Evidence of Super-structures in the Cosmic Microwave Background and Galaxy Distribution

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in collaboration with

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APJ 2010 & new result

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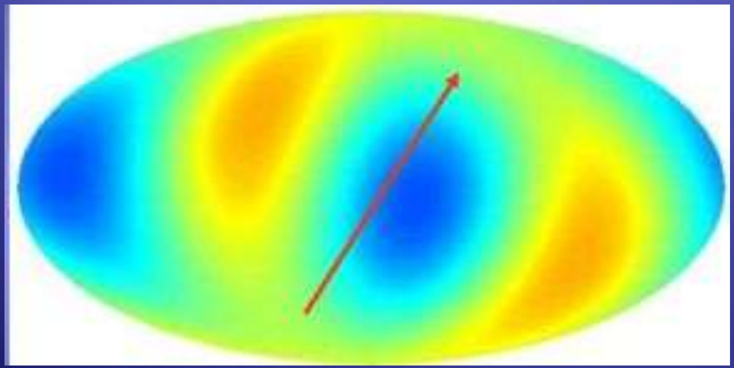
Outline

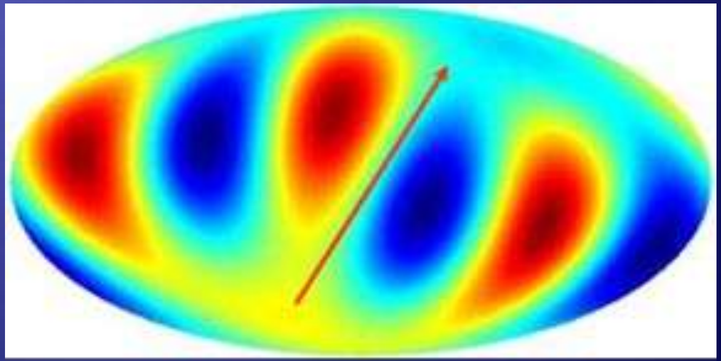
- Introduction
- CMB anisotropy from super-structures
- ISW signals in LSS-WMAP data
- Origin of the Cold Spot (if time is available)
- Summary

Introduction

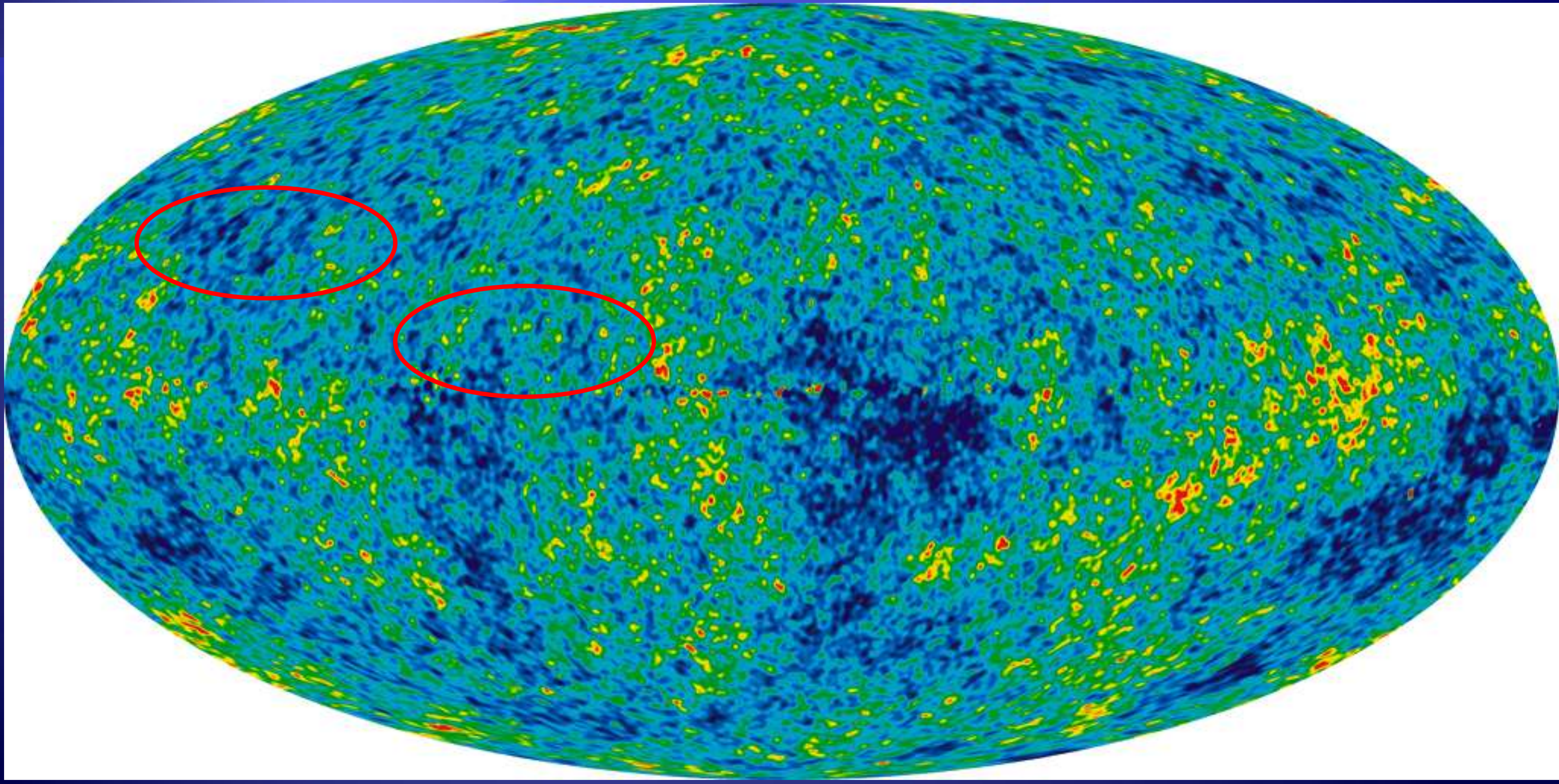
CMB anomalies exist or not?

- Alignment between $l=2$ and $l=3$ (Tegmark et al. 2003)
- A unusually cold spot (Cruz et al. 2003)
- Asymmetry in two hemispheres (Erikesen et al. 2004)
- Correlation with the ecliptic plane (Schwarz et al.2004)

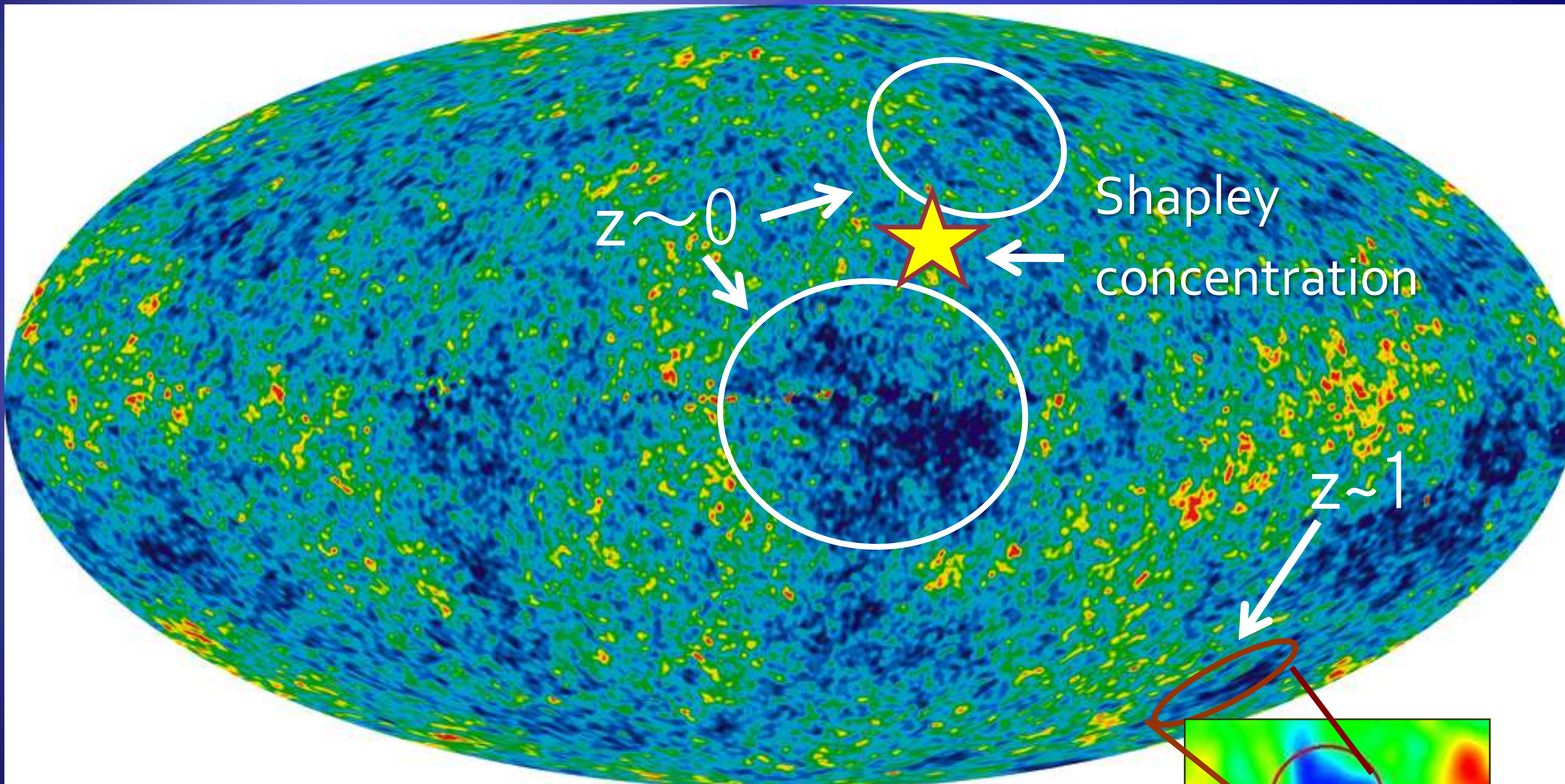


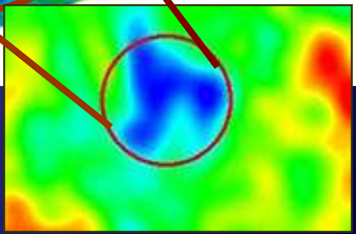


A posterioi choice or optimal filter?



