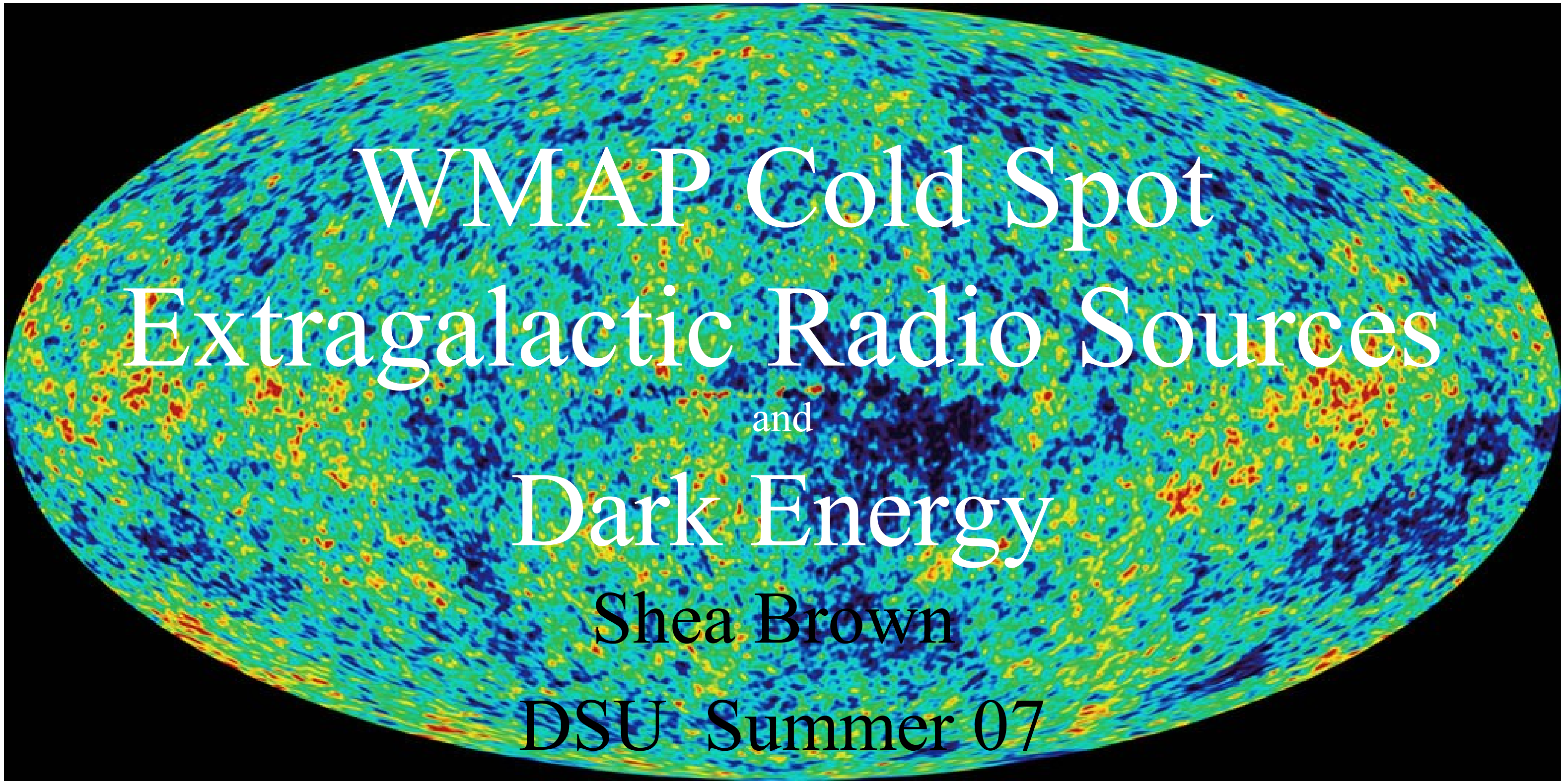


# WMAP Cold Spot Extragalactic Radio Sources and Dark Energy

Shea Brown

DSU Summer 07

Rudnick, Brown & Williams astro-ph/0704.0908

# Non-Gaussian Cold Spot

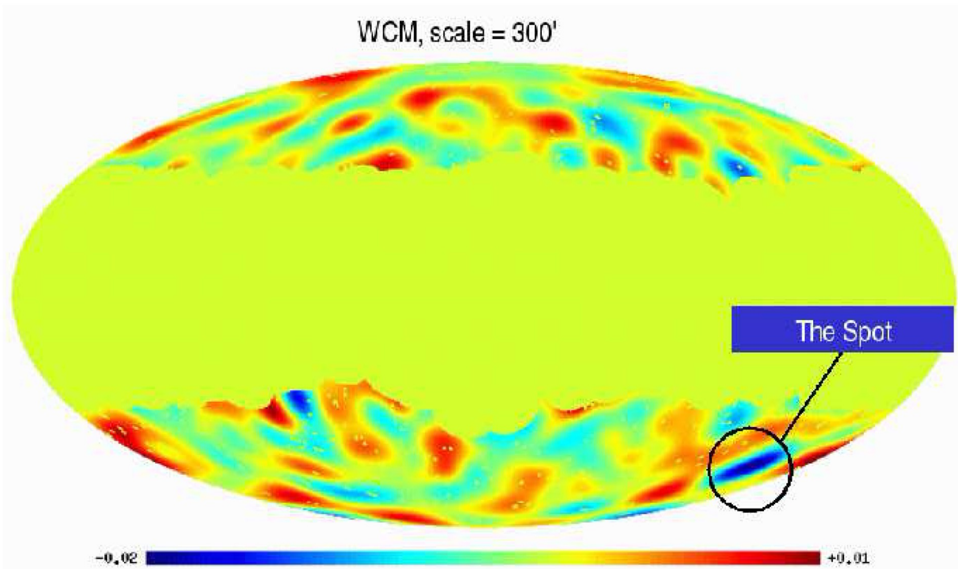


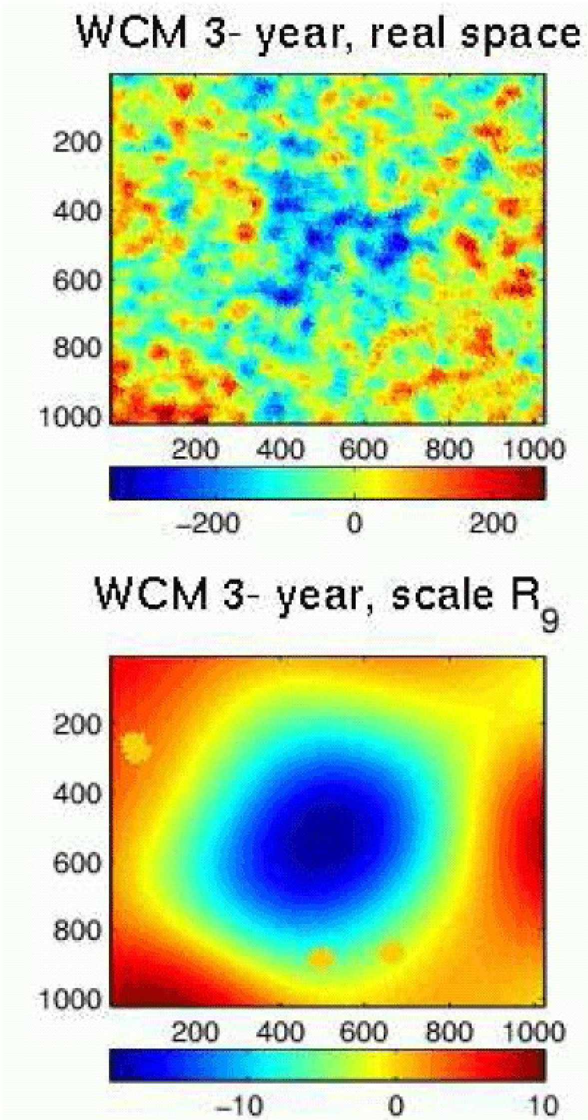

**Figure 1.** The combined and foreground cleaned Q–V–W WMAP map after convolution with the SMHW at scale $R_9$. The position of *the Spot* is marked.

- A non-Gaussian cold spot has been found in WMAP with SMHW
- Many papers have been written on possible origins for the cold spot: e.g.
  - Foreground subtraction errors
  - SZ effect
  - Intrinsic non-gaussianity
  - **Integrated Sachs-Wolfe effect (ISW) by local voids**

Vielva, P., Martinez-Gonzalez, E., Varreiro, R. B., Sanz, J. L., Cayon, L. 2004, ApJ 609, 22

