Cosmic Voids as Probes for Cosmology

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Outline

- I. Void as a test for modify gravity (MG)

  Void statistics and profiles

- II. Void & the ISW effect:

  Simulations and observations (SDSS DR7)

I. Void as a probe of modify gravity (chameleon model)

Chameleon model

Einstein-Hilber action $S = \int d^4x\sqrt{-g}\left\{\frac{M_{\rm Pl}^2}{2}\left[R + f(R)\right] + \mathcal{L}_m(\psi_i)\right\}$

$$\vec{\nabla}^2\delta\phi = \frac{\mathrm{dC}(\phi)}{\mathrm{d}\phi}\rho - \frac{\mathrm{dC}(\bar{\phi})}{\mathrm{d}\bar{\phi}}\bar{\rho} + \frac{\mathrm{dV}(\phi)}{\mathrm{d}\phi} - \frac{\mathrm{dV}(\bar{\phi})}{\mathrm{d}\bar{\phi}},$$

$$\vec{\nabla}^2\Phi = \frac{1}{2M_{\rm Pl}^2}\left[\rho C(\phi) - 2V(\phi)\right]$$

$$M_{\rm Pl} = 1/\sqrt{8\pi G}$$

$$C(\phi) = \exp(\gamma\phi/M_{\rm Pl}),$$
$$V(\phi) = \frac{\rho_\Lambda}{\left[1 - \exp\left(-\phi/M_{\rm Pl}\right)\right]^\alpha}$$

$$V_{\rm eff}(\phi) = V(\phi) + \rho C(\phi)$$

$V(\phi) \sim \rho_\Lambda$ At the late time

$2\gamma^2 = 1/3$ Like in f(R)

$$\alpha = 10^{-6}$$

$$f(R) = -M^2\frac{c_1\left(-R/M^2\right)^n}{c_2\left(-R/M^2\right)^n + 1}$$

$$M^2 \equiv 8\pi G\bar{\rho}_{m0}/3 = H_0^2\Omega_m$$

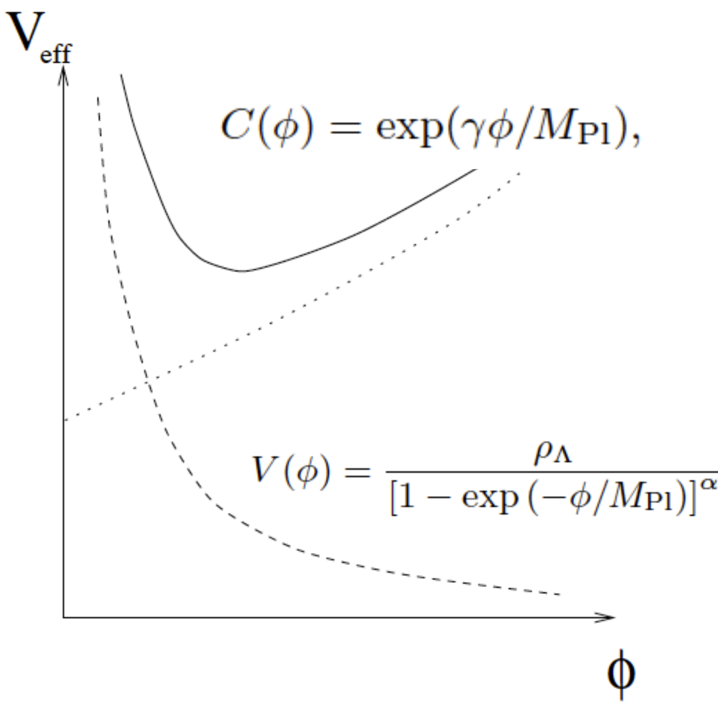
$$|f_{R0}| = 10^{-6}, 10^{-5}, 10^{-4}$$

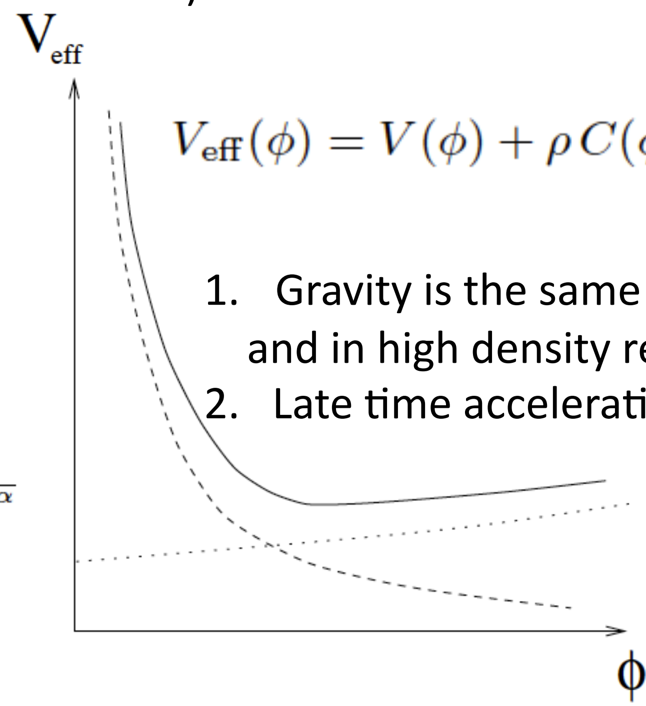
(Hu & Sawicki 2007)

Li & Zhao (2009, 2010); Li & Barrow (2011); Li & Efsthathiou 2012;

Chameleon model

(Khoury & Weltman 2004)



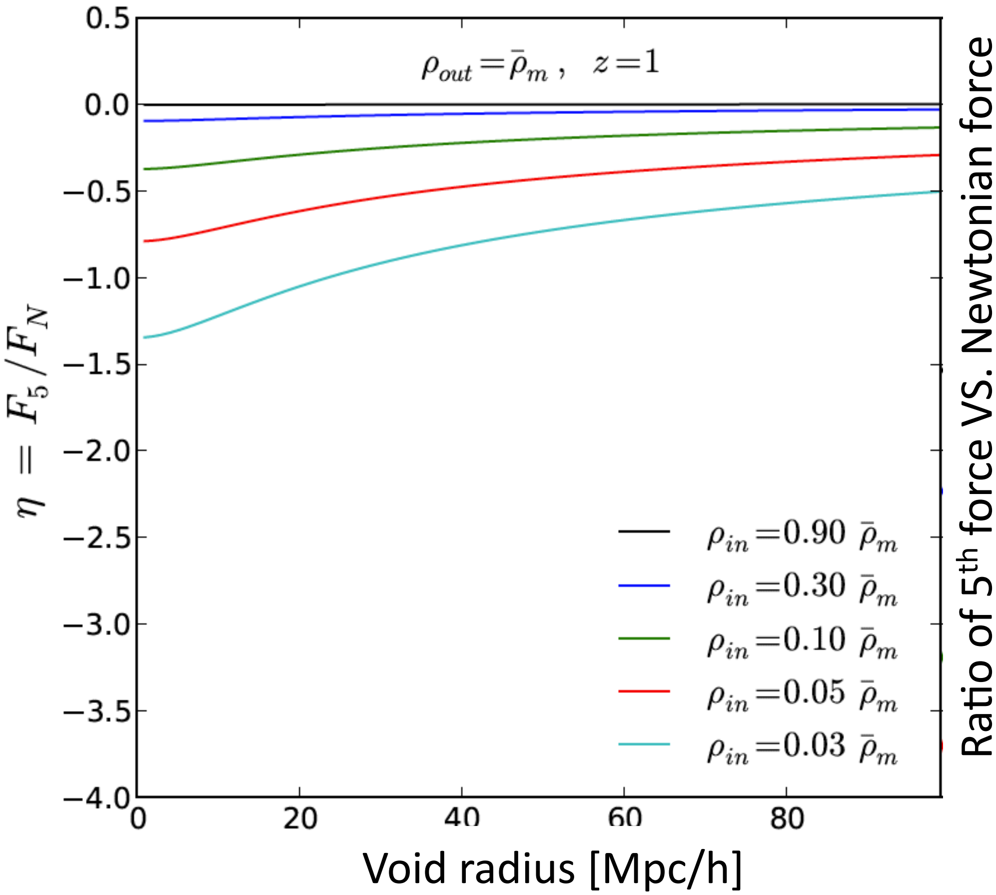


1. Gravity is the same as GR at high-z and in high density region
2. Late time acceleration like LCDM

Large ρ
Small ϕ_{min}
GR

Small ρ
Large ϕ_{min}
Large 5th force

The repulsive 5th force in void



- The 5^{th} force is repulsive in voids
- Its amplitudes is unbound in principle
- In halos, it is no more than 1/3 of Newtonian force
- Emptier voids have larger $|F_5/F_N|$

