Cosmic flows

on 100 Mpc scales: *A challenge to the ΛCDM cosmological model?*

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Watkins, Feldman MH 2009, MNRAS, 392, 743

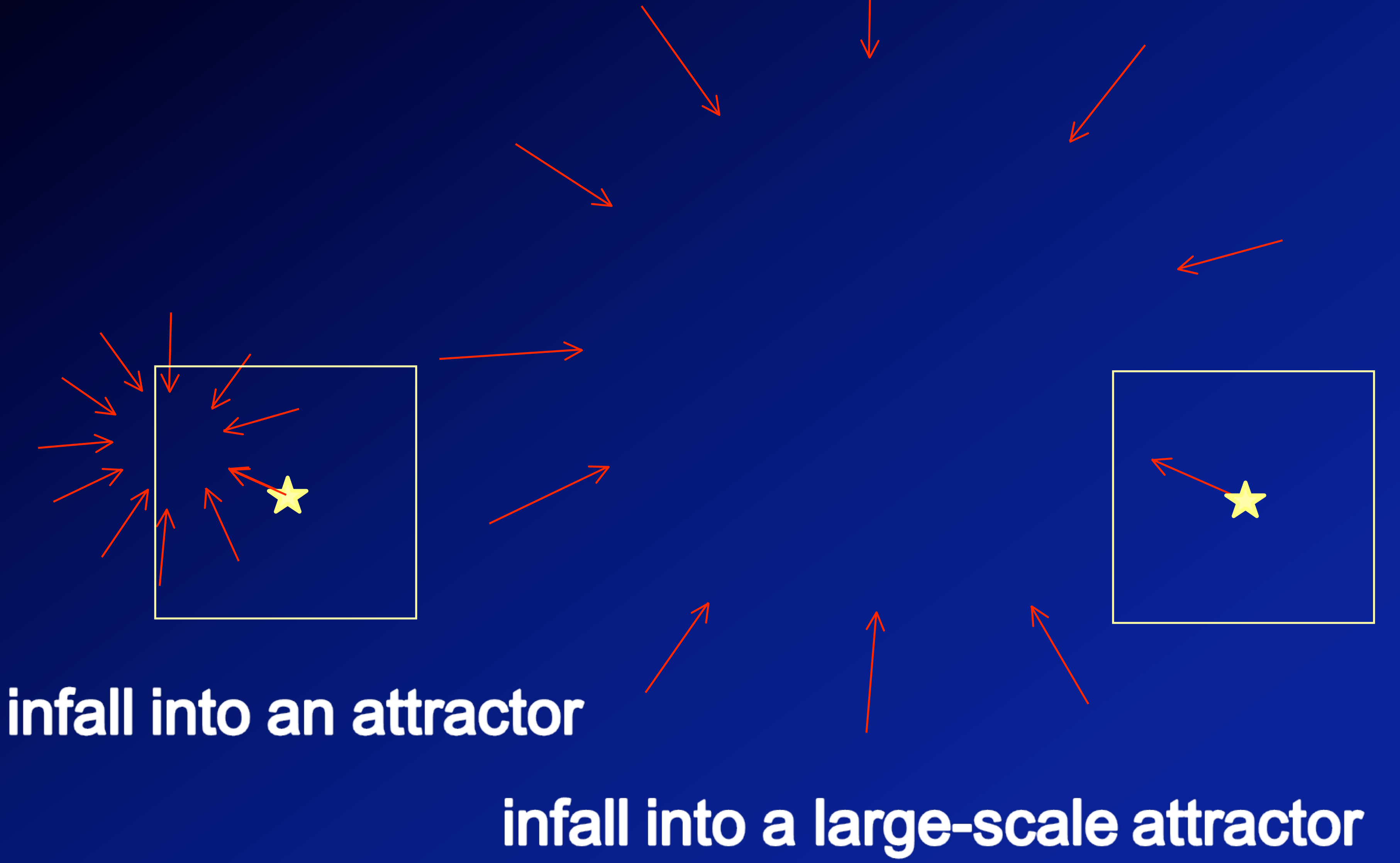
Why Cosmic Flows?