Cruz, M., Martinez-Gonzalez, E., Vielva, P., Cayon, L. 2005, MNRAS 356, 29

# A Closer Look



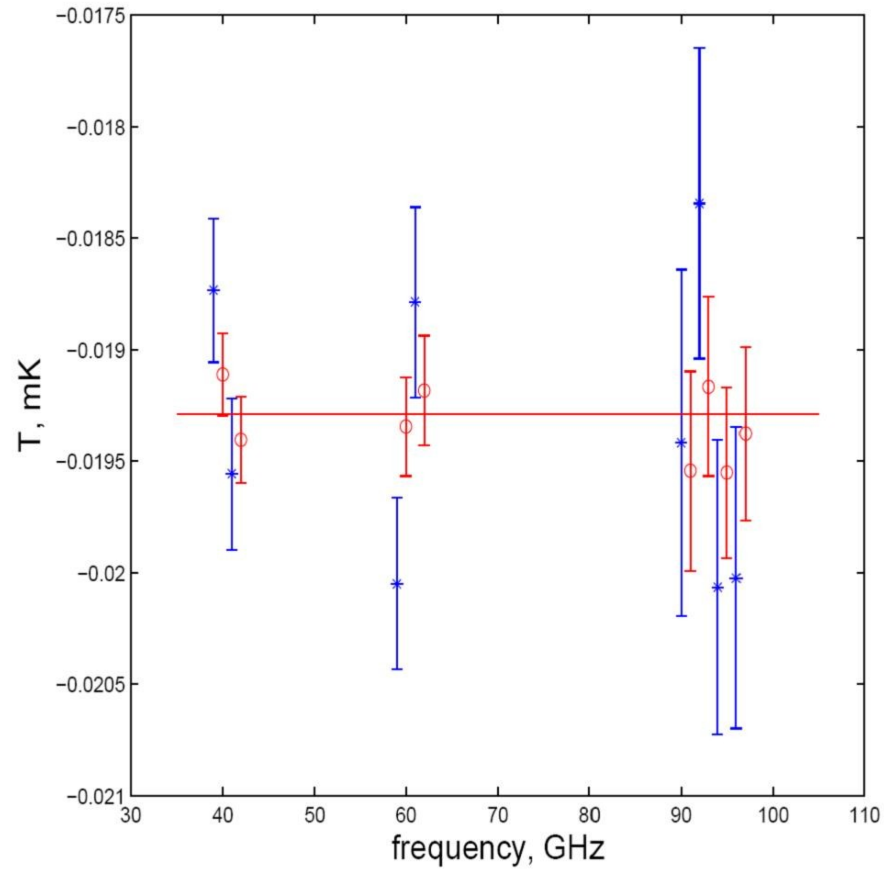
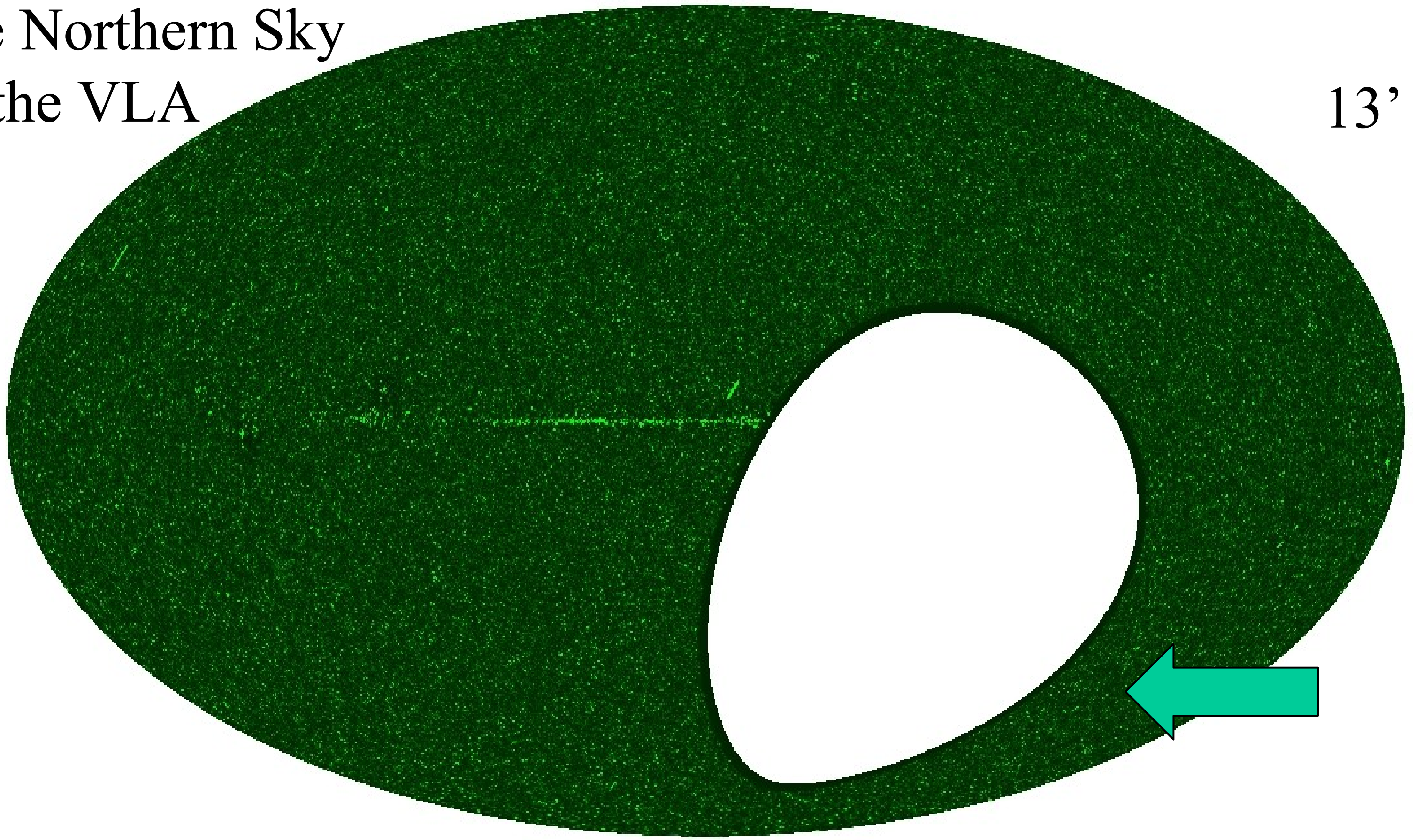




FIG. 10.— Frequency dependence of the temperature at the center of *the Spot* at scale $R_9$. Again the asterisks represent the 1–year data and the circles the 3–year data. The horizontal line shows the value of the 3–year WCM. The data at the same frequency have been slightly offset in abscissa for readability.

Cruz et al. 2007

# The NVSS Survey

1.4 GHz survey
of the Northern Sky
with the VLA




What will we see if we look at NVSS in the area of the cold spot?

# Hole in the NVSS

- Area of the cold spot is also the "coldest spot" in the NVSS @ several resolutions
- Spot is at the extreme end of the brightness distribution, but still part of the distribution

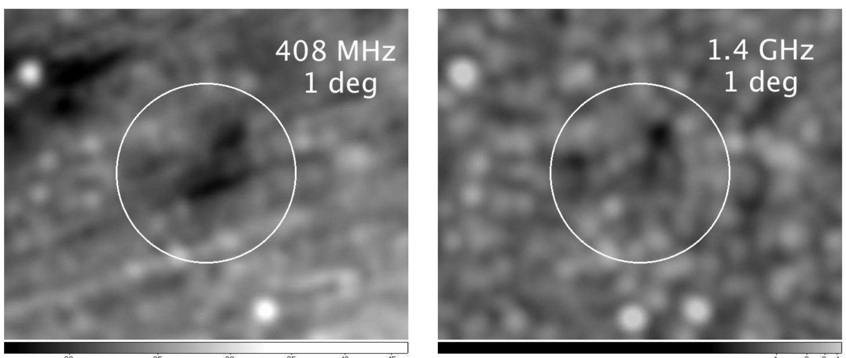



Fig. 1.— 18° fields, with 1° resolution, centered at $l_{II}$, $b_{II}$ = 209°, -57°. Left: 408 MHz (Haslam et al. 1981). Right: 1.4 GHz (Condon et al. 1998). A 10° diameter circle indicates the position and size of the WMAP cold spot.