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

Clampitt, Cai & Li, 2013

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

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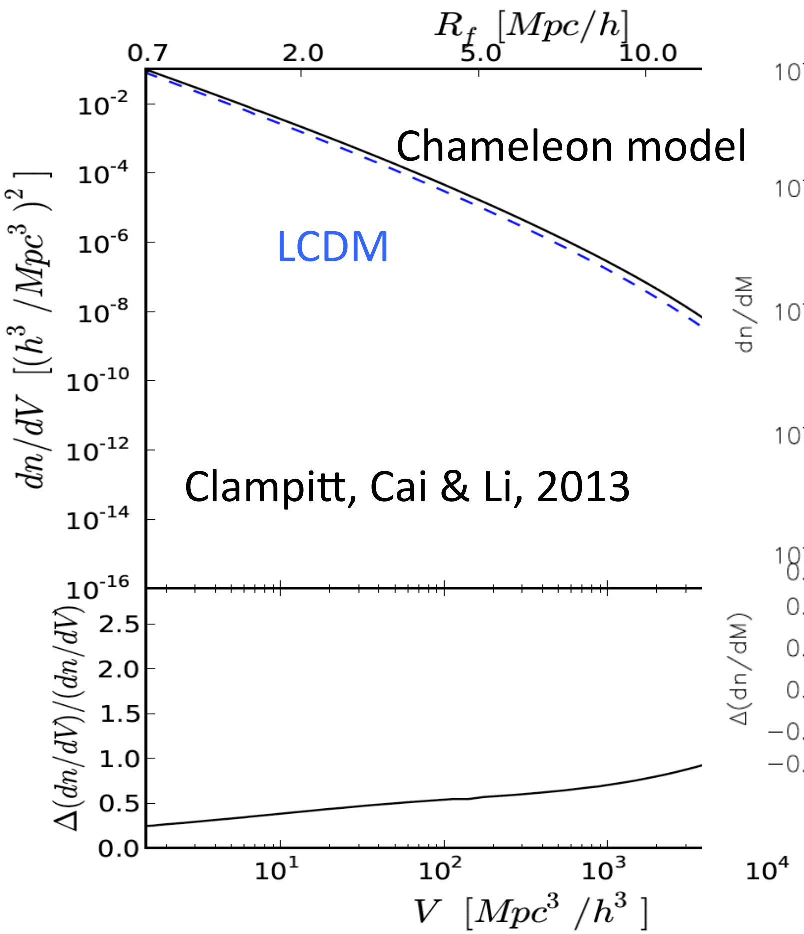
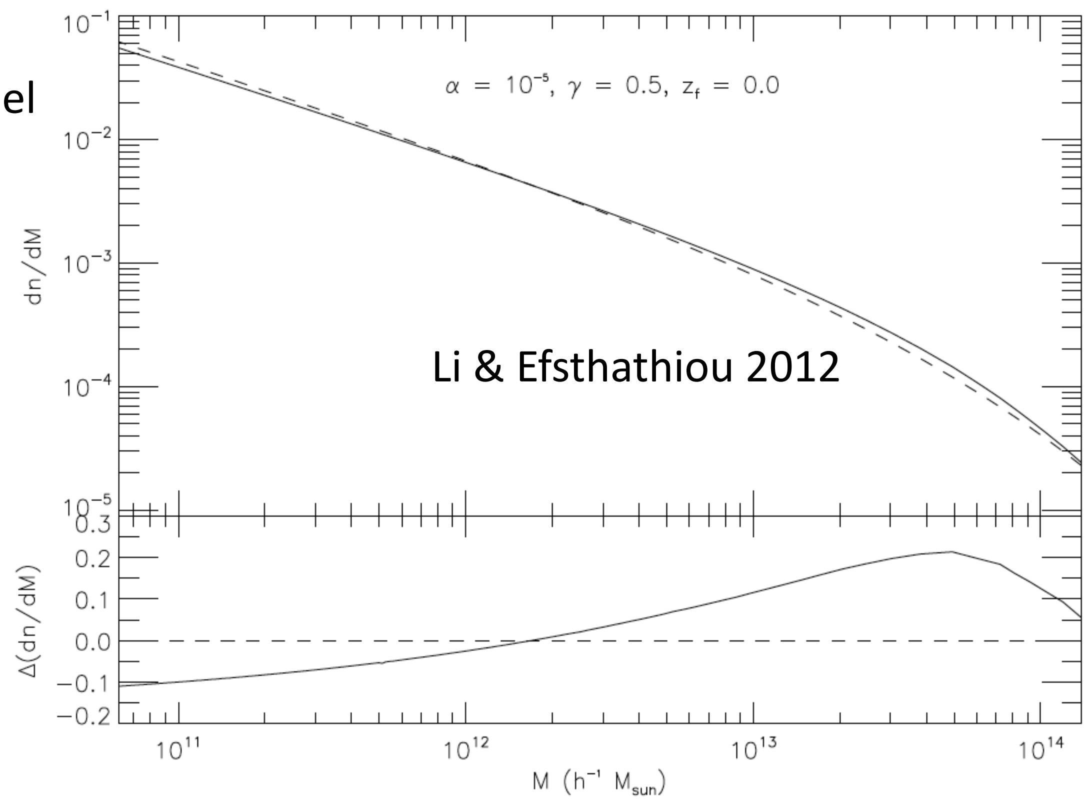
Void abundance