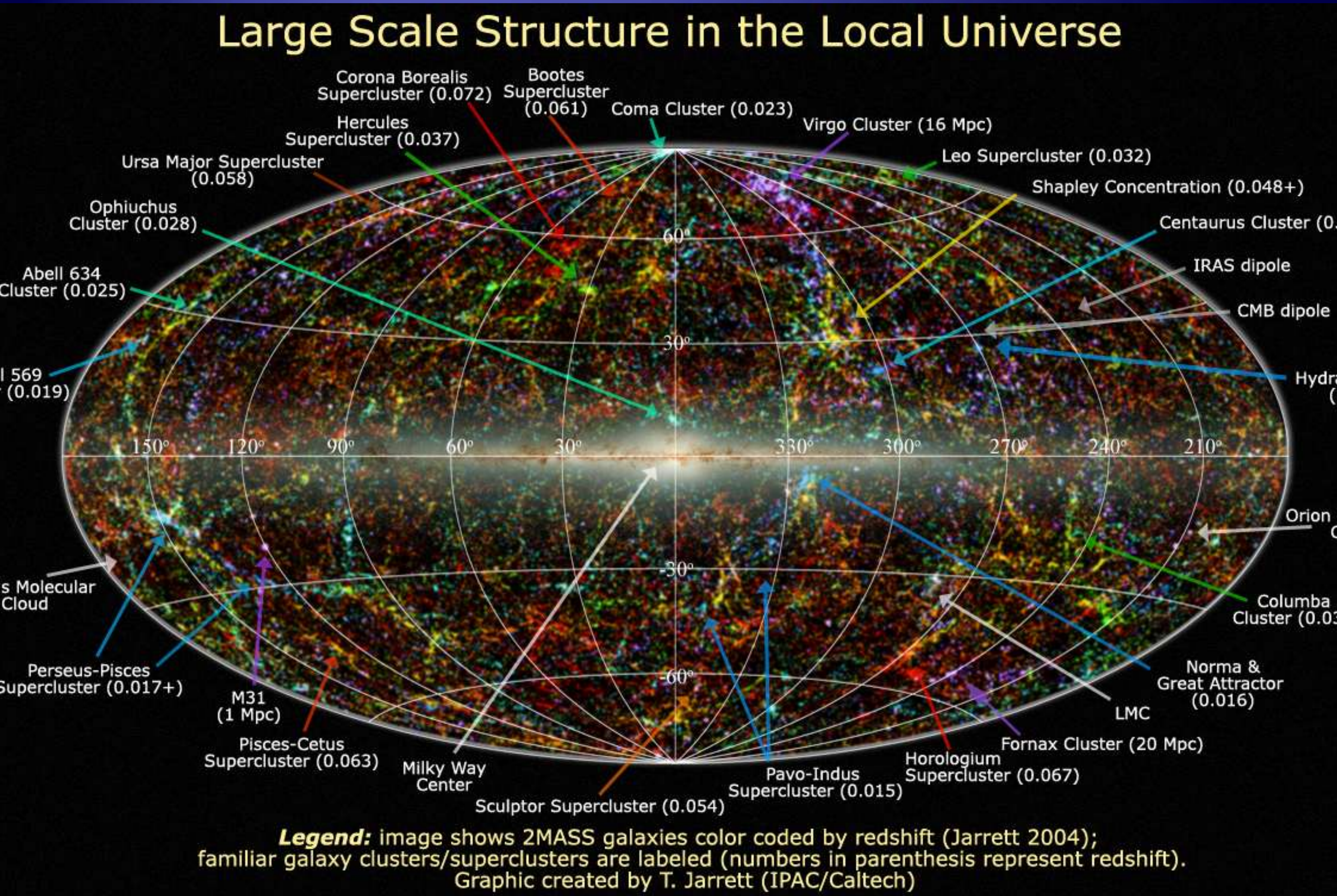
Optimal filters for local supervoids ?





"the Cold Spot"

(Inoue & Silk, 2007&2008)



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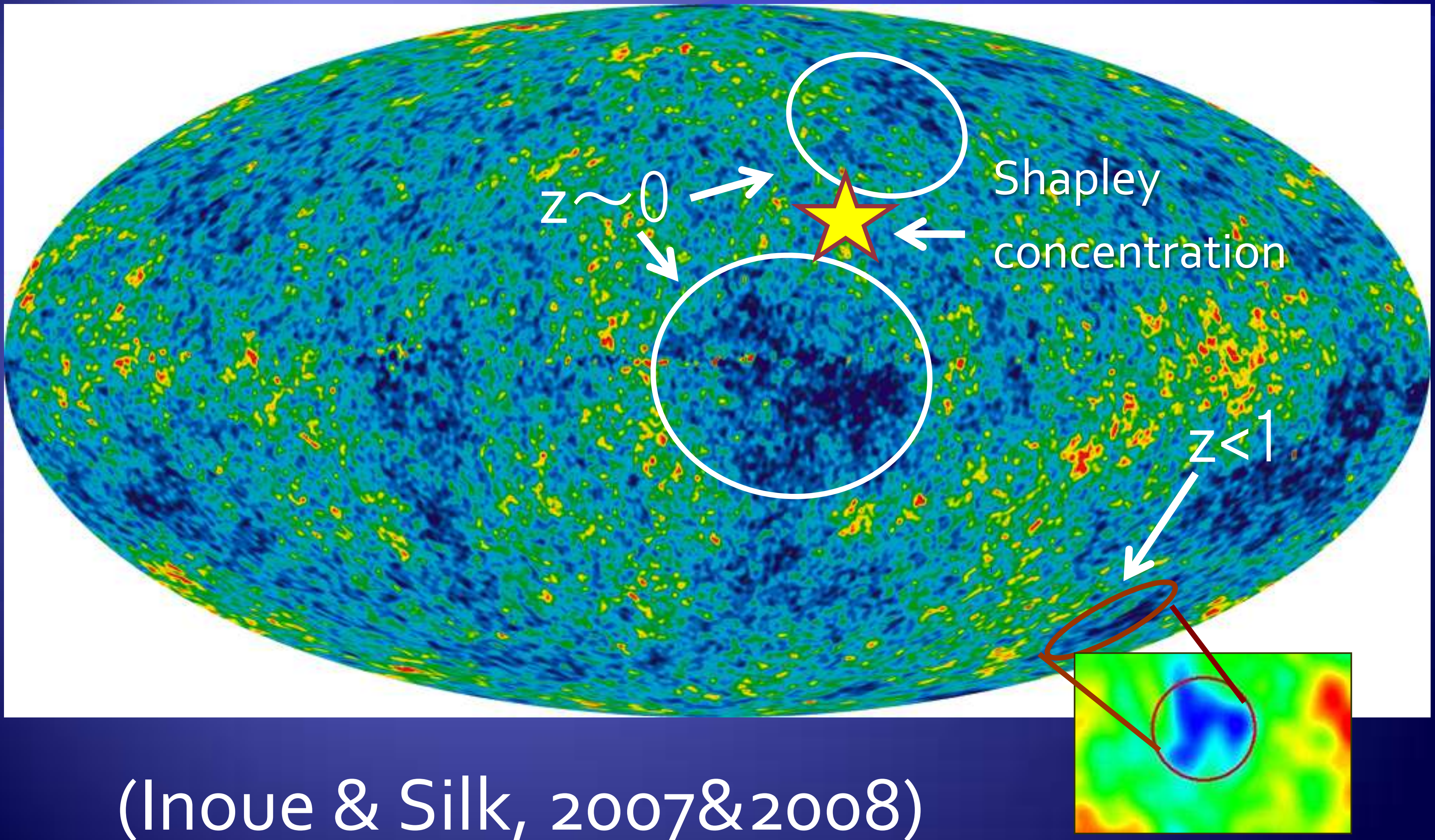

