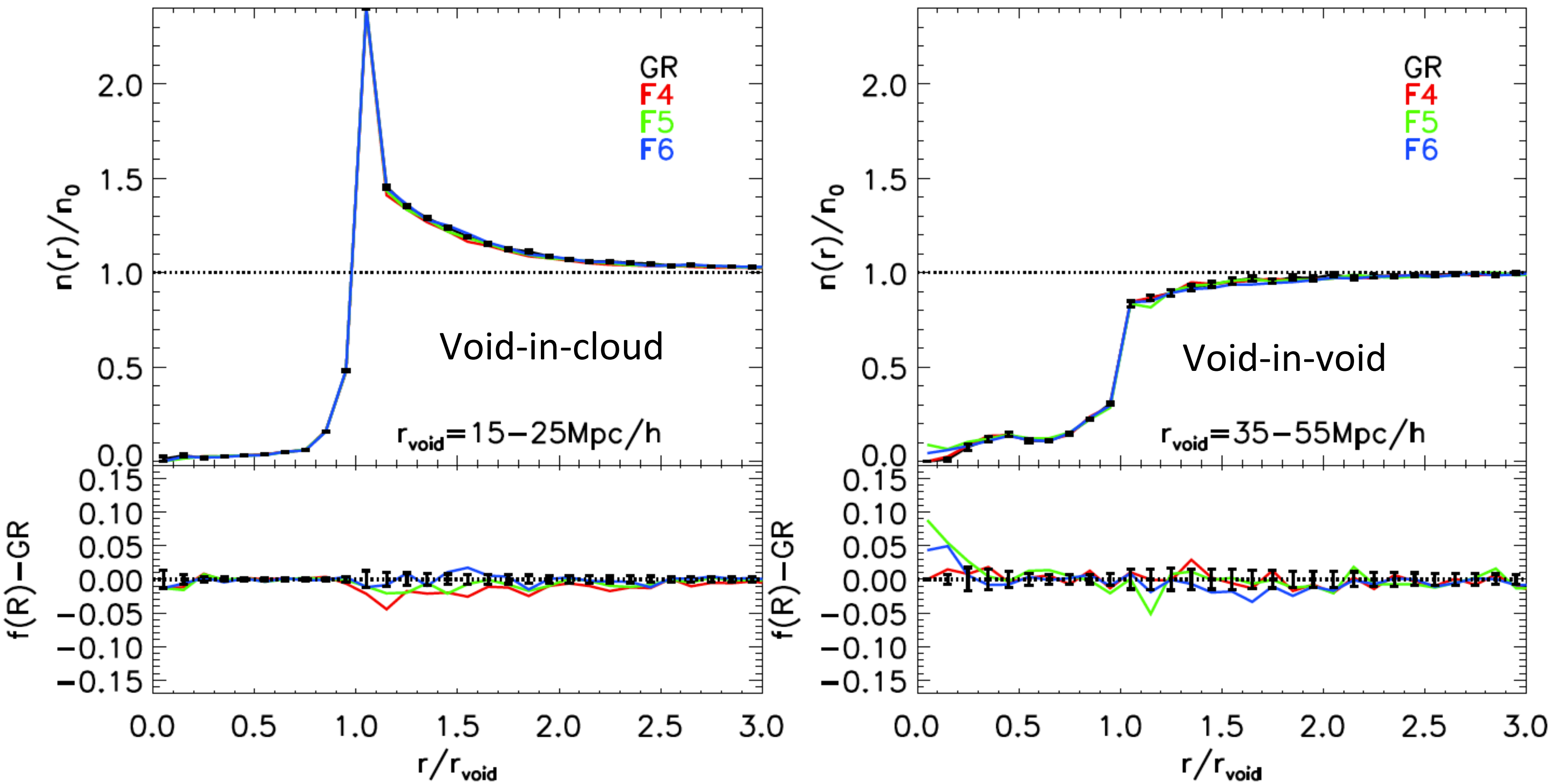
Void abundance





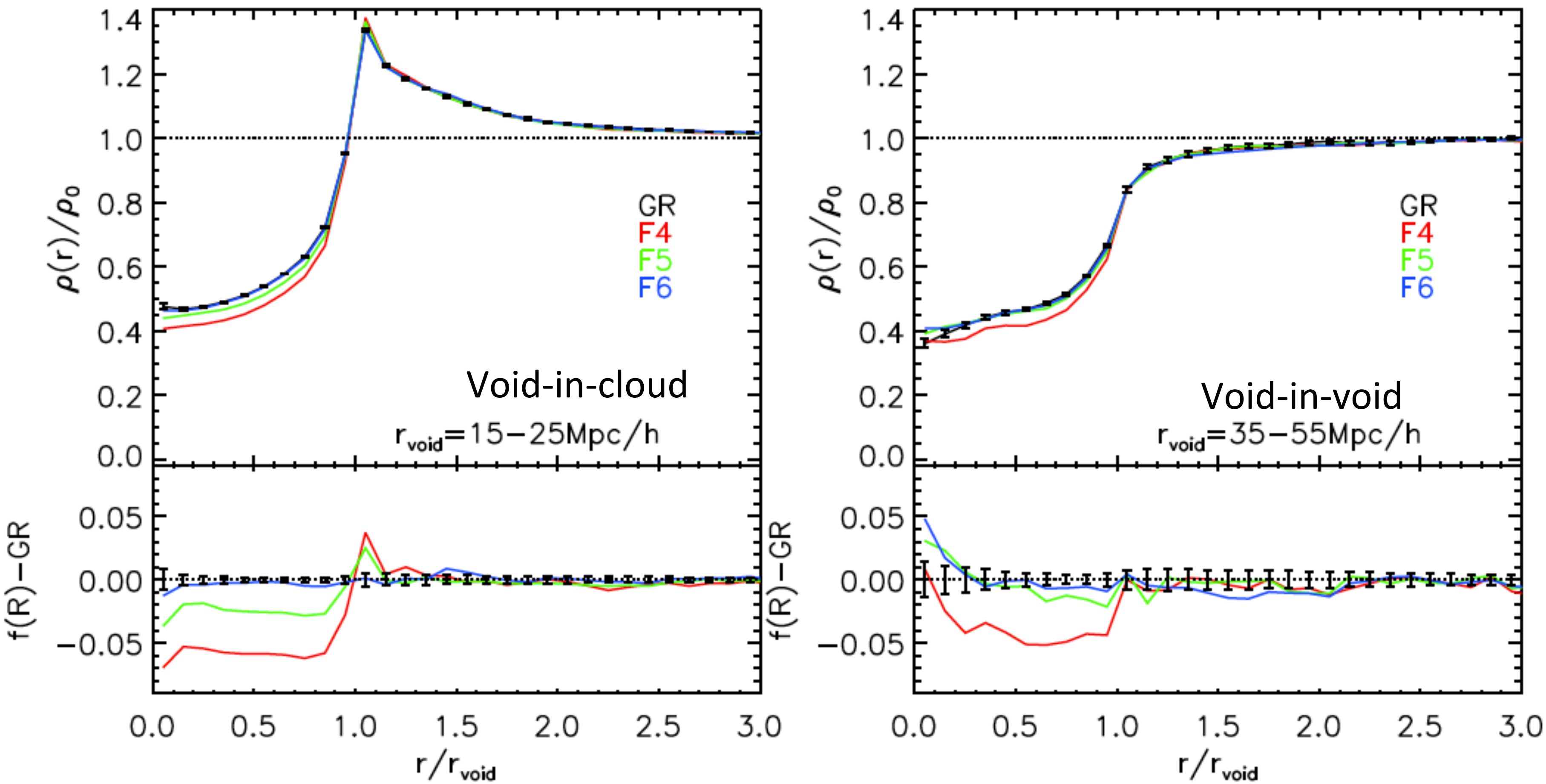