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

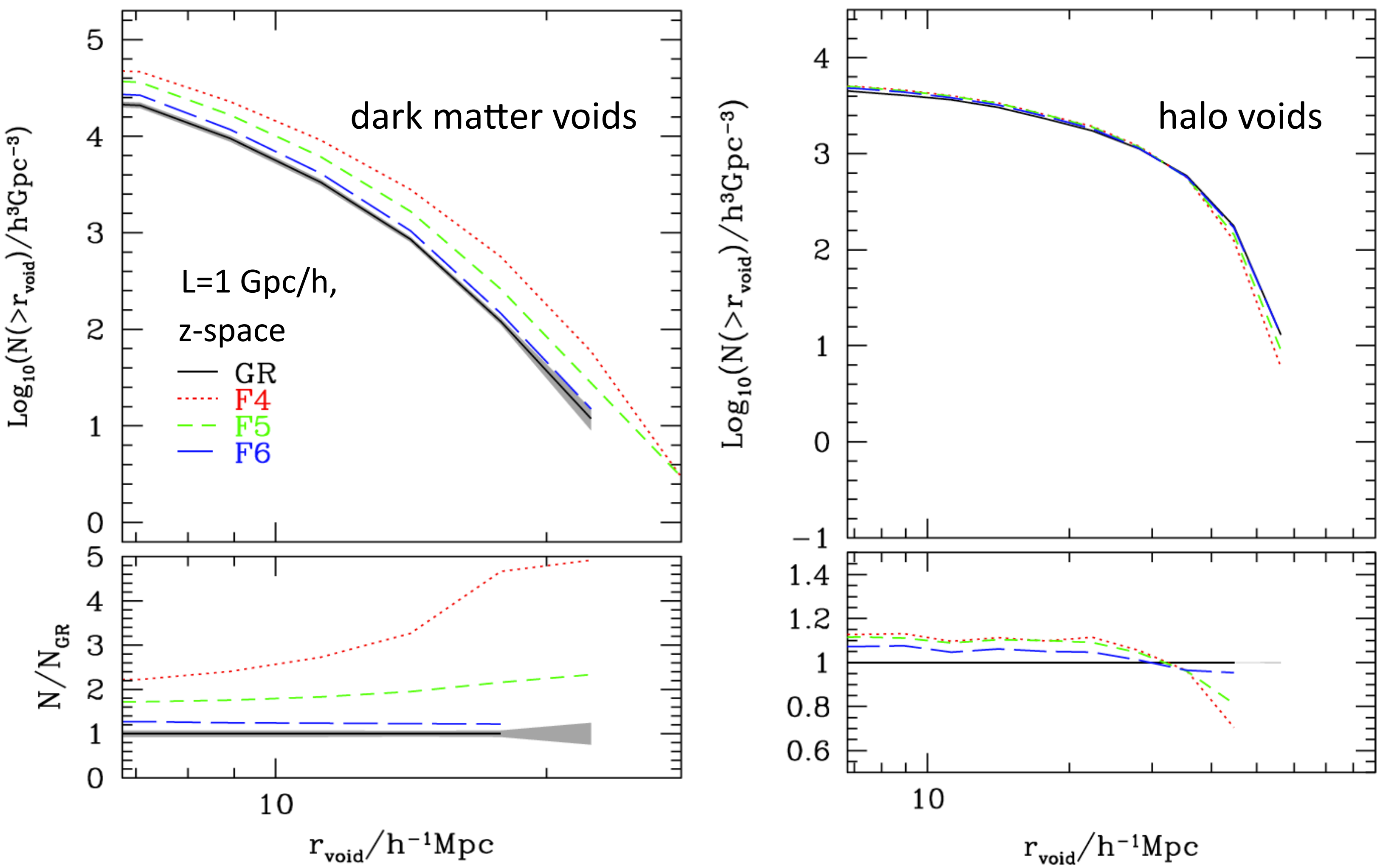
f(R) simulations

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

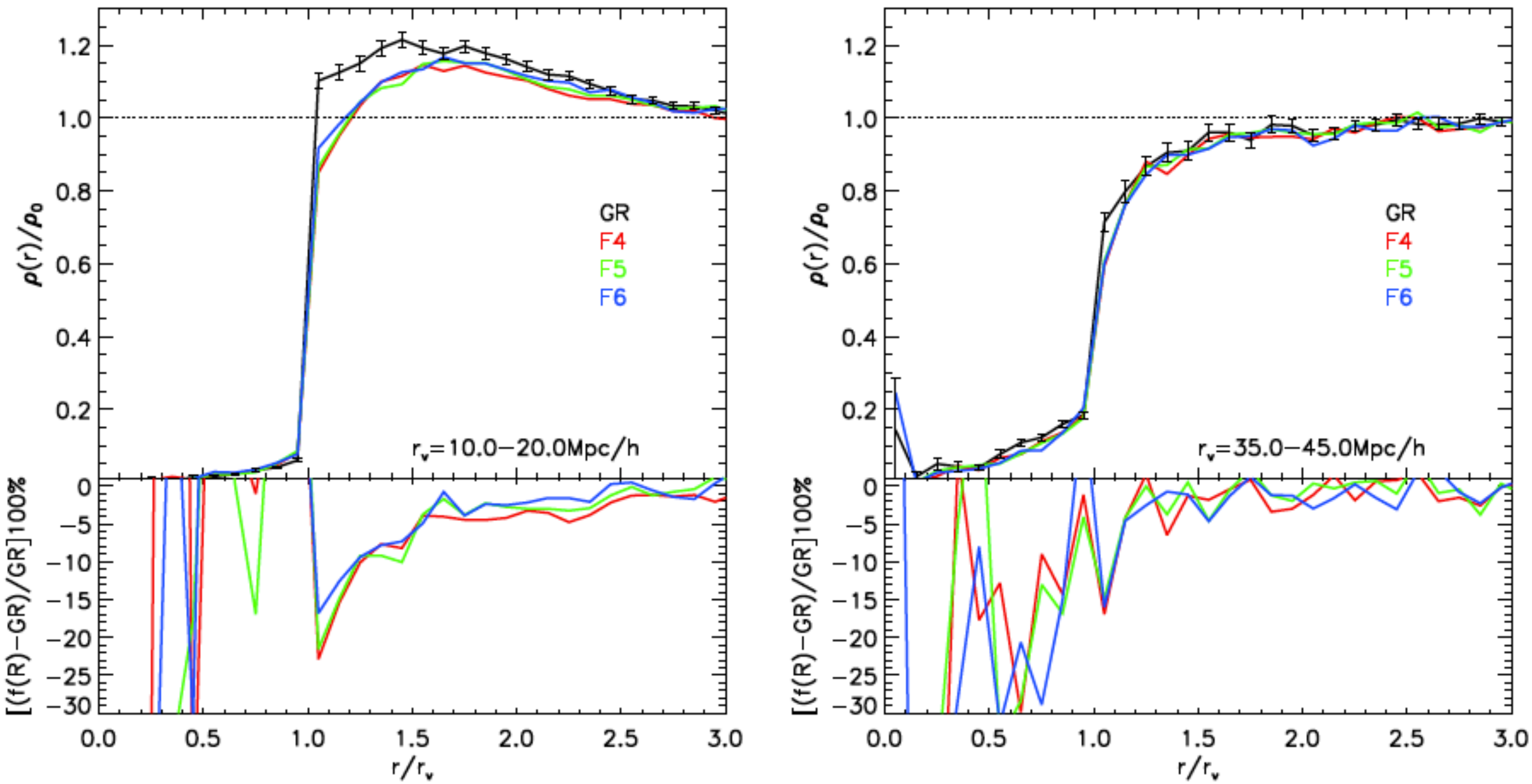
F6, F5 and F4 are labels of the Hu-Sawicki f(R) models for $|f_{R0}| = 10^{-6}, 10^{-5}, 10^{-4}$