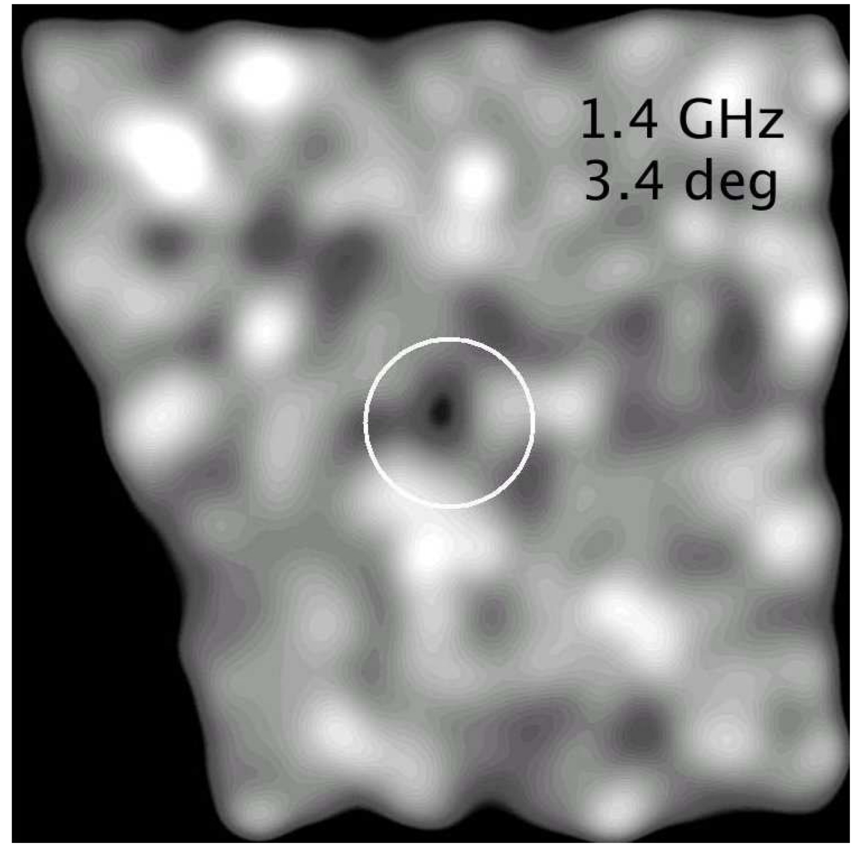
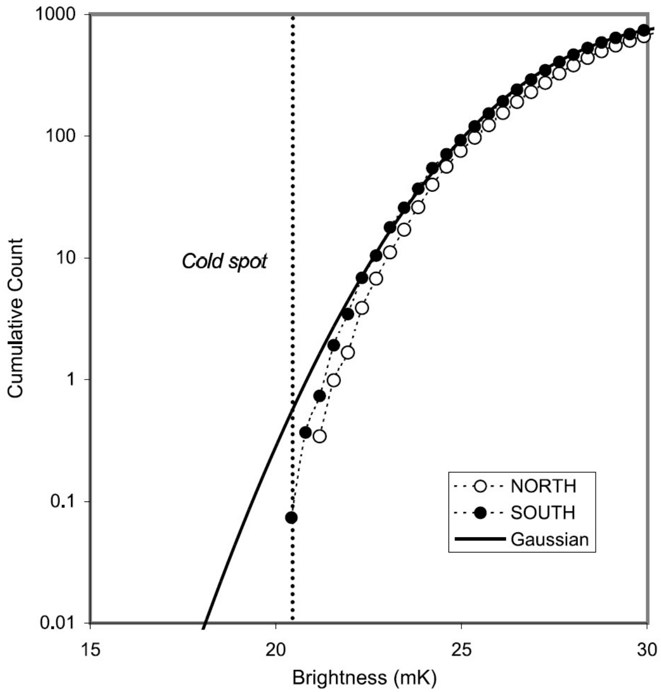
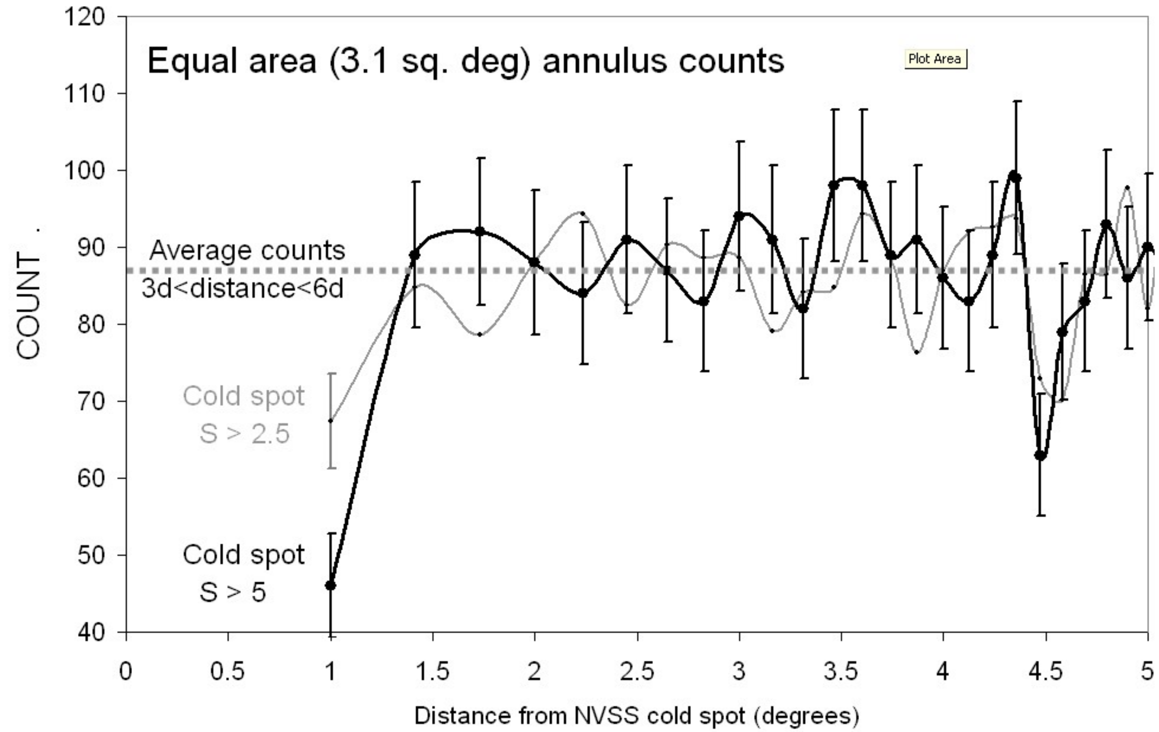



Fig. 2.— 50° field from smoothed NVSS survey at 3.4° resolution, centered at $l_{II}$, $b_{II}$ = 209°, -57°. A 10° diameter circle indicates the position and size of the WMAP cold spot.

