A Supervoid Imprinting the Cold Spot in the CMB

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outline

- Introduction
- Data and method
- Results

The Cold Spot

- Cold region in the Southern Galactic hemisphere (l=209,b=-57)
- Detected in WMAP1 data through SMHW analysis and confirmed by Planck *(Vielva et al. 2004, Planck 2013)*
- Deviation from gaussianity and isotropy
- High significance - rubust to dataset and tools
- Physical origin unknown (systematics, foregrounds, SZ, secondary anisotropies, texture, ...)

(Vielva 2010 for a review)

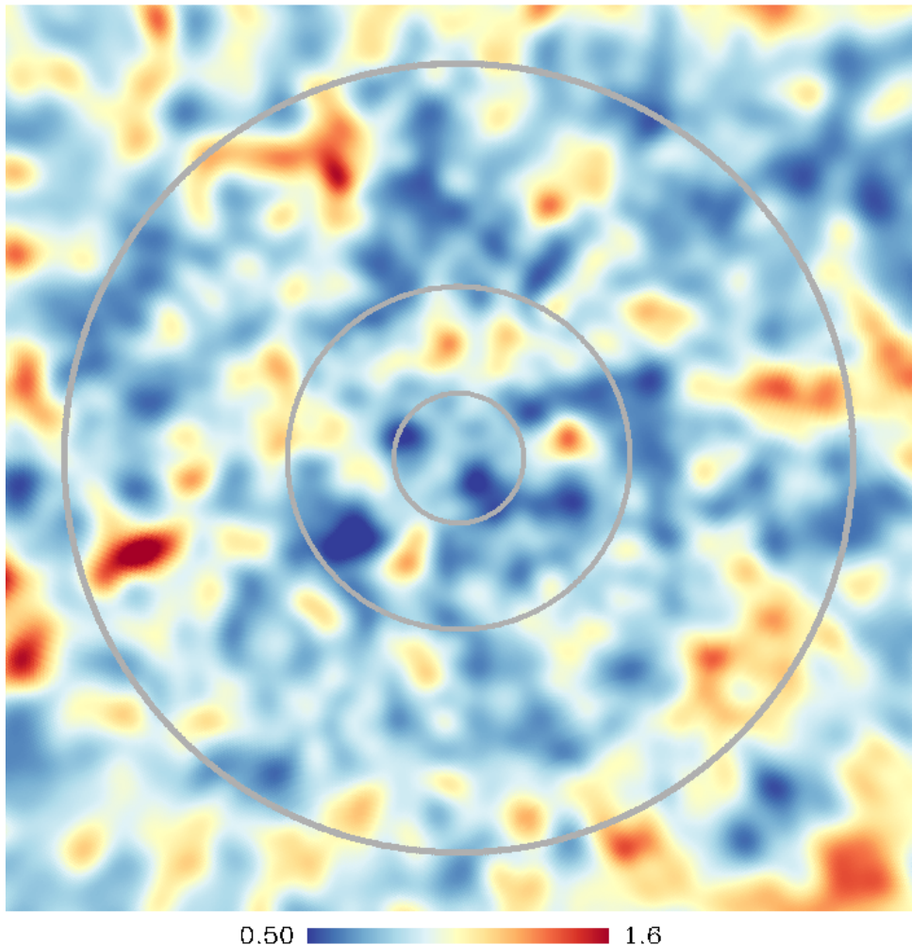
Is there a void along the CS direction?