Spherical voids are found with halos M > 10^13 M_sun/h, $\delta(r < r_v) < 0.2$

Void abundance

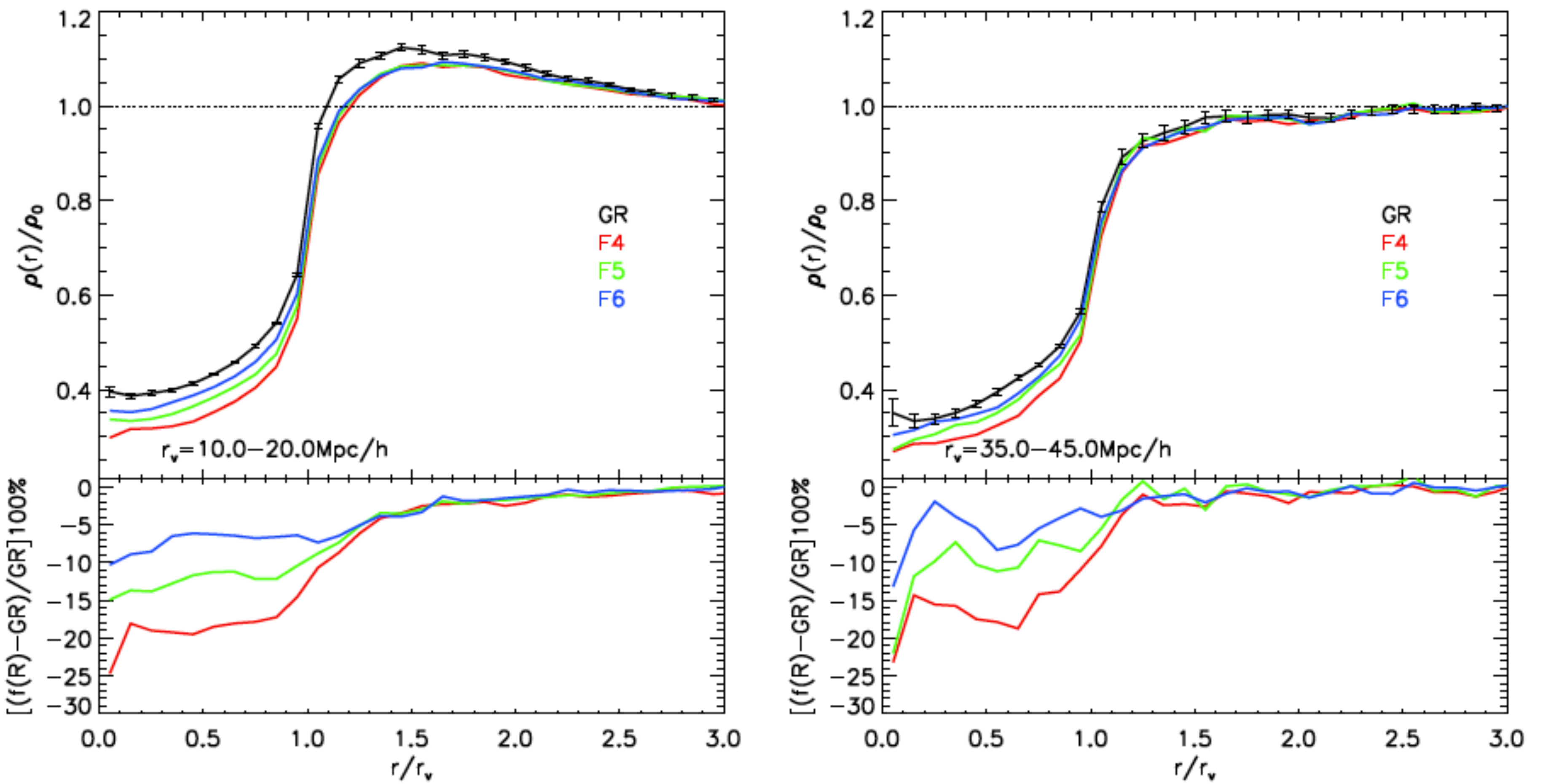


Void profiles: halo number density



Voids are not quite self-similar (from the spherical over density method)
5-20% differences in halo number density profiles,

