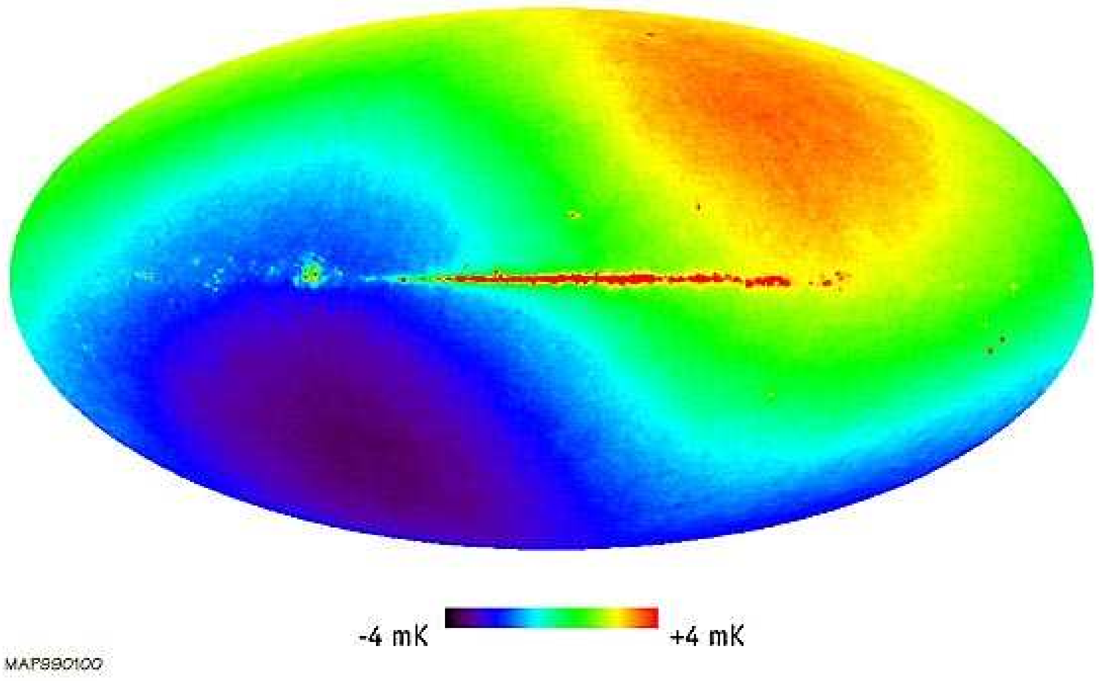
Measurement of a large scale flows with clusters of galaxies.

Fernando Atrio-Barandela.
Física Teória. Facultad de Ciencias.
Universidad de Salamanca.
eml: atrio@usal.es

In Collaboration with:

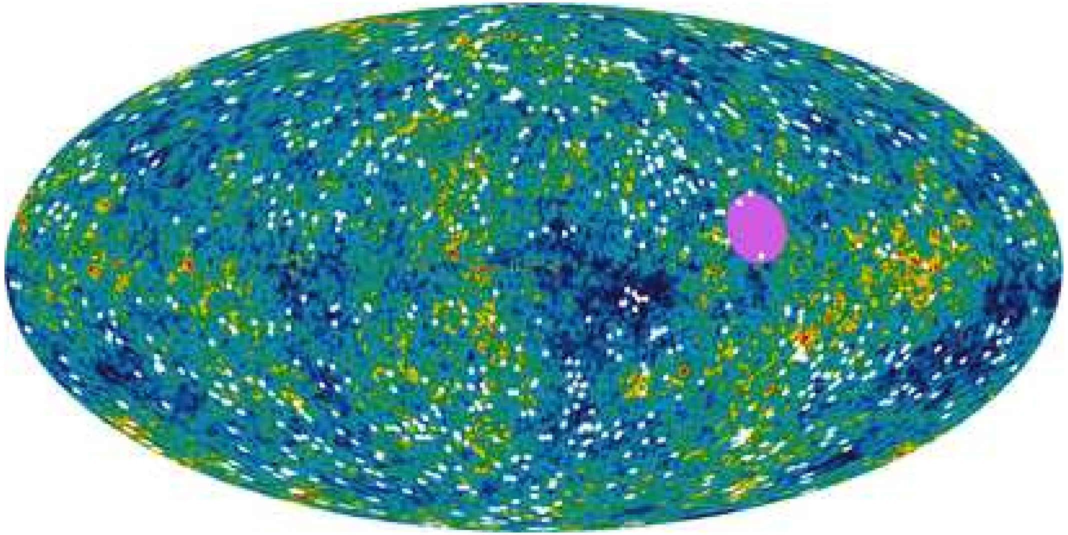
A. Kashlinsky, Goddard SFC, Maryland.
D. Kocevski, UC at Davis.
H. Ebeling, University of Hawaii.

The Cosmic CMB dipole.