- Underdensity in NVSS *(Rudnick et al. 2007)* whose significance is disputed *(Smith & Huterer 2010)*
- Underdensity at $0.5 < z < 0.9$ in CFHT ruled out *(Granett, Szapudi & Neyrinck 2010)*
- Similar results from VIMOS for $0.35 < z < 1$ *(Bremer et al. 2010)*
- Mild underdensity in 2MASS not sufficient to explain the CMB depression *(Francis & Peacock 2010)*

Our dataset

$$\bar{z} = 0.14$$
$$b_g = 1.41 \pm 0.07$$

WISE−2MASS

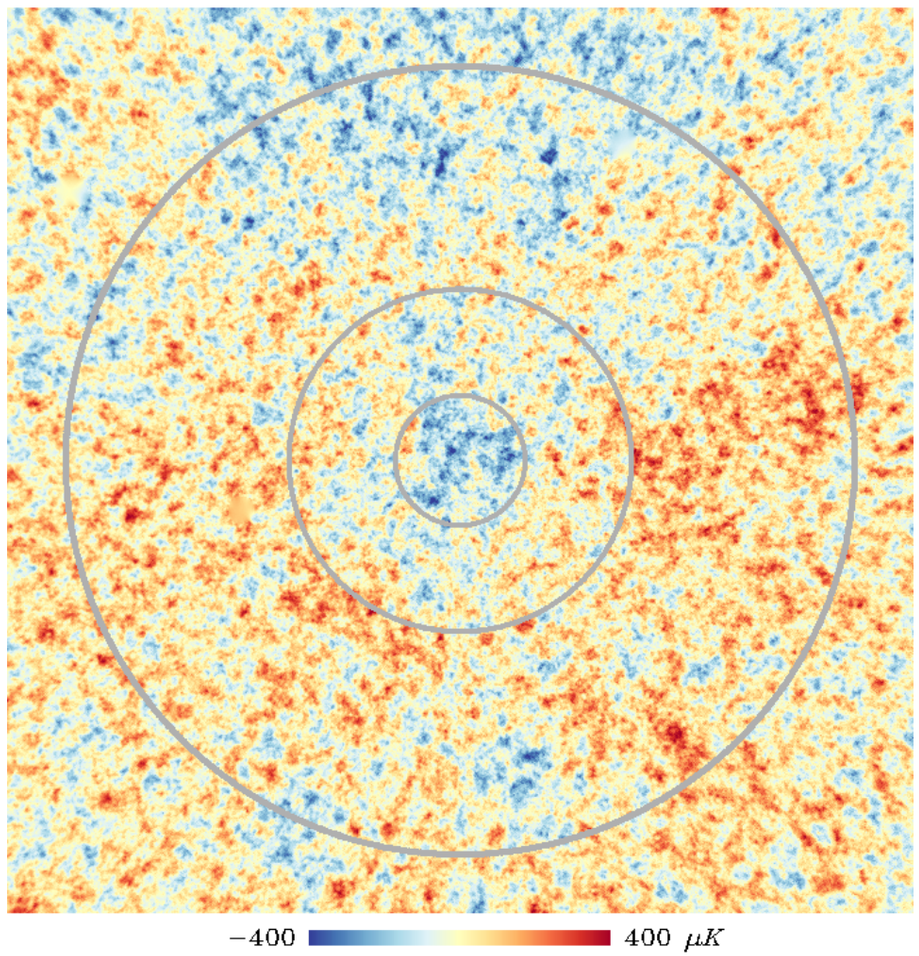


Kovács & Szapudi 2013

+

full res. CMB map

PLANCK SMICA



Planck 2013

Our model

We assume a Lemaitre-Tolman-Bondi metric for the void

$$ds^2 = -dt^2 + \frac{A'(r,t)^2}{1-k(r)}dr^2 + A(r,t)^2 d\Omega^2$$

with a spatial curvature $k(r) = k_0 r^2 \exp(-r^2/r_0^2)$

Garcia-Bellido & Haugboelle 2008

In ΛCDM the void is described by the potential

$$\Phi(\tilde{r}) = \Phi_0 \exp\left(-\frac{\tilde{r}^2}{r_0^2}\right)$$

where the comoving FRW radius is $\tilde{r} = \sqrt{3/4\pi} H_0 r$

Void density profile

via Poisson equation the density profile is defined as

$$\delta(\tilde{r}) = -\delta_0 \left(1 - \frac{2\tilde{r}^2}{3\tilde{r}_0^2}\right) \exp\left(-\frac{\tilde{r}^2}{\tilde{r}_0^2}\right)$$

two-parameter compensated void $\int_0^\infty d\tilde{r}\, \tilde{r}^2 \delta(\tilde{r}) = 0$