Void profiles: dark matter density

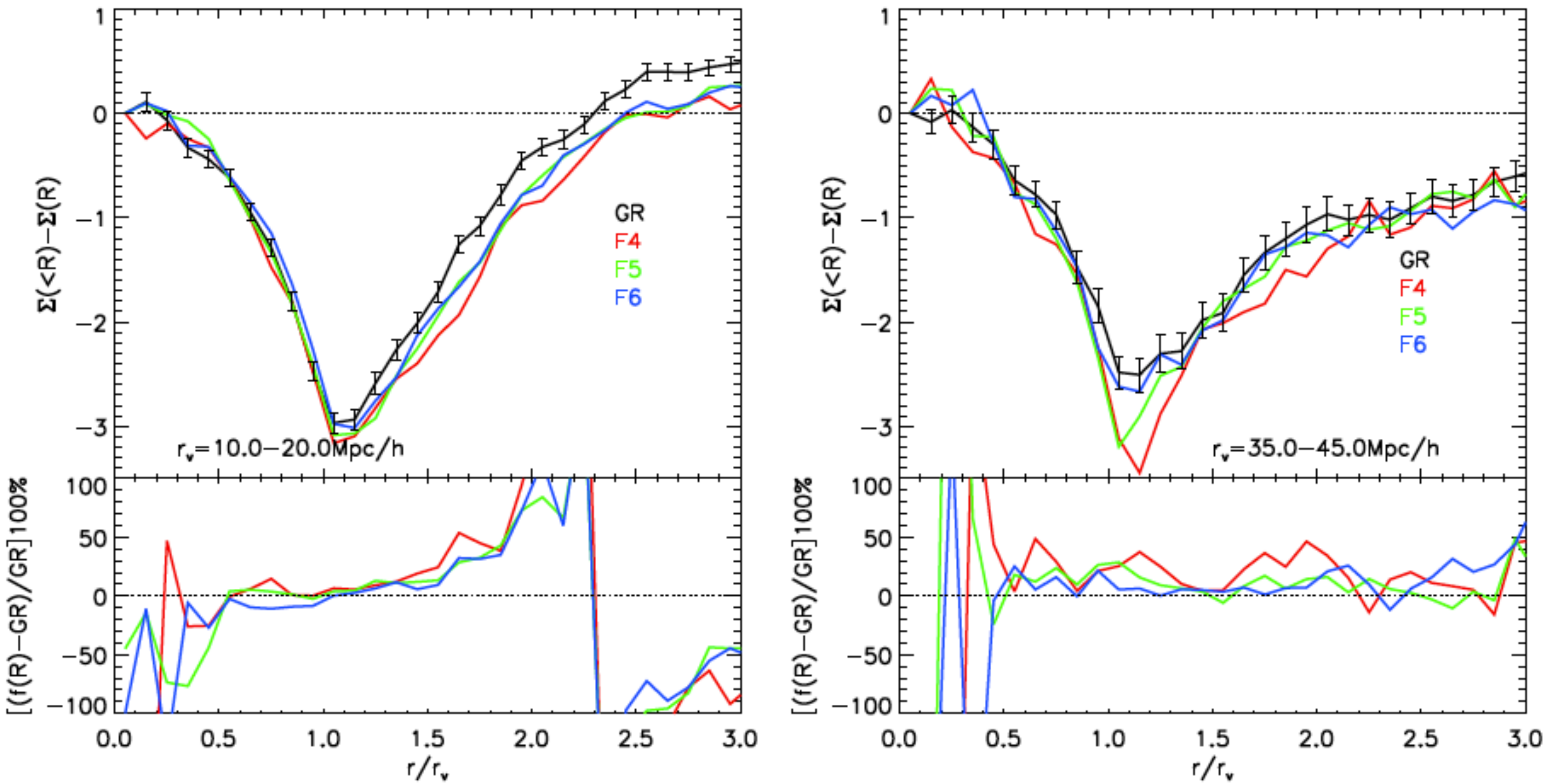


DM voids are not as empty as halo voids, but still very empty

5-20% differences in DM density profiles

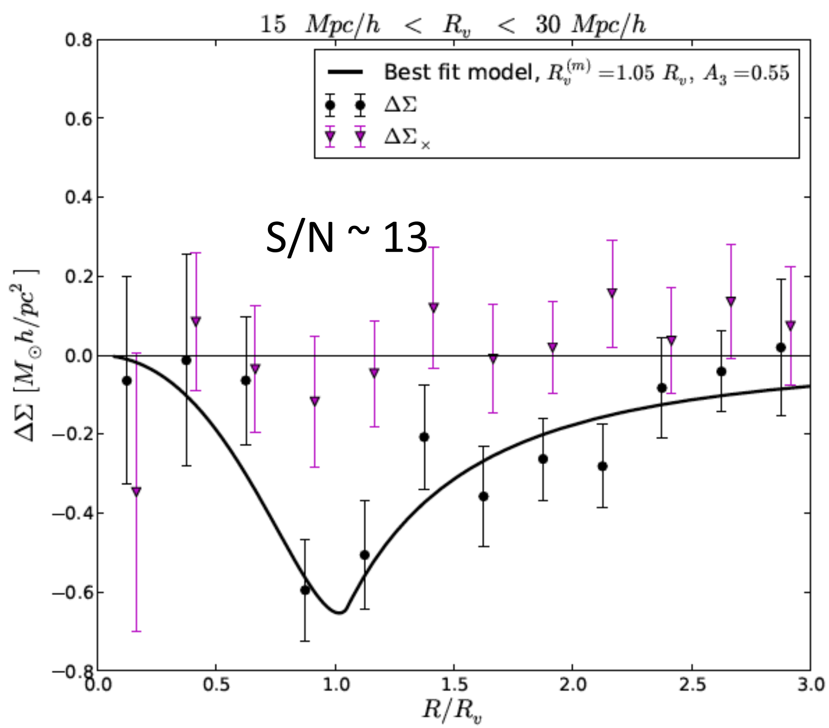
MG voids are emptier

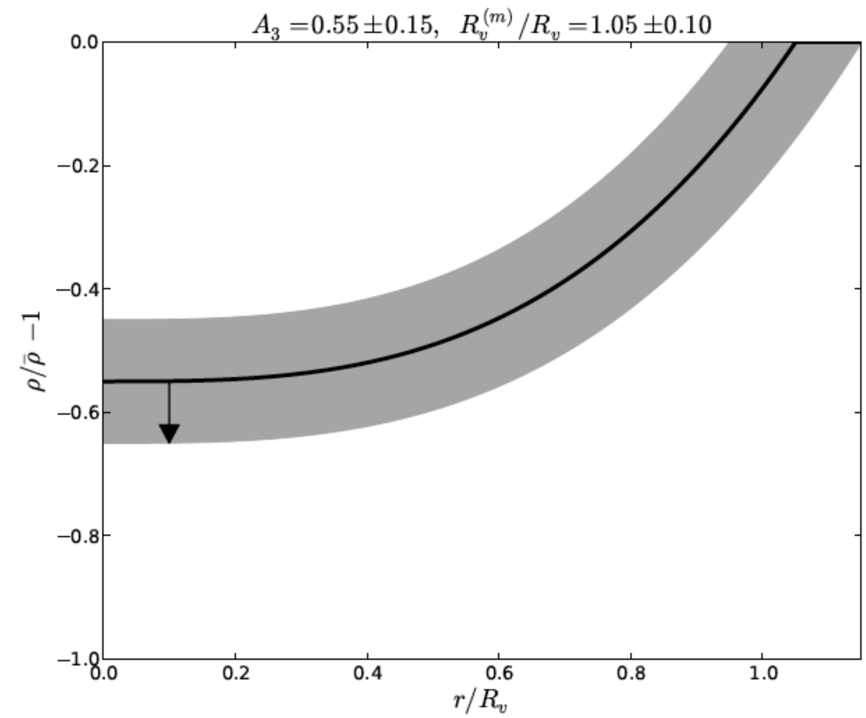
Lensing tangential shear profiles



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

Void profiles from from gravitational lensing of voids in SDSS-DR7 LRG

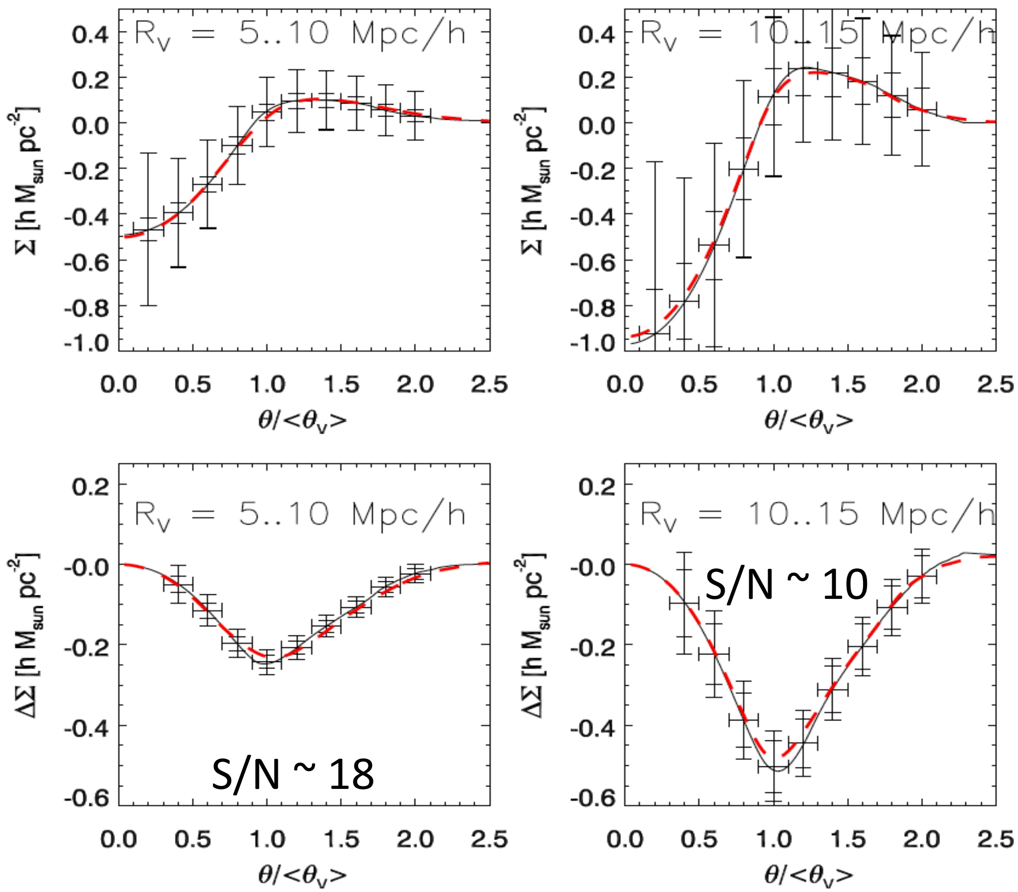




Voids @ 0.16 < z < 0.37, A = 8000 deg^2

Clampitt & Jain 2014 (arXi:1404.1834)