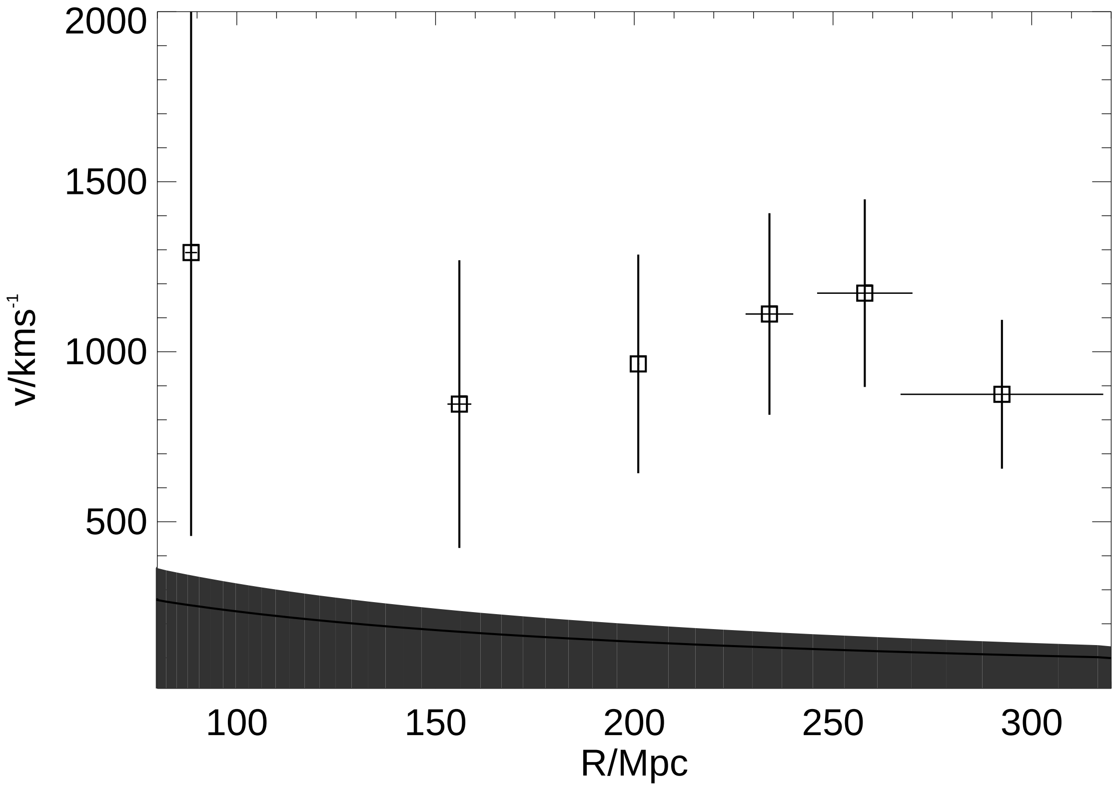
CMB dipole; generated by local gravity?.

Results.



dipole	(l,b)
CMB	$(276^o \pm 3^o; 30^o \pm 3^o)$
Clusters	$(283^o; 11^o) \pm 13^o$

WMAP-3yr data: ILC map. Pink spot: the direction of the matter flow. White spots: Clusters locations.



Amplitude of the Dark Flow for different subsamples.

z median	N_{cl}	N_{pix}
0.03	86	4,872
0.053	292	16,064
0.067	444	24,189
0.076	541	29,127
0.082	603	32,146
0.089	674	35,409

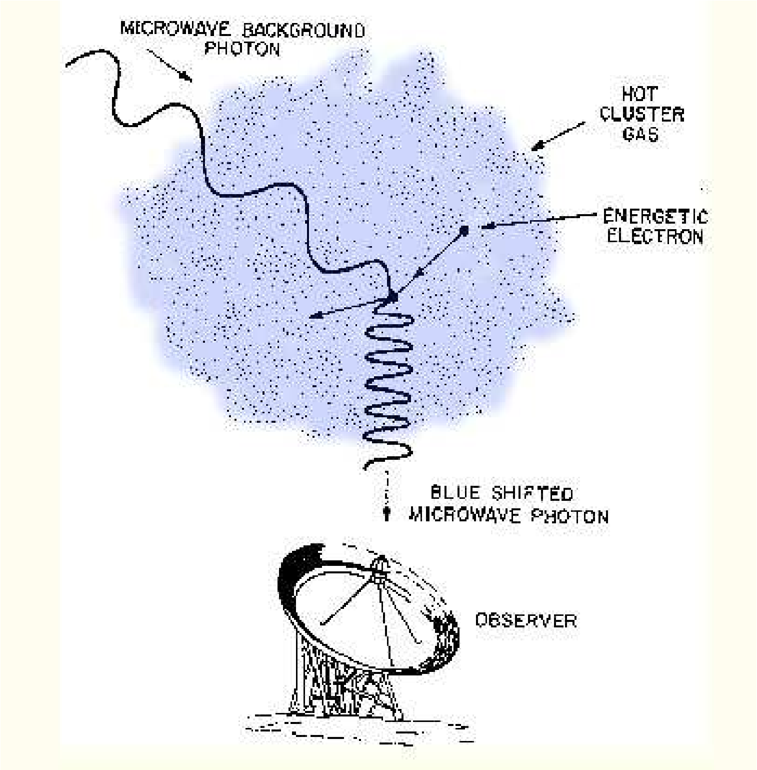
Bulk Flows.

♠ **The horizon scale EQ at matter-radiation equality is $\sim 100 Mpc/h$. For all scales larger than EQ, the peculiar density field remains in the Harrison-Zeldovich regime:**

$$P(k) \propto k \qquad \Rightarrow \qquad V_{rms} \simeq \left(\frac{r}{100 Mpc/h}\right)^{-1} km/s$$

The measured component may provide evidence for new physics.