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2MASS Local ISW

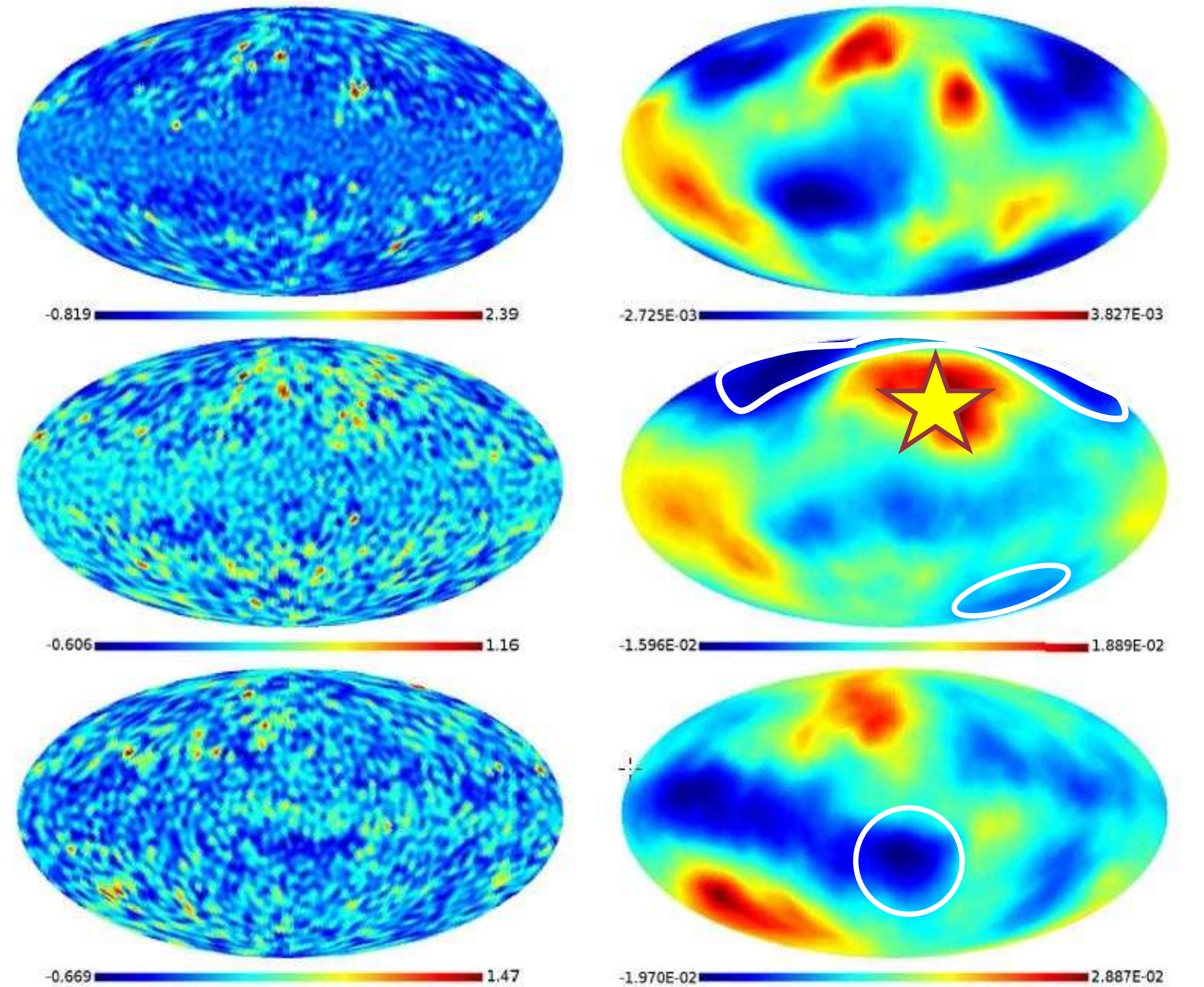


Figure 1. (Left) The 2D reconstruction of the local density field described in Section 2.1 in three photometric redshift shells: $0.0 < z < 0.1$ (top), $0.1 < z < 0.2$ (middle) and $0.2 < z < 0.3$ (bottom). The plots show overdensity δ on a scale $-0.6 \leqslant \delta \leqslant 0.6$. (Right) The corresponding ISW signal in mK computed from the reconstructed density field using equation (4).

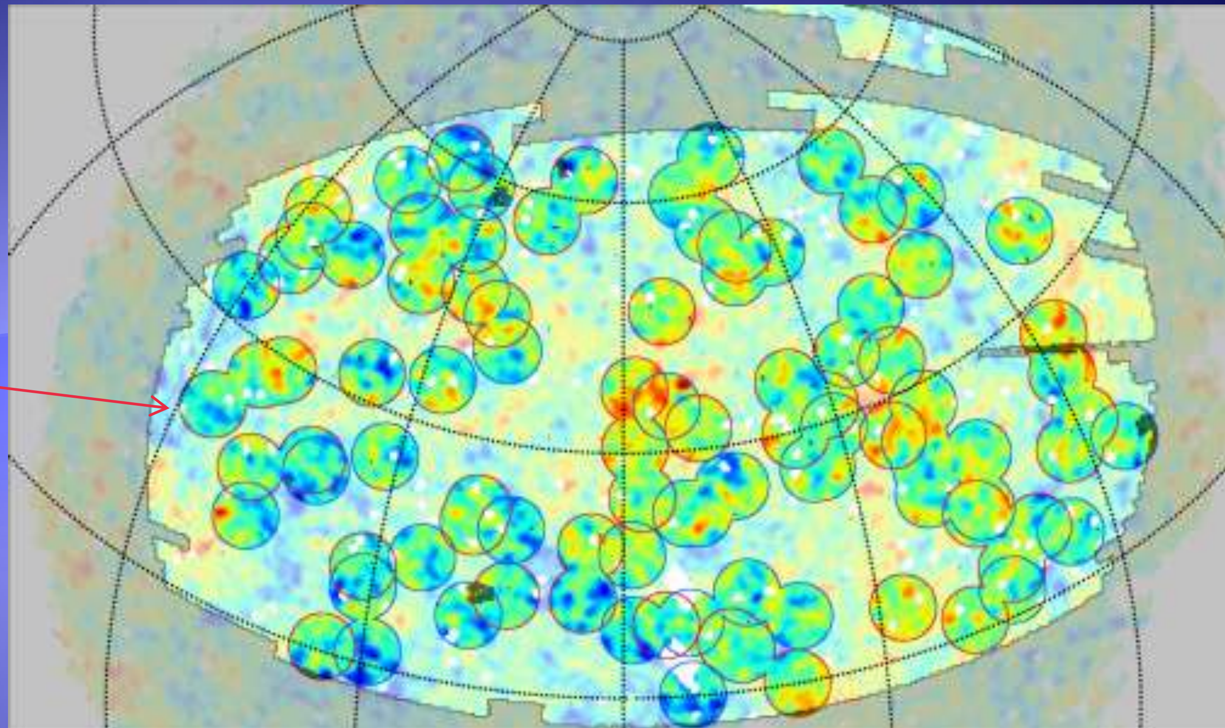
0.0<z<0.1

0.1<z<0.2

0.2<z<0.3

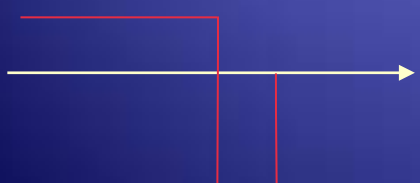
(Francis & Peacock, 2009)

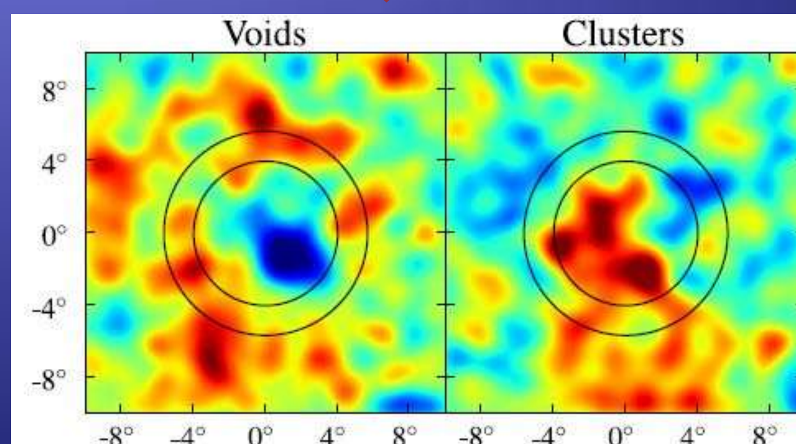
SDSS LRG
voids &
clusrters



stacking

compensating filter





(Granett et al. 2008)

$0.45<z<0.75$

CMB anisotropy from local super-structures

ISW (RS) effects from SSS

Theory

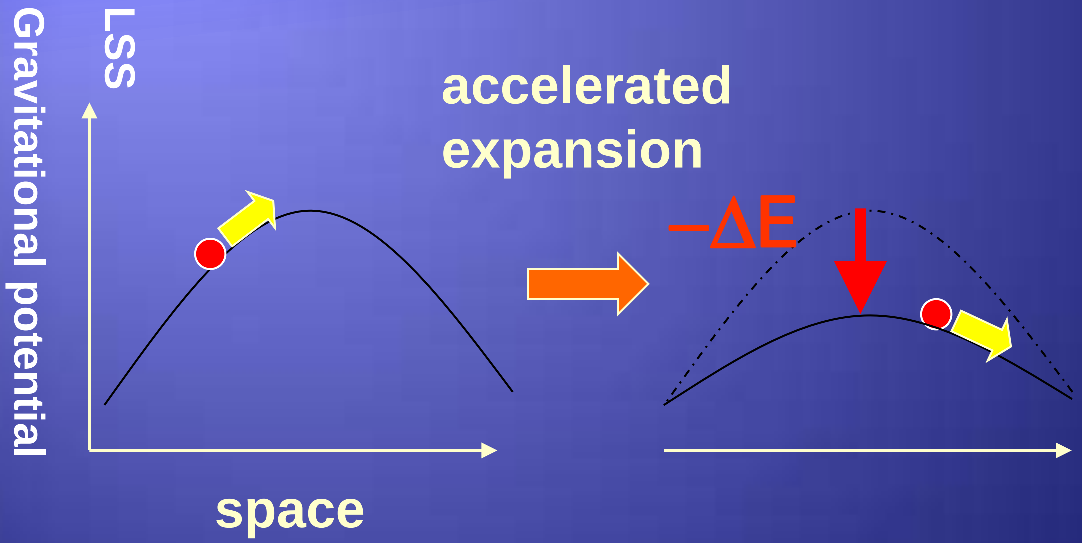
- Thin-shell approx. (Inoue & Silk 2007&2008)
- 2nd order perturbations (Tomita & Inoue 2008)
- LTB solutions (Sakai & Inoue 2008)

