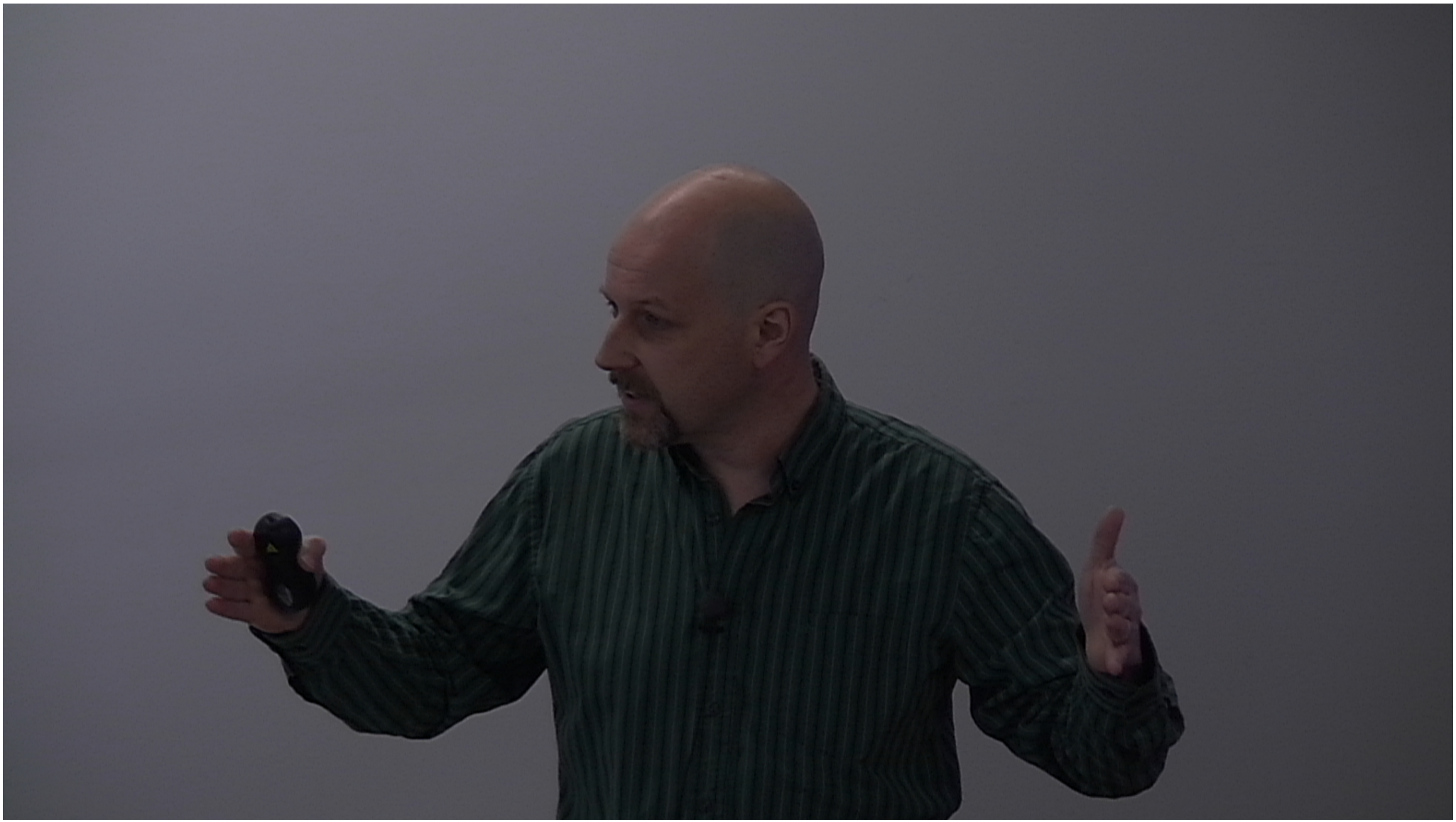
Title: Cosmic Flows: Testing Gravity and the Matter Power Spectrum on Very Large Scales

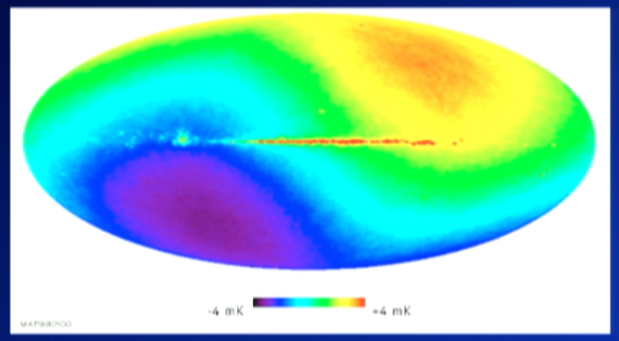
Date: Jan 10, 2012 11:00 AM

URL: http://pirsa.org/12010126

Abstract: TBA



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



What is the source of this motion?

On what scale is the Universe at rest?

