Institute for Computational Cosmology

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Cosmic Voids as Probes for Cosmology

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Outline

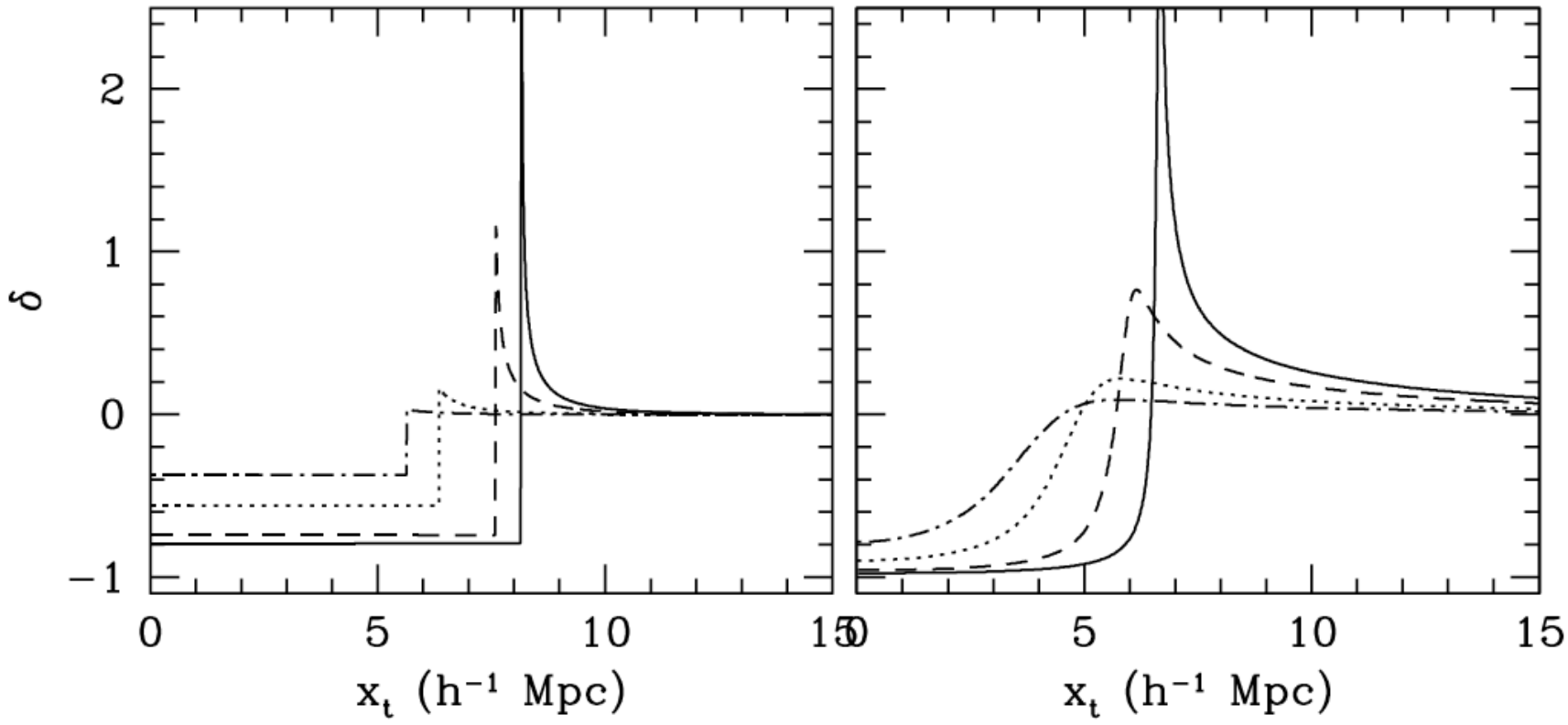
- Introduction
- I. Void as a test for modify gravity (MG)

  Void statistics and profiles
- II. Void & the ISW effect:

  Simulations and observations (SDSS DR7)

Voids in theory

Sheth & van de Weygaert, 2004



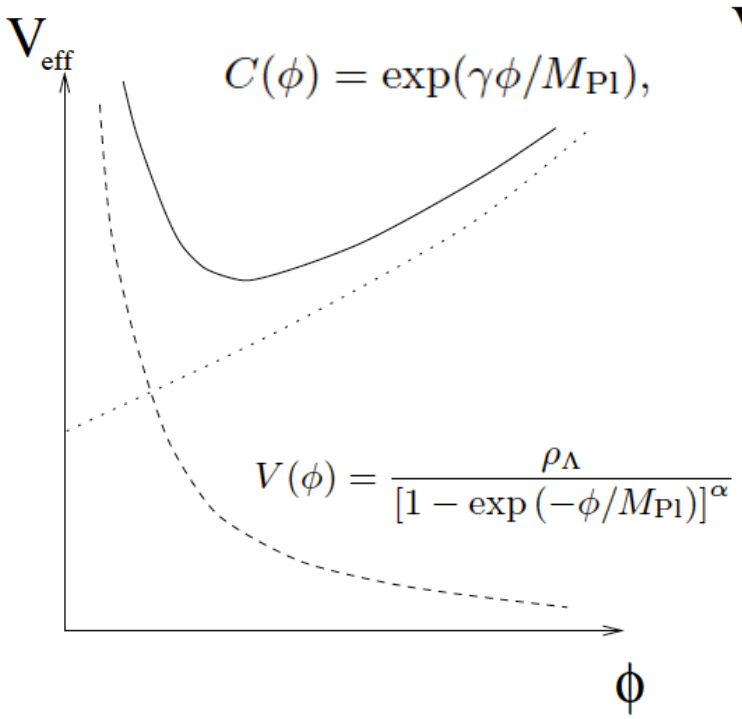
In LCDM, shell-crossing occurs at $\delta = -0.8$

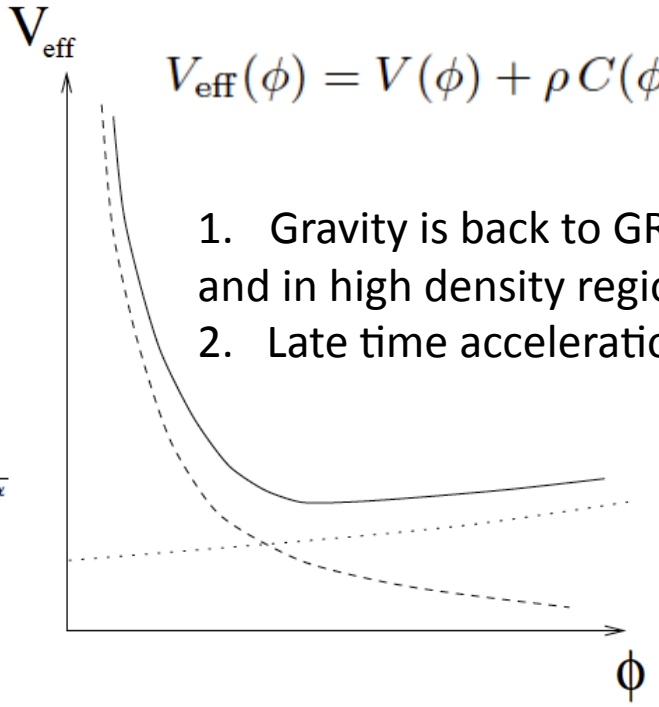
$R_f/R_{int} \sim 1.7$

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

Chameleon model

(Khoury & Weltman 2004)





1. Gravity is back to GR at high-z and in high density region
2. Late time acceleration like LCDM

Large ρ

Small ϕ_{min}

Large m_{min}

Small ρ

Large ϕ_{min}

Small m_{min}

Chameleon model

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

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

$$C(\phi) = \exp(\gamma\phi/M_{\rm Pl}),$$

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

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

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

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

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

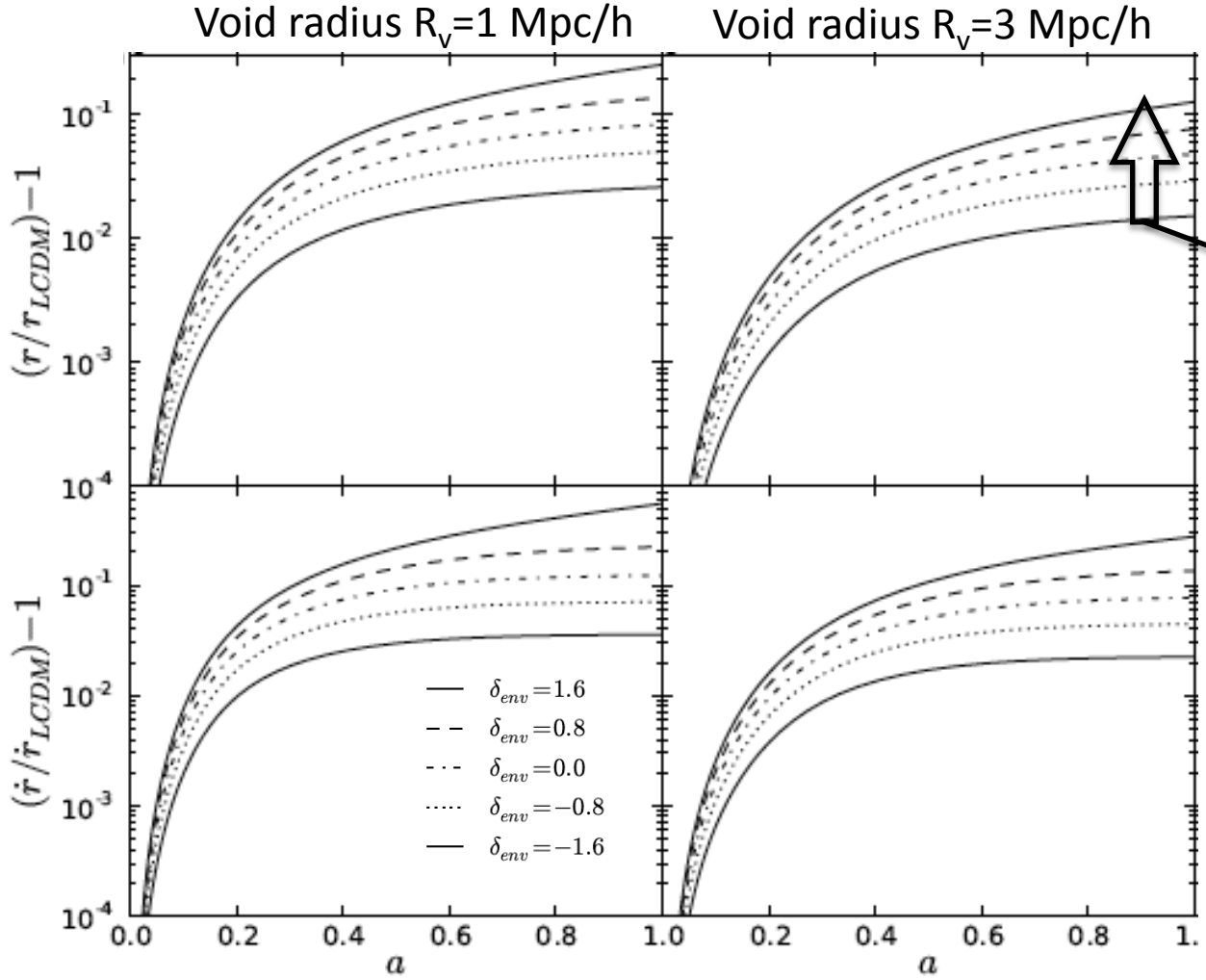
$$\alpha = 10^{-6}$$

The effective potential of the scalar field has a global minimal close to $\phi = 0$ where $\mathrm{d}^2V_{\rm eff}(\phi)/\mathrm{d}\phi^2 \equiv m_\phi^2$ is very large at high density region

The 5th force is suppressed exponentially – gravity is back to GR.