Transverse plane projection $\tilde{r}^2(y,\theta) = y^2 + y_0^2 - 2yy_0 \cos\theta$

$$\longrightarrow \quad \delta_{2D}(\theta) = \int_0^\infty \delta(\tilde{r}(y,\theta)) y^2 \phi(y) dy$$

CMB profile

2 contributions:
linear Integrated Sachs-Wolfe and non-linear Riess-Sciama

RS dominates over ISW

$$\hookrightarrow \quad \delta T(\theta) = -A \left(1 - \frac{28}{13}\frac{\theta^2}{\tilde{\theta}_0^2}\right) \exp\left(-2\frac{\theta^2}{\tilde{\theta}_0^2}\right)$$

(Masina & Notari 2009)

$$A = 51\mu K \left(\frac{r_0}{155.3h^{-1}\mathrm{Mpc}}\right)^3 \left(\frac{\delta_0}{0.2}\right)^2$$

$$\tilde{\theta}_0 = \sqrt{\frac{3}{4\pi}}\frac{180^\circ}{\pi}\frac{r_0}{d_A(z_0)}$$

χ^2 statistic

We compute the galaxy number counts and the temperature mean fluctuations inside concentric rings centered at the CS and compare to the model profile.

Simultaneous fit for the projected LTB void and the corresponding RS effect on the CMB

$$\chi^2(\delta_0, r_0, z_0) = \sum_i \left(\delta_{2D}(\theta_i) - \delta_i^{\rm LSS}\right)^2 / \sigma_i^2 + \\ + \sum_{ij} \left(\delta T(\theta_i) - \delta T_i^{\rm CMB}\right) C_{ij}^{-1} \left(\delta T(\theta_j) - \delta T_j^{\rm CMB}\right)$$