Peculiar velocities probe the large-scale distribution of ***mass*** in the Nearby Universe

The Peculiar Velocity Field

Peculiar Velocities and Gravity

In linear perturbation theory, peculiar velocity is proportional to peculiar acceleration

$$\mathbf{v}(\mathbf{r}) = \frac{f(\Omega_{\mathrm{m}})H_0}{4\pi}\int d^3\mathbf{r}'\delta_{\mathrm{m}}(\mathbf{r}')\frac{(\mathbf{r}'-\mathbf{r})}{|\mathbf{r}'-\mathbf{r}|^3}$$

$$f \equiv \frac{d\ln G}{d\ln a} \simeq \Omega_{\mathrm{m}}^{\gamma}$$

Υ=0.55 in flat ΛCDM

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Measuring Peculiar Velocities

1. Direct distance estimates

$$v = cz - H_0 r$$

2. Kinetic Sunyaev-Zeldovich effect

3. Statistically via “redshift-space distortions”

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Mapping the Peculiar Velocity Field

The peculiar velocity of a single object (e.g. LG) does not distinguish between a *small nearby* overdensity or a *massive distant* overdensity.

By mapping the peculiar velocity *field*, can find the δ *field*:

- Infall into an attractor suggests local source.
- Coherent "bulk flow" with little shear suggests distant sources.

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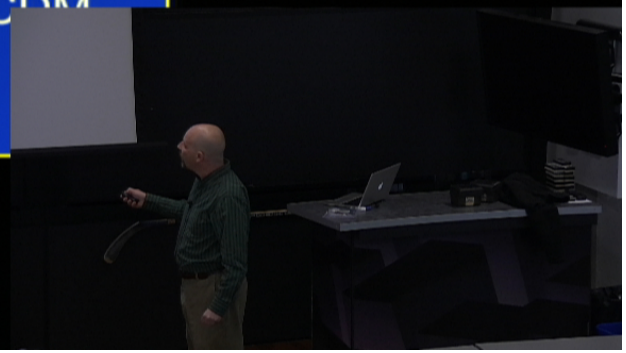

