TESTING LSS AND GRAVITY WITH COSMIC FLOWS

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Ripples in the Cosmos, Durham, July 24, 2013

WHY PECULIAR VELOCITIES?

- The best way to measure the *matter* power spectrum on very large (~Gpc) scales in the low z Universe : **bulk flows**

- Measure deviations from GR+Λ e.g. through growth factor *f*, and by comparison with lensing, "slip" etc: **infall**

BULK FLOWS

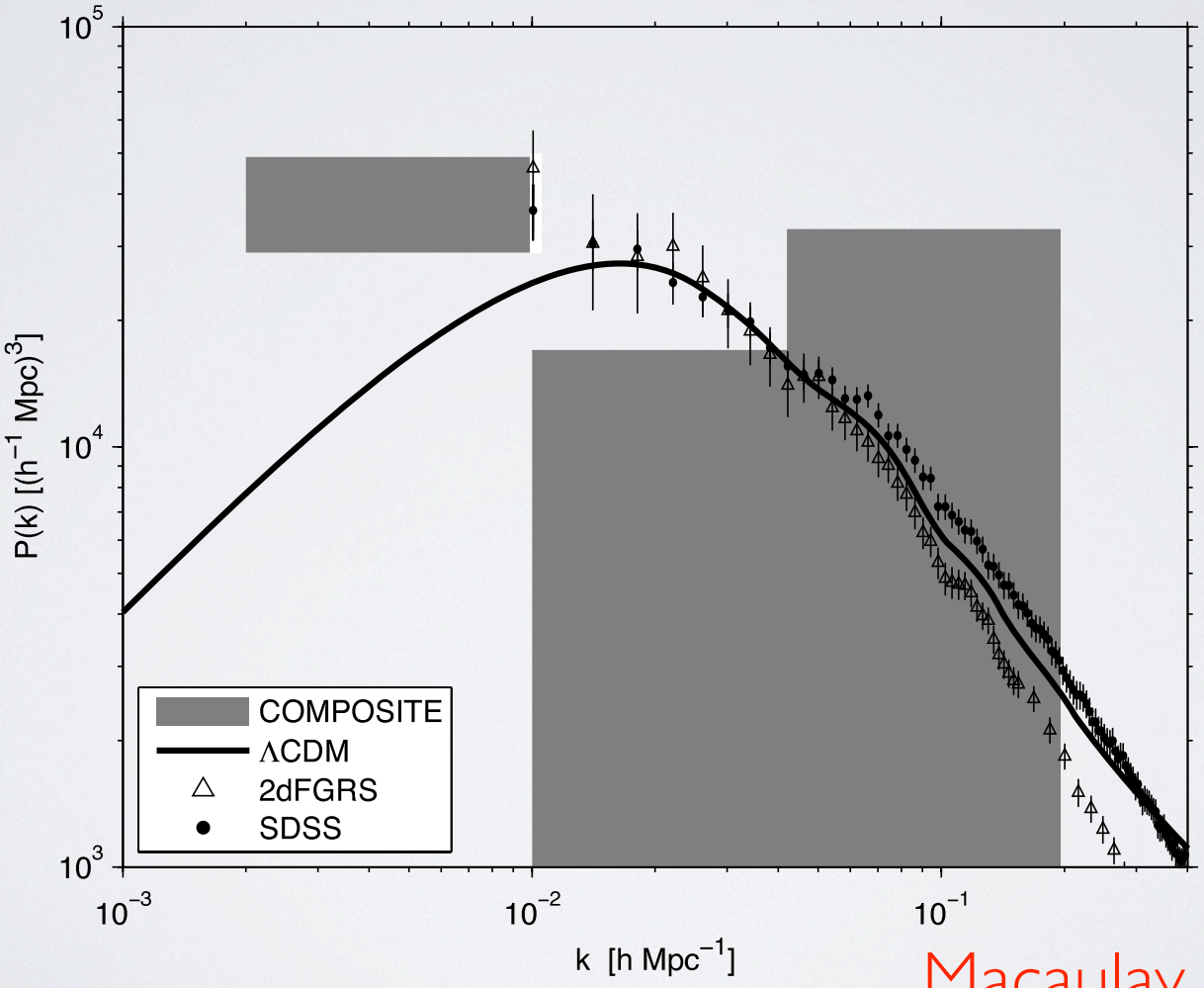
- Bulk flow = **Weighted** mean velocity *V* of a set of sparse, noisy peculiar velocity data

- Watkins, Feldman, MH 2009 designed weights to minimize aliased small-scale power, and applied this method to peculiar velocity compilation "COMPOSITE"

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

~400 +- 80 km/s bulk flow inconsistent with LCDM (~100 kms) at ~98% level

VERY LARGE-SCALE POWER?