σ_i Uncorrelated Poisson errors for the galaxy distribution

C_{ij} CMB Covariance matrix - through simulations

Best-fit parameters

$\delta_0 = 0.25 \pm 0.10$ matter density decrement

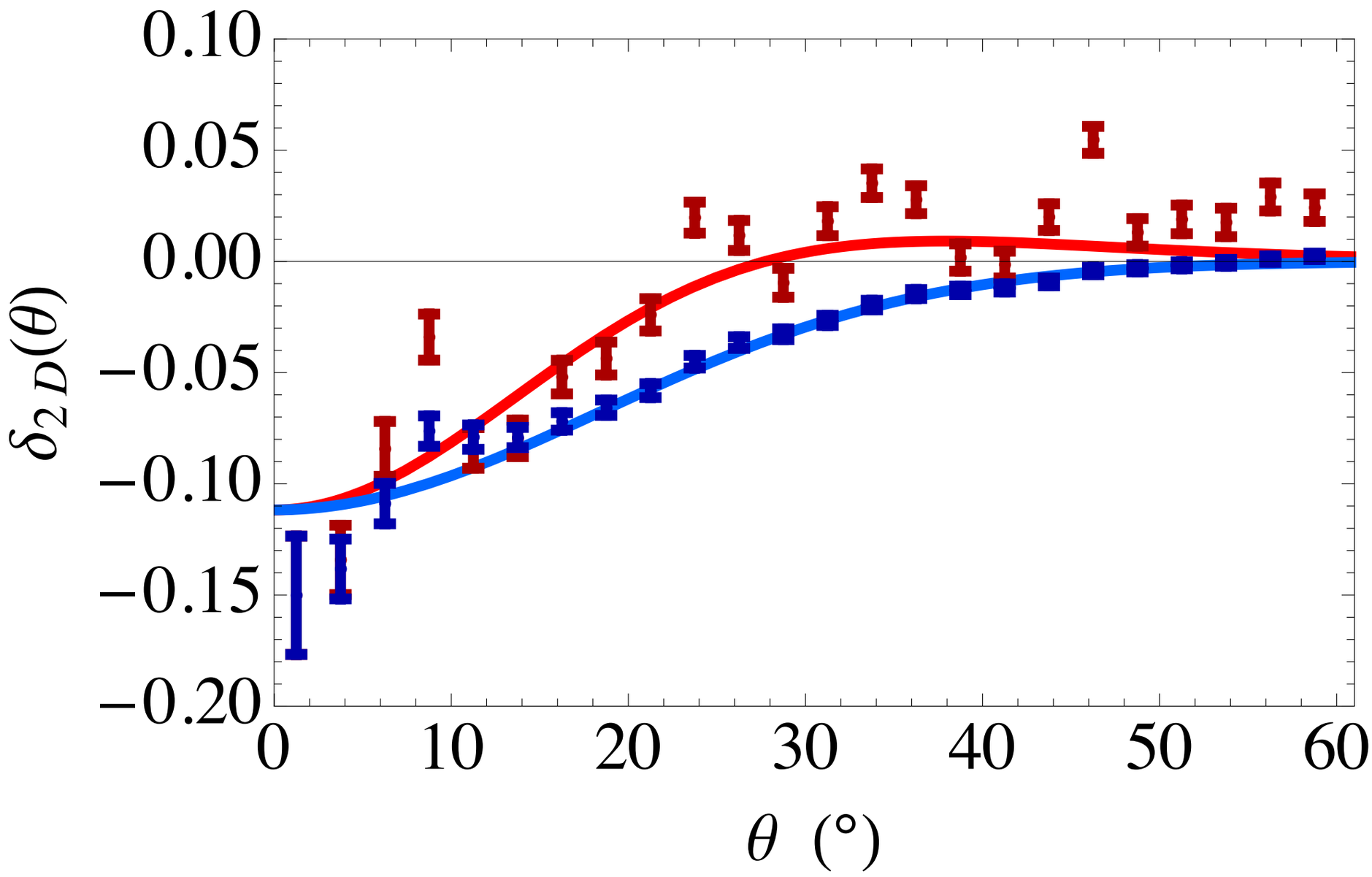
$r_0 = 195 \pm 35 \quad (\mathrm{Mpc}/h)$ void radius