Observation

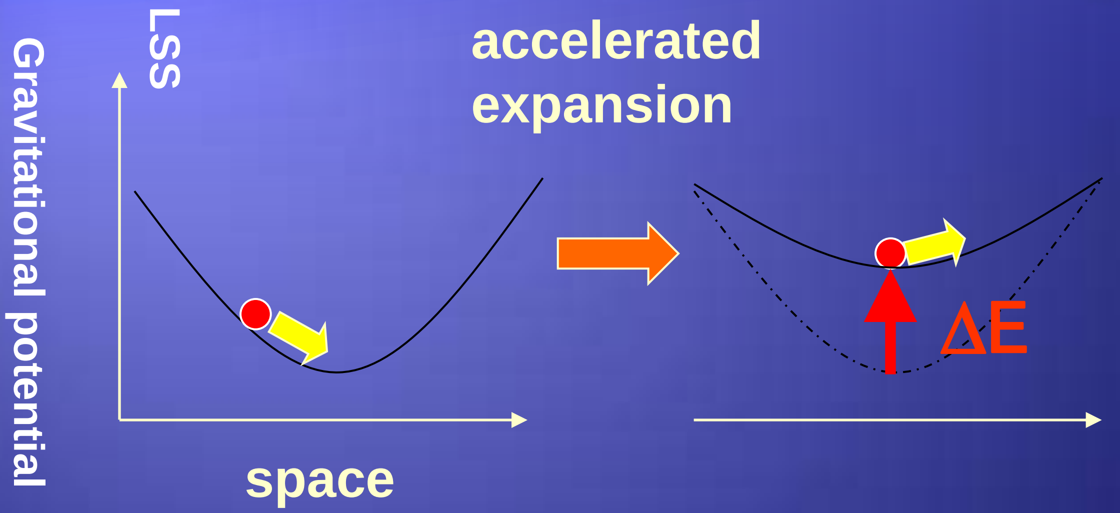
- SDSS LRGs (Granett et al. 2008)
- 2MASS photo-z (Francis & Peacock 2009)

Integrated Sachs-Wolfe (ISW) Effect

temperature fluctuation due to time-evolving gravitational potential

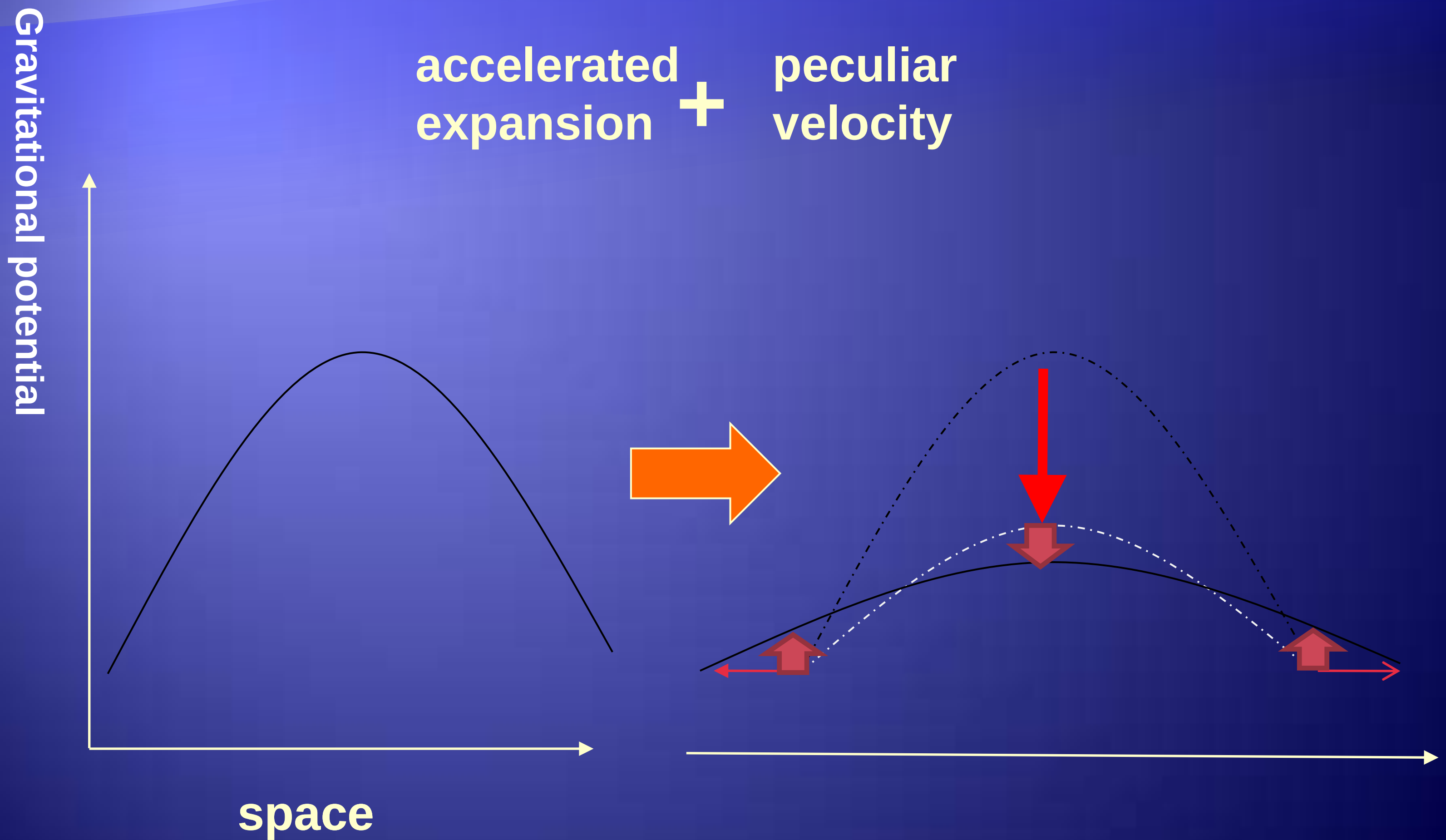


→low temperature for CMB photons that pass through a void temperature fluctuation due to time-evolving gravitational potential