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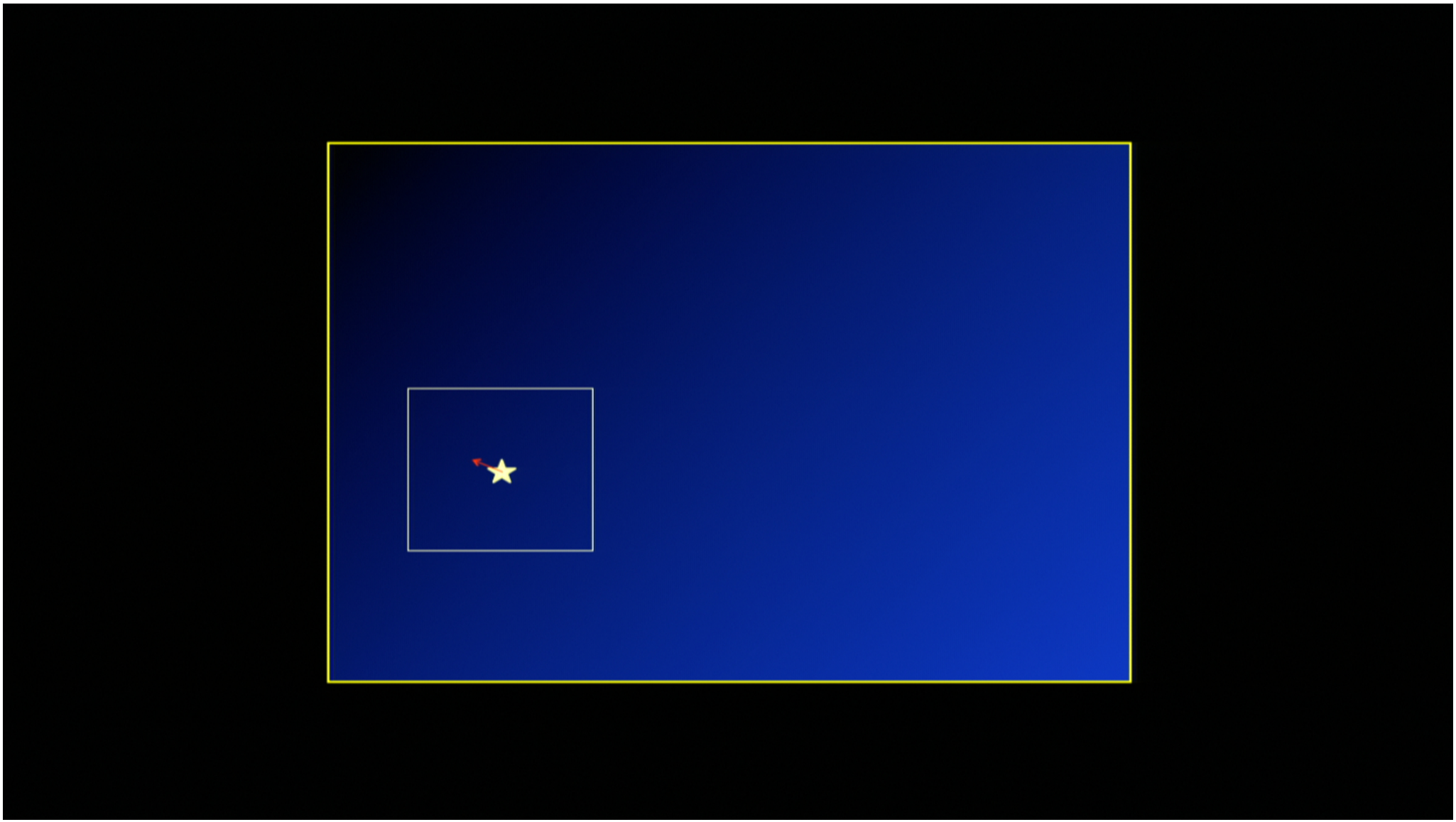
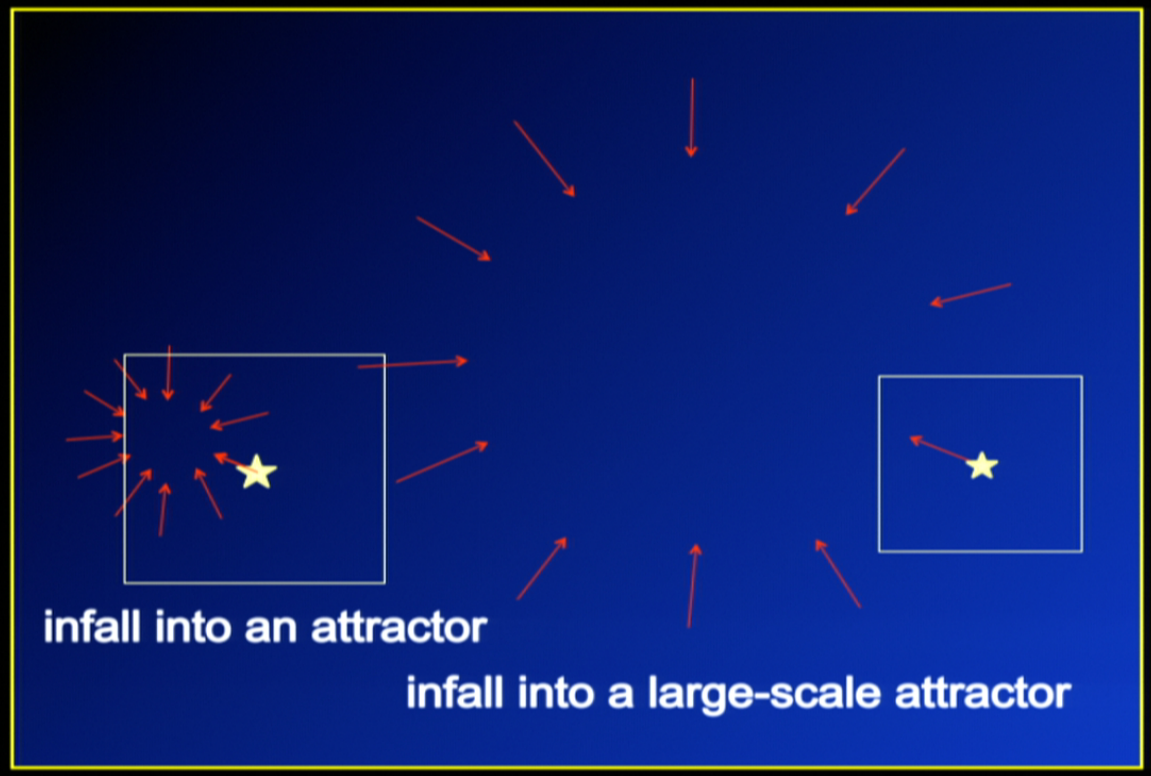
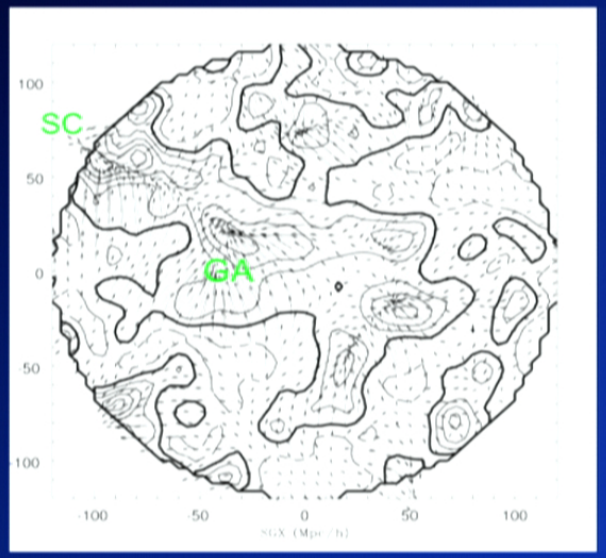



infall into an attractor
infall into a large-scale attractor

A more realistic peculiar velocity field



Bulk flow

The bulk flow is the *average* peculiar velocity over some volume.

Less noisy than individual measurements

This statistic is sensitive to structures on scales *larger* than the scale being averaged.

Bulk Flow Cosmic Variance

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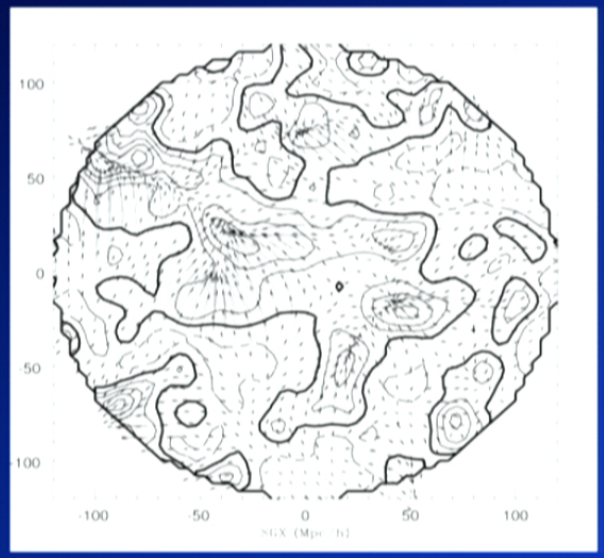