# NVSS "Dip"



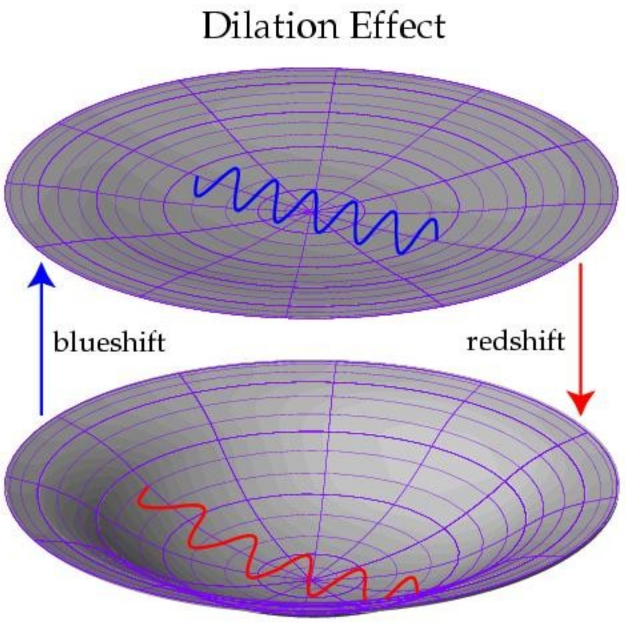

The brightest sources in NVSS tend to be found around $0.5<z<1.0$

**CLAIM:**
**This observation lends supporting evidence to the theory that the WMAP cold spot is a local effect created by the late integrated Sachs-Wolfe effect**

# Review of the late ISW effect

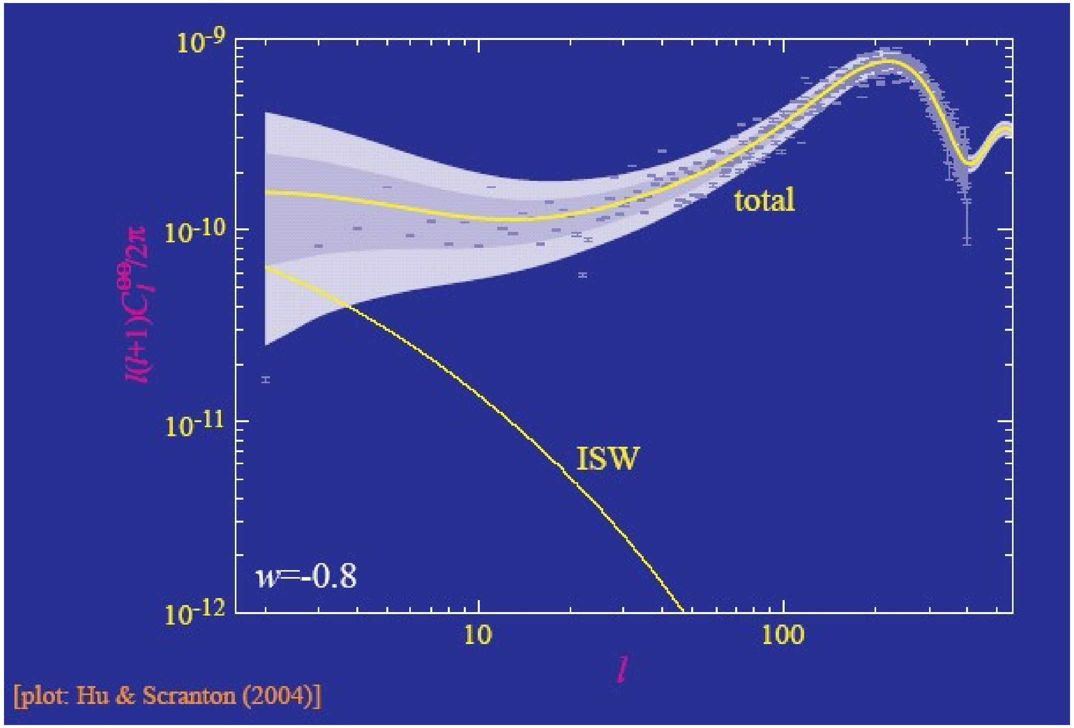
- A CMB photon will change energy as it traverses a potential well if that well evolves during the transit.
- In linear theory, $\Phi = \Phi(t)$ only when the Cosmological Constant or Dark Energy dominates the energy density ($z < 1$, "late" ISW)
- **Detection of late ISW effect in a flat universe is direct evidence of dark energy**

Peebles & Ratra 2003




$$\left(\frac{\Delta T}{T}\right)_{ISW} = 2\int_i^f dr\,\dot{\Phi}(\eta,\vec{r})$$