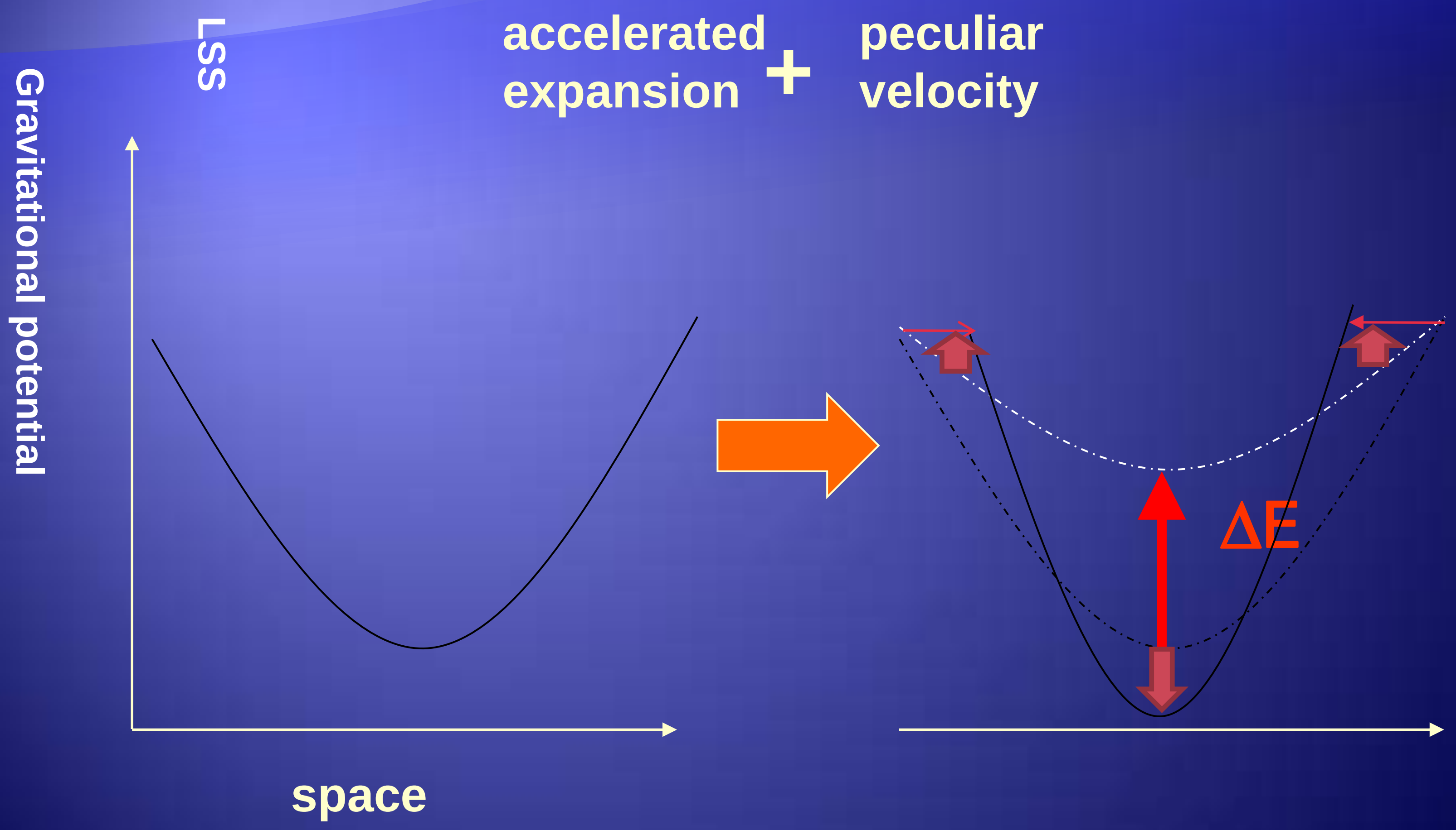


→high temperature for CMB photons that pass through a cluster

Second order ISW (RS) Effect

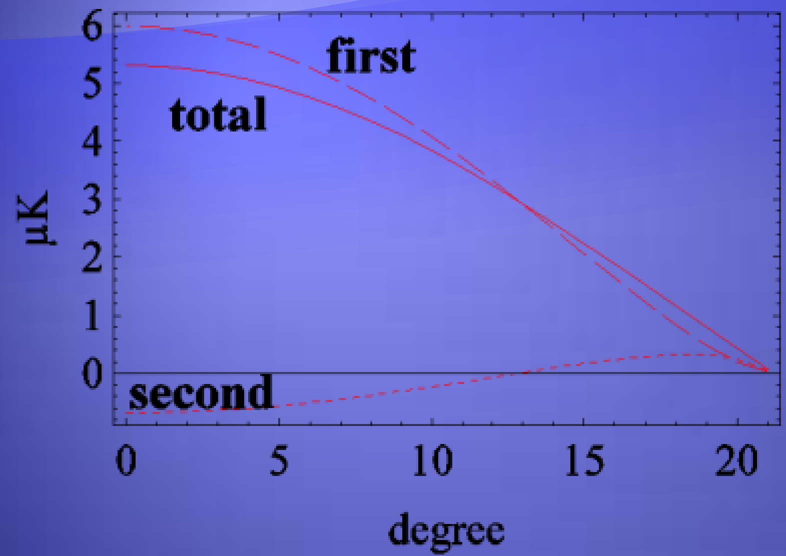


Second order ISW (RS) Effect

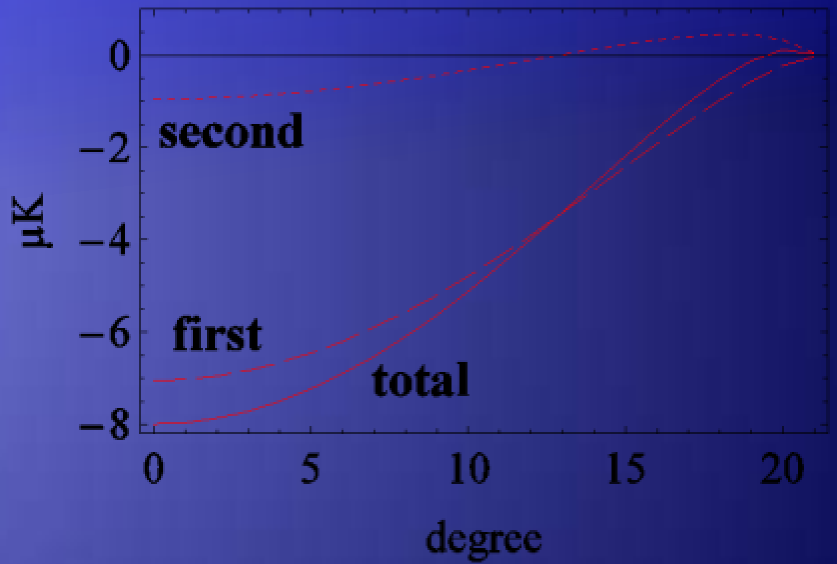


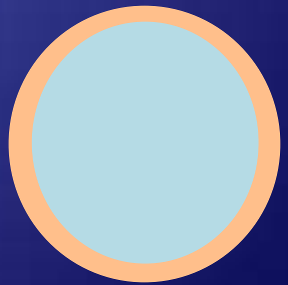
1^{st} & 2^{nd} order ISW effects

cluster



void





ISW signals in LSS-WMAP data

CMB-galaxy cross correlation for prominent structures

- Stacked images enhances S/N for 3D images
- Analytic formula suitable in quasi-linear regime
- Sensitive to initial non-Gaussianity

⇨ **Obtain statistical significance of the stacked images!**

Settings

- Top-hat spherical void/cluster with a thin-shell
- Homogeneous collapse without a shell
- One-to-one correspondence between linear and non-linear density fluctuations
- Parameters:

δ_H Hubble contrast

r comoving radius

δ_m density contrast

N Number of voids/clusters

Equations

$$\frac{\Delta T}{T} = \frac{1}{3}\Big[\xi^3 \cos\psi\Big(-2\delta_H^2 - \delta_H^3 + (3+4\delta_m)\delta_H\Omega_m + \delta_m\Omega_m(-6\gamma+1) + (2\delta_H^2 + \delta_H^3 + \delta_m\Omega_m + (3+2\delta_m)\delta_H\Omega_m)\cos 2\psi\Big)\Big], \quad \xi = arH \qquad (1)$$

Temperature fluctuations due to a thin shell void/cluster

$$\left(\frac{d\eta}{dz}\right) = -[-\Omega_{m,0}(1+z_i)\delta_{mi} + \Omega_{m,0}(\eta/(1+z))^{-1} + \Omega_{\Lambda,0}(\eta/(1+z))^2]^{1/2}[\Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0}]^{-1/2} + \frac{\eta}{1+z}. \qquad \eta = r/r_i \qquad (8)$$

Time evolution of Homogeneous FRW patch

$$\delta_m^L(z) = \frac{3\,\delta_{mi}H(z)}{5}\int_z^\infty du \frac{u+1}{H^3(1/u-1)}, \qquad (9)$$

Time evolution of linear density perturbation

Result I

TABLE 1
EXPECTED AND OBSERVED AMPLITUDE OF MEAN TEMPERATURE FOR A COMPENSATED FILTER $\theta_{th} = 4°$

N	void (μK)	cluster (μK)	average(μK)
1	-1.2	1.08	1.14
5	-0.96	0.88	0.92
10	-0.85	0.78	0.82
30	-0.65	0.60	0.63 (11.1 ±2.8)[a]
50	-0.54 (11.3 ±3.1)[a]	0.51 (7.9 ±3.1)[a]	0.52 (9.6 ±2.2)[a]
70	-0.46	0.43	0.45 (5.4 ±1.9)[a]

[a] Taken from Granett et al. (2008).

$$(\Omega_0, \Omega_\Lambda, \Omega_b, h, \sigma_8, n) = (0.26, 0.74, 0.044, 0.72, 0.80, 0.90)$$

TABLE 2
EXPECTED AND OBSERVED DENSITY CONTRAST FOR SUPER-STRUCTURES IN 2MASS GALAXY CATALOG

radius	expected	observed	radius	expected	observed
370	-0.013	-0.049	230	0.037	0.20
250	-0.037	-0.15	150	0.094	0.69

SSS based on LTB solutions

metric & equation

$$ds^2 = -dt^2 + \frac{R'^2(t,r)}{1+f(r)}dr^2 + R^2(t,r)(d\theta^2 + \sin^2\theta d\varphi^2)$$

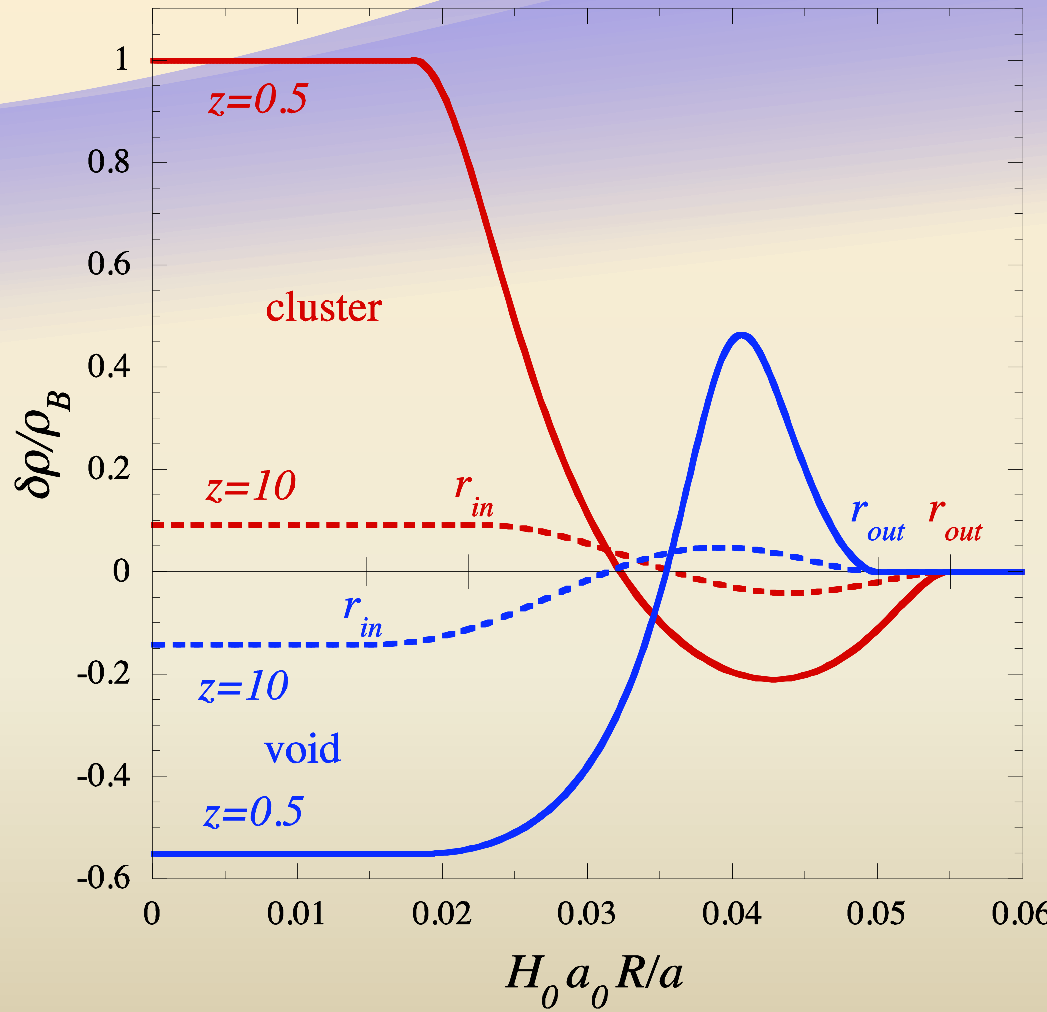
$$\dot{R}^2 = \frac{2Gm(r)}{R} + \frac{\Lambda}{3}R^2 + f(r)$$