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

Individual void: size and velocity



Increasing environmental density

- In MG, void grows larger and expands faster than in GR
- Large differences in overdense environment (void-in-clound)

$$\frac{\ddot{r}}{r} = -\frac{1}{6M_{\rm Pl}^2}\left[\rho_{\rm v}(1+\eta) - 2\rho_\Lambda\right].$$

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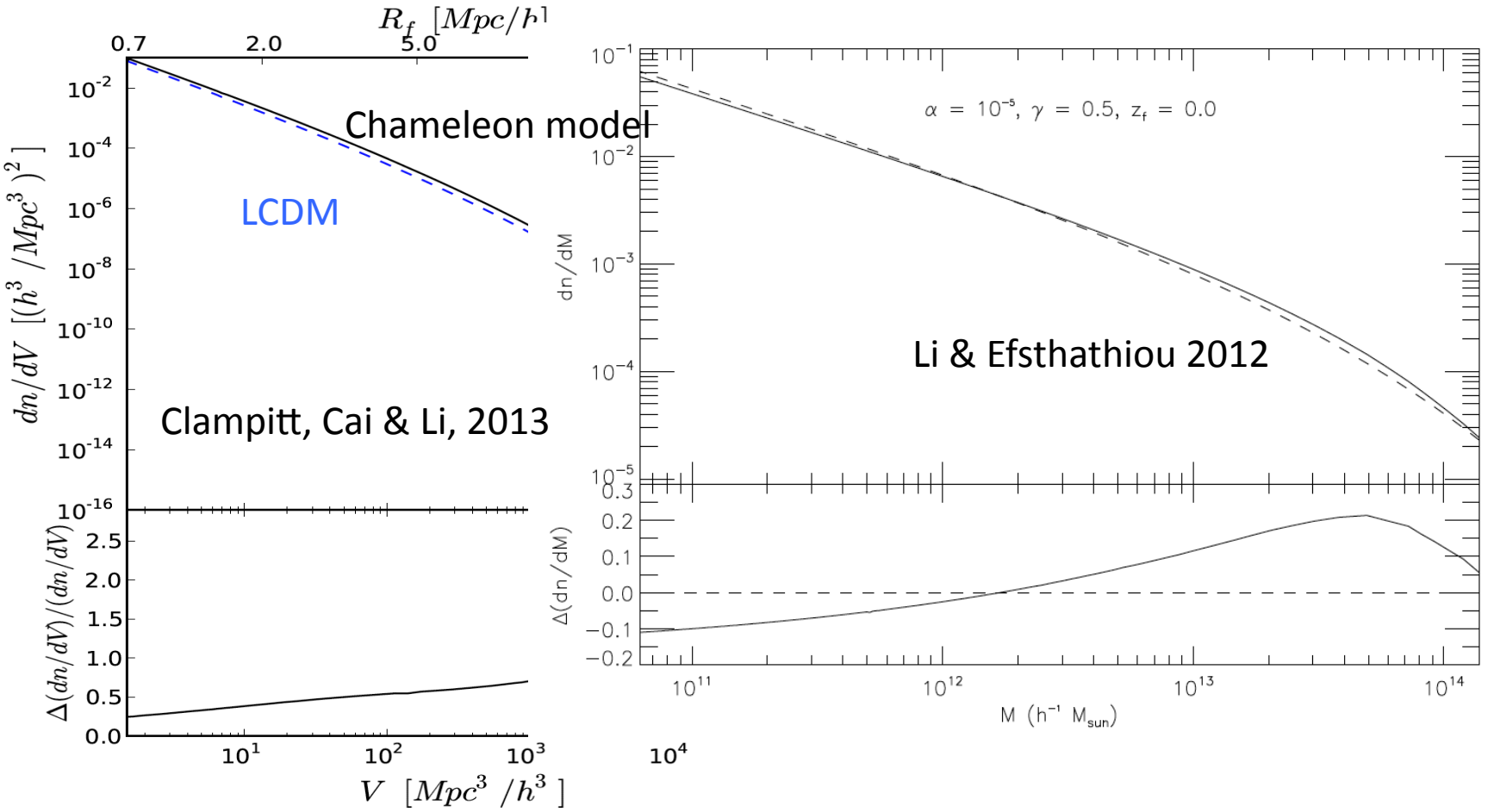
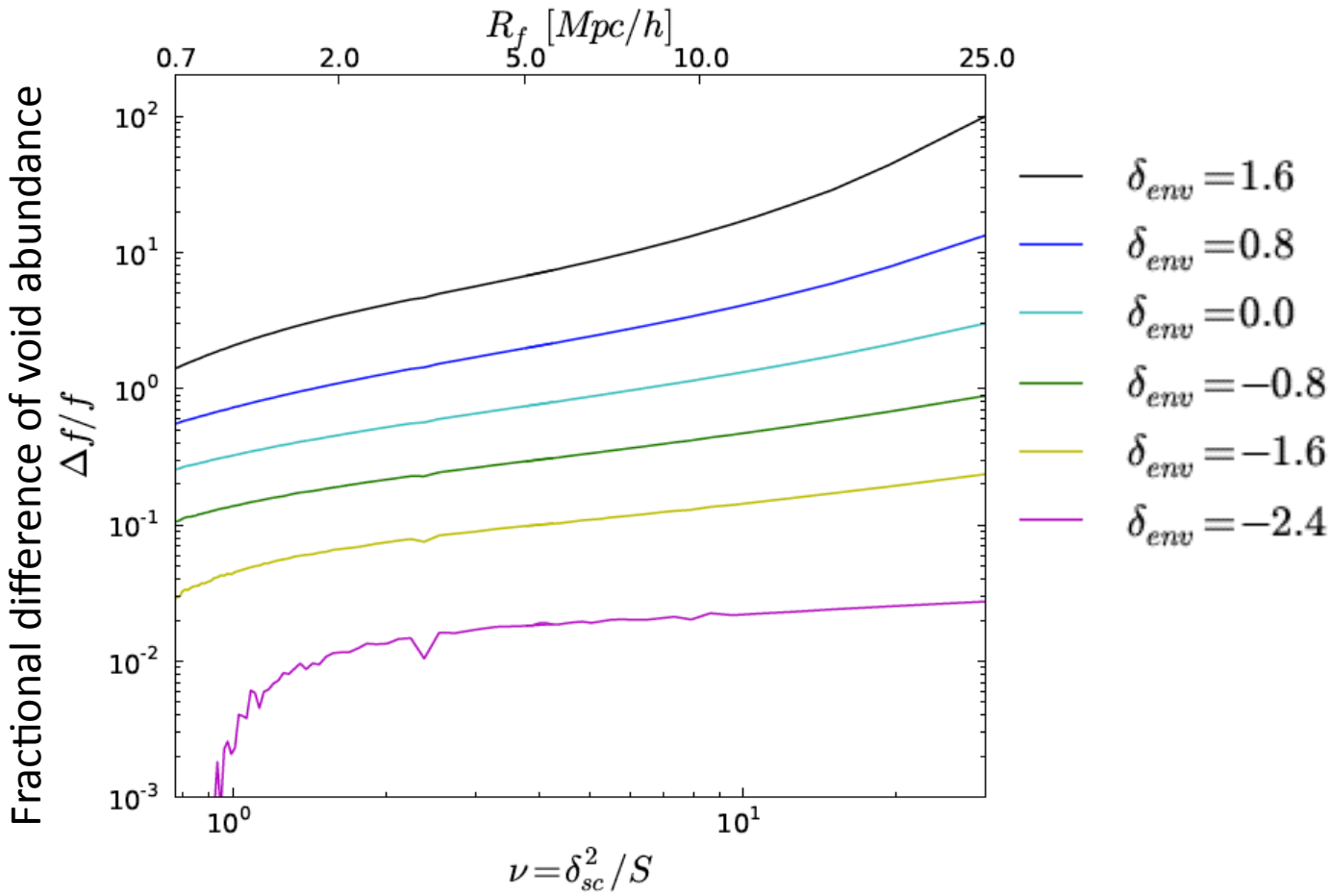
Void abundance



- Void abundance can be 10 times more sensitive to gravity than the case of halos

Environmental dependence



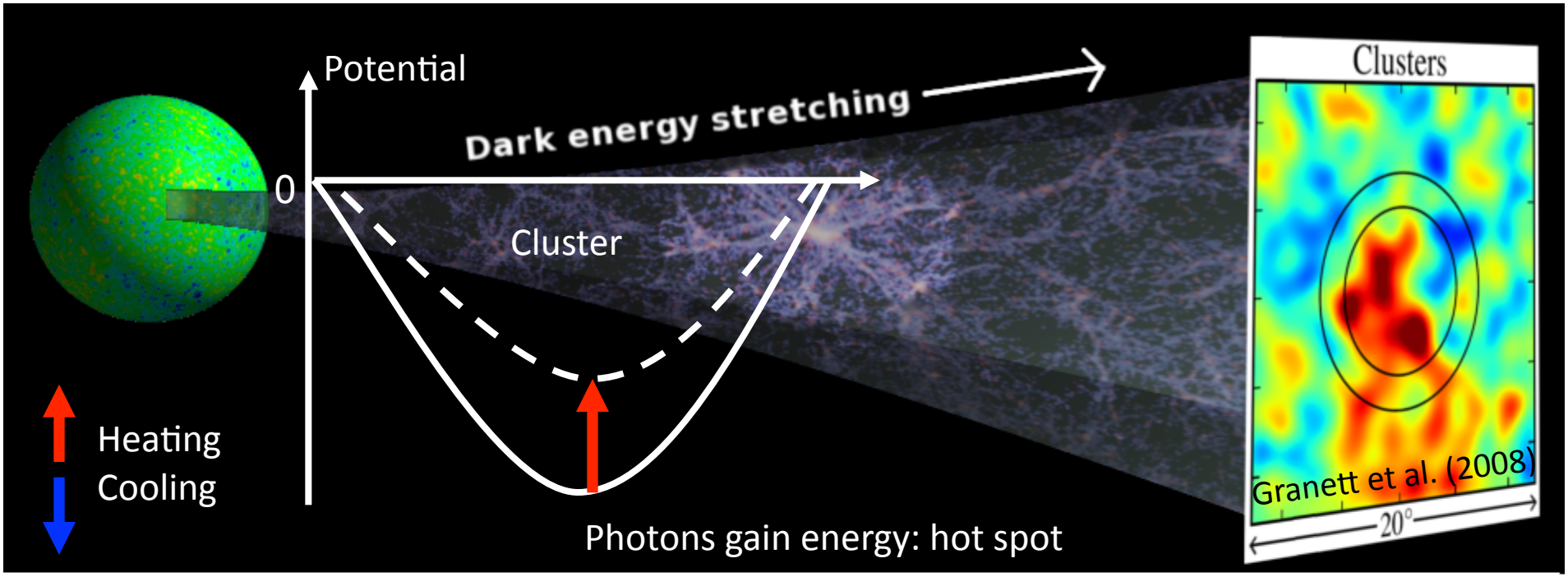
- Strong environmental dependence: voids-in-clouds differ more from GR