# How Do We Detect It?

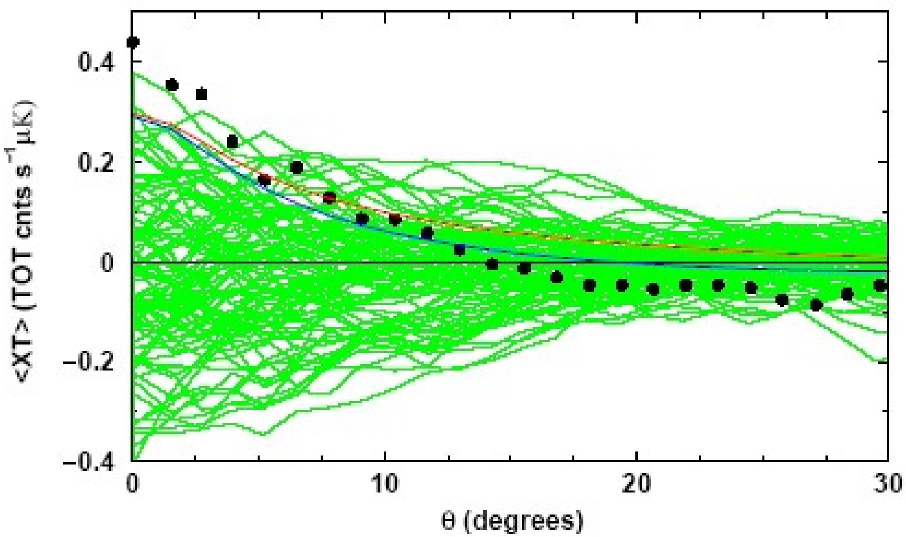



- ISW hard to disentangle from CMB power spectrum alone
- If the potentials are decaying at late time, the ISW should be **correlated with the matter distribution in the local universe**
- Cross-correlate the CMB with tracers of local mass

Crittenden, R. G., Turok, N. 1996, PRL 76, 575

# Previous Detections

- Correlation was attempted with COBE data & NVSS, but was unsuccessful
- With WMAP, many authors have found positive correlations with different tracers of the local mass distribution: e.g.
- SDSS (Peiris & Spergel 2000)
- HEAO-1
- NVSS
  - Boughn & Crittenden 2003
  - Nolta et al. 2004
  - Pietrobon, Balbi,& Marinucci 2006
  - Vielva et al. 2006
  - McEwen et al. 2006,2007

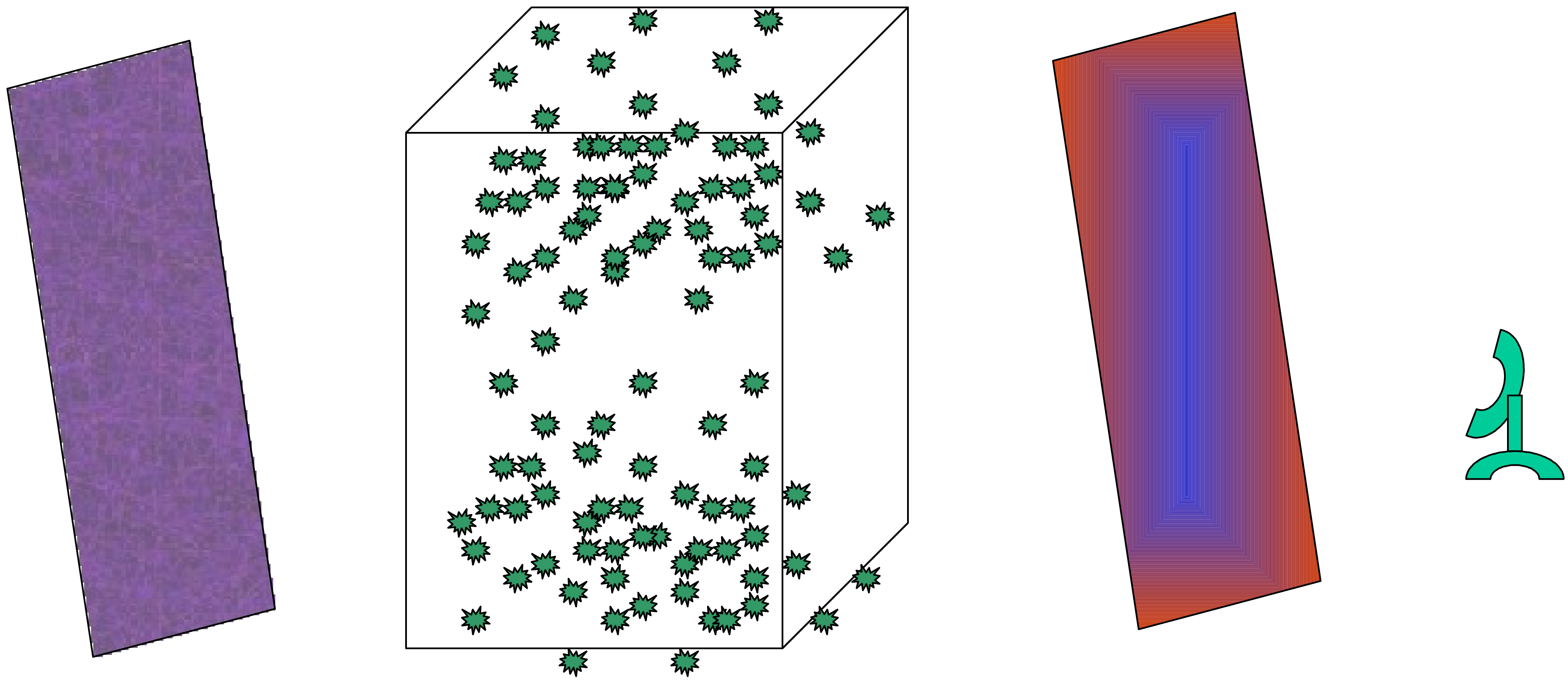



Boughn & Crittenden 2003

**Correlation with hard X-ray background as seen by HEAO1. Green lines are correlations of the X-ray map with 100 independent Monte Carlo realizations of the CMB with the same power spectrum as the WMAP data**

# Simple Picture for the Cold spot

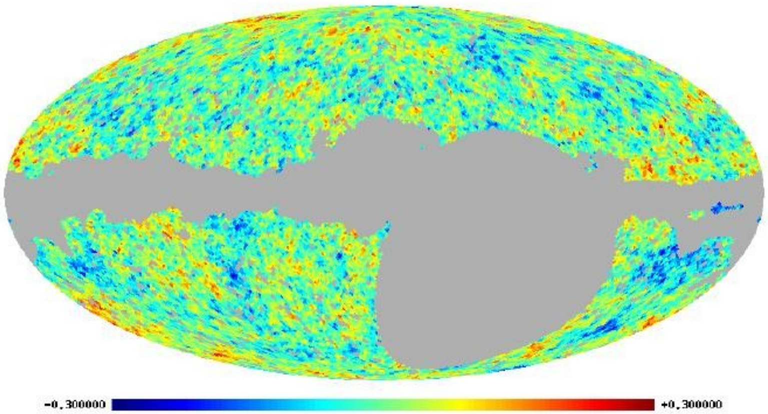
CMB | Mass distribution at $z < 1$ | Observed CMB at $z=0$