$$\rho = \frac{m'(r)}{4\pi R^2 R'}$$

discretization in radial coordinates

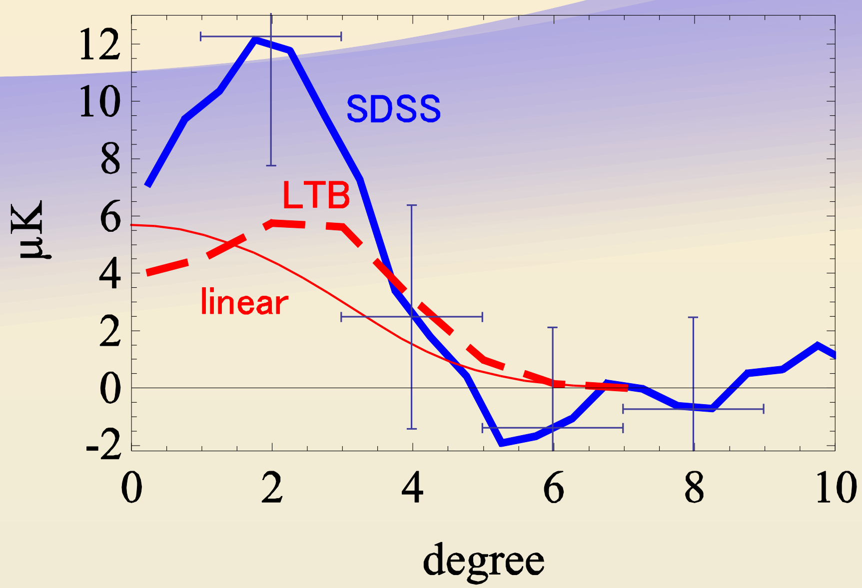
$$r_i = i\Delta r, \quad i = 1, ..., N, \quad \Delta r = \frac{r_{out}}{N}.$$

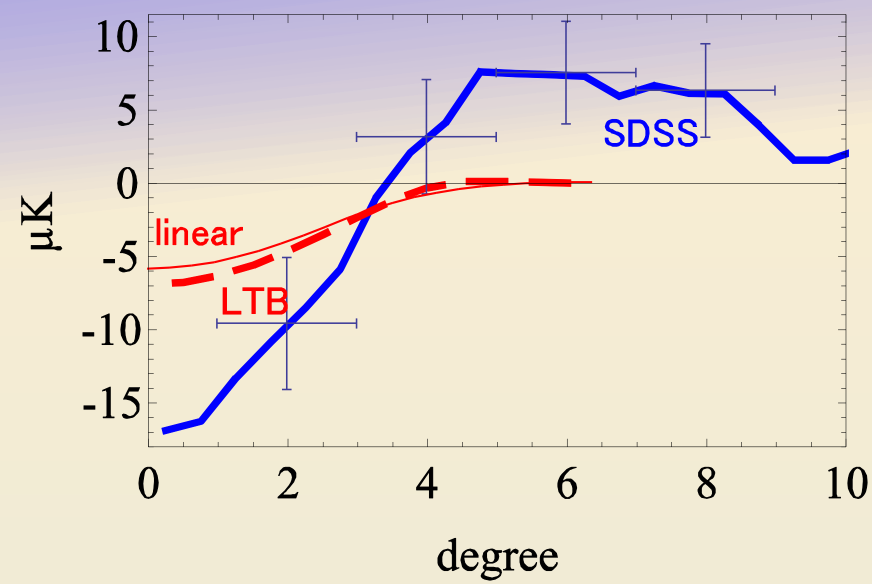
LTB model

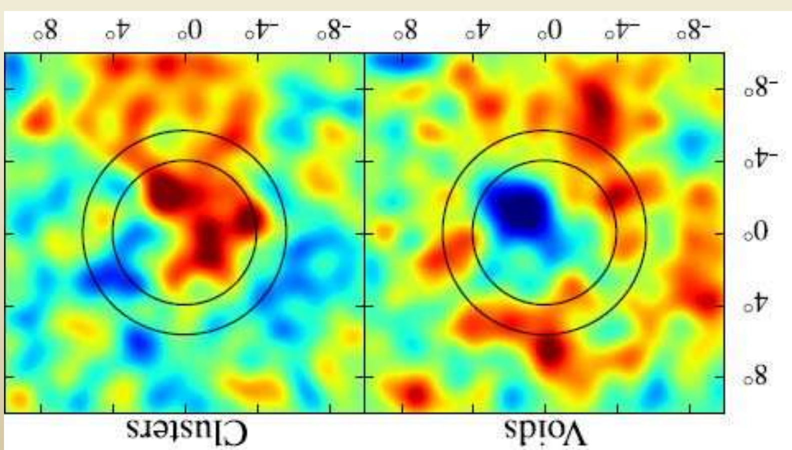


1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
$\delta\rho/\rho_B$
z=0.5
cluster
z=10
r_{in}
r_{out}
r_{out}
r_{in}
z=10
void
z=0.5
0
0.01
0.02
0.03
0.04
0.05
0.06
$H_0 a_0 R/a$

Result II







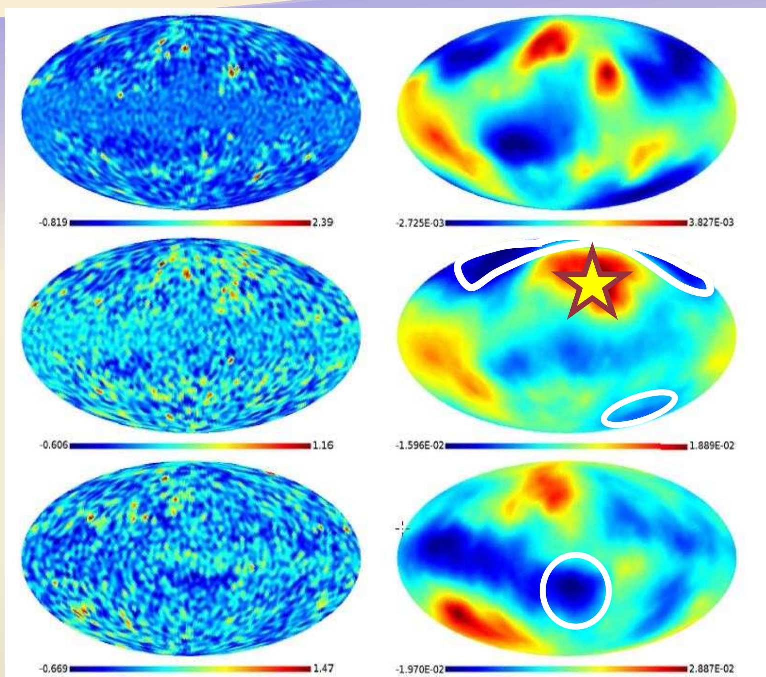
SDSS : (Granett et al. 2008)

LTB,linear (compensating)

z=0.5 : (IST 2010)

Result III

galaxy CMB



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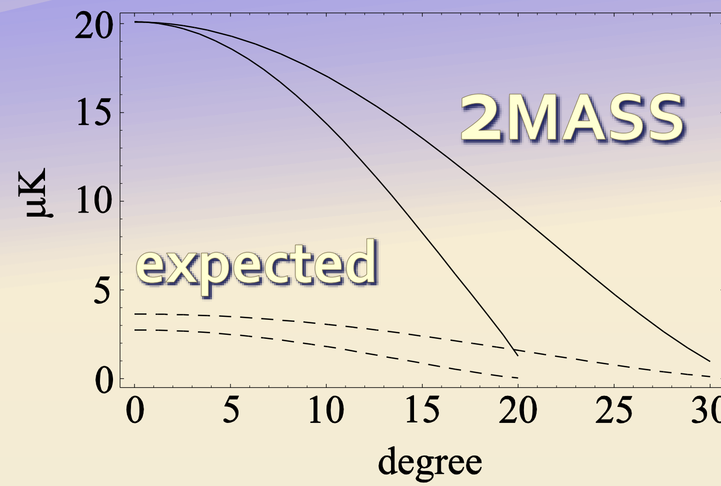
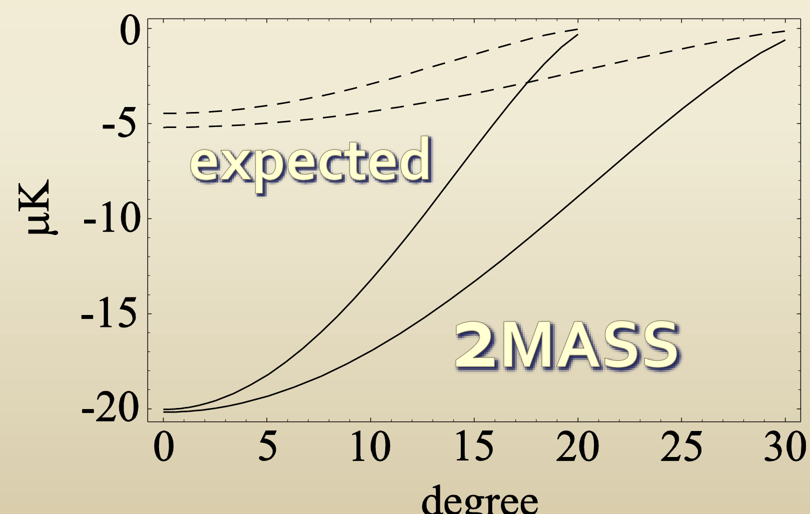