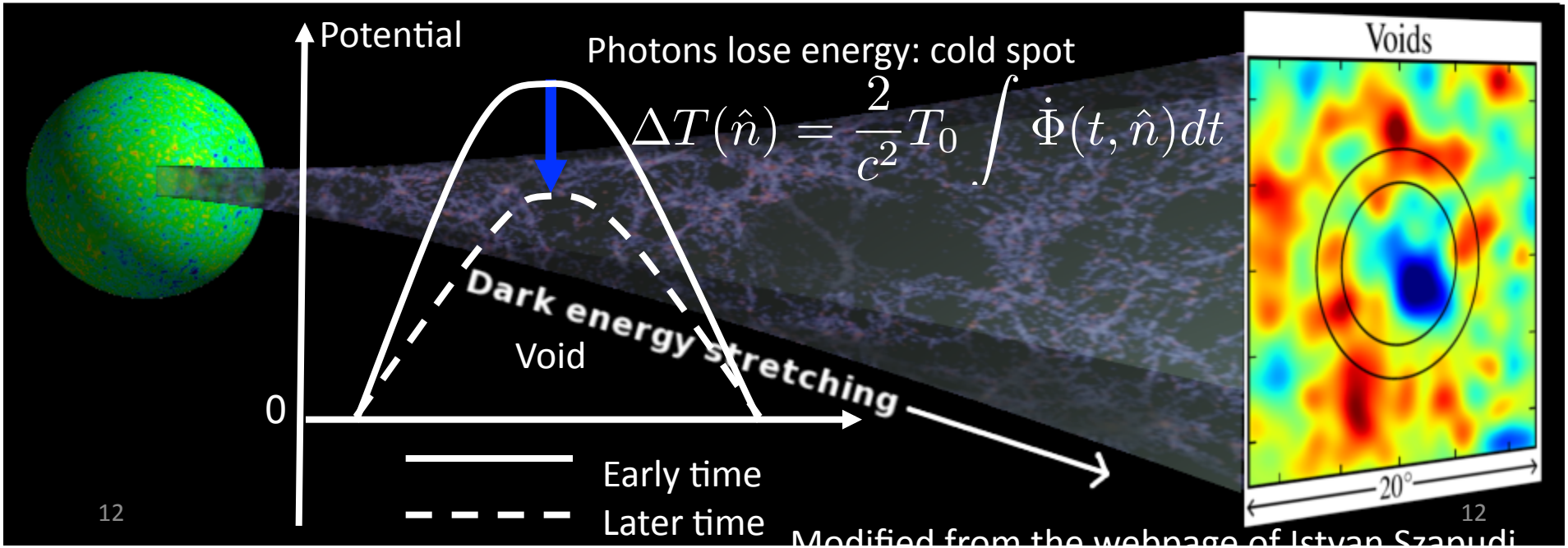
Clampitt, Cai & Li, 2013

Summary so far

- The repulsive 5^{th} drives voids to grow larger and faster in MG
- Void abundance can be 10 times more sensitive than halo abundance in distinguishing chameleon model from GR
- Void properties is strongly environmental dependent in MG
- Void profiles from lensing is promising to constraint MG

II. Probing the Emptiness
— ISW from stacking superstructures





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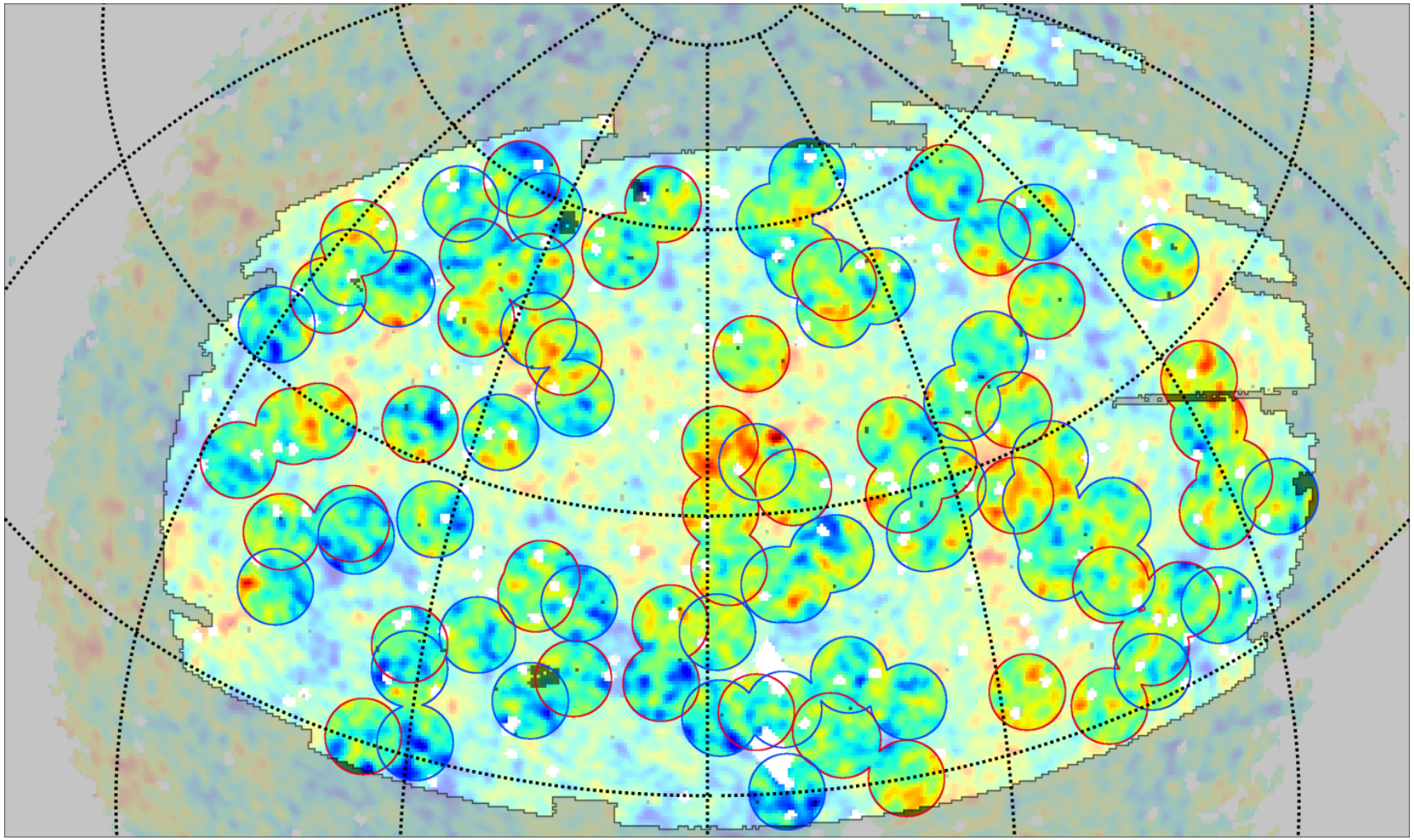
Modified from the webpage of Istvan Szapudi



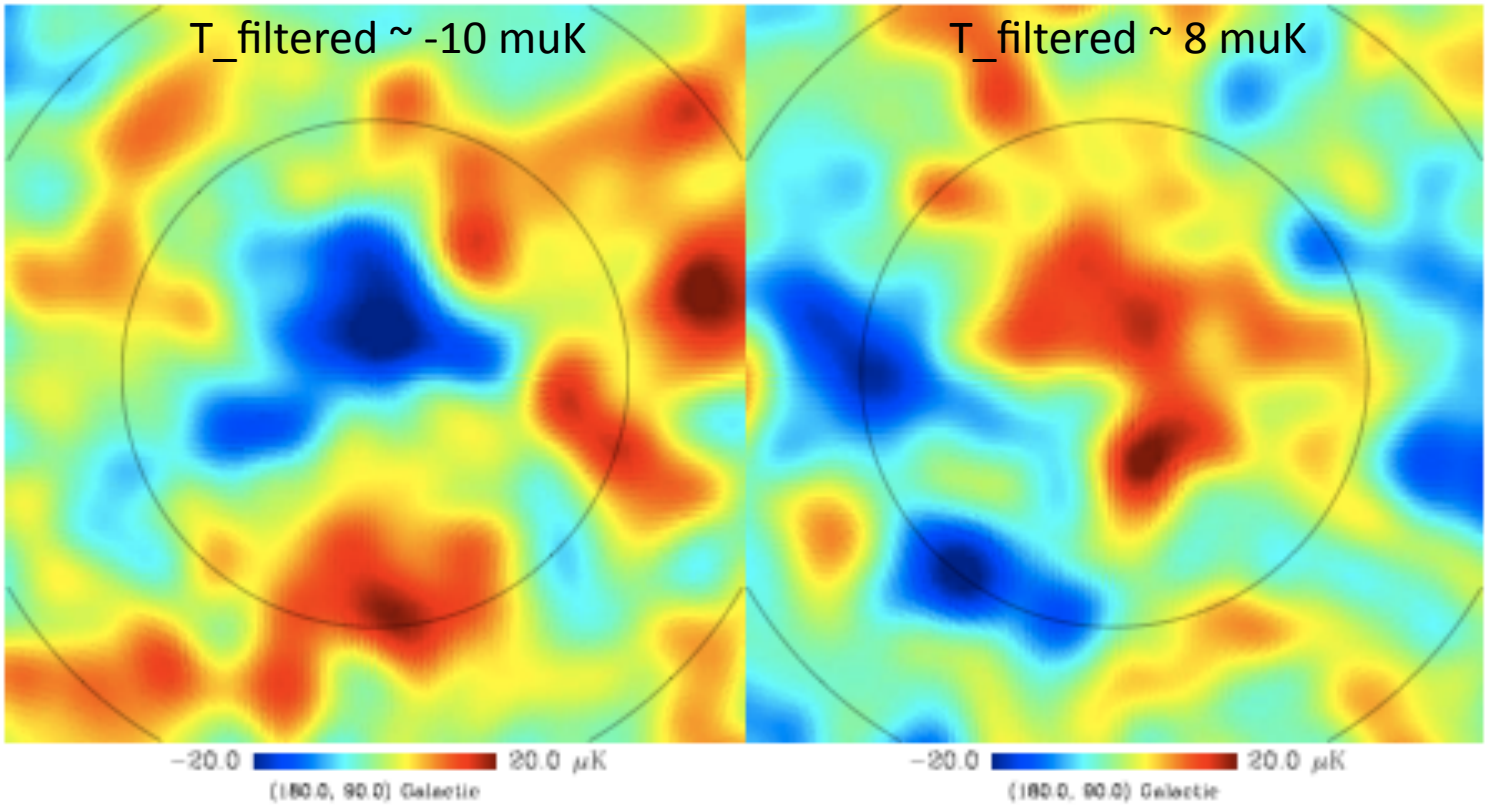
50 super voids/clusters (ZOBOV) from SDSS DR6, LRG Mega-Z catalogue, z ~ 0.4-0.75