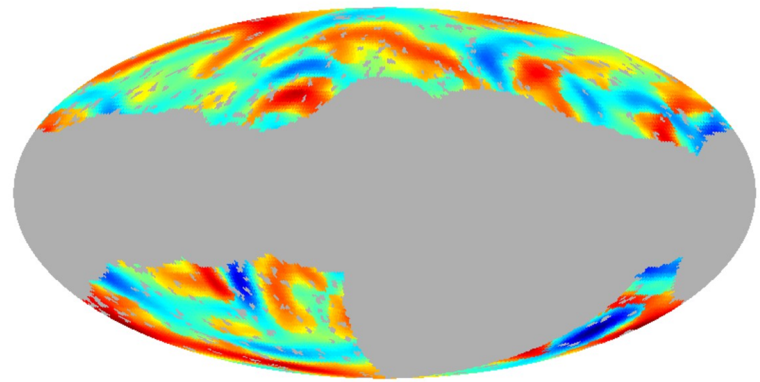
NVSS survey – traces mass distribution
WMAP- CMB anisotropies

Should be correlated

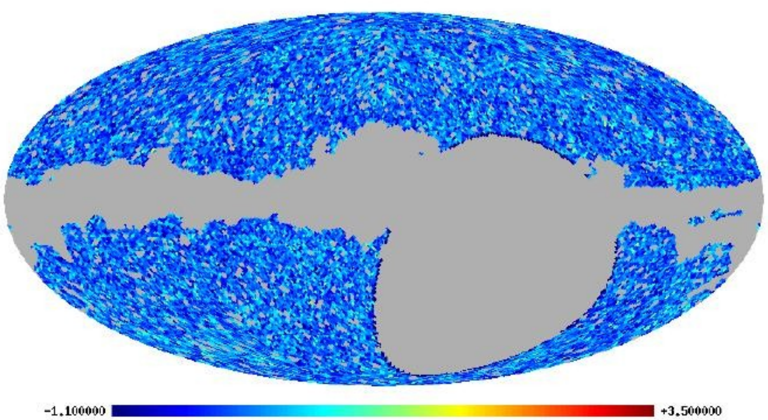
# Correlation Between the NVSS and WMAP



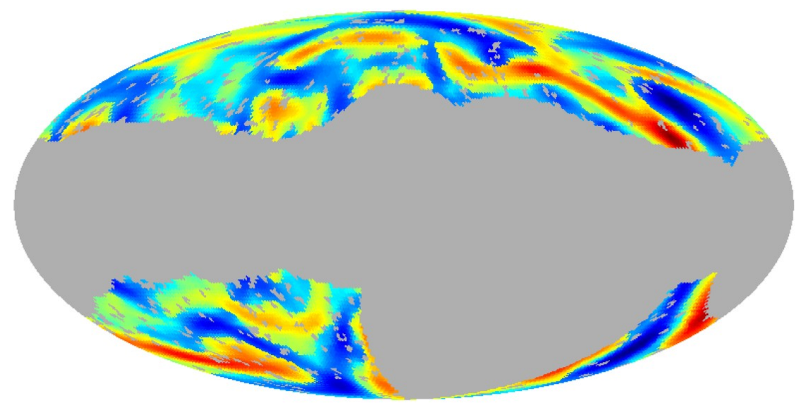

(a) WMAP



(a) WMAP for independent features




(b) NVSS

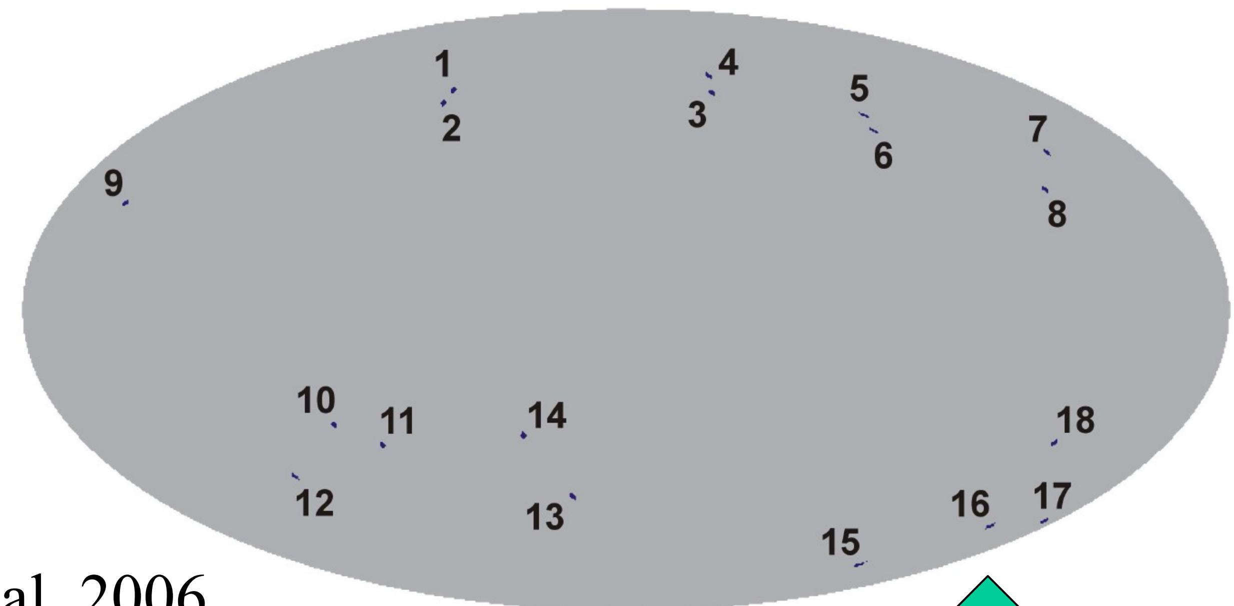


(c) NVSS

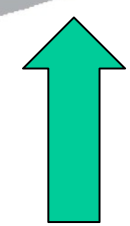
McEwen et al. 2006, 2007

# Isolated Regions of Strong Correlation

**Figure 11.** Approximate localised regions flagged for closer examination (see Table 2 for more details).




McEwen et al. 2006



- In effect, a detection of the ISW effect has already been made in this region

"Cold Spot"