The Sunyaev-Zeldovich effect.



Inverse Compton Scattering of CMB photons with free electrons in clusters of galaxies produces secondary anisotropies on the CMB radiation.

- **Thermal Distortion of the CMB; redshift independent, changes with frequency.**

$$\frac{\Delta T}{T}(\hat{n}) = G(\nu)\sigma_{Th}\int dl \frac{n_e T_X}{m_e c^2} \simeq G(\nu)\tau\frac{n_e T_X}{m_e c^2}$$

- **Kinematic: Associated to the motion of the WHOLE CLUSTER with respect to the matter rest frame!!!.**

$$\frac{\Delta T}{T}(\hat{n}) = \frac{\hat{n}\cdot\vec{v}_{cl}}{c}\sigma_{Th}\int dl n_e = \tau\frac{\hat{n}\cdot\vec{v}_{cl}}{c}$$

Moments of the velocity field.

Adding the velocities of all clusters gives their CM motion $\Rightarrow$ BULK FLOW.

$$\Delta T(\hat{n}) = (\Delta T)_{CMB}(\hat{n}) + T_0\tau[G(\nu)\frac{T_X}{mc^2} + \frac{v\cos\theta}{c}] + N(\hat{n})$$

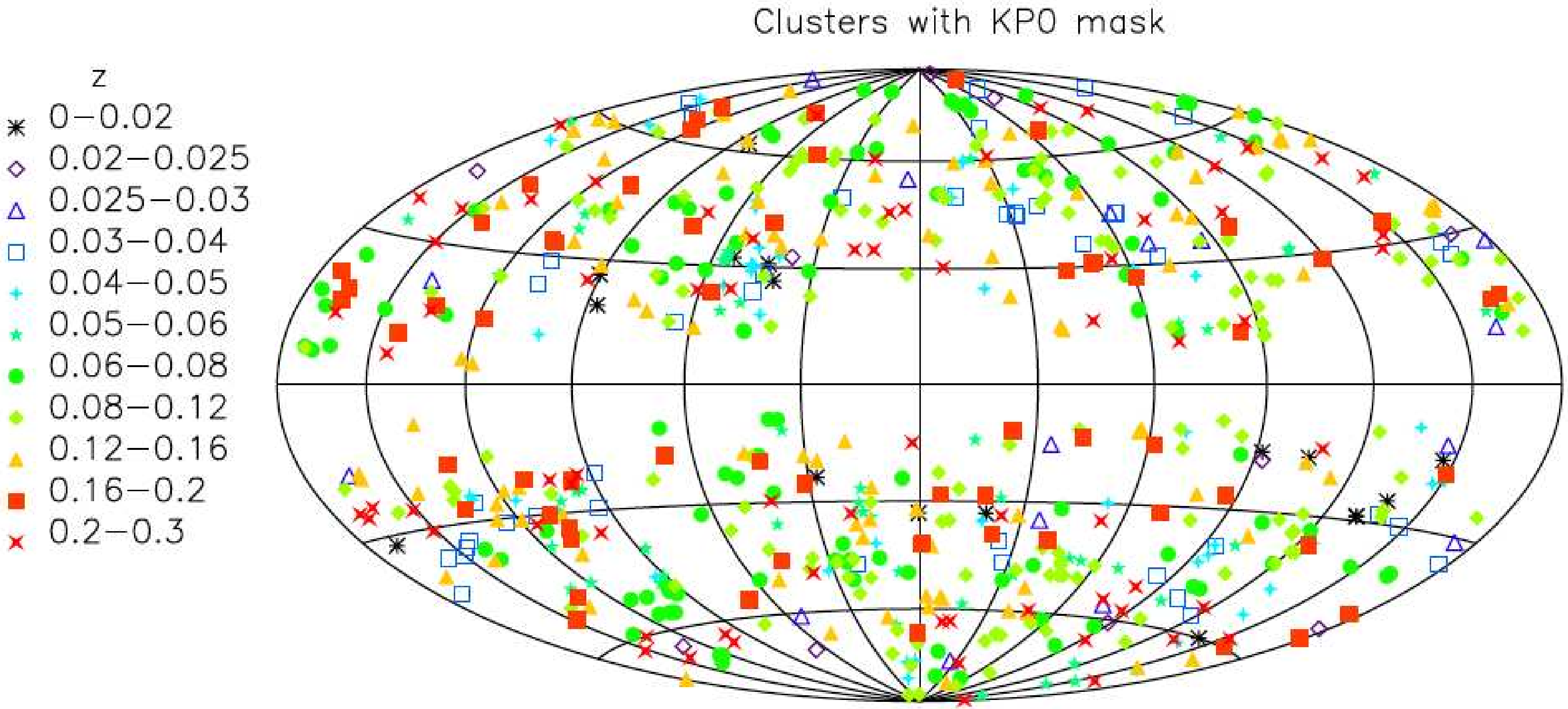
$$a_{1m} = 1\mu K\frac{v}{300km/s} \pm 3\mu K\left[\frac{N_{cl}}{1000}\right]^{1/2} \pm 0.6\mu K\left[\frac{N_{pixels}}{10000}\right]^{1/2} \pm 0.2\mu K\left[\frac{N_{cl}}{1000}\right]^{1/2}$$

The dominant source of error is the cosmological CMB signal.