Origin of the Cold Spot

Temperature profile of the Cold Spot

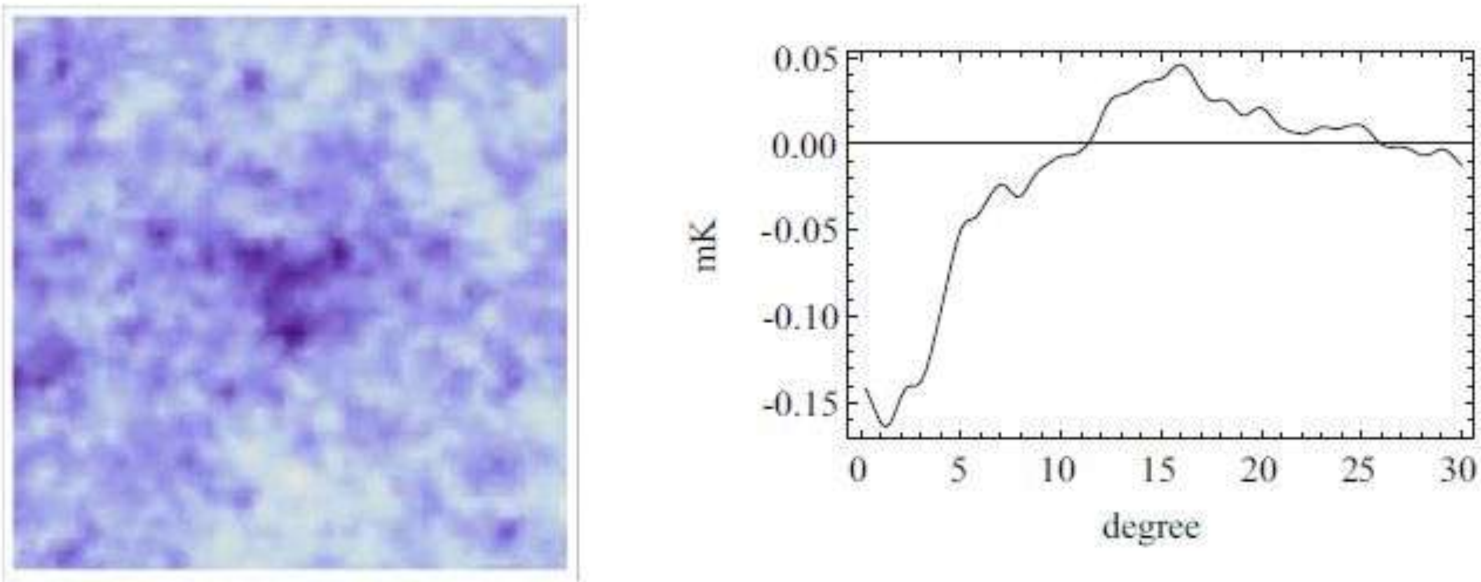
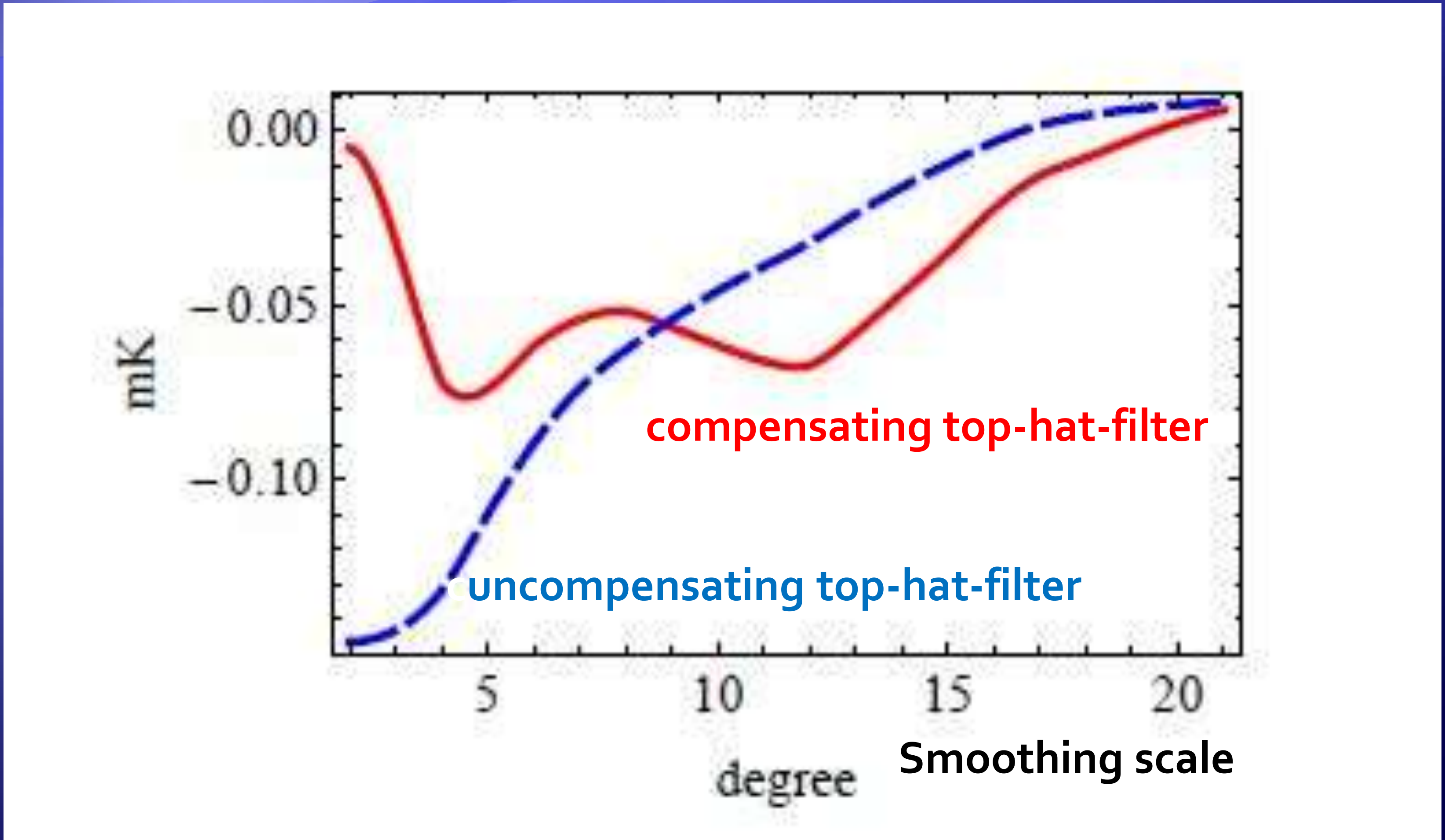
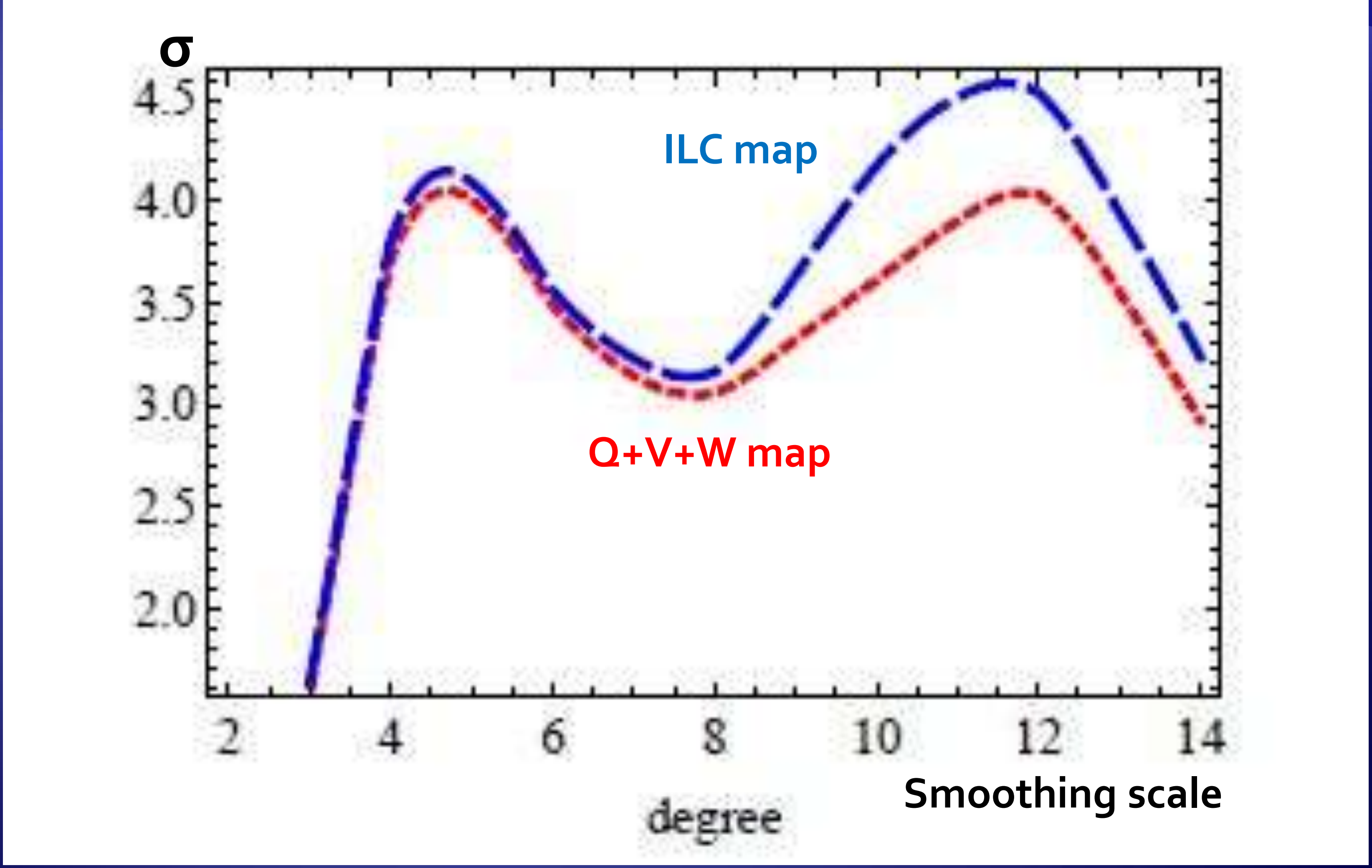


Fig. 10.— Left: the WMAP7 ILC temperature map ($40^\circ \times 40^\circ$) smoothed at 1° scale. Right: the averaged radial profile of the ILC map as a function of inclination angle θ from the center of the cold spot $(l, b) = (207.8^\circ, -56.3^\circ)$. A peak at $\theta \sim 15^\circ$ corresponds to a hot ring.