CMB probes *mass* fluctuations on large scales at z ~ 1100

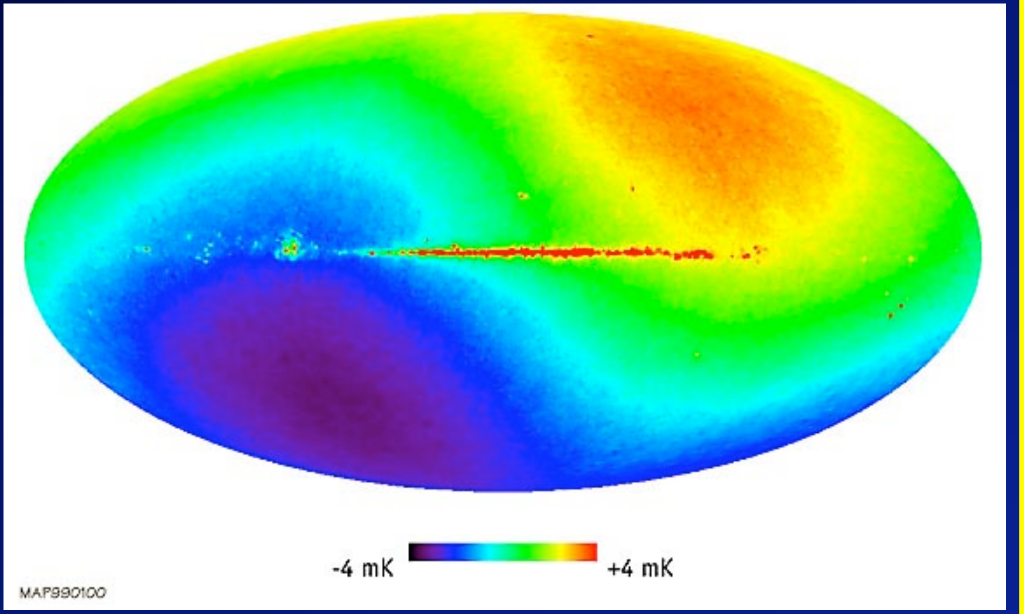
At *low* z, there are only a few probes of *mass* on very large scales:

- peculiar velocities
- Integrated Sachs-Wolfe effect

Peculiar Velocities



Our Local Group has a peculiar velocity of ~600 km/s with respect to the Cosmic Microwave Background



What masses are the source of this motion?

Are they nearby or distant?

On what scale is the Universe at rest?

Bulk Flow

… is the average velocity (w.r.t. the CMB) of a sample/volume.

The expectation is that the bulk flow should get smaller on larger scales, and asymptotically approach zero.

Total data set: 4000 peculiar velocity meaurements via different methods (Tully-Fisher, SNeIa, Fundamental Plane)

Problem: peculiar velocity samples are sparse

Accounting for Sparse Sampling

Construct *optimal weighting* scheme to allow for not only the measurement noise but also the *sampling noise* due to “internal” flows.