How to remove the CMB signal?.

How can we measure the kSZ dipole?

Step I: Get Hold of a Large Sample of Clusters.



Our data.

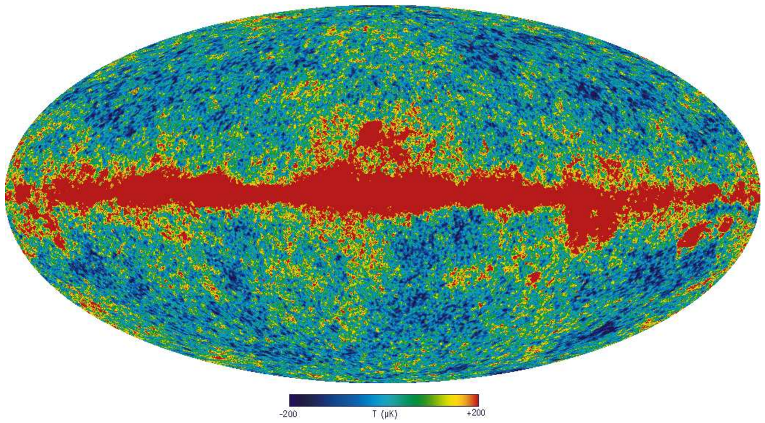
♠ **We use a Cluster Sample derived from Rossat All Sky Survey. All properties were recomputed in a consistent manner for all clusters.**

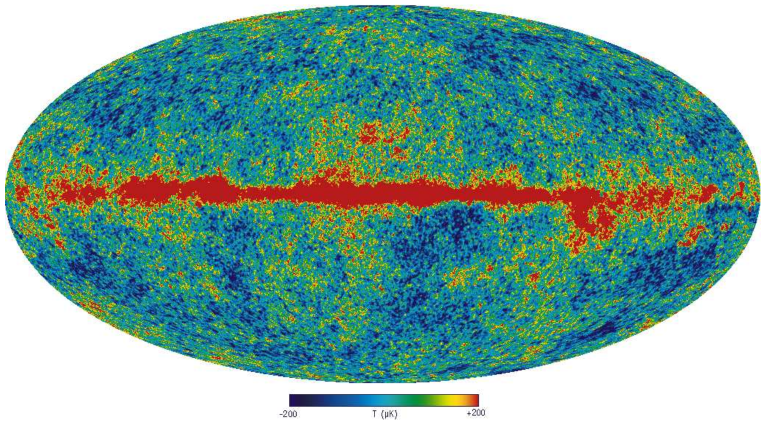
- **Angular positions:** l, b.
- **Spectroscopic redshifts.**
- **X-ray fluxes at ROSSAT broad band [0.1-2.4]KeV and bolometric luminosities.**
- β **model parameters: electron densities, core radii,** $\beta = 2/3$.

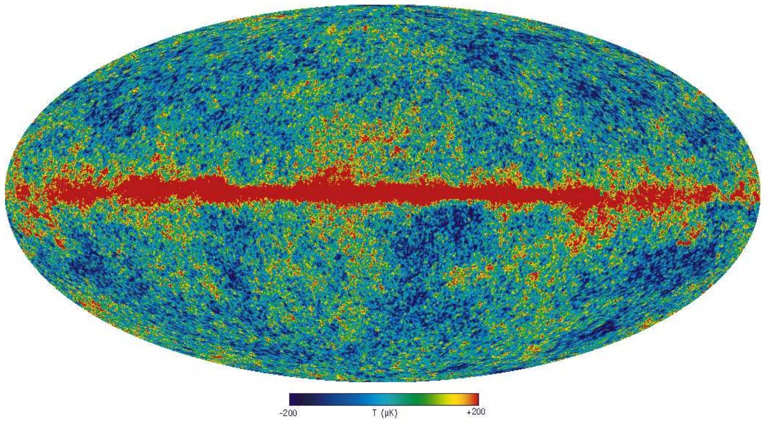
$$S(r) = S_0[1 + (r/r_c)^2]^{-3\beta+1/2}$$

- **X-ray extent of the cluster.**
- **In total** 660 **clusters are used in the analysis, the largest homogeneous X-ray cluster sample ever compiled.**

Step II: High Quality and Low Noise CMB data is available.