Cai et al. 2015

Void profiles: halo number density



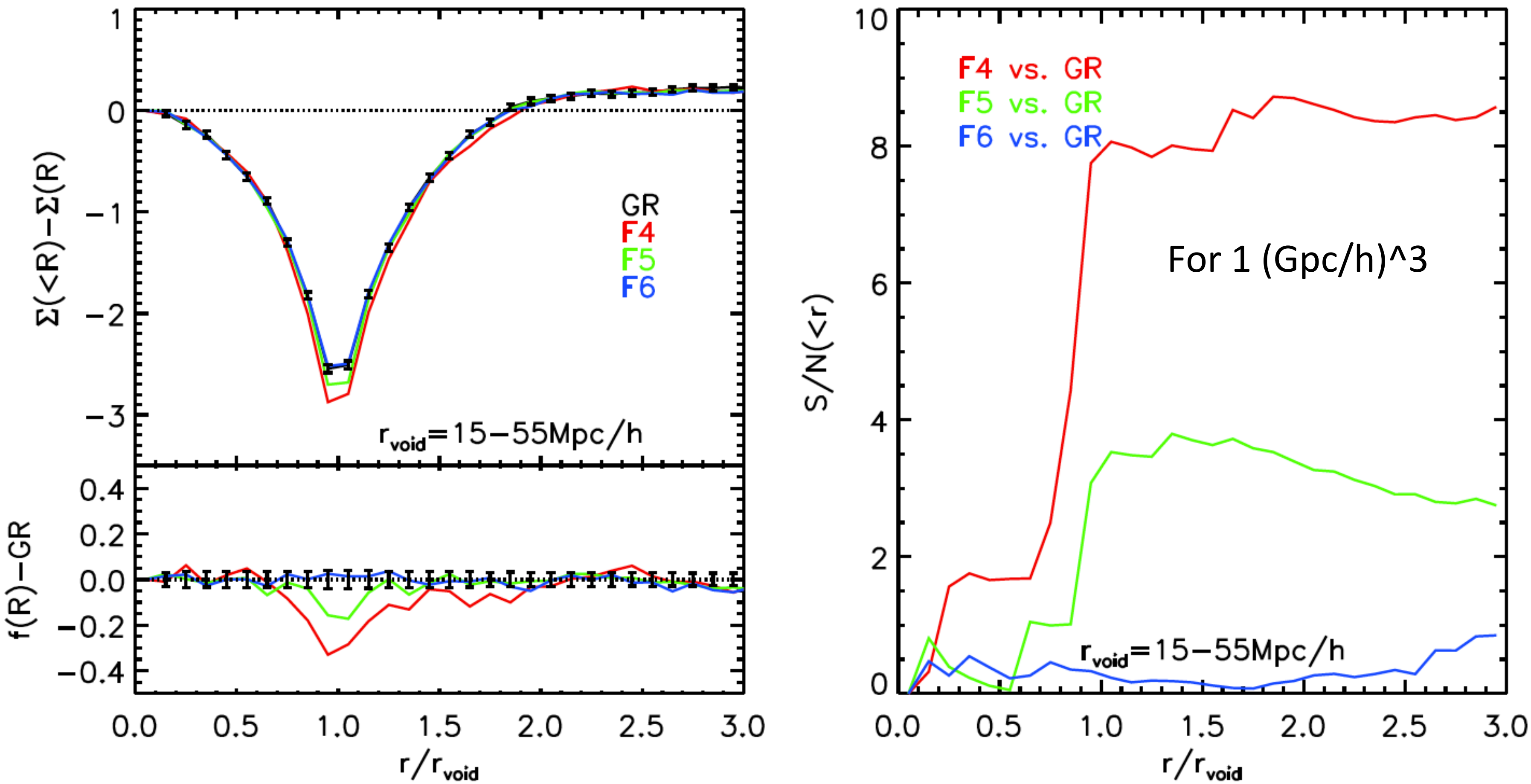
- Halo voids are not distinguishable between f(R) and GR
- Voids are not self-similar (from the spherical over density method)