Granett et al. 2008

Stacking of voids/clusters

cold spot surrounded by hot ring

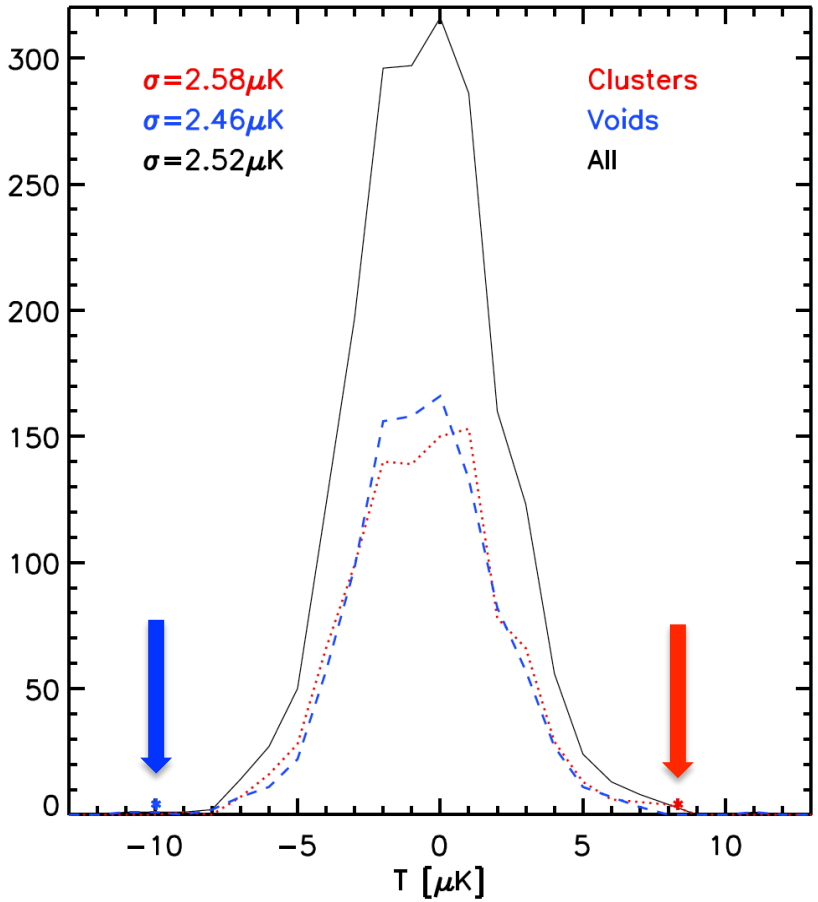
hot spot surrounded by cold ring



Stacked CMB temperature from WMAP5 V-band, using
50 voids and 50 clusters positions from SDSS galaxy
Weak frequency dependence

Reproducing Granett et al. 2008

A 4sigma detection, a problem?



Stacked CMB temperature, filtered by compensated filter of 4-deg radius, R~100 Mpc/h at z~0.5

If ISW, the amplitude (~10 muK) is too high compared to LCDM expectation (3-sigma?), e.g.
Granett et al. (2008), Papai et al. (2011), Nadathur et al. (2012), Flender et al. (2013), Hernandez-Monteagudo & Smith (2013)

The same stacking on the reconstructed ISW map from galaxy density field find no signal
Granett et al. (2009)

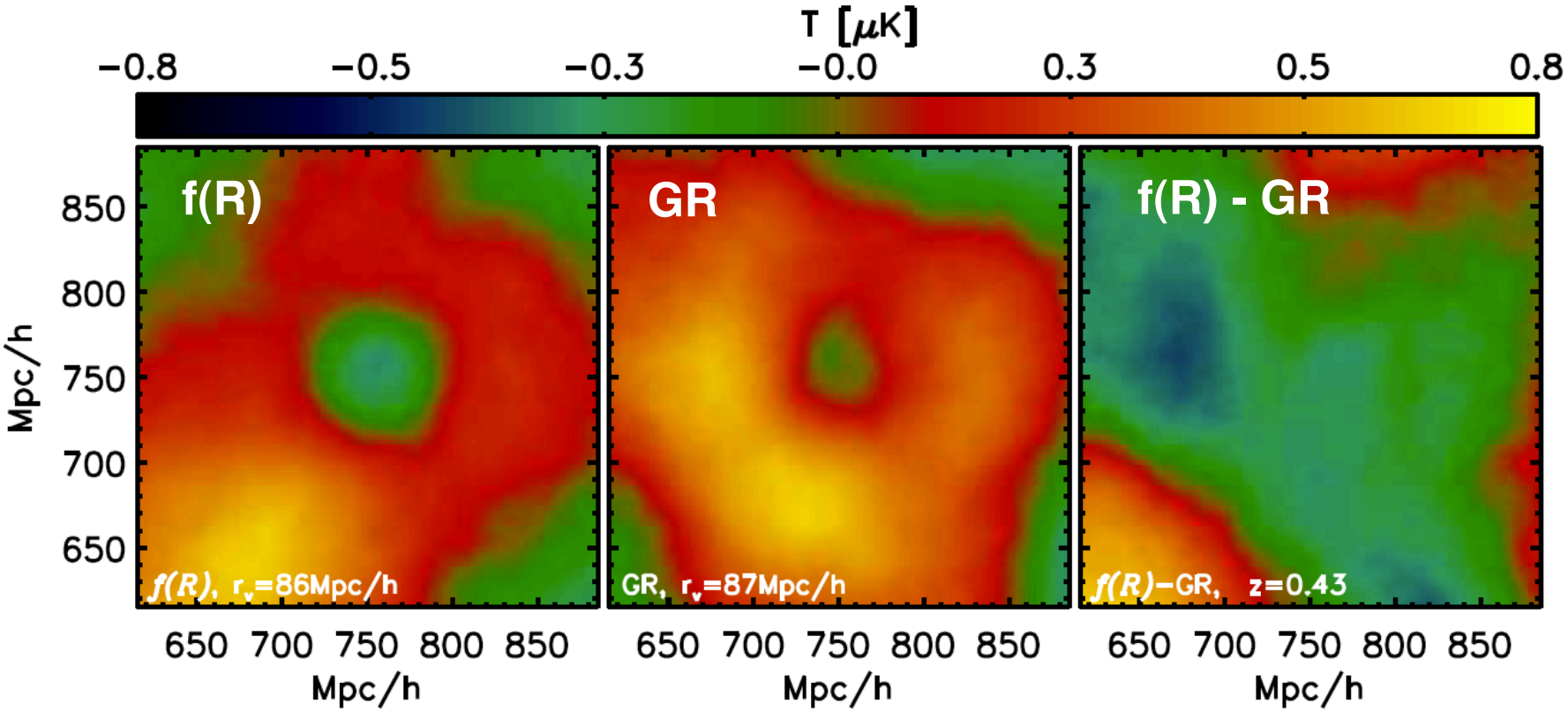
a tension? what's missing?

Possible way out

- A.) If the signal is real, can it be accommodated by alternative models?

- B.) Does similar signal exist in other dataset?

Stacking voids for the ISW

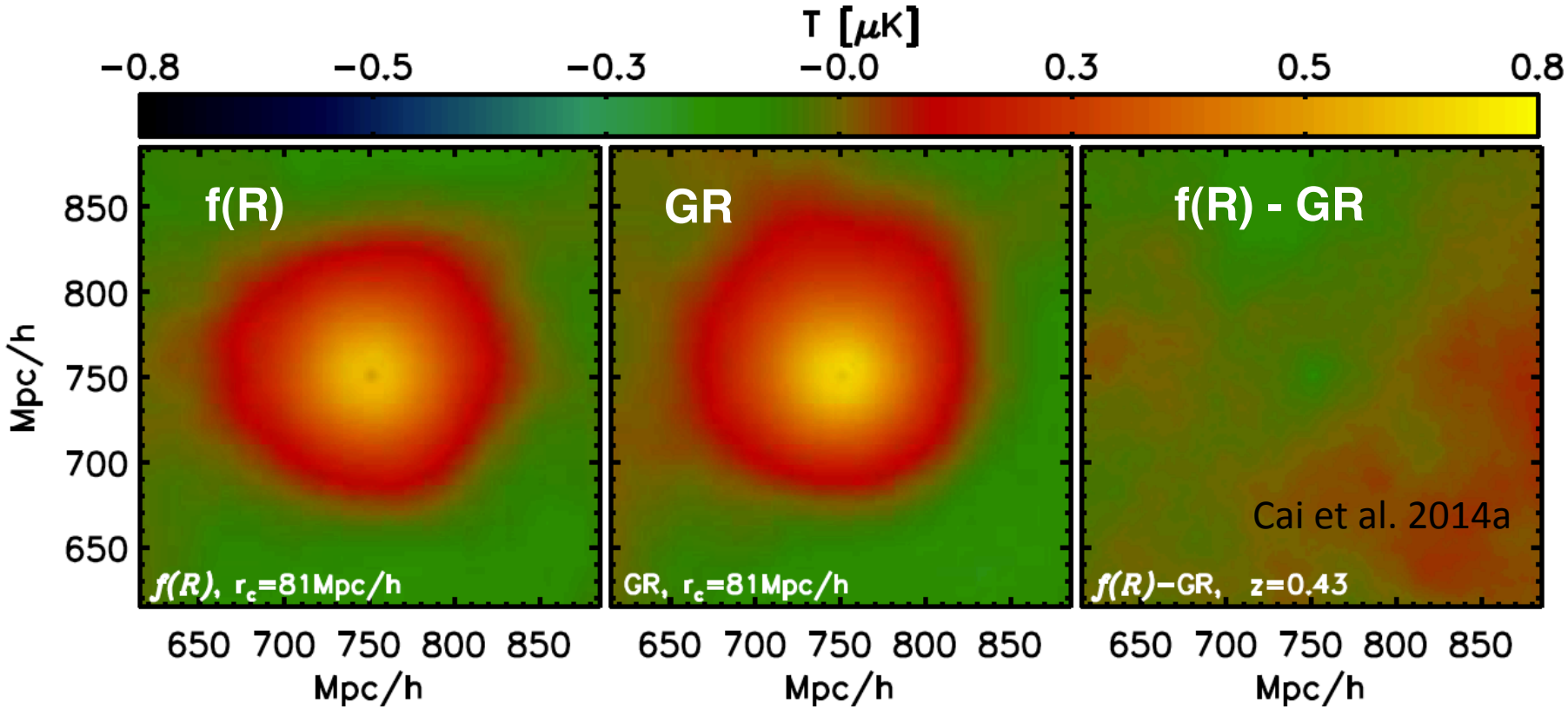


LCDM and f(R) simulations of the same expansion history, L=1.5 Gpc/h
Voids and superclusters from ZOBOV by Neyrinck et al. (2005, 2008)

ISW cold spot is colder in f(R)