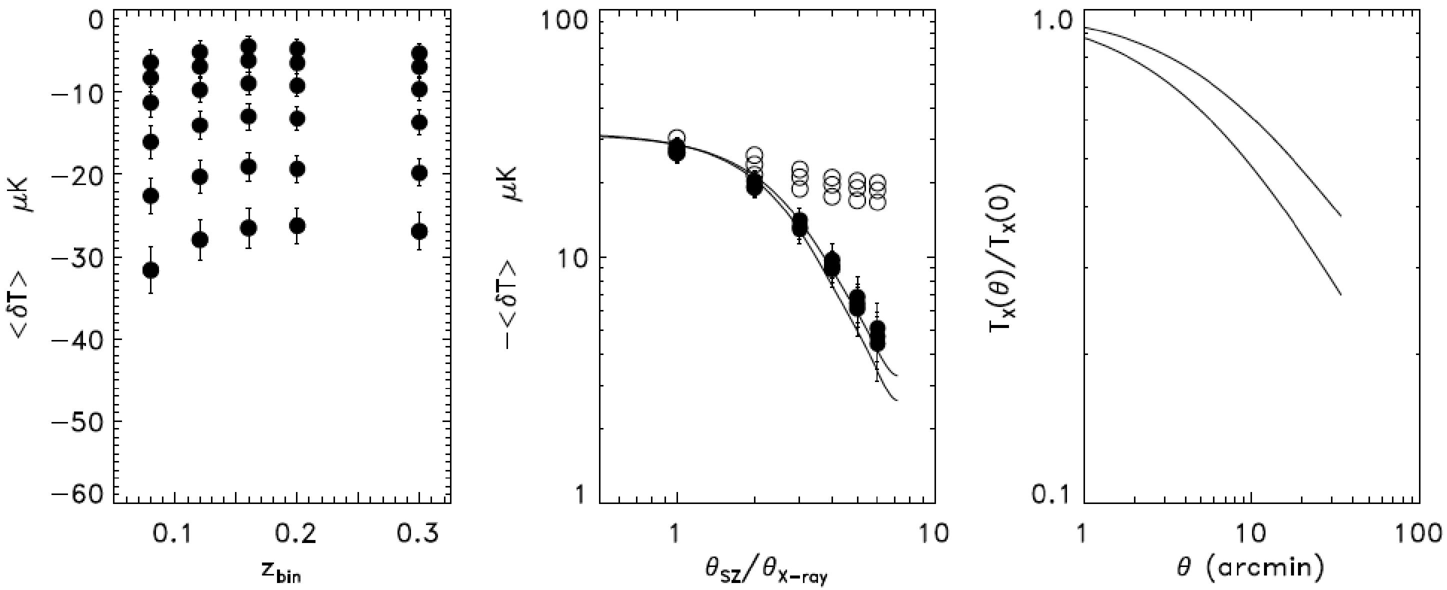






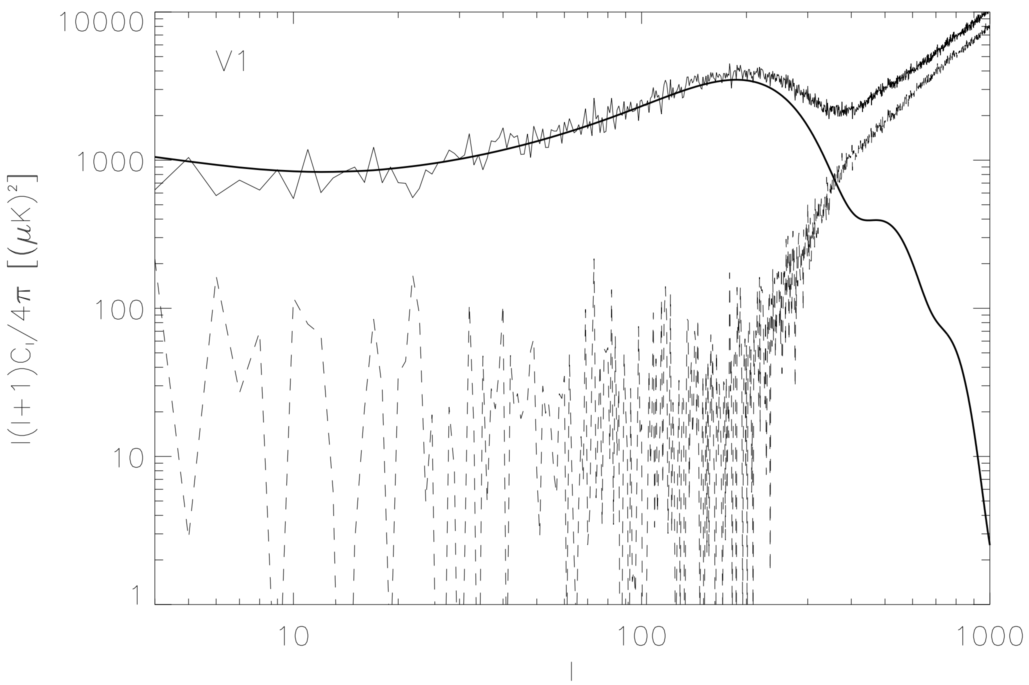
WMAP 3rd yr data.
Linear scale from -200 to 200μK.
Q: 41GHz
V: 61GHz
W: 94GHz

Step III: Check WMAP data is sensitive to tSZ signal.