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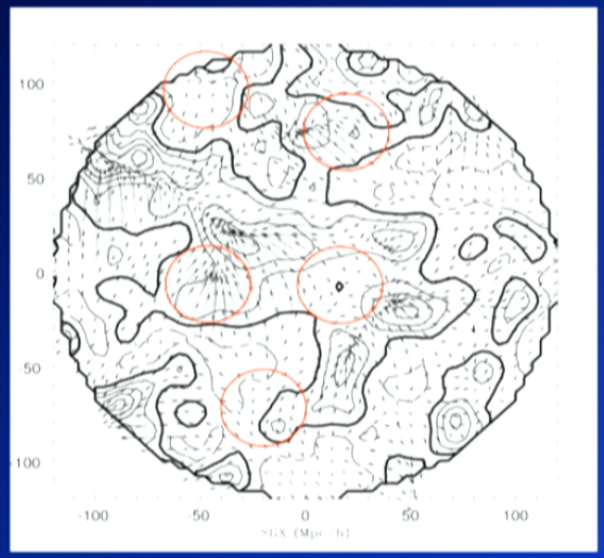

Expectations for the Bulk Flow

$$\sigma_V^2 = \frac{\Omega_m^{1.1}}{2\pi^2} \int_0^\infty dk\, \mathcal{W}^2(k)\, P(k)$$

Fourier transform of survey geometry

For a Gaussian window (50 Mpc/h) and LCDM:
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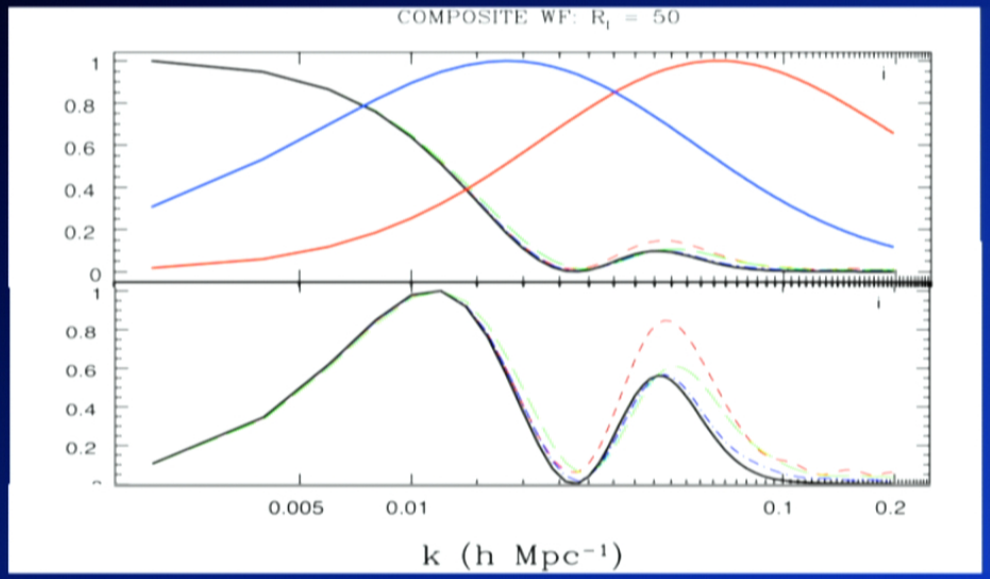

Measuring peculiar velocities

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- Measuring redshifts (*cz*) is easy.
- Measuring *r* is much more difficult, and less accurate.
  - Tully-Fisher (~20% uncertainty per gal)
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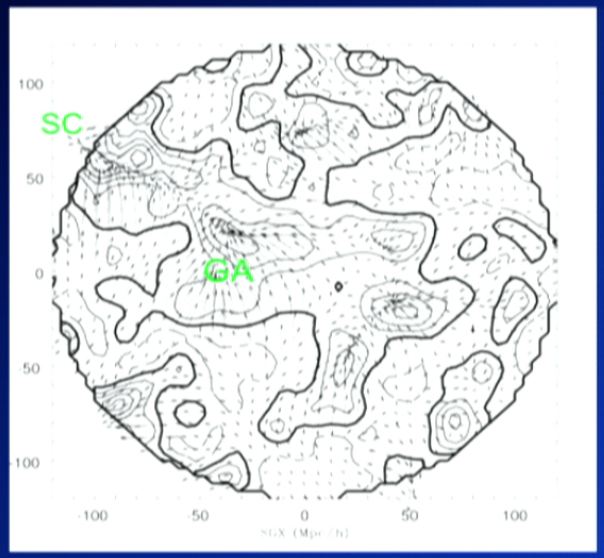