# How Large of a Void is Needed?

- We can do an order of magnitude calculation to find the size of the void need to create the "cold spot"

$$\Delta\Phi \approx -\frac{\Omega_m}{2}\left(\frac{r_c}{c/H_0}\right)^3 (1+2z)^{1/2}(1+z)^{-2}\,\delta \approx \frac{1}{2}\frac{\Delta T}{T}$$

- If we assume δ = -1 and z = 0.5-1.0, we calculate that a ~280 Mpc void is need.
- Void statistics done so far find that the probability of finding a 280 Mpc void is ~5x10$^{-10}$
- Second order effects could change the size of the void(s) needed

Inoue & Silk astro-ph/0612347

# Void Statistics

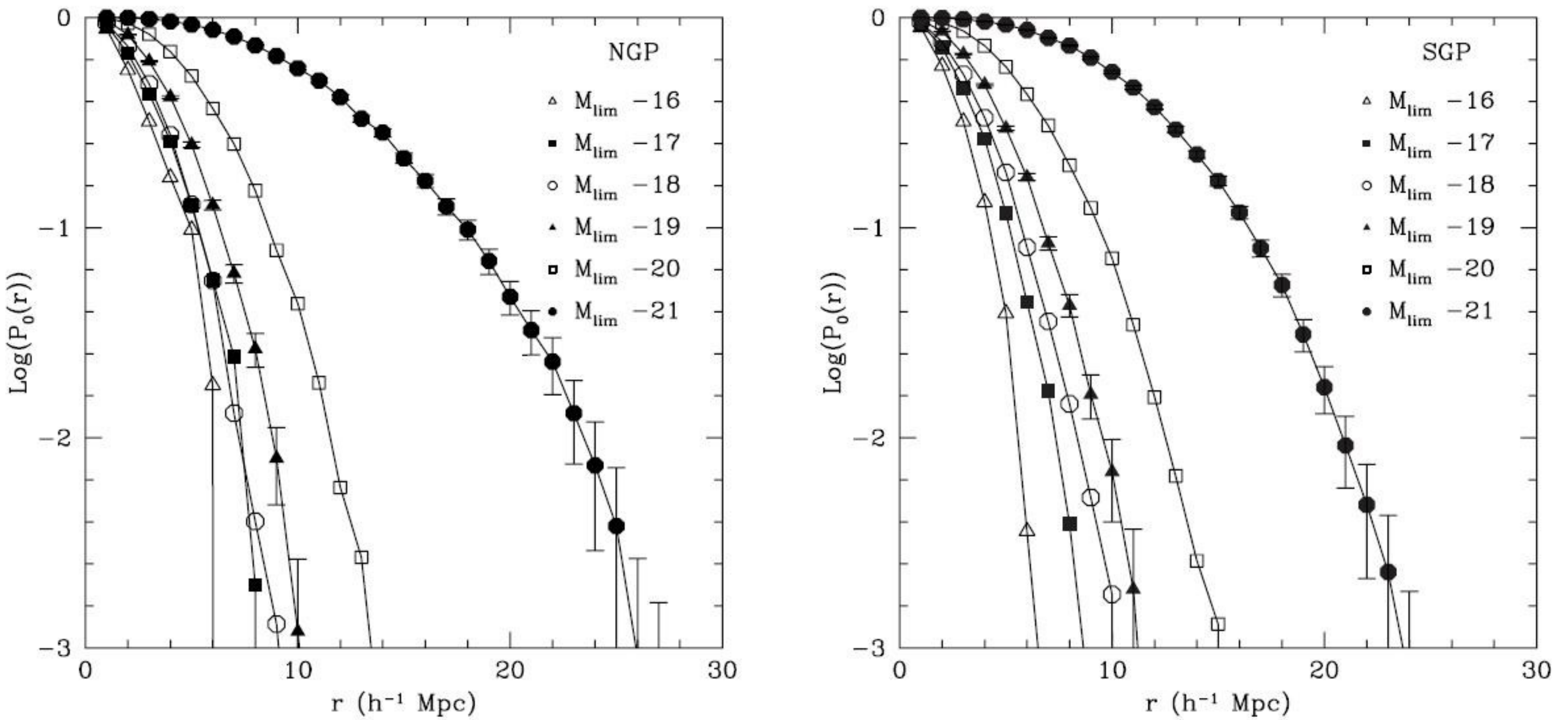



FIG. 6.—VPFs for volume-limited samples extracted from the NGP (*left*) and SGP (*right*) of the 2dFGRS. The details of each of the samples are given in Table 2. Error bars on the $M_{\rm lim} = -19$ and $-21$ samples represent the 1 $\sigma$ variation due to the finite number of independent volumes in the 2dFGRS.

Average: $\delta = -0.94 \pm 0.02$; $R = (15.61 \pm 2.84)\ h^{-1}$ Mpc

- Although such a void seems very unlikely given the current void statistics, such large scales have not been investigated either in observations or simulations

Hoyle & Vogeley 2004

# Conclusions

- An observed dip in the number of bright radio galaxies in the NVSS toward the direction of the WMAP cold spot makes the ISW effect a likely explanation for its non-Gaussian temperature
- The apparent consequence is the need for a ~280 Mpc local void
- We can now see the effects of Dark Energy working on individual regions, not just through cross-correlation studies

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