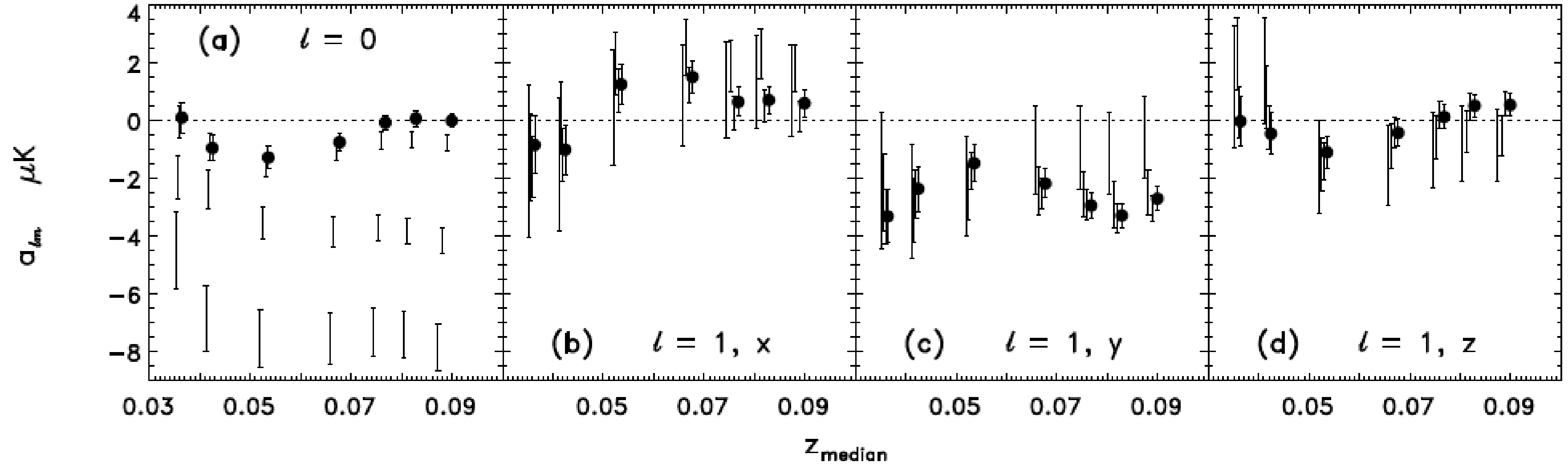
Left: tSZ contributions to WMAP 3rd yr data in subsamples with redshifts $z \leq z_{bin}$ and different X-ray extents. Middle: Measured signal (solid circles) and β model prediction (open circles); solid line is a NFW profile. Right: Temperature decrement for 2 NFW profiles.

Step IV: remove the CMB signal.



Power spectrum of the original WMAP V1 DA, best theoretical model and power spectrum of the filtered data.

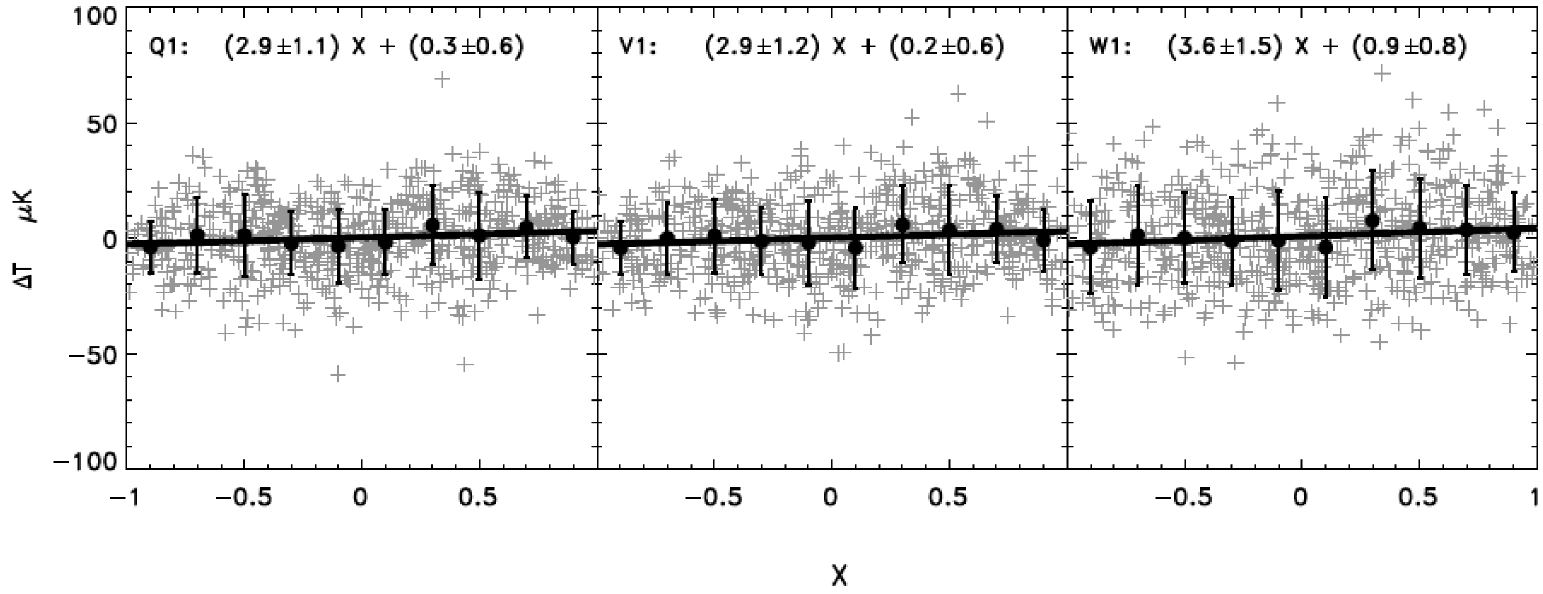
Monopole and dipole components.