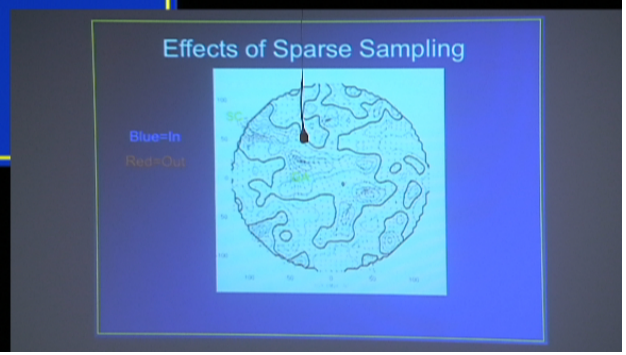

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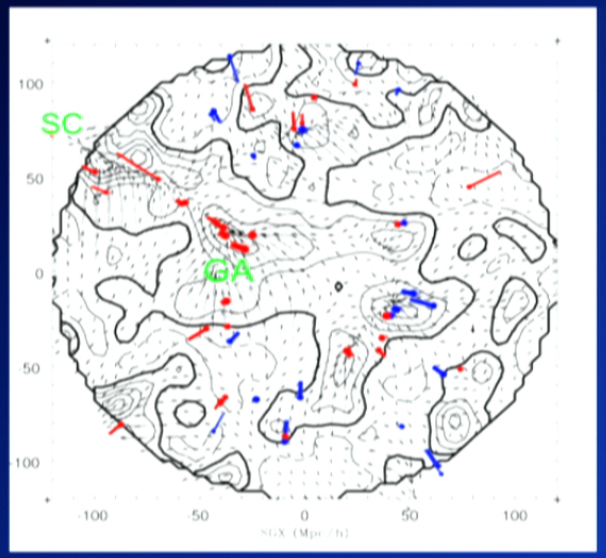


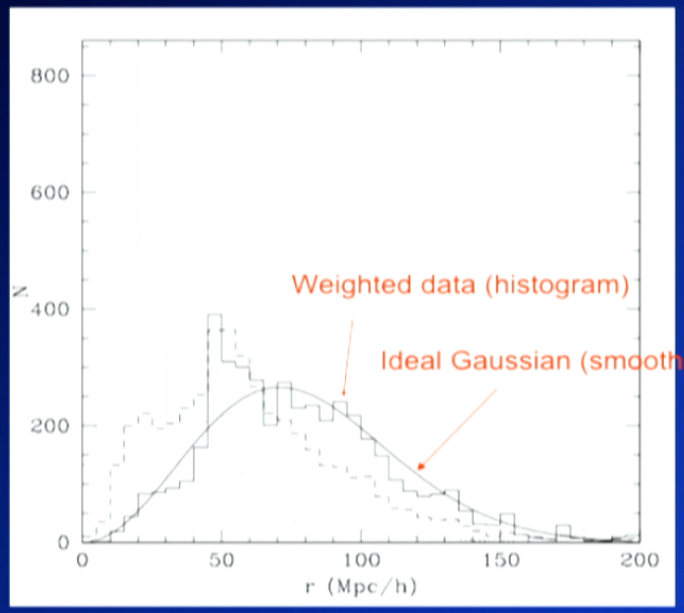
SMAC

Optimal Weights

Watkins, Feldman MH 2009
Feldman, Watkins MH 2010

Optimal Weighting schemes

Force the data to match an idealized geometry



Once we allow for sparse sampling, all of the peculiar velocity surveys agree with each other

(except for Lauer & Postman's BCG survey)

Comparison of Independent Samples

SFI++
(Springob, Giovanelli et al.)

Tully-Fisher
in field

Bulk flow:
430 ± 90 km/s
towards
l=284, b=12

"DEEP" Compilation

Clusters: FP, TF + SNe

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New SN peculiar velocities

S. Turnbull, MH *et al.* 2011 analyzed 254 SNe within 200 Mpc/h.

$V = 250 \pm 75$ km/s for R_G=50 Mpc/*h*.

By itself, this is consistent with ΛCDM

WIRED SCIENCE

NEWS FOR YOUR NEURONS

Supernova Research Challenges Cosmic 'Dark Flow' Mystery

By Adam Mann | December 16, 2011 | 2:31 pm | Categories: Space

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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 1D cosmic r.m.s. is ~ 110 km/s.

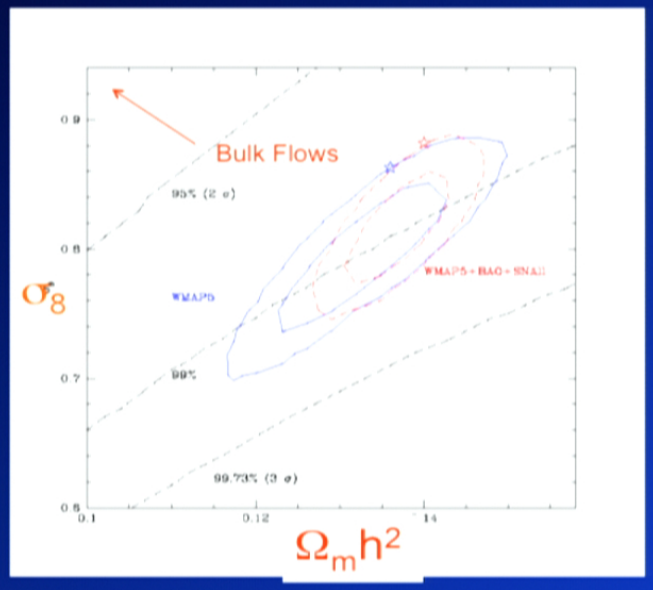
… but we measure 340 km/s.