Macaulay et al. 2011

"If your experiment needs statistics, you ought to have done a better experiment."

E. Rutherford

SNE

- "Constitution" + Carnegie SNe = "First Amendment" sample :
  - 254 SNe within 200 Mpc/h
- V = 250±75 km/s for a R_G=50 Mpc/*h*.
- Similar direction but lower amplitude compared to previous
- *By itself,* this is **consistent** with ΛCDM

Turnbull, MH, et al. '12, MNRAS, 420, 447, 1111.0631

COMPOSITE+SNE BULK FLOW

- The MV-weighted *V* of Composite and A1 SNe are consistent with each other.
- Taking both samples *together* the BF is *V=340* ± *~40* km/s towards *l=293, b=6*
- This combined BF is still slightly inconsistent with LCDM at the 97.5% (2.2 σ) level (vs. 99% for "Composite").

PREDICTING PECULIAR VELOCITIES USING THE GALAXY DENSITY FIELD

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

$$\delta_g = b\delta \qquad f(\Omega_\mathrm{m}) = \Omega_\mathrm{m}^\gamma$$

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

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

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

Measurable

SNE VS. PSCZ

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

We find

β=0.53 ±0.08

Residual *U = 150±43* km/s, towards l=345±20 b= 8±13

Turnbull, MH, et al.'12, MNRAS, 420, 447, 1111.0631

COSMOLOGICAL PARAMETERS

Combined with galaxy clustering measurements, peculiar velocities yield:

$$f\,\sigma_8 = 0.40 \pm 0.07$$

Compare with WMAP7 + BAO + SN : 0.39 +- 0.04

Peculiar velocities are consistent with other cosmological probes on small (~20 Mpc/h) scales.