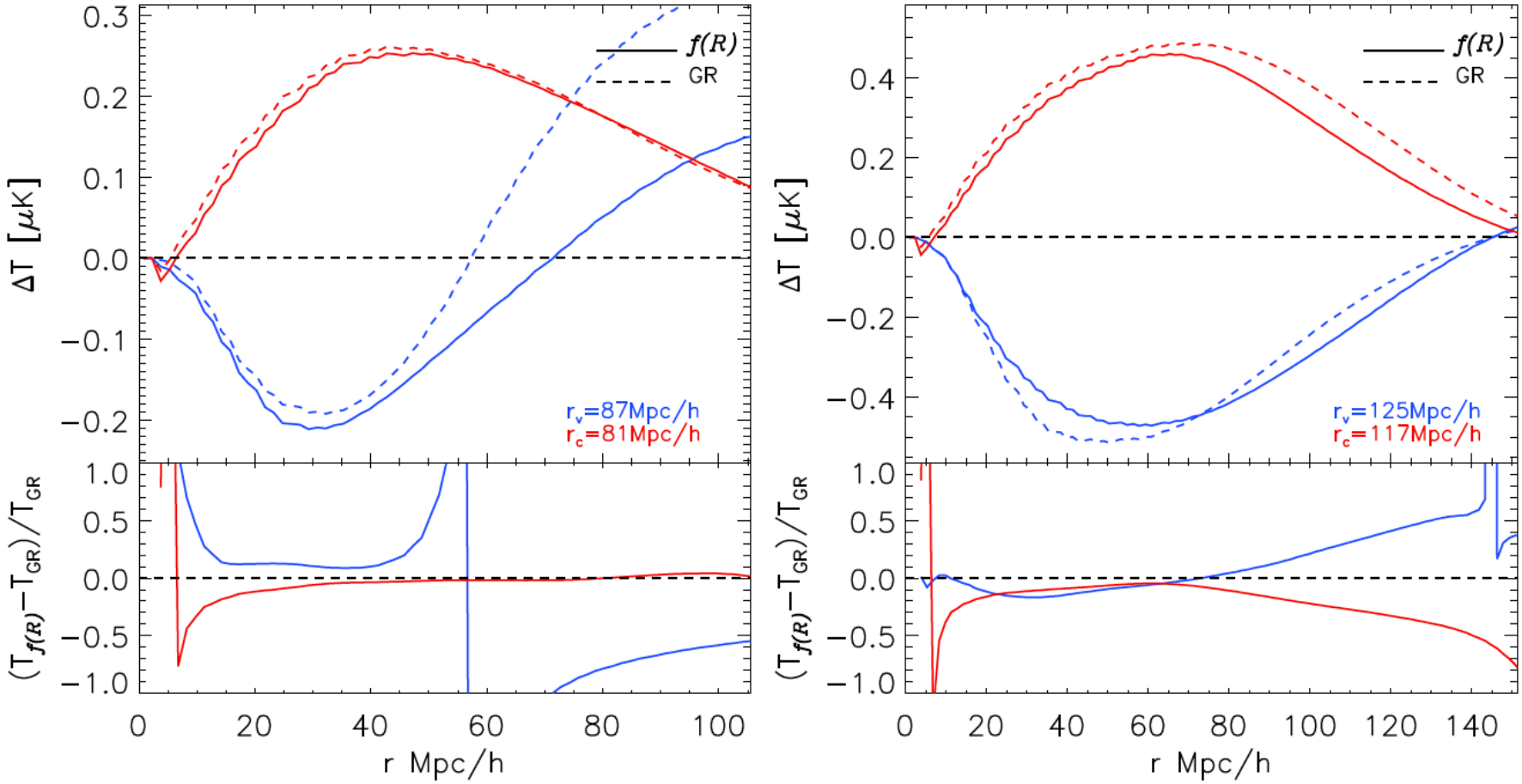
Cai et al. 2014a

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

Top-hat filtered temperature



Filtered ISW signal differs by no more than 20% between f(R) and GR

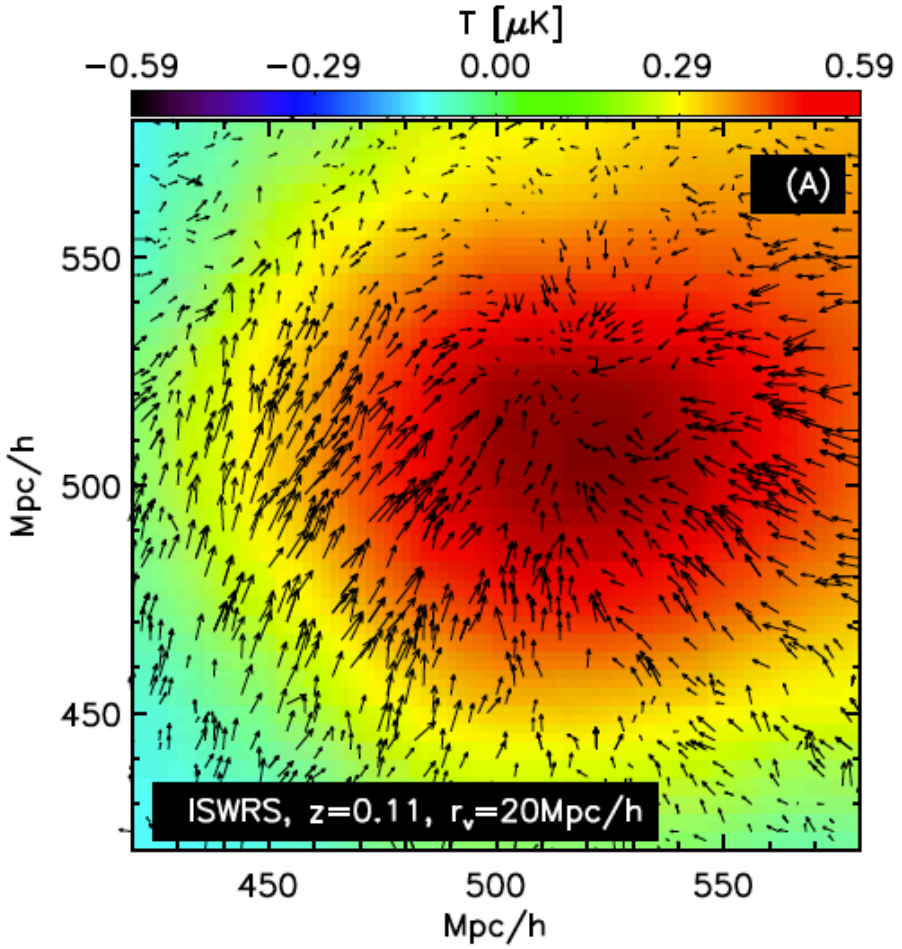
Cai et al. 2014a

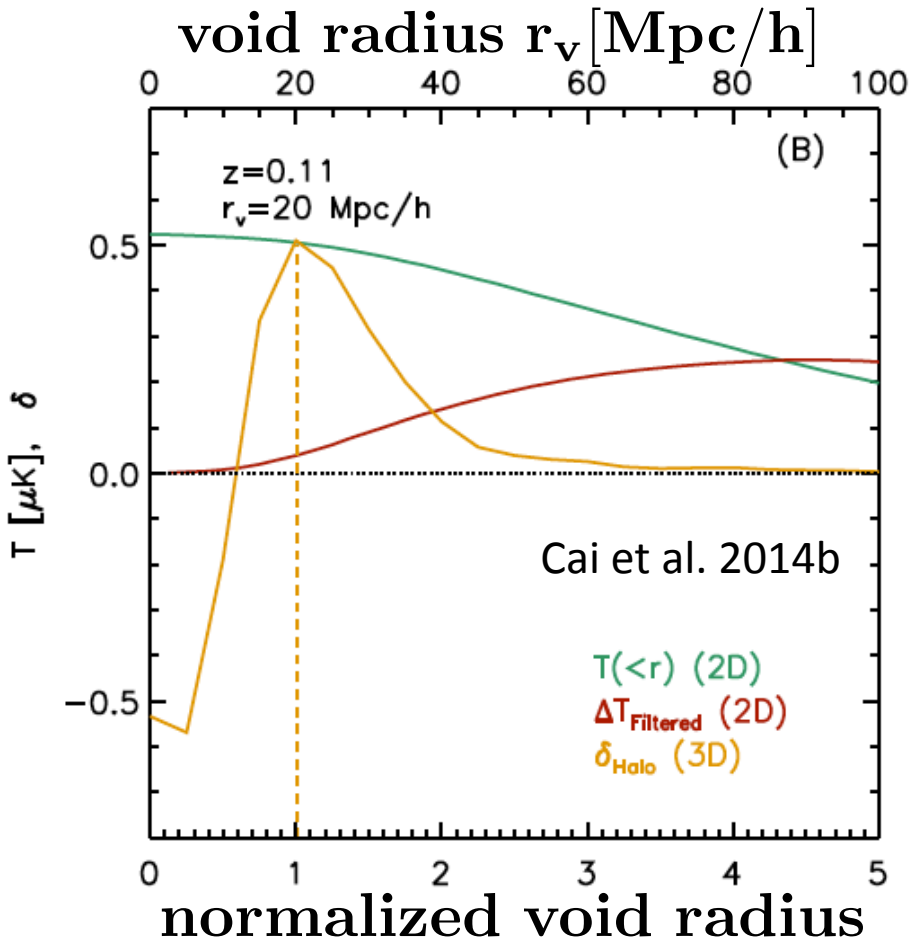
Possible way out

- A.) If the signal is real, can it be accommodated by alternative models?

- B.) Does similar signal exist in other dataset?