This model is then rejected at the 97% 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

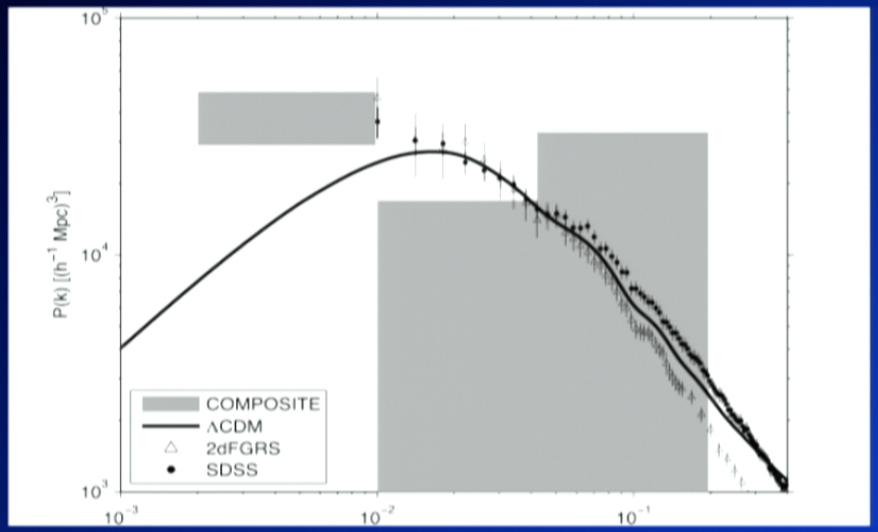
Beyond the Bulk Flow: Shear Moments

We have measured the dipole (bulk flow), quadrupole (shear) and octupole:

Only the dipole, which probes the largest scales, is unusually high

The low “tidal” shear suggests a distant source for the flow (>300 Mpc/h).

Matter Power Spectrum from large-scale flows



Macaulay et al 2010

Explanations

- Systematic errors?

  But very different surveys agree well

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- There is more large-scale power than LCDM predicts …

- Or more exotic explanations?

Other Probes

Kinetic SZ effect

The kinetic SZ (kSZ) effect: the CMB temperature decrement will depend on the peculiar *velocity* of the cluster w.r.t to the CMB frame.

The signal depends on the amount of hot plasma in the cluster and the cluster's line-of-sight velocity.

Kashlinsky et al. “Dark Flow”

- Kashlinsky et al. averaged the kSZ effect from 700 clusters within z < 0.3 in WMAP
- Their claim is that local volume out to ~900 Mpc/h is moving at a velocity 600-1000 km/s.
- The direction of the flow that they find is within 6 deg of our result.

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- The direction of the flow that they find is within 6 deg of our result.
- BUT Keisler ‘09 and Osborne et al ’10 claim that Kashlinsky et al. underestimated their uncertainties.

Other probes

There are few independent ways to measure the fluctuations 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

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.

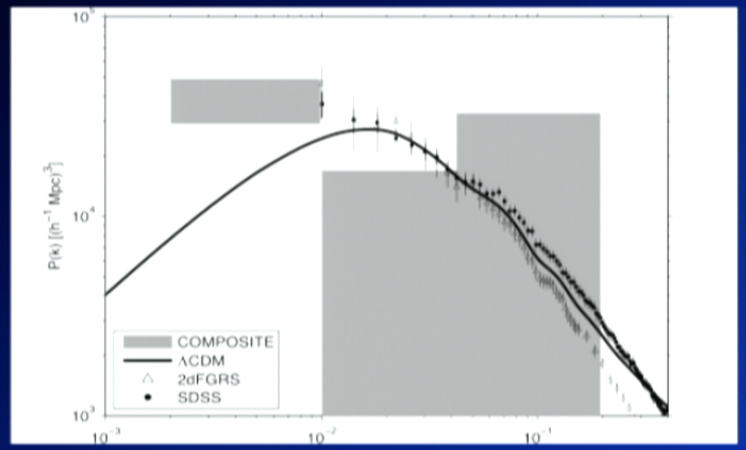
Sample	Amplitude ($A \pm \sigma$)	# Sigmas
2MASS0	2.01 ± 11.41	0.18
2MASS1	$+3.44 \pm 4.47$	0.77
2MASS2	$+2.86 \pm 2.87$	1.00
2MASS3	$+2.44 \pm 1.73$	1.41
LRG0	$+1.82 \pm 1.46$	1.25
LRG1	$+2.79 \pm 1.14$	2.46
QSO0	$+0.26 \pm 1.69$	0.16
QSO1	$+2.59 \pm 1.87$	1.38
NVSS	$+2.92 \pm 1.02$	2.86
All Samples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

ΛCDM predicts: A=1

Observed: A=2.23+-0.60

- Ho et al '08 and Granett et al '08/ Papai et al '10 also find a higher signal
- … but Giannantionio et al. '08 find no excess

Galaxy Power Spectra



On large scales, SDSS and 2dFGRS agree with each other

… but both exceed ΛCDM predictions.

Percival et al 07

Large-Scale Voids

Large-scale (~Gpc) voids would produce a bulk flow, but we would have to live close to (<50 Mpc/h) to the center of such a void to not produce *too much* bulk motion.

Even less Copernican!

Peculiar Velocities and the Growth Rate *f*

Modifying Gravity?

It has been suggested that, instead of increasing the large-scale power, one might modify the growth rate and hence *f*

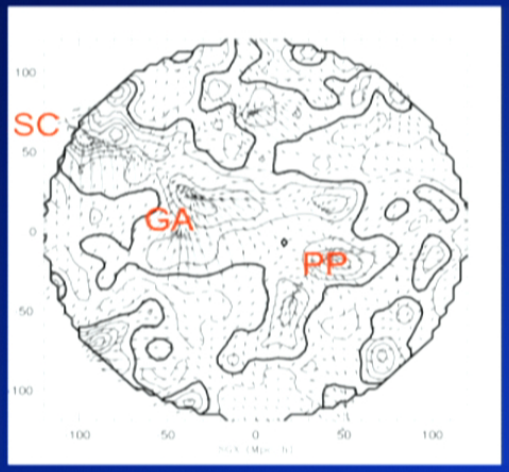
e.g.