$z_0 = 0.155 \pm 0.037$ void redshift

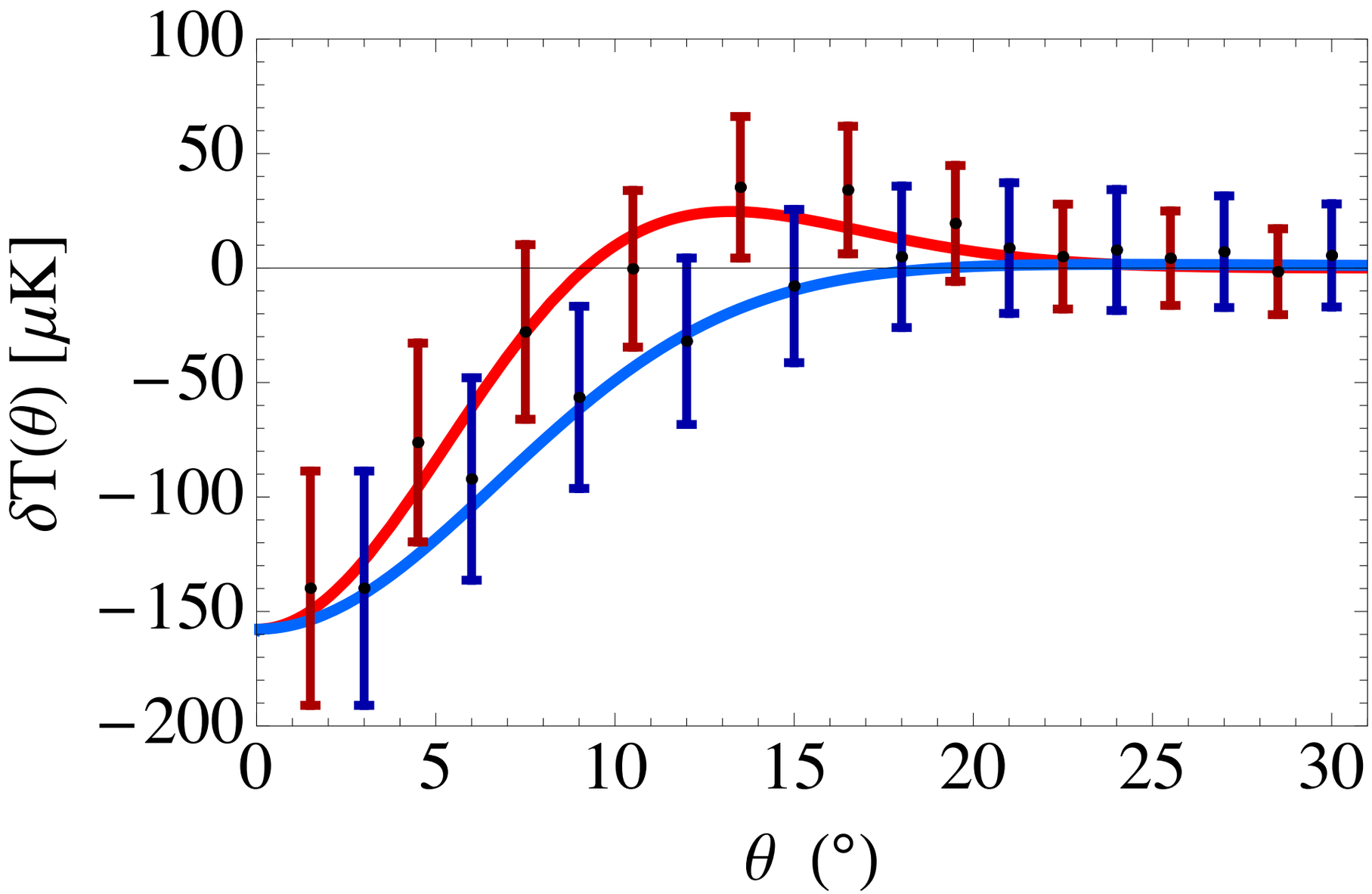
from which we derive a top-hat-averaged density

$$\bar{\delta} = \frac{3}{r^3} \int_0^{r_0} dr\, r^2 \delta(r) = -0.10 \pm 0.03$$