Void profiles: dark matter density



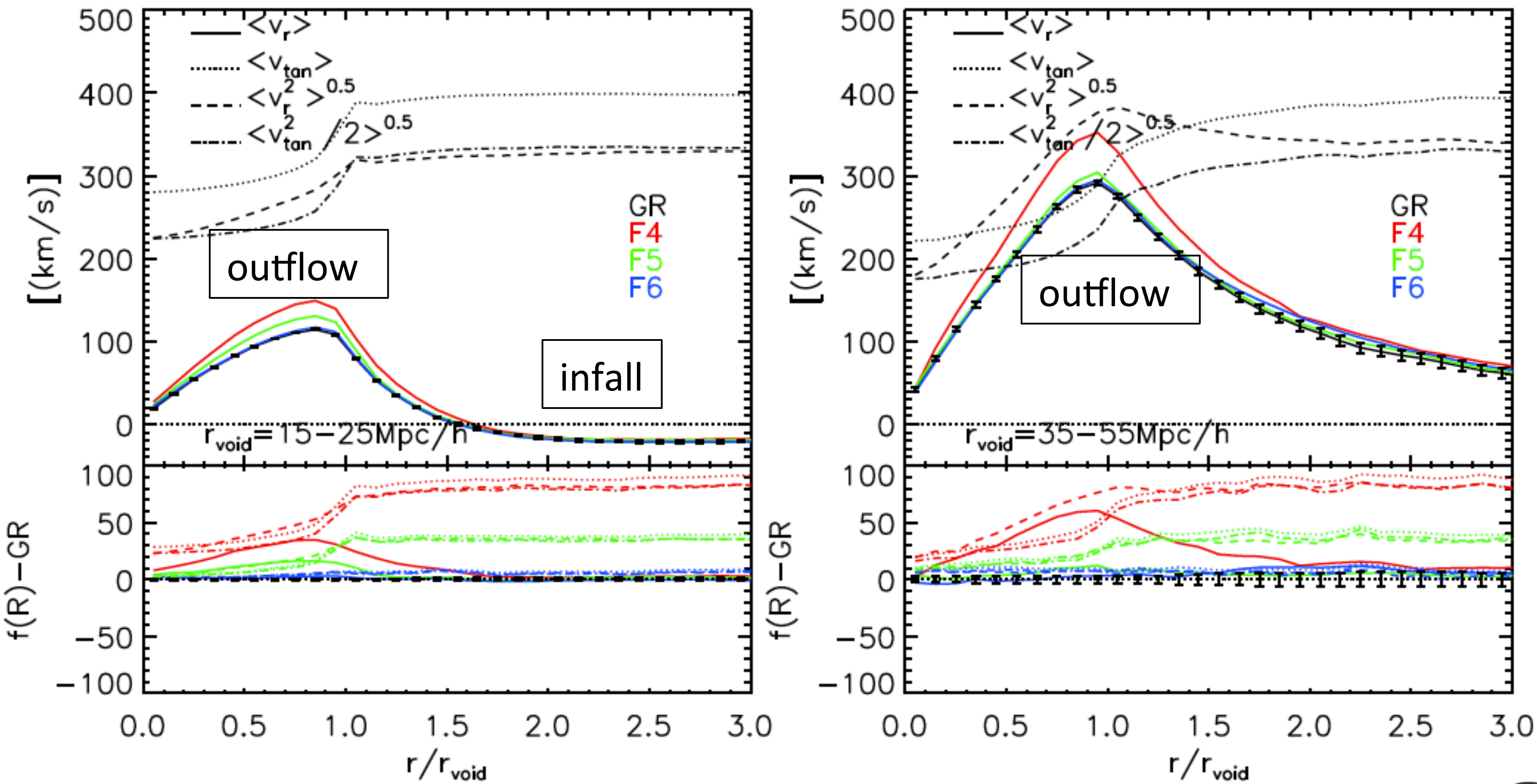
- DM voids are not as empty as halo voids
- f(R) voids are emptier than GR voids

Void profiles from gravitational lensing



$$\Sigma(R) = \bar{\rho} \int [1 + \xi_{vm}(\sigma, \pi) d\pi], \;\; \Delta\Sigma(R) = \gamma_t \Sigma_c = \Sigma(< R) - \Sigma(R)$$

Velocity profiles



Summary

- Repulsive 5th forces in voids in chameleon models
- Voids grow larger and expand faster in MG
- Similar void profiles in halo fields between GR & MG,
- Different dark matter profiles
- Observable: Void lensing, RSD
- Modeling for RSD in GR & MG

ApJ, 2014, 768, 110
MNRAS, 2013, 431, 749
MNRAS, 2015, 451, 5555