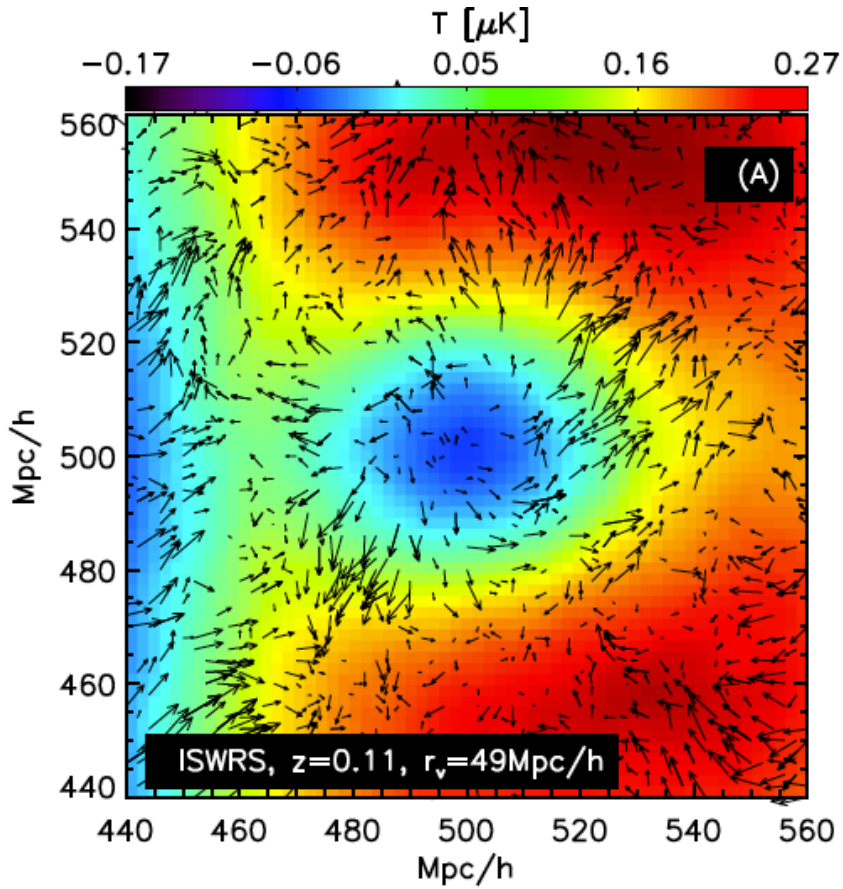
Void in Cloud – Contracting

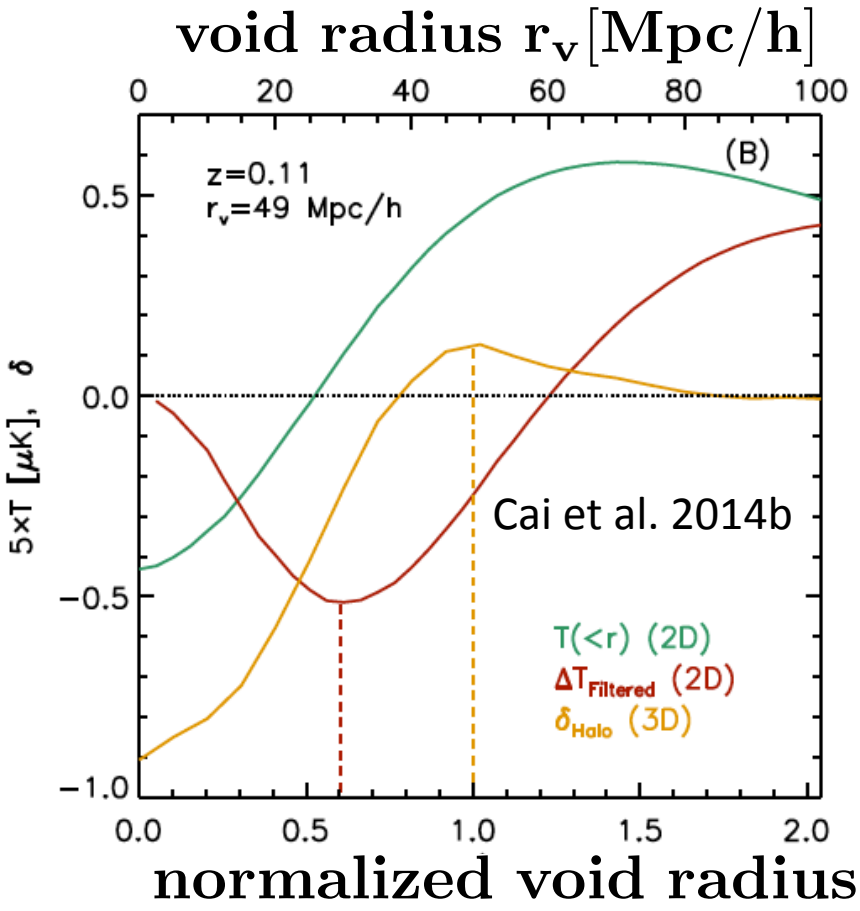




- Small voids are more likely to reside in overdense environment;
- Stacking void-in-clouds yield an ISW hot spot, rather than a cold spot!

Void in Void – Expanding

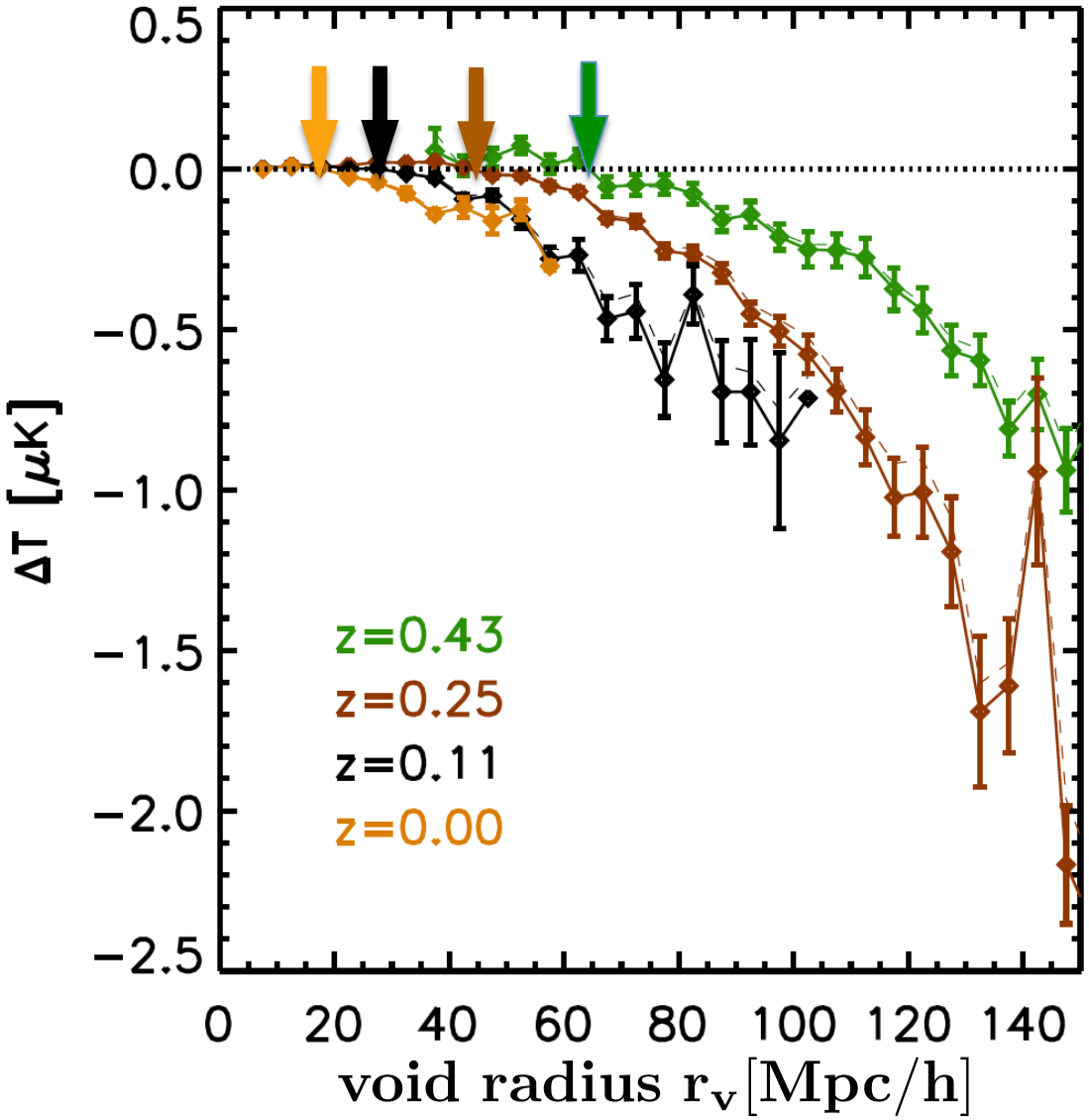




ISW stacking using simulated SDSS DR7 voids

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

DR7 voids, how to clean the sample



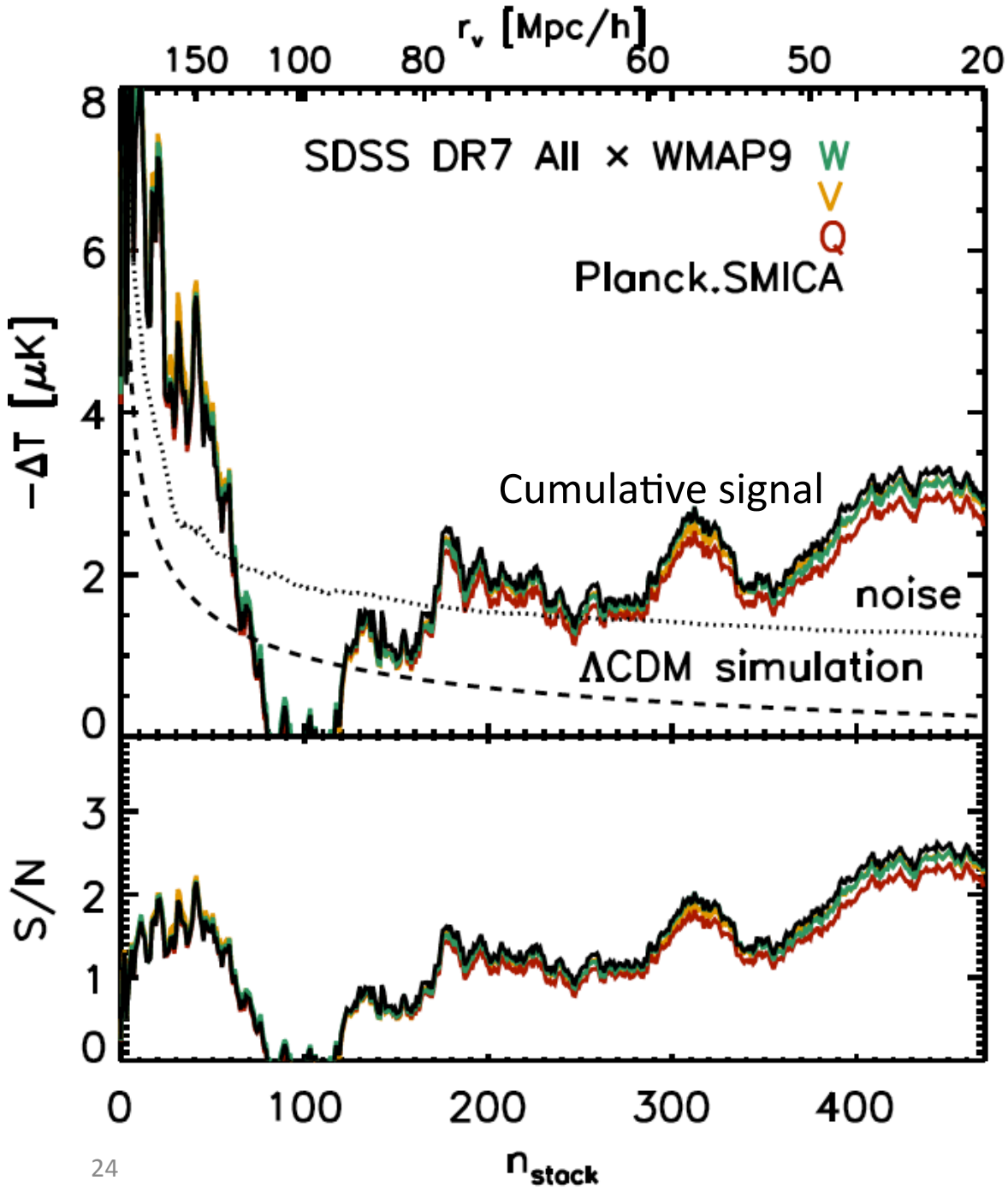
Simulations:

Omega_m =0.24
Omega_L = 0.76
n_s = 0.958
Sigma_8 = 0.77
h = 0.73

Different boxsizes and mass resolution to match the number density of galaxies in SDSS