Goal: optimize the sensitivity to large scales, minimize effect of small scales

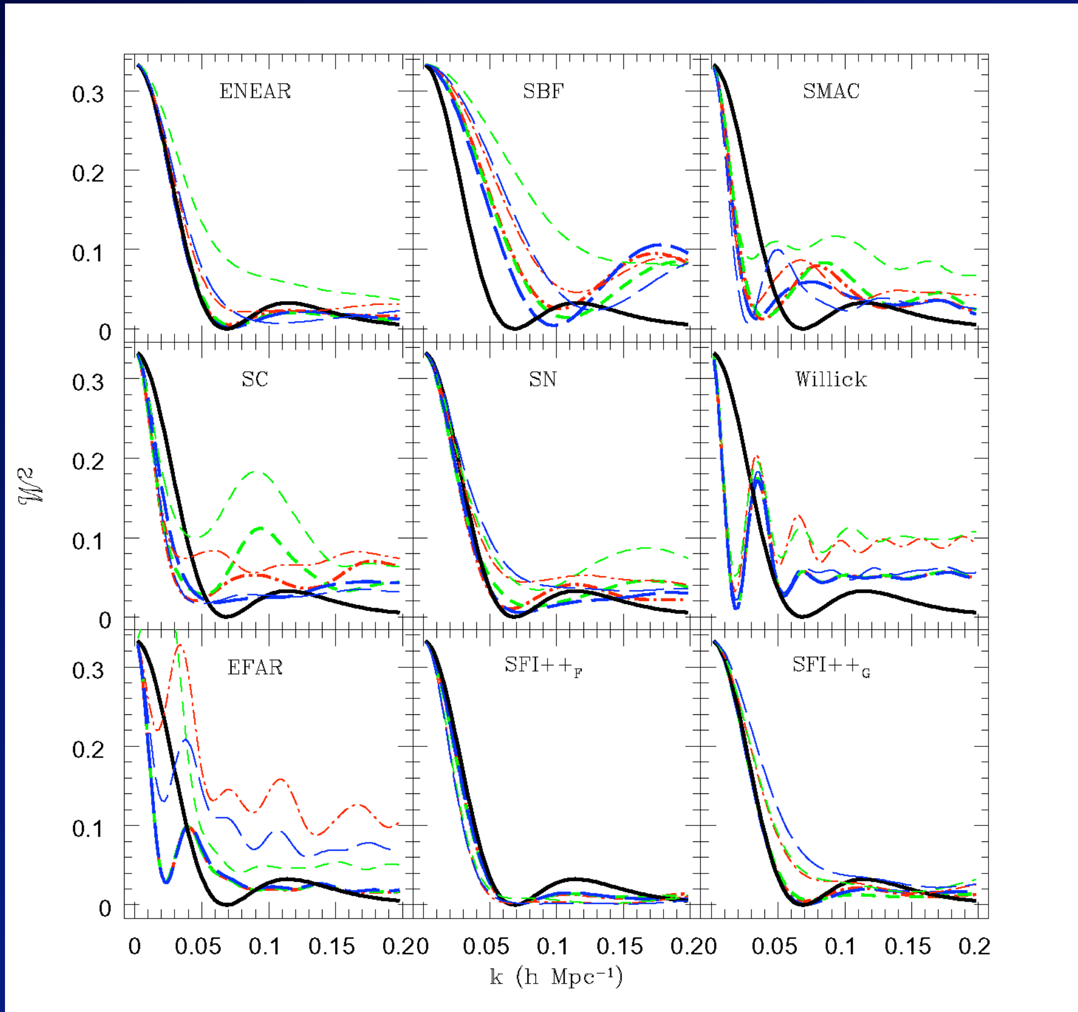
… skip many pages of ugly math ….

Window Functions

The expected flow depends on an integral in Fourier space of the power spectrum and the window function.

We have a new ***weighting scheme*** which minimizes the effects of sparse sampling, leaving the measurement sensitive to only the largest scales (small wavenumber k)

(Compare thin and thick coloured lines).



Results

Once we allow for the effects of sparse sampling, we find:

(1) all of the published peculiar velocity surveys agree with each other

(2)When combined, the sample extends to 100 Mpc/h, and its bulk flow is 407+-81 km/s, towards l=287, b=8

Consistency with ΛCDM Models

What bulk flow do we expect for this combined sample?

Allowing for the sparse sampling and assuming a flat ΛCDM power spectrum with WMAP5 parameters n=0.96, $\Omega_m h^2 = 0.13$ and σ_8 ~0.8 then the cosmic r.m.s. is ~ 110 km/s.