Afshordi, Geshnizjani & Khoury 2009

Khoury & Wyman 2009

Mass vs. Light

Mass (Zaroubi)
Inversion of peculiar velocity field



(Far-infrared) Galaxy Light
(PSCz : Branchini)

"Biasing"

Averaged over large scales, one might assume that

$$\delta_g = f(\delta) \quad \text{where}$$

$$\delta = (\rho - \overline{\rho})/\overline{\rho}$$

The simplest case is $\delta_g = b\delta$

where *b* is the linear biasing parameter.
but this need not be true: biasing might be non-linear and depend on other parameters

- Use galaxy $\delta_g = b\,\delta$
- Model external flows as bulk flow

$$\mathbf{v}(\mathbf{r}) = \frac{f}{b}\frac{H_0}{4\pi}\int_0^{R_{\max}} d^3\mathbf{r}'\,\delta_g(\mathbf{r}')\,\frac{(\mathbf{r}'-\mathbf{r})}{|\mathbf{r}'-\mathbf{r}|^3} + \mathbf{U}$$

Cosmological Parameters

$$\delta_g = b\delta$$

$$\sigma_{8,g} = b\sigma_8$$

$$\beta = \frac{f}{b}$$

$$f\sigma_8 = \beta\sigma_{8,g}$$

Measure from clustering:

$\sigma_{8,K}$ =0.90 +- 0.10

$\sigma_{8,IRAS}$=0.85 +- 0.05

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Growth of Structure

Using only peculiar velocities at different *z*, it is possible to break degeneracies between f and σ_8

Combine direct PV measurements at low *z* with redshift-space distortion measurements at high *z*

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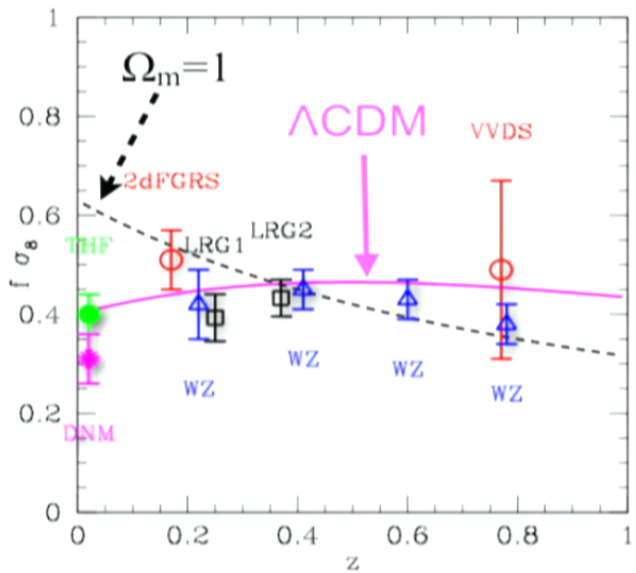
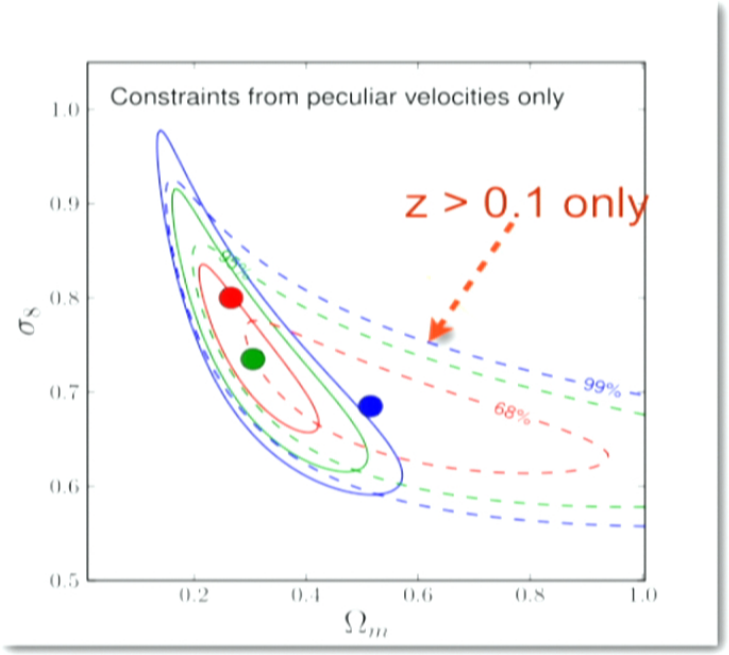