Void profiles from lensing



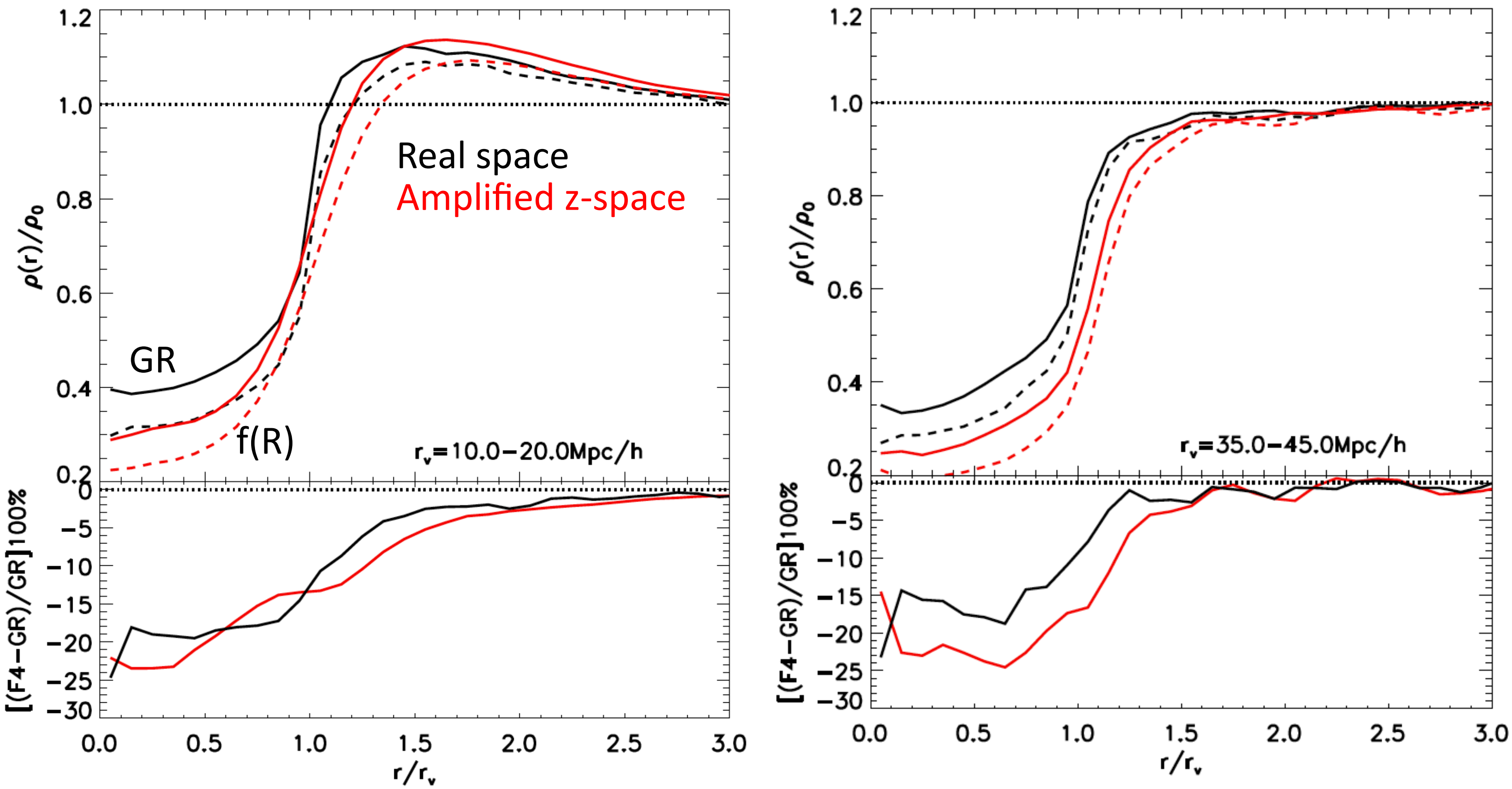
Krause et al. (2013, ApJ 762L, 20K)

Voids @ 0.4 < z < 0.6,
A = 5000 deg^2

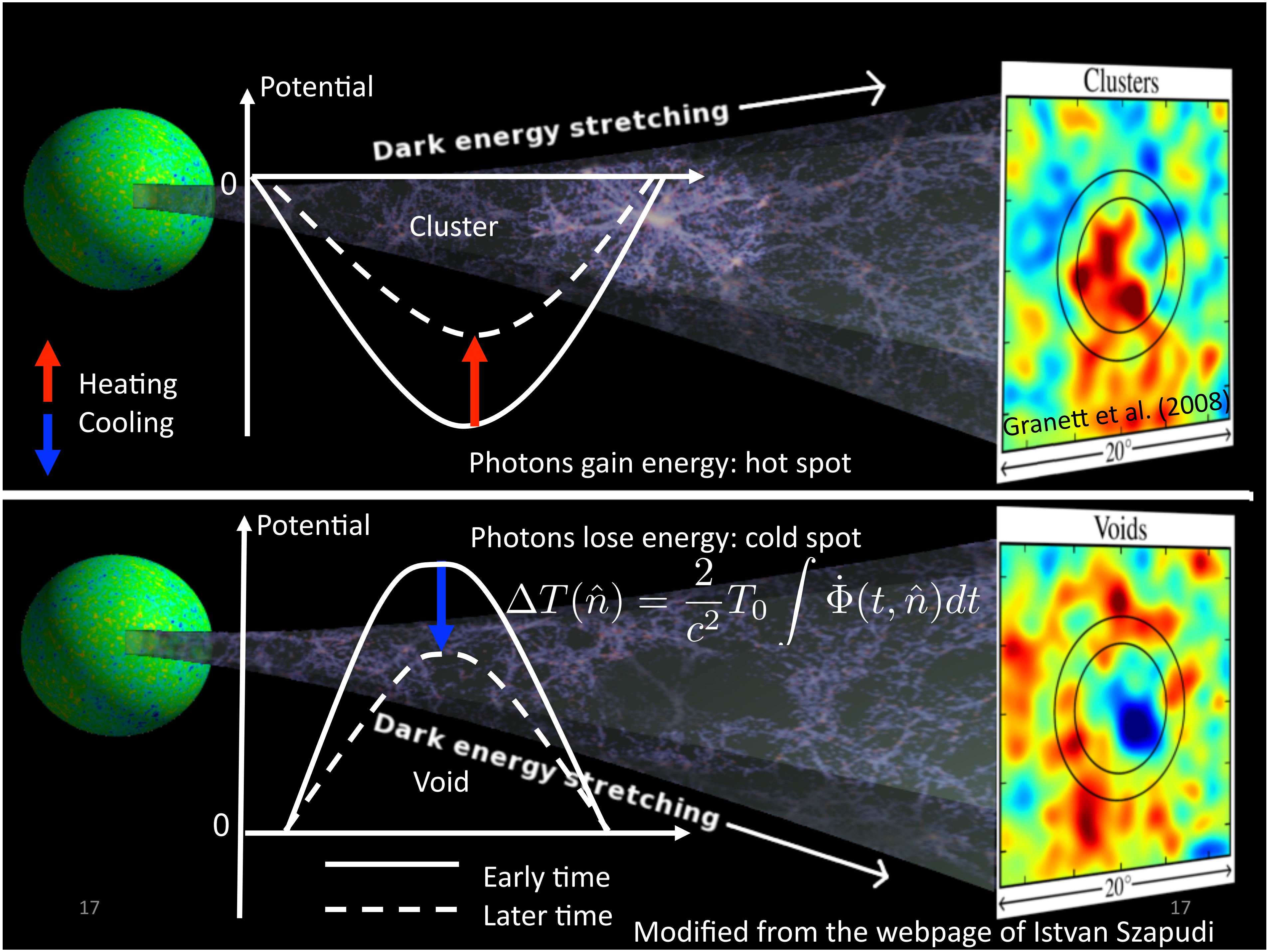
Lensing source galaxies:
mean z ~ 1,
A = 5000 deg^2
N_g = 12 / arcmin^2
Shape noise ~ 0.3