Turnbull, MH, et al. '12, MNRAS, 420, 447, 1111.0631

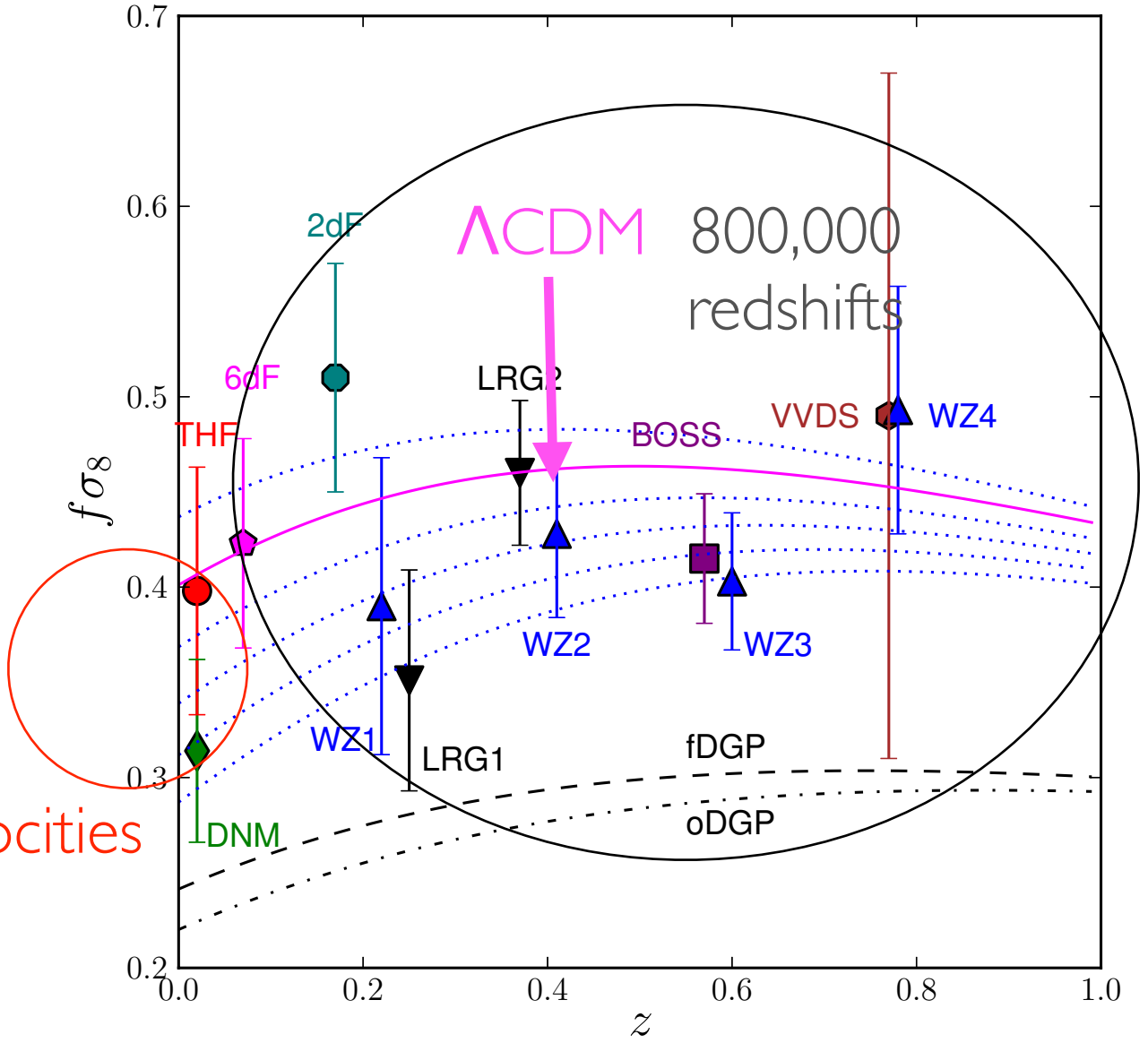
GROWTH OF STRUCTURE

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

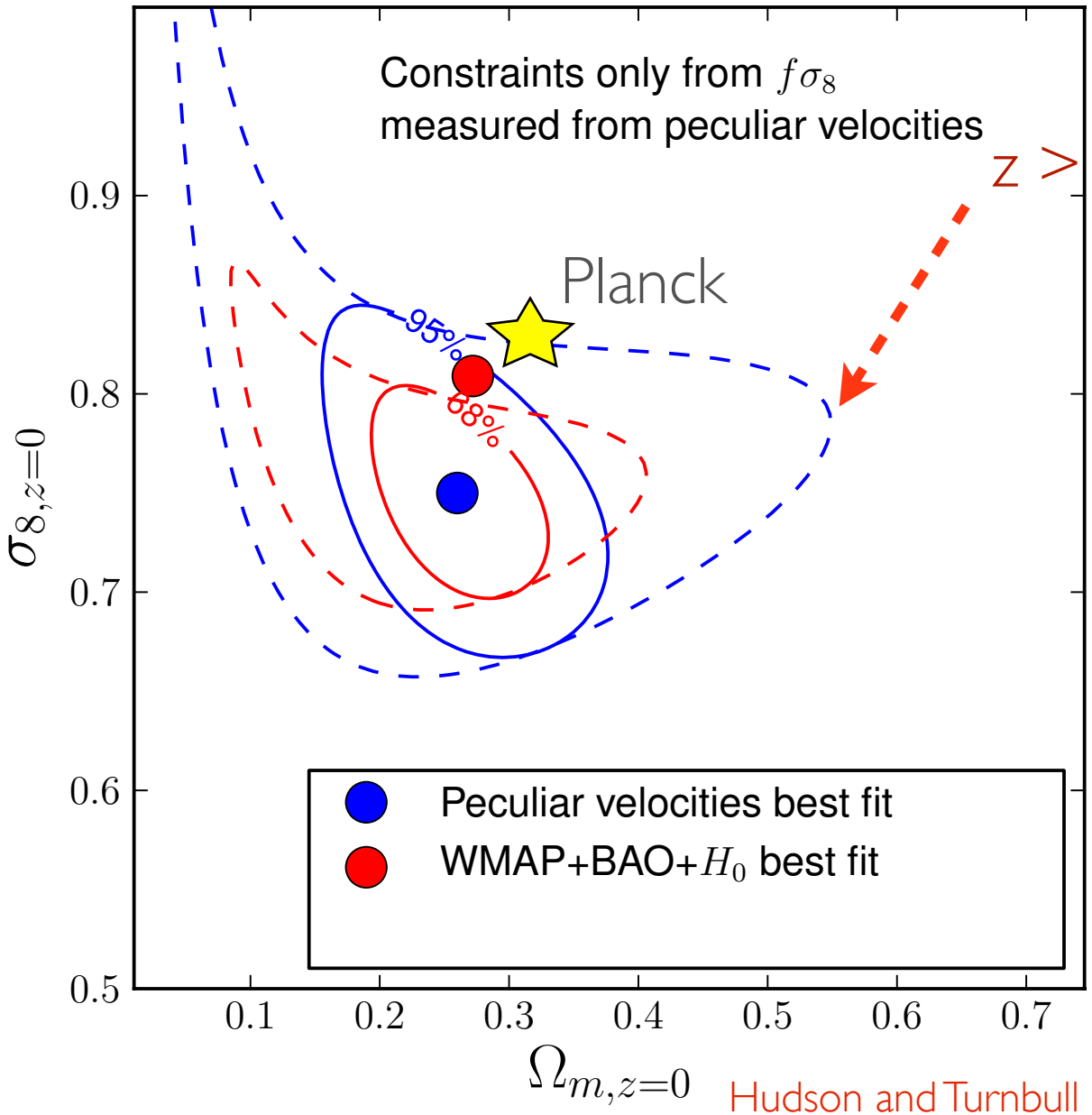
- At higher redshift we need to add redshift space distortions

USING ONLY PECULIAR VELOCITIES AT ALL REDSHIFTS

6000 peculiar velocities



Hudson and Turnbull 2012, ApJL, 751, L30, arXiv:1203.4814



Hudson and Turnbull 2012, ApJL, 751, L30, 1203.4814

KINETIC SUNYAEV-ZELDOVICH FROM GALAXIES

Lavaux, Afshordi & MH '13, MNRAS, 430, 1617

- kSZ measures **momentum** of electrons; most electrons are expected to be in galaxy halos and intergalactic space.
- Use ***nearby* galaxy** distribution as a template for large-scale free electron density field; model velocity as bulk flow.
- Fit template to WMAP, primordial CMB is noise
- V = **533 +- 263** km/s , in the direction **l ~ 324 °, b ~ −7 °** similar in amplitude and direction to previous measurements on this scale