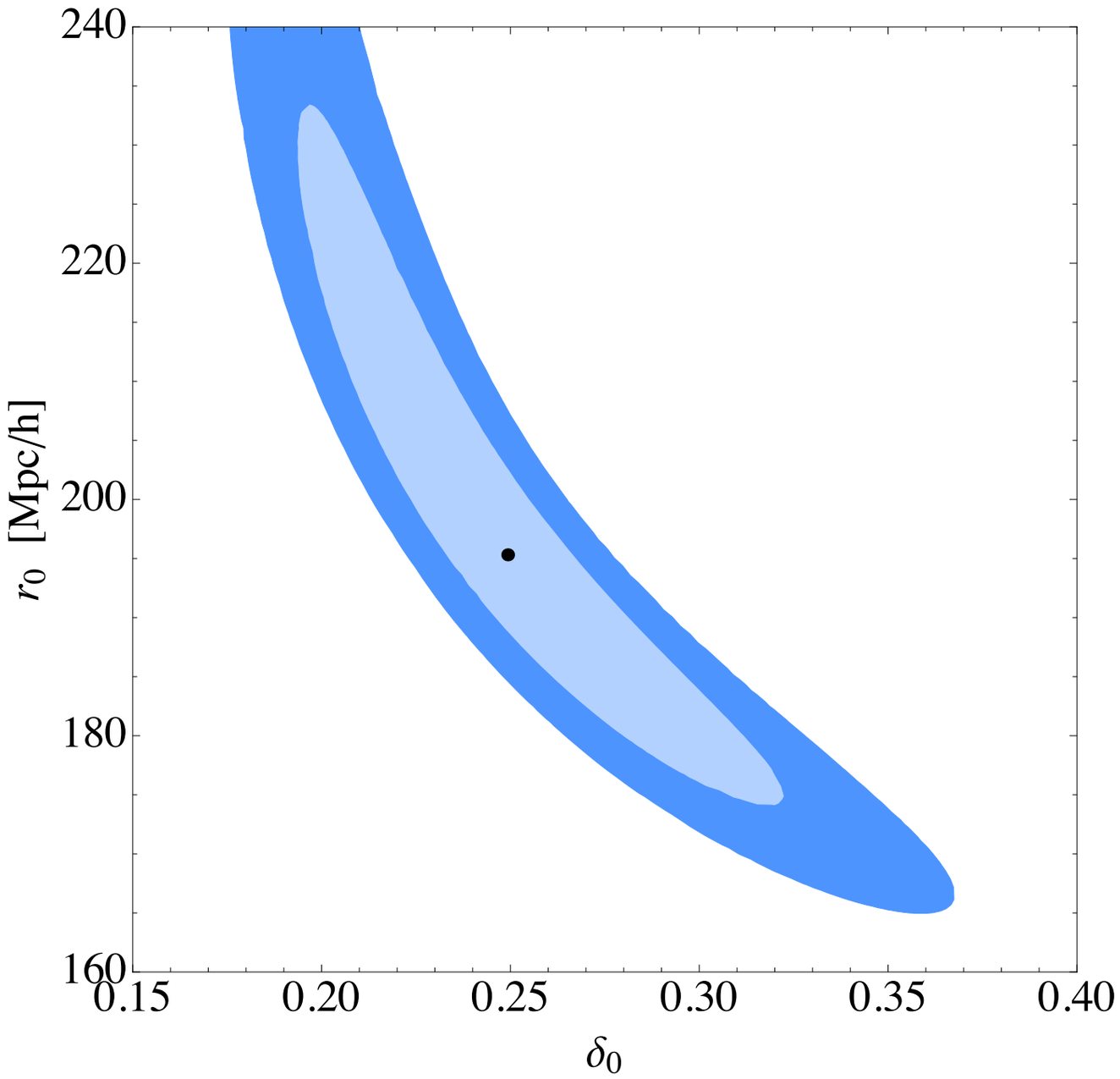
Density profile



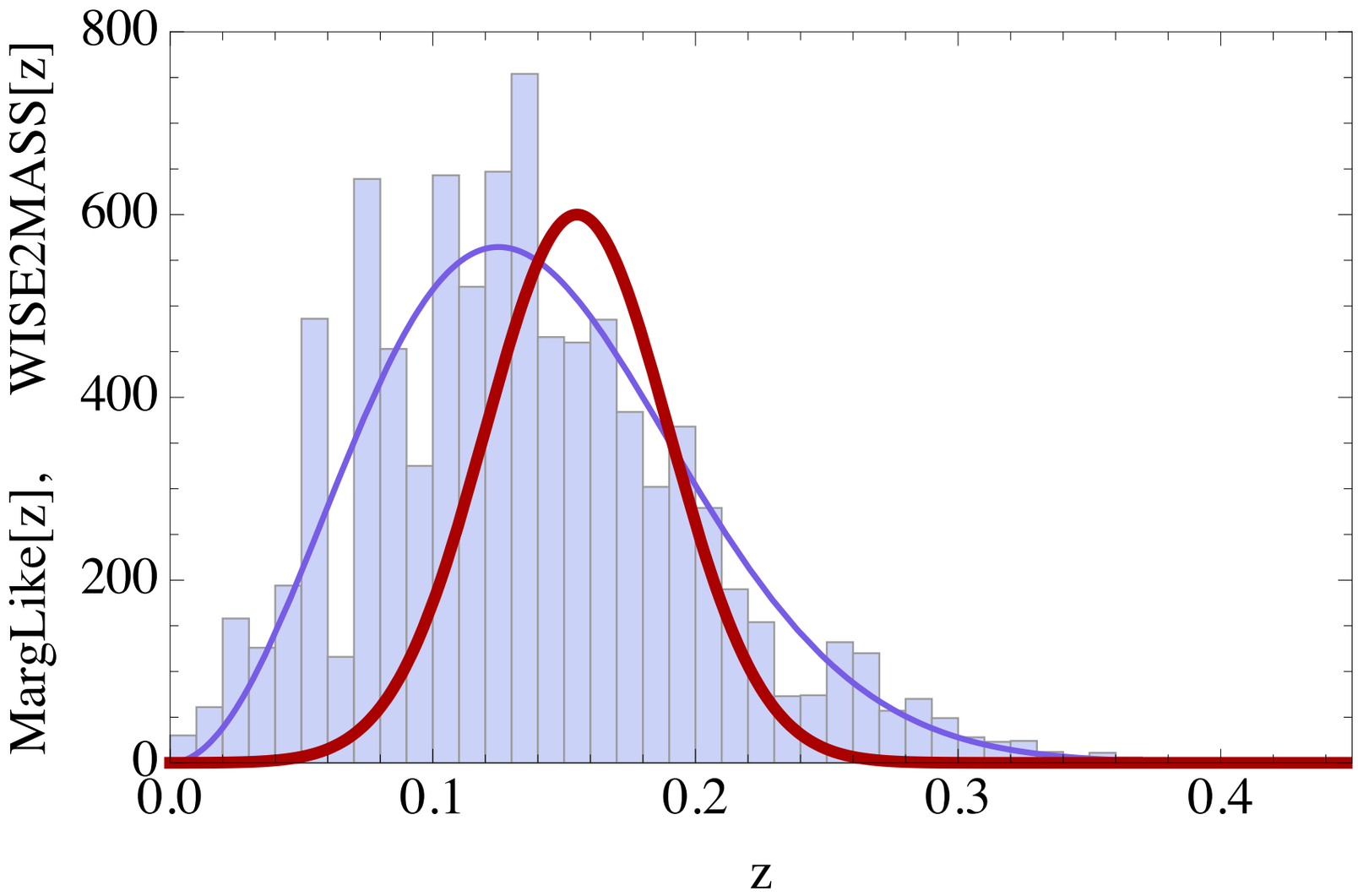
Temperature profile



size - density



redshift



Very good agreement with WISE-2MASS-PanStarrs I *(Szapudi et al. 2014)*

$$\bar{\delta} = -0.12 \qquad r_0 = 192 \pm 15 \quad (\mathrm{Mpc}/h) \qquad z_0 = 0.22 \pm 0.01$$

Only-CMB fit

For a comparison with a texture origin of the CS

$$\chi^2_{\rm LTB} = 7.06 \qquad \chi^2_{\rm null} = 27.35 \qquad \chi^2_{\rm texture} = 9.35$$

$$\text{d.o.f.} = 10 - 3 = 7$$

Bayesian evidence

$$\ln E_{\rm LTB} = -9.54 \qquad \ln E_{\rm null} = -13.68 \qquad \ln E_{\rm texture} = -15.47$$

LTB strongly favored!

Conclusions

- A supervoid in the WISE-2MASS is detected, aligned with the CMB Cold Spot
- Excellent LTB fit for both galaxy counts and CMB

$$\bar{\delta} = -0.10 \pm 0.03 \qquad r_0 = 195 \pm 35 \quad (\mathrm{Mpc}/h)$$

$$z_0 = 0.155 \pm 0.037$$

- Consistency with the WISE-2MASS-PSI analysis
- Towards the first physical description of the CS