From left to right: m, d_x, d_y, d_z **for 4 different extents.**

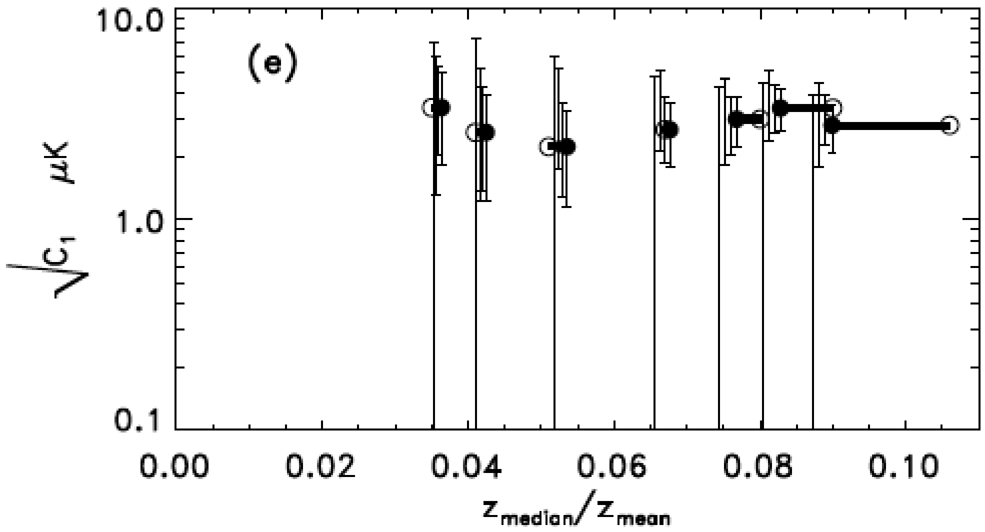
For the largest extent, the monopole gets erased while the d_y **component remains!!.**

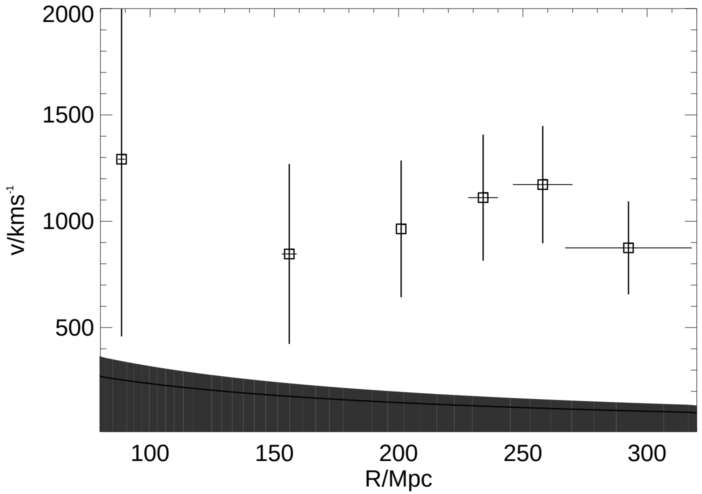
kSZ signal with respect to the Apex.



ΔT **versus** $X = \cos\theta$**, where** θ **is the angle between the cluster position and the direction of motion.**

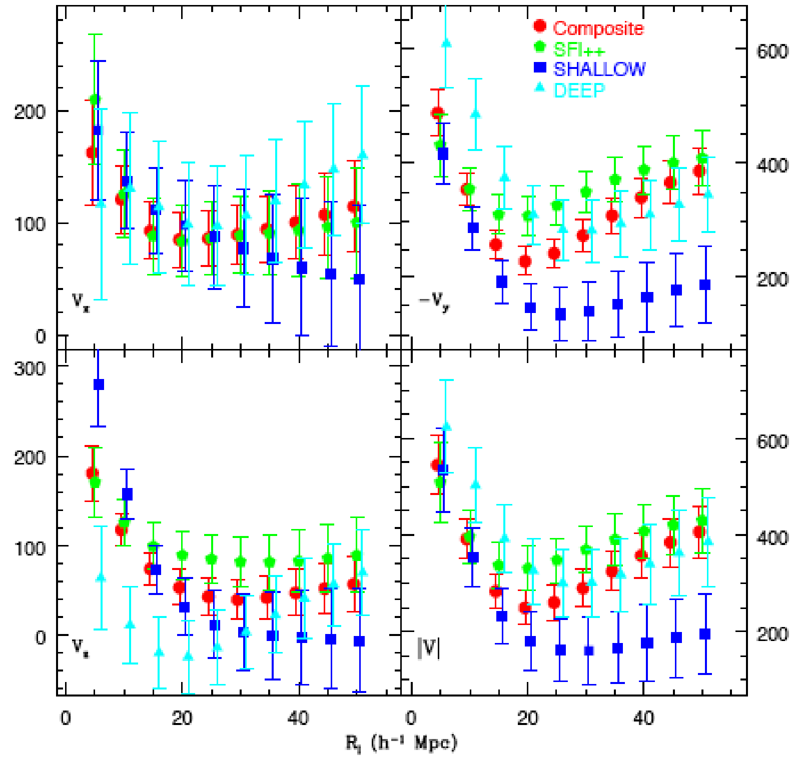
Results.





Dipole amplitude measured in μK. Conversion factor between temperature and velocity is needed.

Is the motion real?: Comparison with other observations.