For the SDSS sub-samples
$r_{\rm cut} = [20, 25, 30, 35, 45, 65]{\rm Mpc}/h$

Cai et al. 2014b



- 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

2.2σ

Cai et al. 2014b

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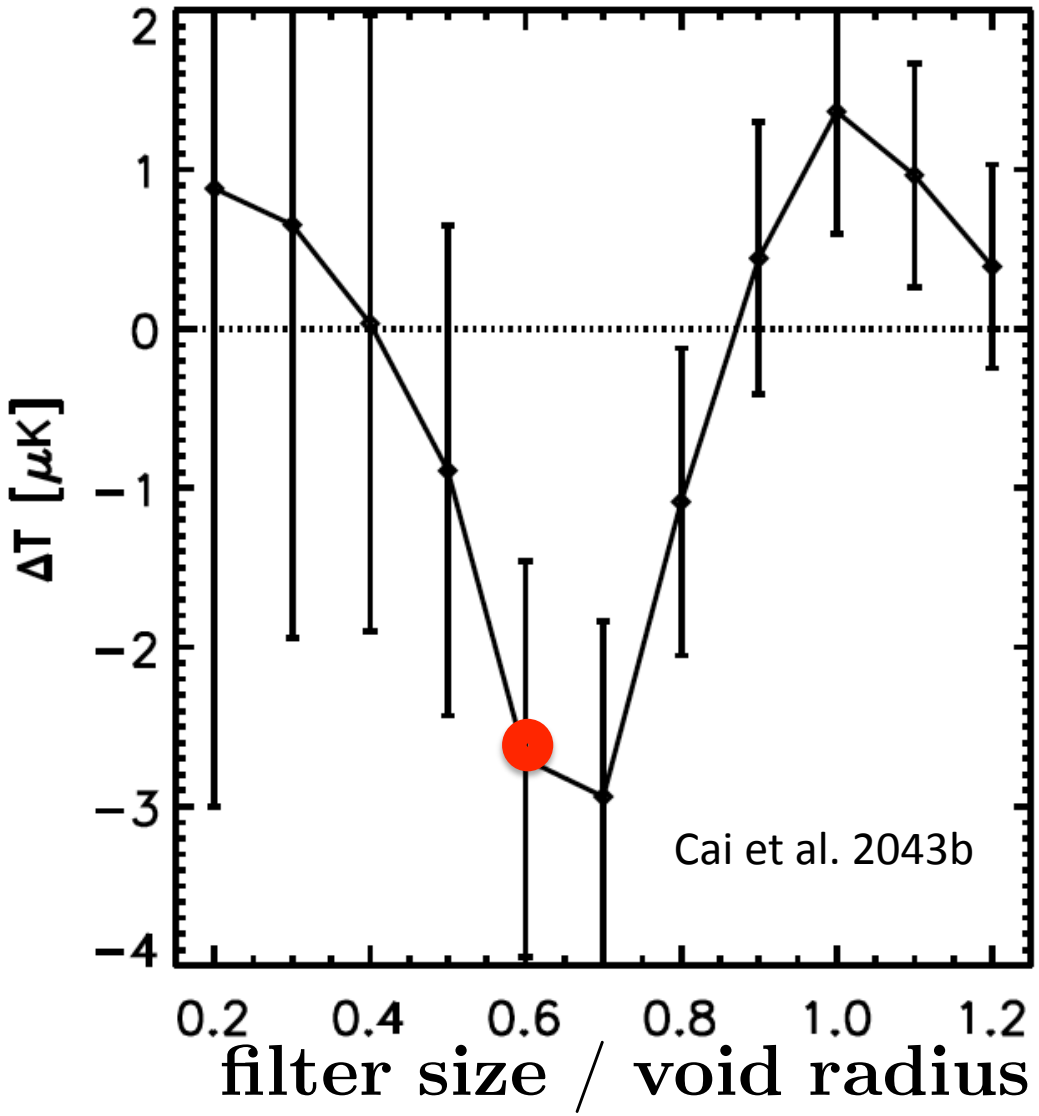
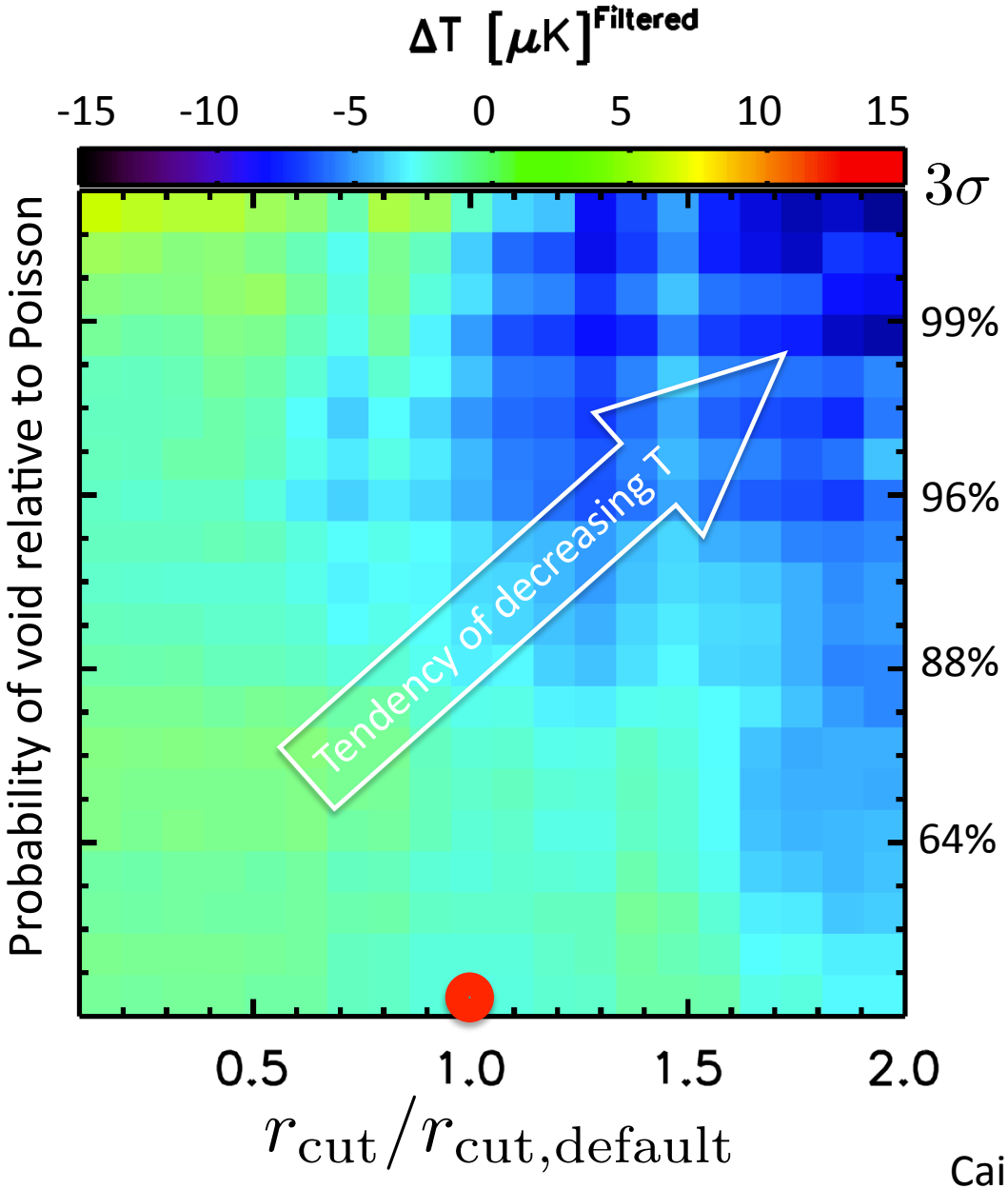
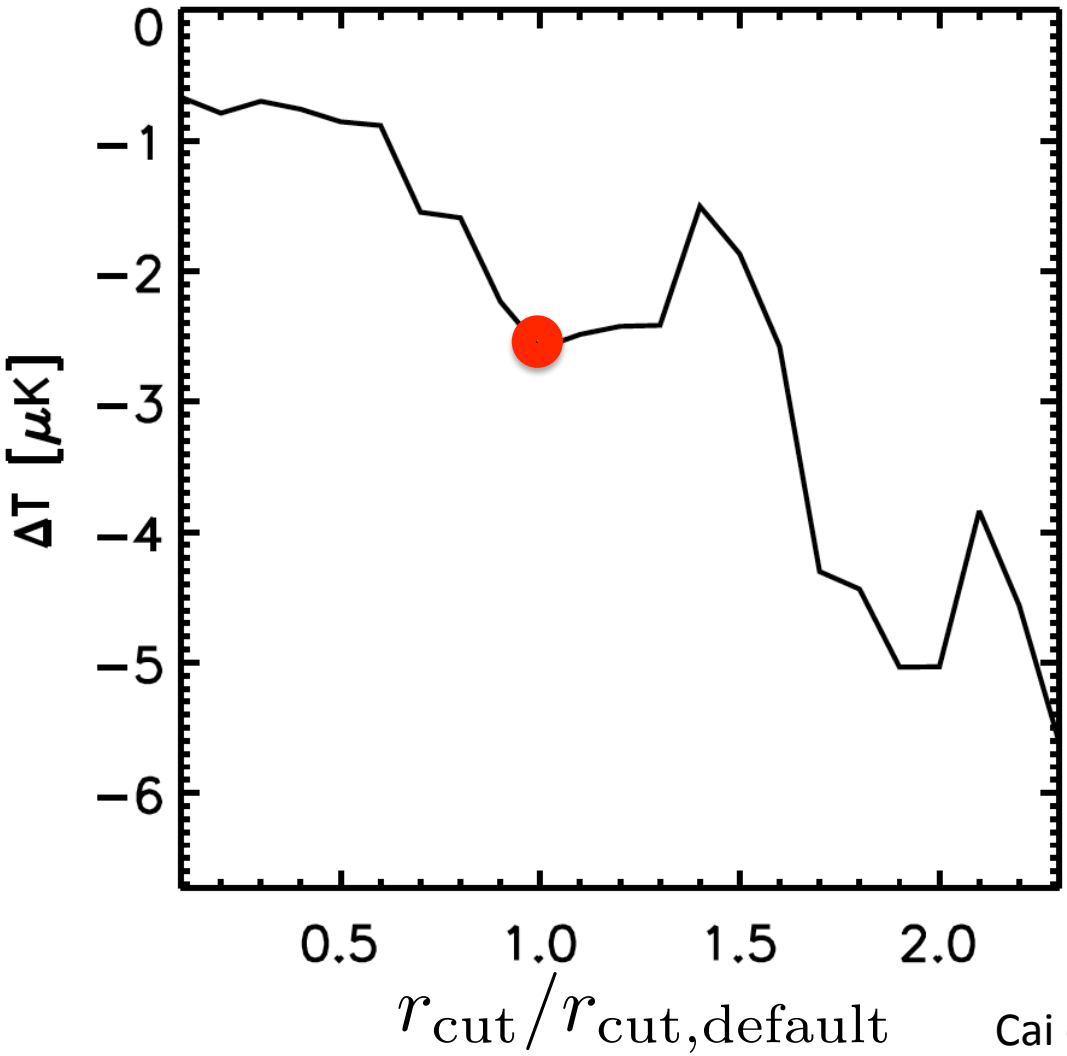
Varying filter size