EUCLID: S/N ~ 33 S/N ~ 13

Void profiles in z-space

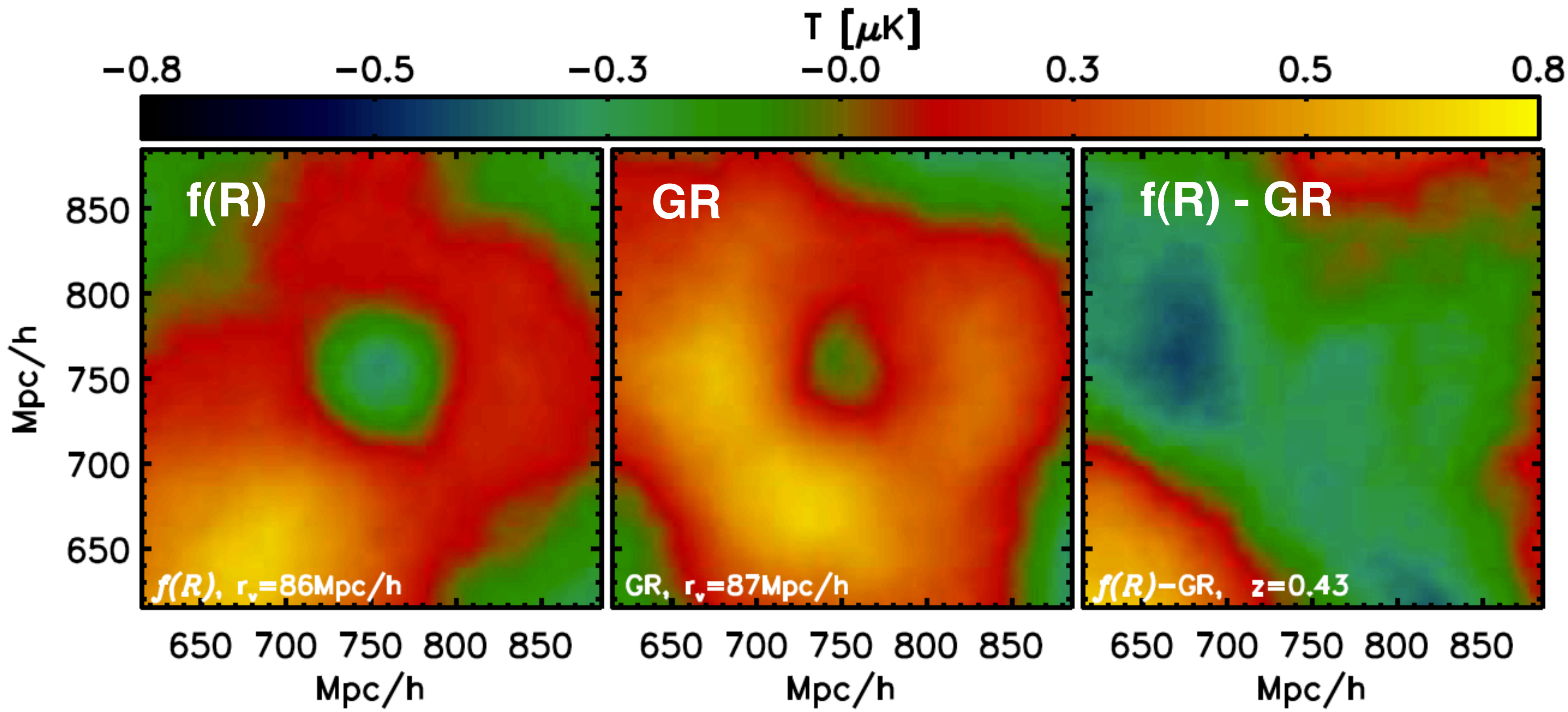


II. ISW from stacking of voids and superclusters



Potential
Dark energy stretching
0
Cluster
Clusters
Heating
Cooling
Photons gain energy: hot spot
Granett et al. (2008)
20°
Potential
Photons lose energy: cold spot
$\Delta T(\hat{n}) = \frac{2}{c^2} T_0 \int \dot{\Phi}(t, \hat{n}) dt$
Voids
Dark energy stretching
Void
0
Early time
Later time
20°
Modified from the webpage of Istvan Szapudi

Stacking voids for the ISW

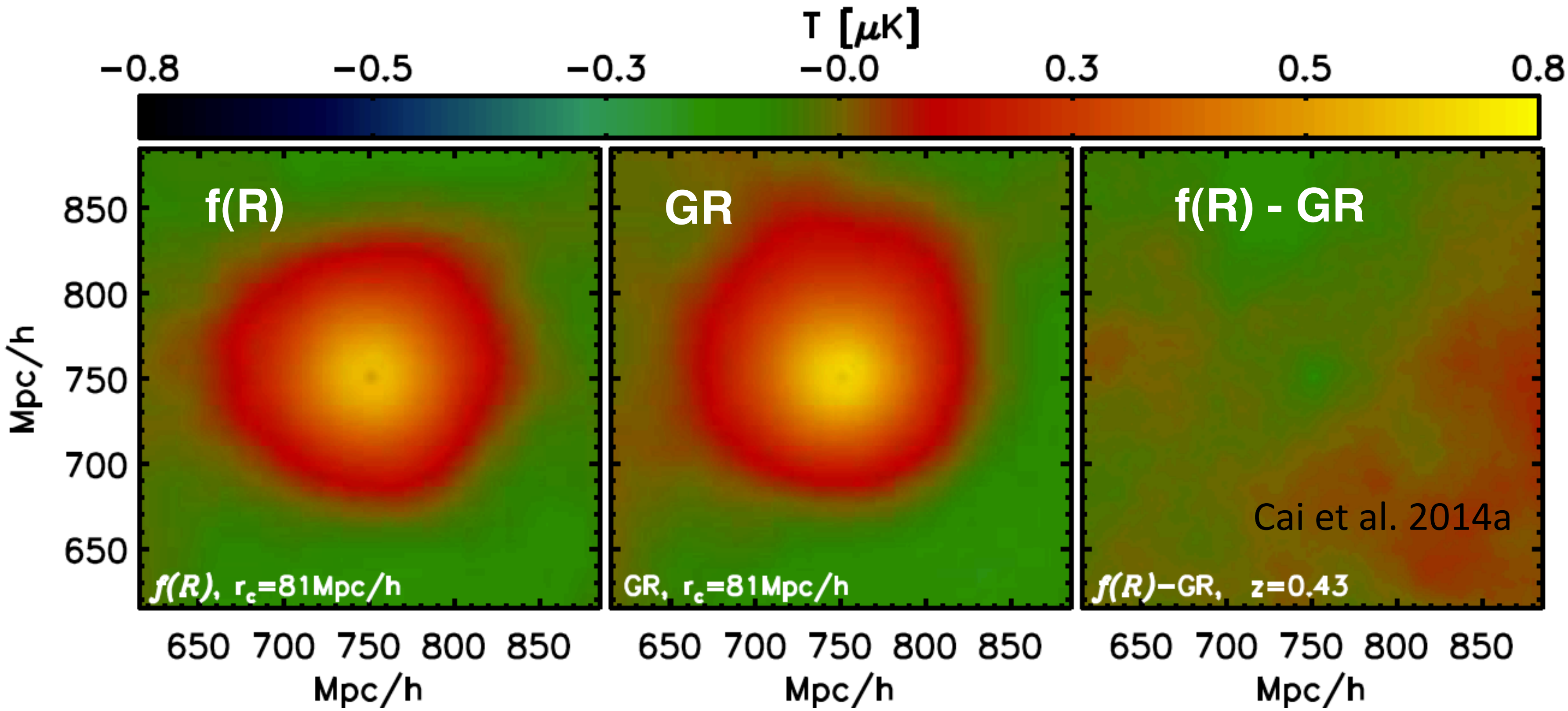


LCDM and f(R) simulations of the same expansion history, L=1.5 Gpc/h
Voids and superclusters from ZOBOV by Neyrinck (2005, 2008)