RESIDUAL BULK FLOW

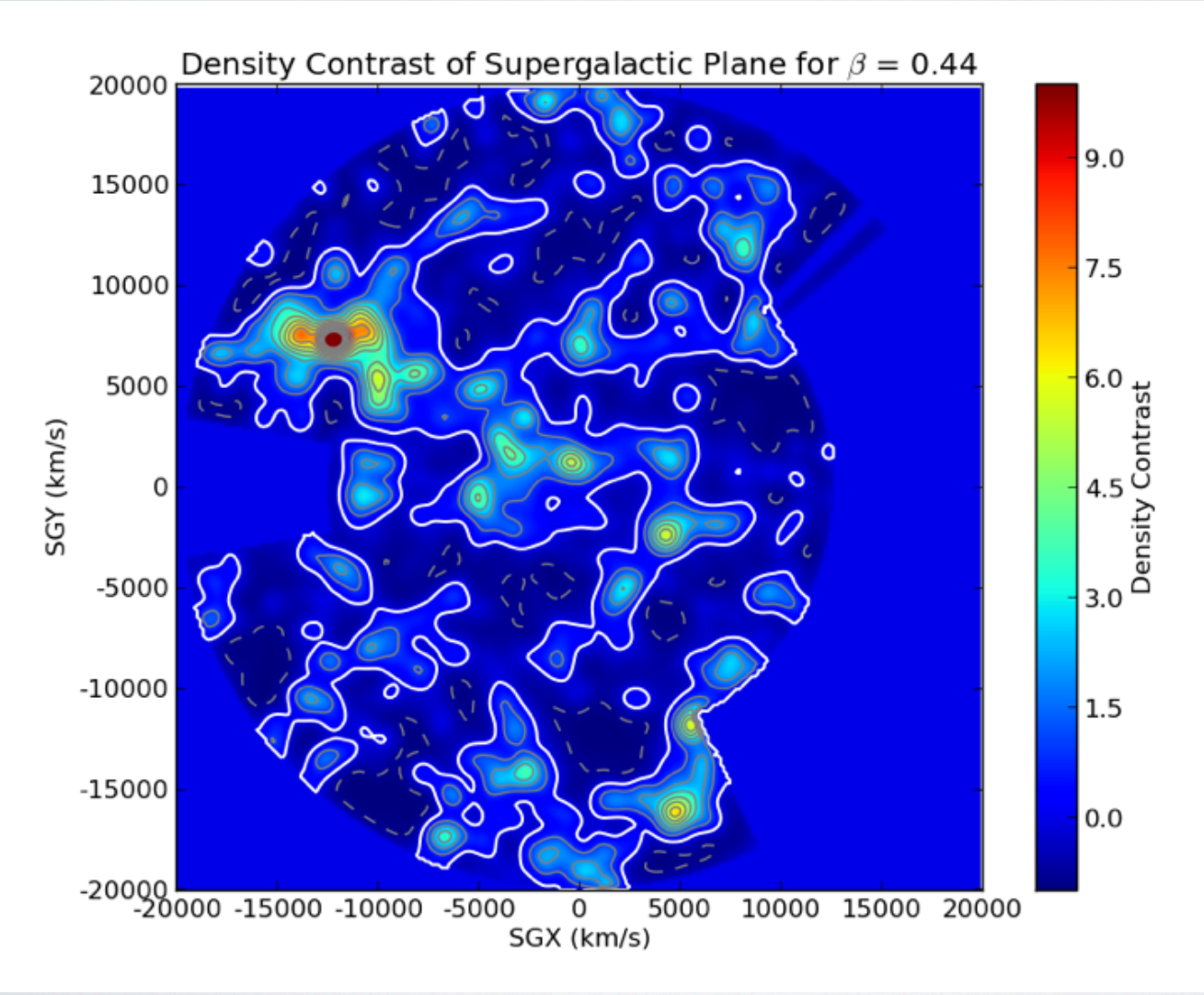
- The residual bulk flow suggests that PSCz does not account for all of the local motions
- Is the missing contribution:
  - Beyond 200 Mpc/h?
  - In the ZoA
  - Or *within* the volume spanned by the PSCz data?

2M++

Lavaux & Hudson 2011, MNRAS, 416, 2840

- Combine 2MRS (K<11.5), 6dF (K<12.5) and SDSS (K<12.5)
- ~70k galaxies
- Reach 200 Mpc/h in 6dF and SDSS areas