Top-hat filtered observed temperature profiles of CS



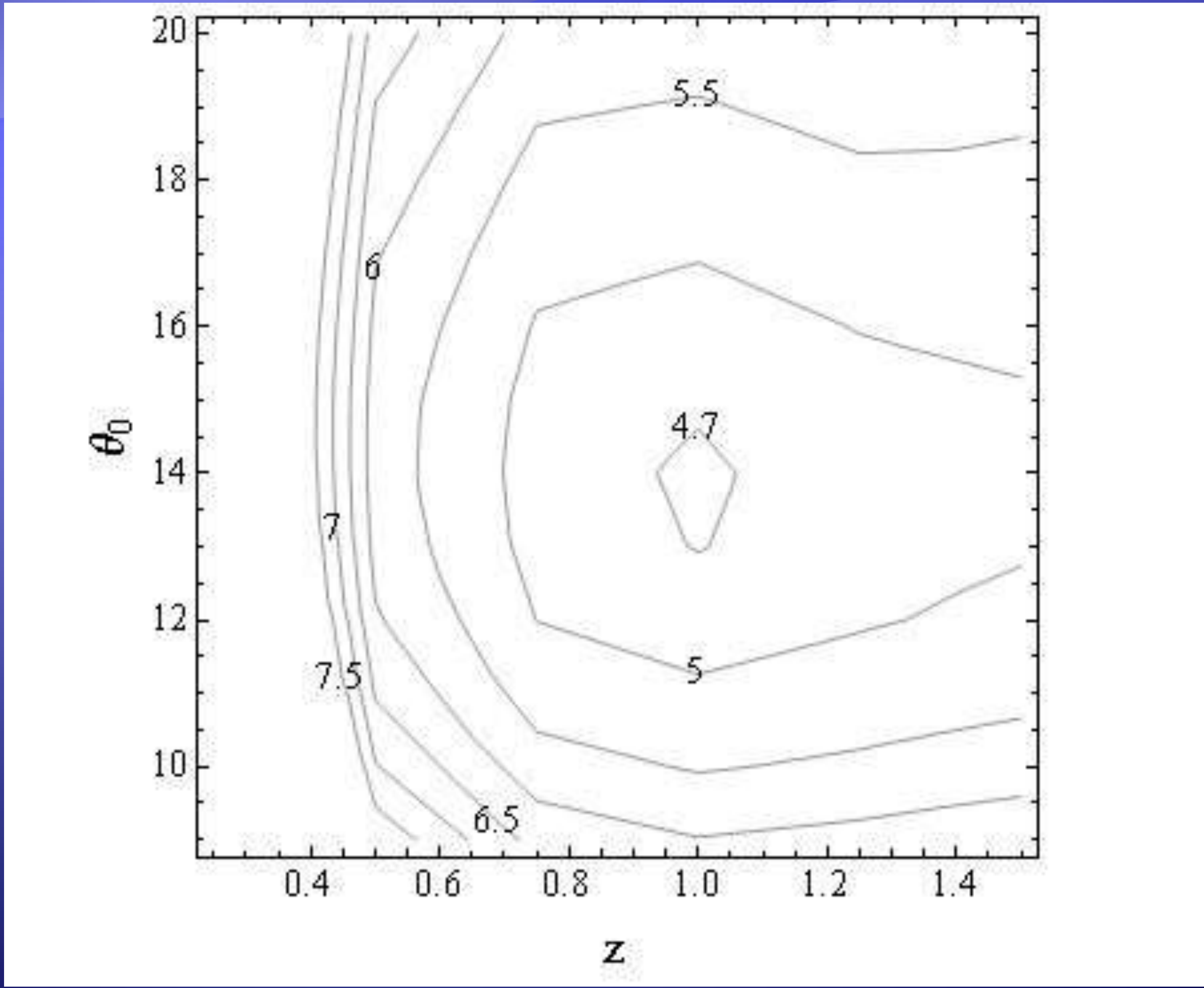
Statistical significance



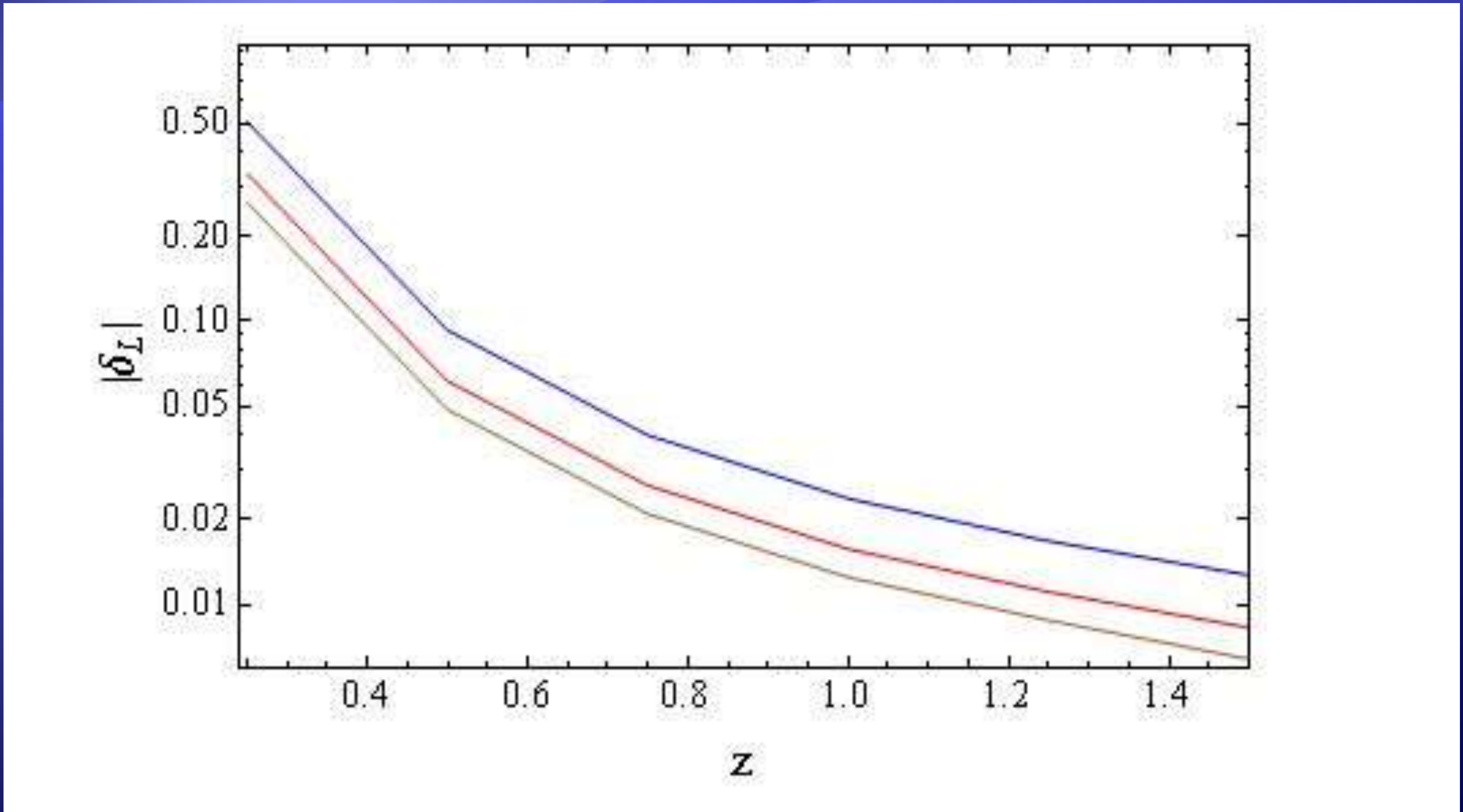
Statistical significance

- Sample number~observed area/size of filtering
- At =5 degree , significance is 0.7-1 %(~2σ)
  at =12 degree, significance is 0.01-0.2%(~3σ)
- Suppose 18 μK ISW contribution (1σ) from a supervoid, the significance is 0.001% (~4.4σ) in standard ΛCDM (preliminary).

Size and positions



Density contrast and positions



δ_L as a function of z for θo=12(blue), 15(red), 18(brown) degree

Summary

- ISW signal from SDSS –WMAP stacked images is inconsistent with the prediction for a concordant LCDM model at >3σ level.
- ISW signals in photo-z 2MASS data ($z<0.3$) are several times larger than the LCDM prediction.
- Non-linear effects (hot-ring around cold spot & dip at the center of hot spot) seem to be present in the SDSS data.

Discussions

- However, it seems difficult to make prominent non-linear signals as in observations.
- Suggesting non-compensating mass profiles or deviation in the growth factor?
- Suggesting non-Gaussianity or f(R)?