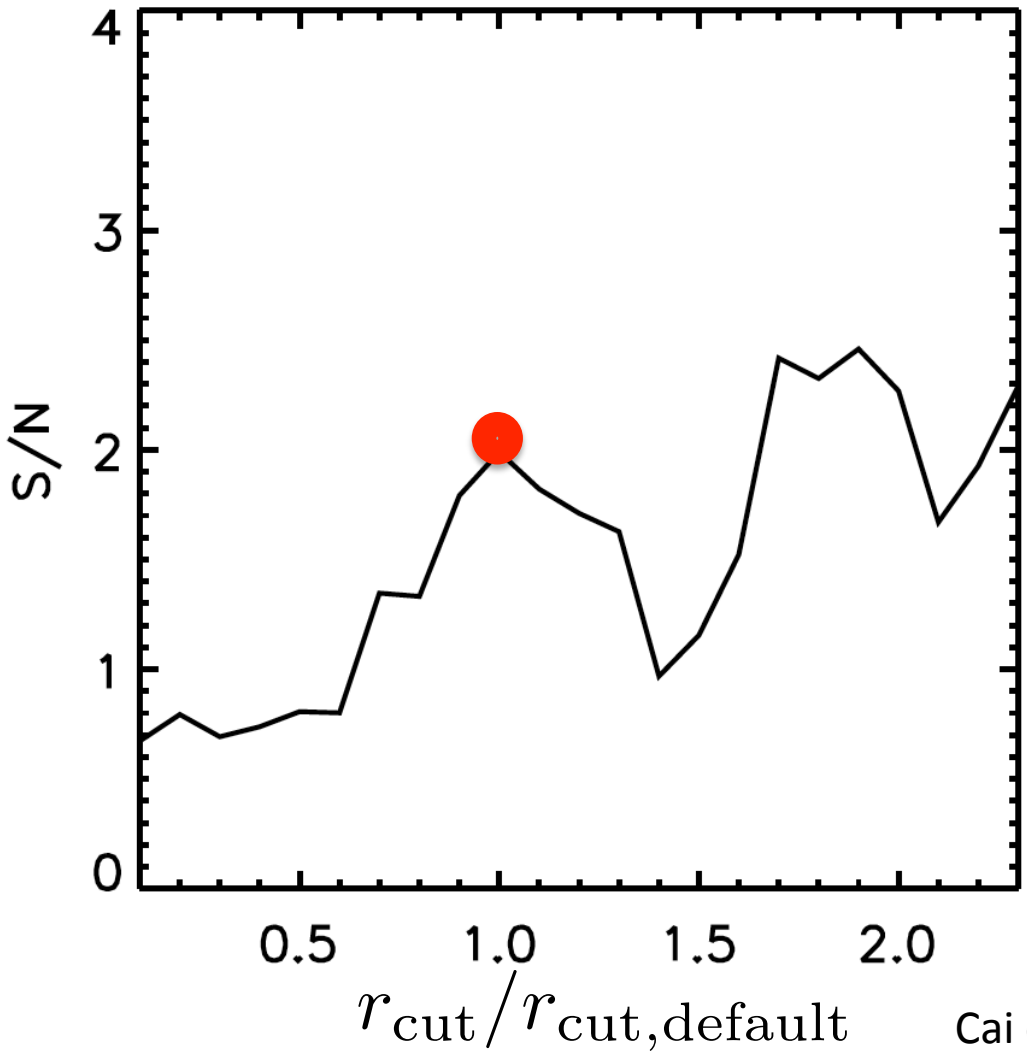
Cai et al. 2014b

Larger voids have more signal



Cai et al. 2014b

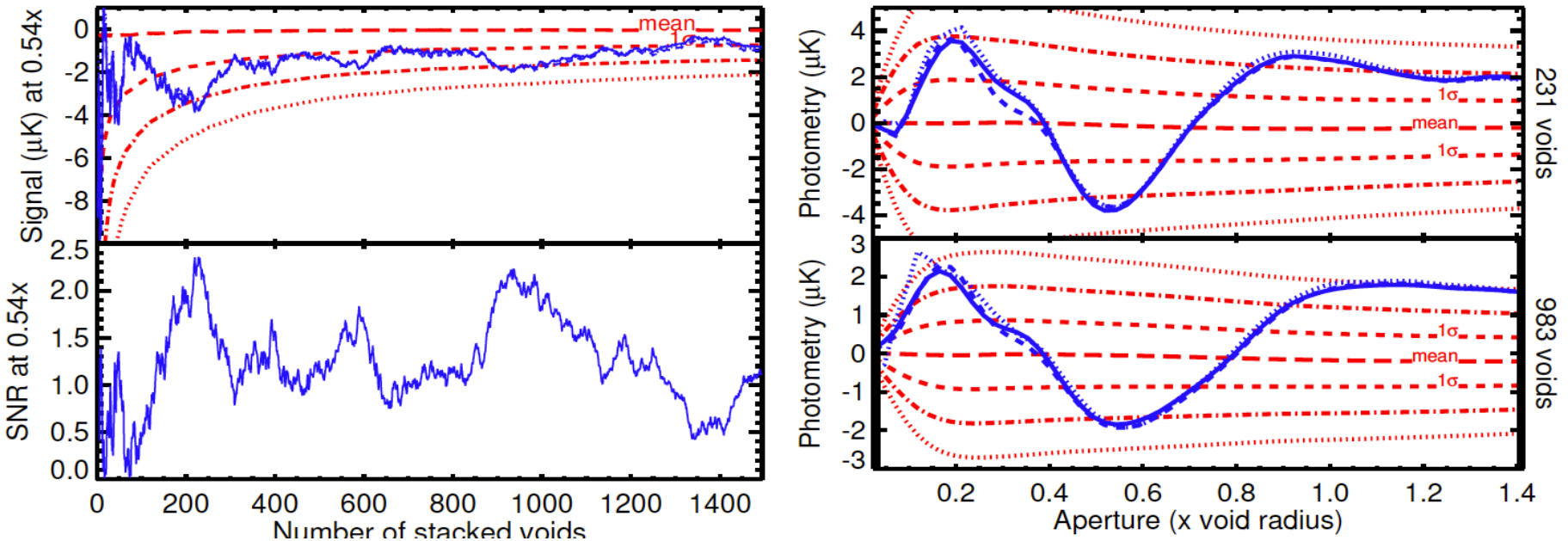
Larger voids have more signal

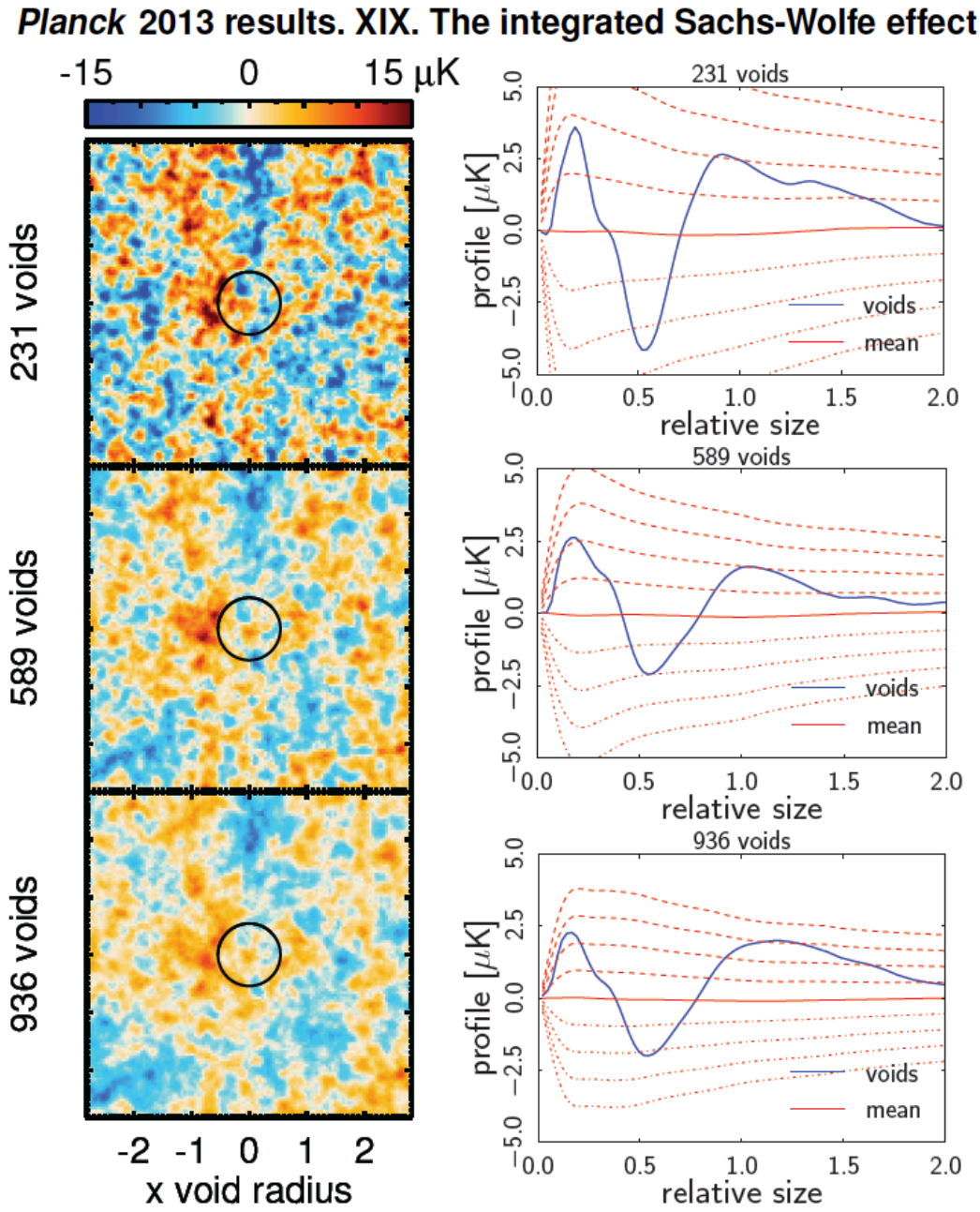


Cai et al. 2013b

On the detection of the integrated Sachs-Wolfe effect with stacked voids

Stéphane Ilić, Mathieu Langer, Marian Douspis 2013





Ade et al. 2013, arXiv: 1303.5079

Summary

- Voids are potentially powerful in distinguishing GR from MG;
- Mapping between model and simulation/observation is needed
- ISW cold spot is colder, and hot spot is less hot in f(R) model
- 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

1. 'Voids in Modified Gravity: Excursion Set Predictions'
Joseph Clampitt, *Yan-Chuan Cai & Baojiu Li*
MNRAS, 2013,431,749C

2. 'A Possible Cold Imprint of Voids on the Microwave Background Radiation'
Yan-Chuan Cai, Mark Neyrinck, Istvan Szapudi, Shaun Cole & Carlos Frenk
arXiv: 1301.6136, ApJ, in press

3. 'The Integrated Sachs-Wolfe effect in f(R) gravity'
Yan-Chuan Cai, Baojiu Li, Shaun Cole, Carlos Frenk & Mark Neyrinck
MNRAS, 2014, 439, 2978

Thank you!