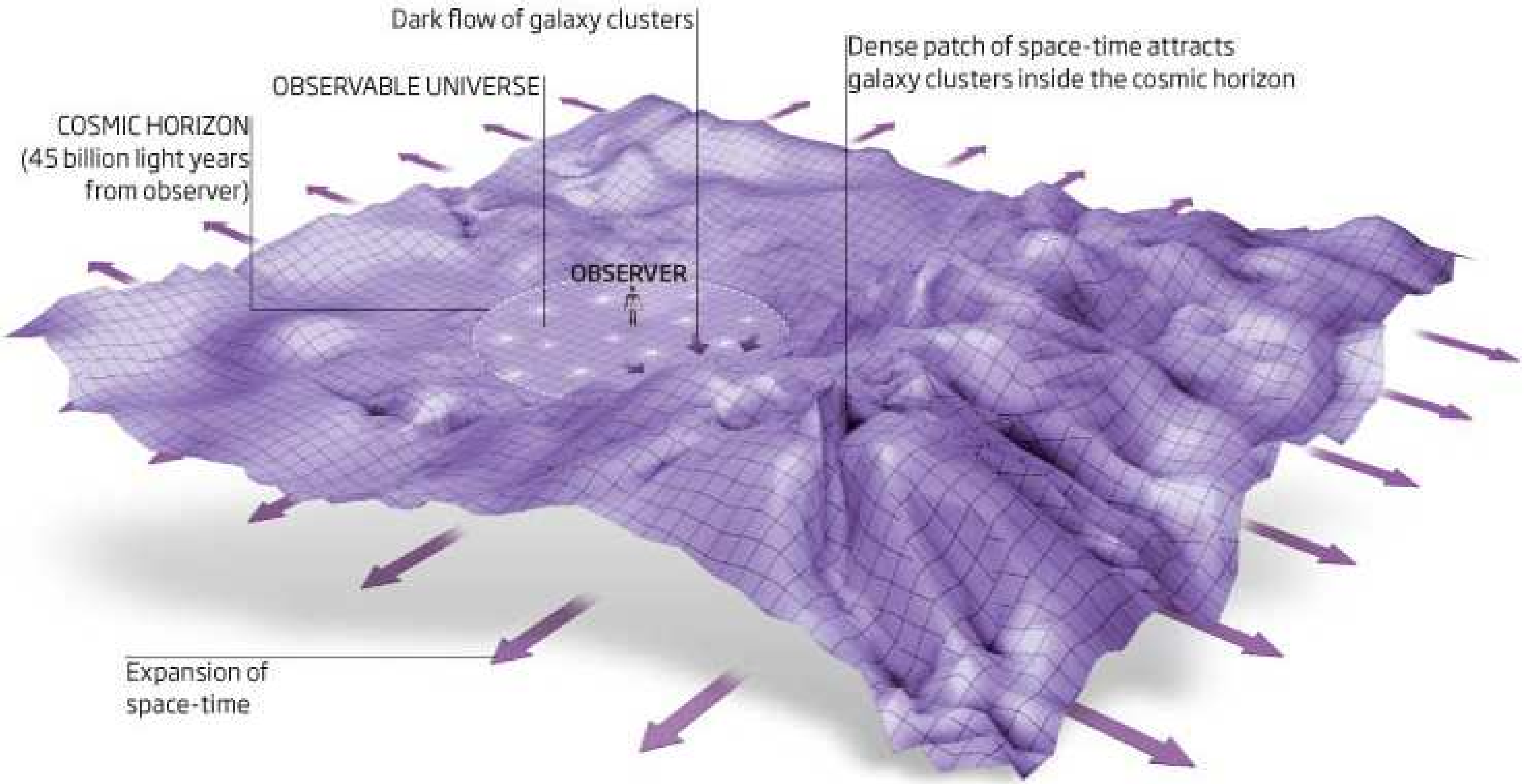
"Consistently Large Cosmic Flows on Scales o 100/h Mpc: a Challenge for the Standard ΛCDM Cosmology". Watkins, Feldman & Hudson (2009) MNRAS, 392, 743

Bulk flow of the composite velocity catalogs as a function of Depth. Data points are not independent. Consistent and robust Bulk Flow in the Galactic Y direction (upper right panel).

Cosmological Implications.

Origin of the flow:

- Subhorizon
  - 1Gpc void [Garcia-Bellido & Haugboelle ArXiv0810.4939]
  - Dark Energy and Dark Matter reference frames move with respect to each other [Beltran-Jimenez & Maroto ArXiv0812.2206]
  - Higher-dimensional modification of gravity [Afshordi et al ArXiv:0812.2244]. [Carroll, Tseng & Wise ArXiv0811.1086].
- Superhorizon
  - Grizhuk-Zeldovich effect: Intrinsic Gradient in the Metric [Sov Astron (1978) 22, 125].
  - Quantum coherence of vacua in the string landscape [Mersini-Houghton & Holman ArXiv0810.5388].
  - Breaking translational invariance during inflation



From New Scientist, Jan 2009.

Conclusions.

- **We have developped a new method to measure peculiar velocities.**
- **Our measurement are free of systematic biases.**
- **We have determined a coherent bulk flow on the direction. of the CMB dipole on a scale of ~ 300Mpc/h.**
- **The amplitude of the flow is $600 - 1000$km/s.**
- **This large scale flow could be generated by density perturbations on superhorizon scales.**