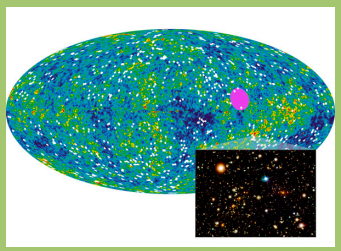
Bulk Flow Determination from Galaxy Clusters's Kinetic Sunyaev-Zel'dovich effect: Measurement in WMAP and Planck

D.S.Y. Mak (USC), S.J. Osborne (Stanford), E. Pierpaoli (USC), S.E. Church (Stanford)

Publication of this work:
Mak et. al. 2010 (arXiv1101.1581)
Osborne et. al. 2010 (arXiv1011.2781O)

Credits: This research is supported by NASA and NSF

Mystery of Large scale bulk motion



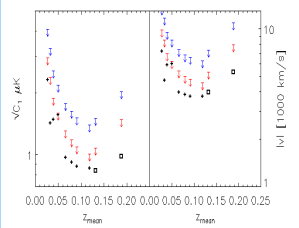
Measurements of the large scale peculiar bulk flow velocities of galaxy cluster in different wavebands tend to indicate higher values than expected from the ΛCDM predictions. Watkins et. al. (2009) used optical observations of elliptical galaxies and detectedt a significant bulk of v=407 km/s at scale of r= 50 Mpc/h, which is above 3σ level with the ΛCDM rms expectation of ~180 km/s

Recently, Kashlinsky et. al. (2009) (hereafter KAKE) studied the kinetic Sunyaev-Zeldovich (kSZ) effect as observed by WMAP in known X-ray clusters and claimed a detection of a bulk flow of 600-1000 km/s out to r > 300 Mpc/h at 8σ level. This finding exceeds the theoretical prediction of the expected bulk flow for a ΛCDM model. This result, however is quite controversial (Keisler 2009) and should be better investigated.

What do we know from *WMAP* ?

- We find **no evidence of a cluster dipole in the WMAP 7 and WMAP 5 year data and ROSAT X-ray catalogs**, consistent with predictions from the ΛCDM theory.
- We find a 95% confidence upper limit to the flow of 4970 km/s in the direction of the CMB dipole, and 4640 km/s in the direction of the KAKE claimed flow (l=267◦, b=34◦).

- Cluster dipole are **contaminated by thermal SZ with an amplitude equivalent to a kSZ signal with a bulk flow velocity of ~ 2000 − 4000 km/s**. Therefore , the WMAP sensitivity is limited.



- Instead of Wiener filter, measurement with the **unbiased tSZ removing filter** can **increased** the S/N of the cluster dipole, by **almost an order of magnitude**, a consequence of using only three frequency bands in our analysis.

What can we learn from *Planck* ?

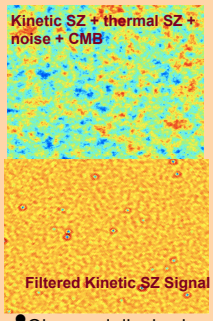
Things needs to be overcame:

- Avoid geometric bias due to sparse cluster positions
  - →**Planck** provide the first high resolution **all-sky CMB maps** and galaxy clusters catalog
- Deep enough to probe large-scale flow
  - →Upcoming **Planck and eRosita cluster survey** provide deeper cluster survey
- Extract kinetic SZ signal at cluster locations
  - →**Modified tSZ removing filter** can lower the thermal SZ contamination on kinetic SZ signal. **Low noise level** from Planck sky maps reduce uncertainties.

Methodology:

1. Create simulations of realistic Planck SZ maps in channels 44 GHz to 353 GHz.
2. Model SZ signal of clusters with properties expected from ROSAT, Planck, eRosita all –sky survey. Assign a coherent bulk flow to whole cluster sample for the kinetic SZ signal.
3. Reconstructed the cluster kSZ dipole and compare to the input bulk flow to determine the sensitivity.

Velocity probe by kinetic SZ effect



Cluster Dipole

- Scattered CMB photons redshifted due to motion of clusters

$$\frac{\Delta T_{\rm kSZ}}{T_{\rm CMB}} = \int \tau \frac{v_p}{c} dl$$

- The total dipole moment of clusters in full sky is related to the bulk flow velocity:

$$C_{1,\rm ksz} = T_{\rm CMB}^2 \langle \tau \rangle^2 \frac{V_{\rm bulk}^2}{c}$$

- Observed dipole signal of CMB maps at cluster location contains several components

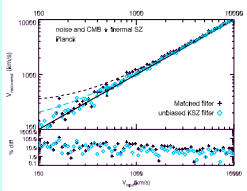
$$a_{1m} = a_{1m}^{\rm CMB} + a_{1m}^{\rm noise} + a_{1m}^{\rm TSZ} + \mathbf{a_{1m}^{KSZ}}$$

- Require filtering to remove intrinsic CMB, instrument noise, thermal SZ (tSZ) signal to increase S/N of kSZ signal.

Main Results

UF result	Recovered Bulk Flow (km/s)	Upper limit on ΛCDM (km/s)	Statistical Error (km/s)	Systematic Bias (%)	Error in bulk flow direction at 95% CL
Input bulk flow: 500 km/s at l=280, b=30;		*For z=0.5, ΛCDM predicts 40 km/s*			
ROSAT	**720 ± 94**	**470**	**94**	**44**	**30°**
Planck	**516 ± 73**	**160**	**73**	**5**	**15°**
eRosita	**500 ± 24**	**60**	**24**	**0**	**5°**

- Dominant uncertainty is **thermal SZ signal that causes systematic overestimation** to bulk flow amplitude. Instrument noise and intrinsic CMB contribute to subdominant statistical error
- tSZ removing filter is effective in filtering out thermal SZ signal as only a **<1σ thermal SZ signal is detected**, owing to wide frequency coverage and low noise level of Planck



Improvements

1. ***Planck* vs WMAP:** sensitivity increases by at least a factor of 8 at all redshift.
2. **Cluster catalog**: Planck and eRosita clusters provide bulk flow measurement with higher precision by an order of magnitude because of more number of clusters at greater depth.

Prospects in improving the statistics :
(i) work out with other cluster surveys such as ACT, SPT, eRosita; (ii) better modeling of the cluster spatial profiles.