Hudson & Turnbull 2012



Hudson & Turnbull 2012

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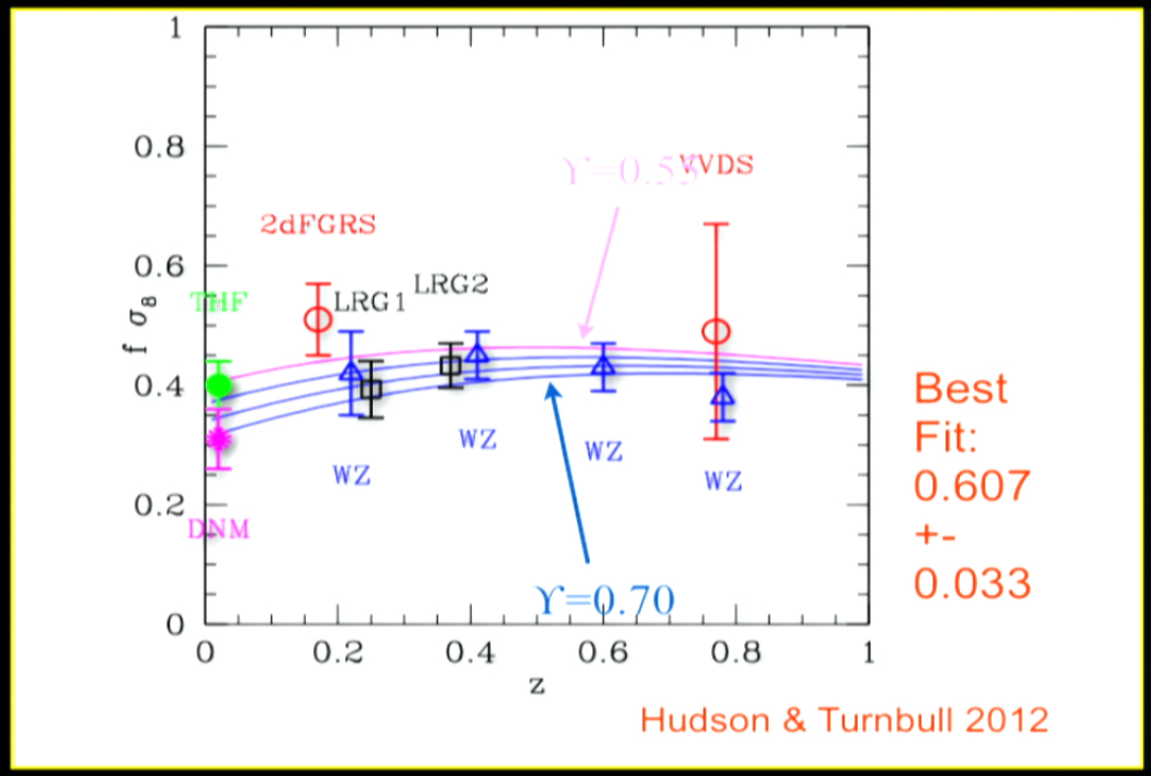
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
z
f σ8
2dFGRS
VVDS
LRG1
LRG2
THF
DNM
WZ
WZ
WZ
WZ
Υ=0.70
Best
Fit:
0.607
+-
0.033
Hudson & Turnbull 2012

Future

Conventional distances indicator methods
(TF, FP) running out of targets in the nearby Universe

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- Supernovae
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- kSZ - independent volumes, Planck

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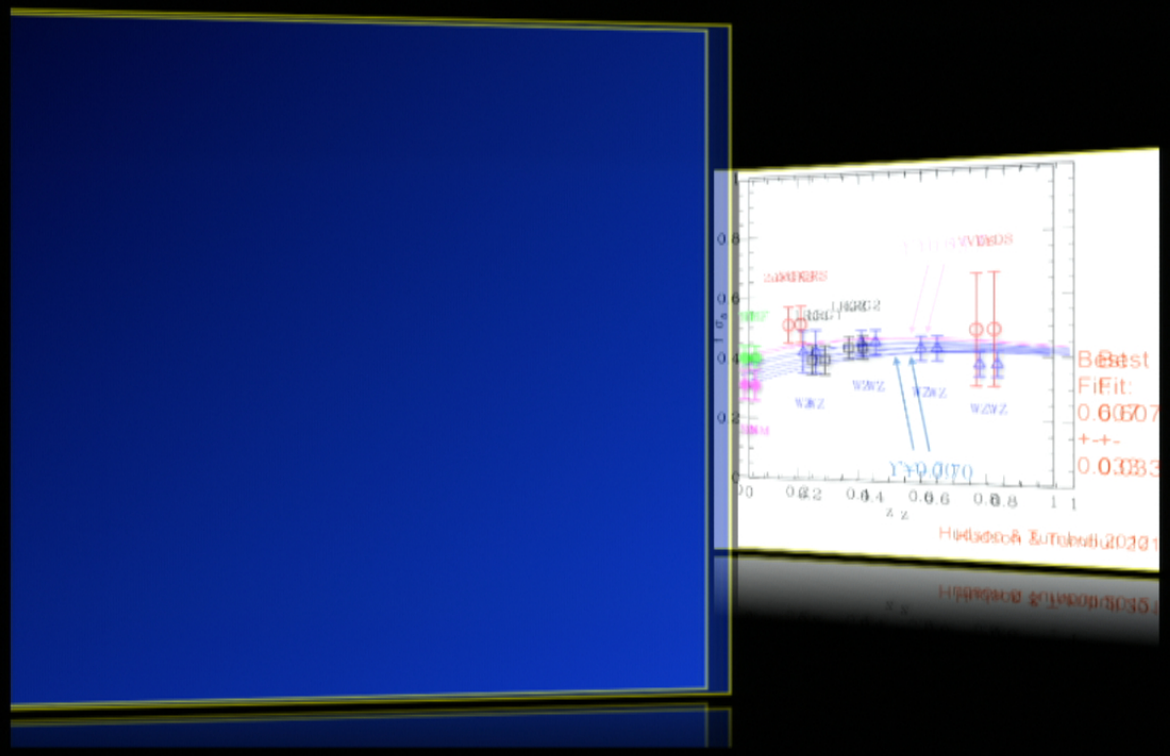

Conclusions

- Peculiar velocity surveys are consistent and suggest a bulk velocity larger than expected in ΛCDM (at the ~97% level)
- Some other probes also suggest large fluctuations on large scales.
- Growth of structure consistent with LCDM, at least on intermediate scales