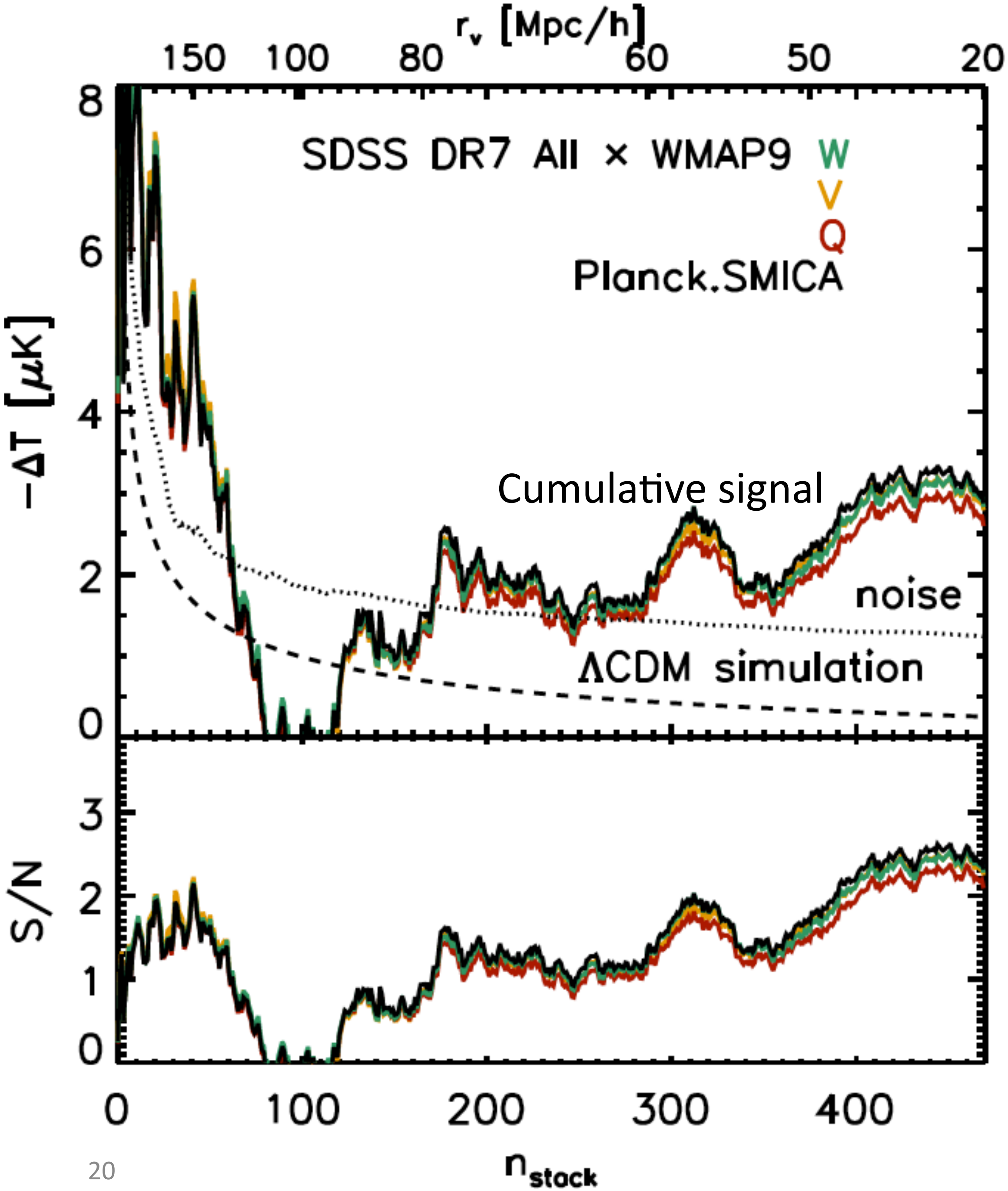
ISW cold spot is colder in f(R)

Cai et al. 2014a

Stacking Superclusters for the ISW



- ISW hot spot is less hot in f(R)
- Rule out the possibility of generating Granett08 results in f(R) model



- 1521 voids at 0<z<0.44 from SDSS DR7 galaxy sample using ZOBOV
- Clean off 2/3 voids that are likely to be void-in-cloud or noise
- 2.2sigma, not as significant as Granett08

$$2.2\sigma$$

Cai et al. 2014b

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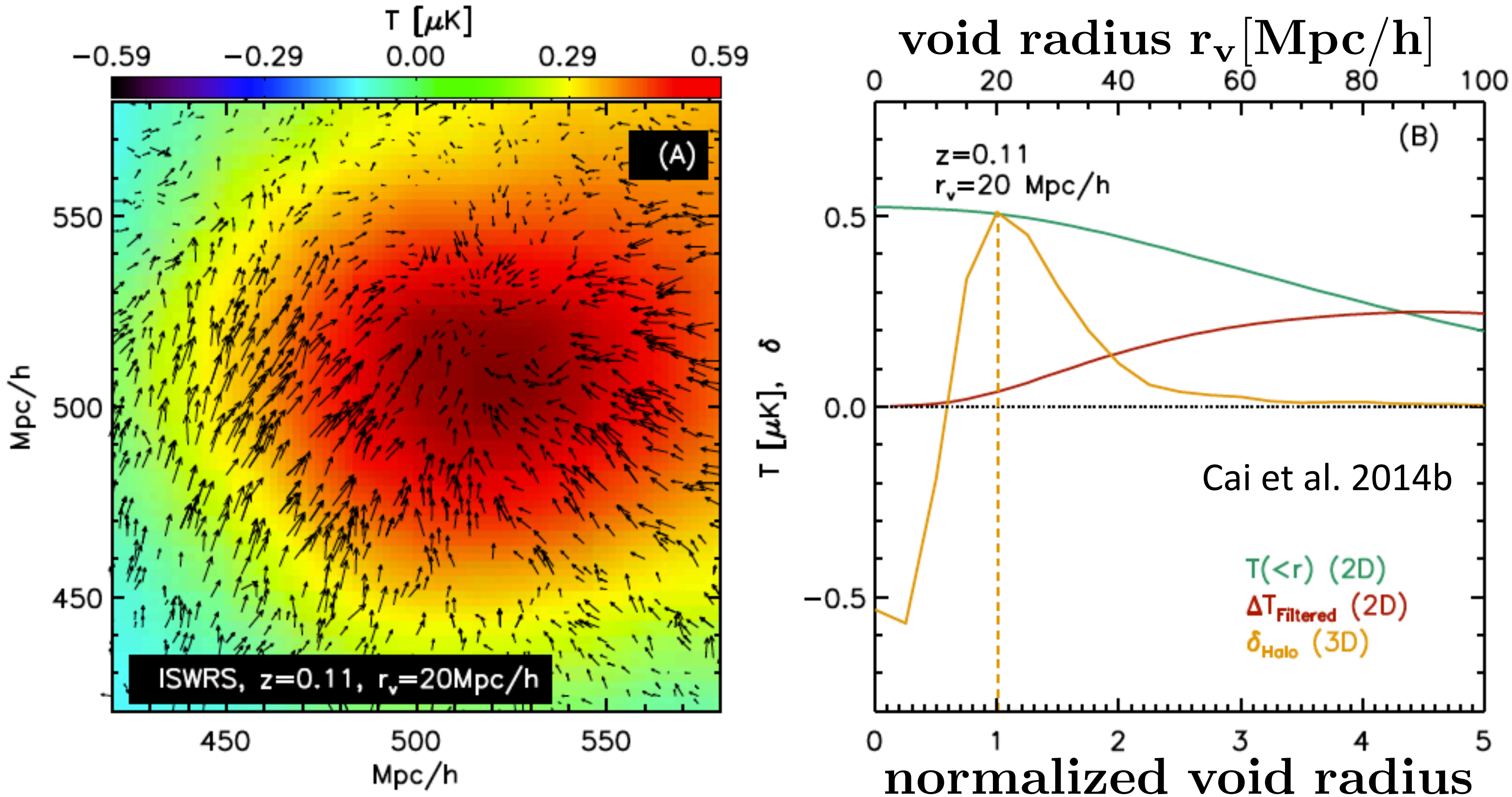
Void in Cloud – Contracting



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

Summary

- The repulsive 5th drives voids to grow larger and faster in MG
- Void abundance may be more sensitive than halo abundance in distinguishing chameleon model from GR
- Void properties is strongly environmental dependent in MG
- 3 ways to constrain MG from void profiles:

A.) halo/galaxy number density profiles,

B.) weak lensing tangential shear profile

C.) z-space void-galaxy cross-correlation

- ISW cold spot is colder, and hot spot is less hot in f(R)
- 2-sigma indication of an ISW signal when stacking SDSS DR7 voids
- No strong ISW as in Granett08 is found at z<0.4 from SDSS DR7