2M++ RECONSTRUCTION

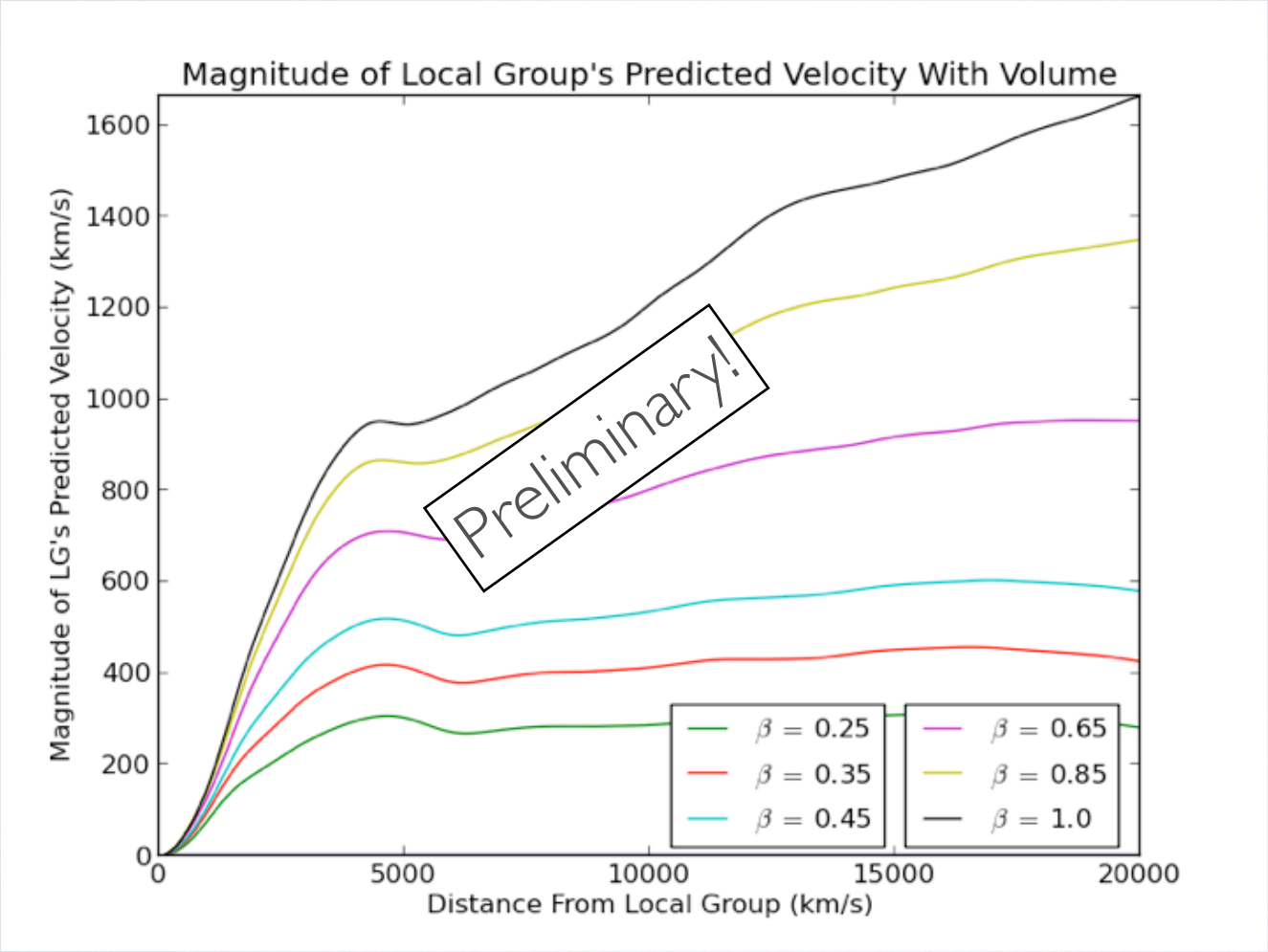


Jonathan Carrick

with Guilhem Lavaux

Preliminary

2M++ GRAVITY DIPOLE



In ΛCDM we expect 40 km/s per component from material beyond 20000 km/s.

If β ~ 0.4 for this sample, then we have ~recovered LG dipole.

Carrick et al. 2013, in prep

FUTURE

- Deeper ***all-sky*** redshift surveys (6dF + WALLABY+ TAIPAN + WNSHS + ? ...) will help to identify sources

- *N*ew peculiar velocity data from FP (6dF+TAIPAN), SNe, TF (WALLABY) and Planck kSZ

- Better treatments of "biasing" (halo model)

- Better non-linear treatment of predicted peculiar velocities (e.g. Least Action, MAK)

SUMMARY

- Bulk flow on large scales still in slight tension with LCDM
- On smaller scales, only ~6000 peculiar velocities give strong constraints on $f(z)\sigma_8(z)$, consistent with WMAP+
- kSZ around *galaxies* is a promising new probe ... Planck analysis underway.
- 2M++ may be recovering the full LG motion wrt CMB

Cosmic flows estimated from direct peculiar velocity estimates have great potential : need systematic SDSS-like surveys!