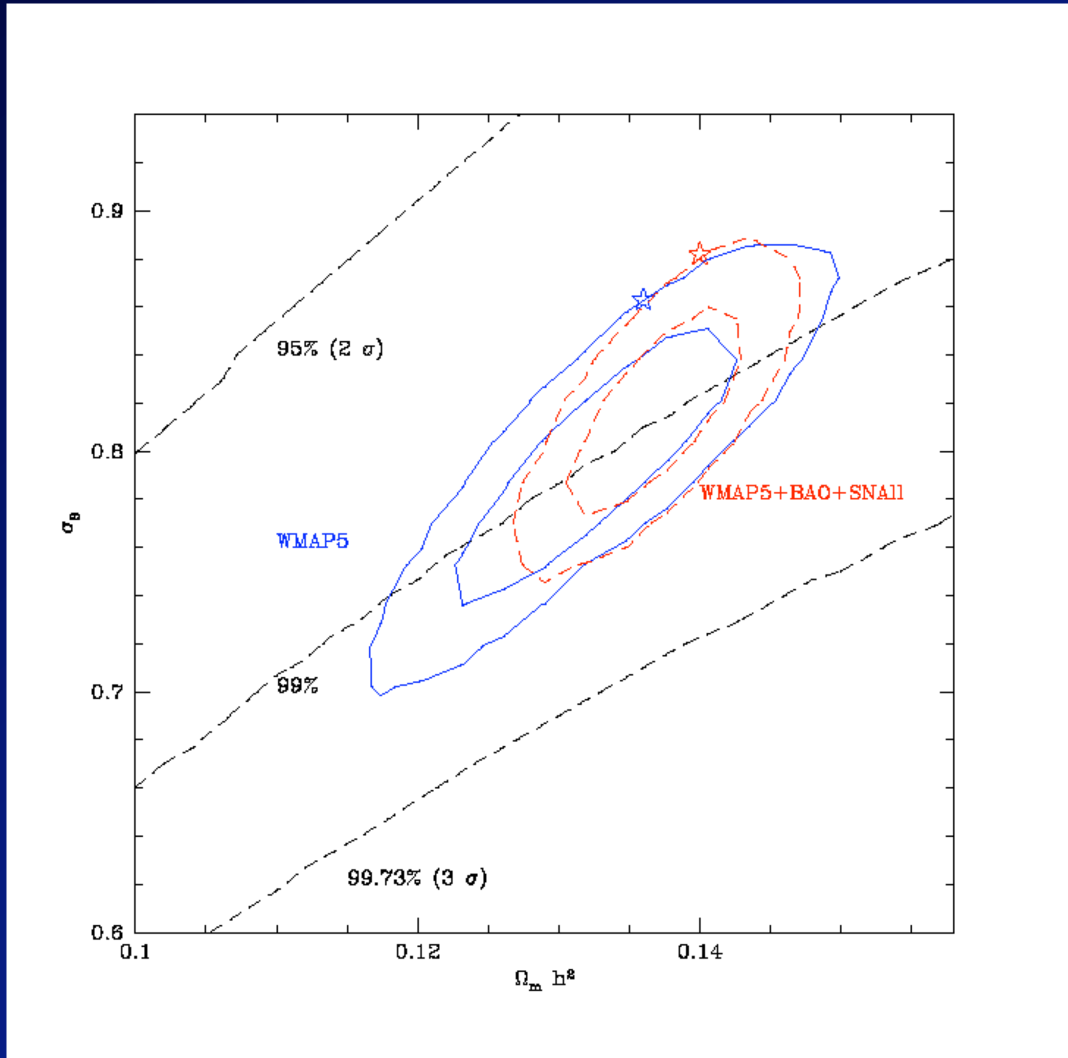
… but we measure 400 km/s.

This model is then rejected at the 99% CL.

Likelihood contours in $\Omega_m h^2$ vs σ_8

WMAP in colour;
bulk flows in black.

WMAP5 cosmology rejected at 2.5 σ (98%).



Watkins, Feldman and MH 2009

Kashlinsky et al 2008

Kashlinsky et al. averaged the kinetic Sunyaev-Zel'dovich effect from 700 clusters within $z < 0.3$.

Their claim is that local volume out to ~900 Mpc/h is moving at a velocity 600-1000 km/s, but the *systematic uncertainty* on the amplitude of the velocity is very high.

The direction of the flow that they find is within 6 deg of our result.

Other probes

There are few independent ways to measure the fluctuations in the *mass* density on very large scales (~100 Mpc/h) in the *nearby Universe*.

- Integrated Sachs-Wolfe effect (decay of potential)
- SDSS galaxy power spectrum

Integrated Sachs-Wolfe effect

ΛCDM predicts:

A=1

Observed:

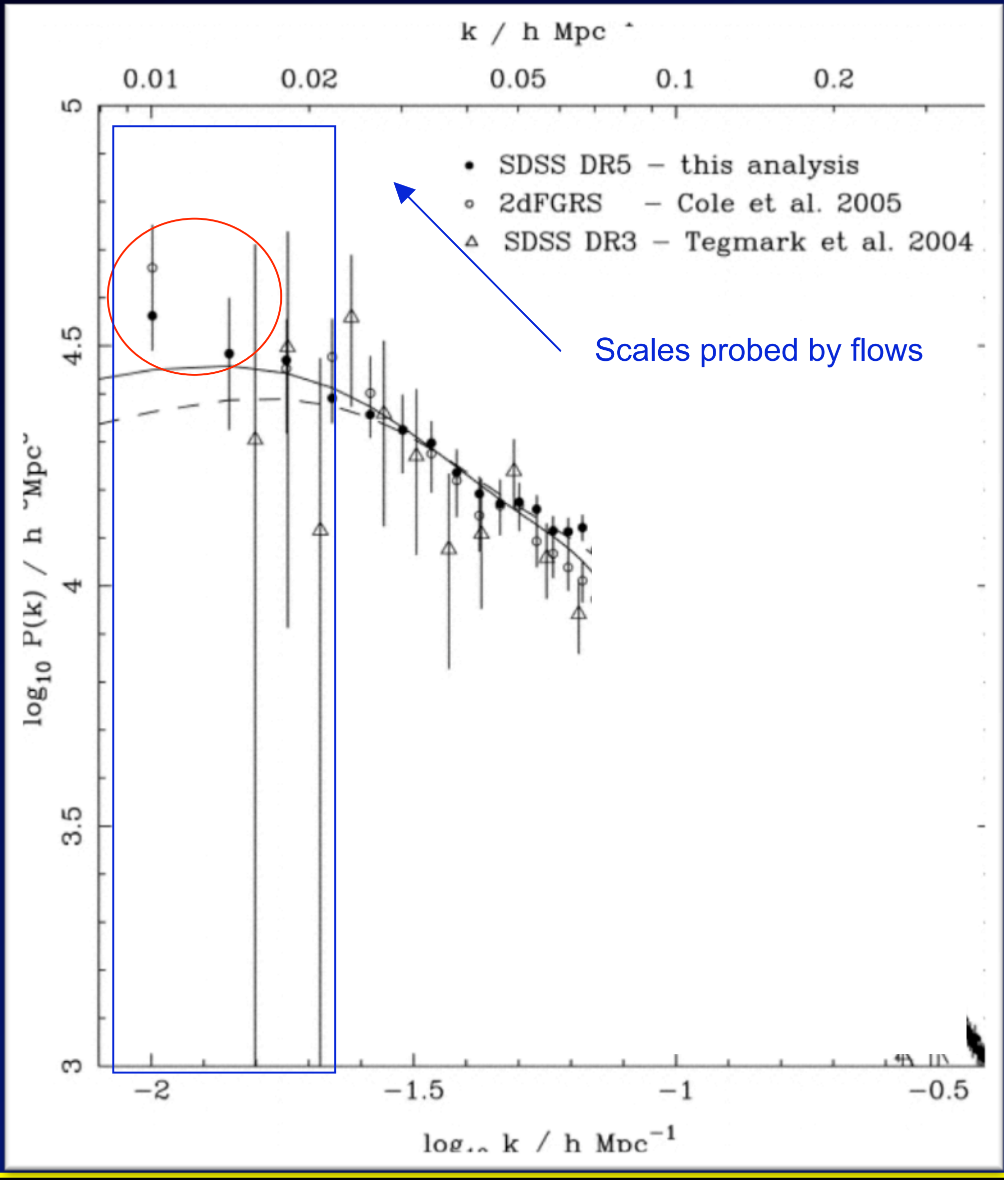
A=2.23+-0.60

HO, HIRATA, PADMANABHAN, SELJAK, AND BAHCALL

TABLE VI. Amplitude of ISW signal and the associate one sigma error relative to WMAP3 model and significance of detection for each of the sample and when we combine all samples. These are calculated using the covariance matrix that are derived from the correlations with the Monte Carlo CMB maps [as described in Eq. (47)].The overall signal is two sigma higher than the WMAP3 model prediction.

Sample	Amplitude ($A \pm \sigma$)	# Sigmas
2MASS0	-2.01 ± 11.41	-0.18
2MASS1	$+3.44 \pm 4.47$	0.77
2MASS2	$+2.86 \pm 2.87$	1.00
2MASS3	$+2.44 \pm 1.73$	1.41
LRG0	$+1.82 \pm 1.46$	1.25
LRG1	$+2.79 \pm 1.14$	2.46
QSO0	$+0.26 \pm 1.69$	0.16
QSO1	$+2.59 \pm 1.87$	1.38
NVSS	$+2.92 \pm 1.02$	2.86
All Samples	$+2.23 \pm 0.60$	3.69

Galaxy Power Spectra



SDSS (more red gals) and 2dFGRS (more blue) disagree on small-scales.

On large scales, they are expected to agree (and they do)

… but both exceed ΛCDM predictions

Percival et al 07

Conclusions

- Once sampling effects are considered no conflict between large-scale sparse peculiar velocity surveys.
- Combined sample bulk flow (~100 Mpc):
  - Combined: 407+- 81 km/s, towards l=287, b=8
  - No convergence to CMB yet …
- Marginally inconsistent with ΛCDM (98% CL)
- Some other measurements also suggest large density fluctuations on large scales.

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