COSMIC FLOWS

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PECULIAR VELOCITIES AND GRAVITY

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

$$\mathbf{v}(\mathbf{r}) = \frac{f H_0}{4\pi} \int d^3\mathbf{r}\, \delta_m(\mathbf{r}') \frac{(\mathbf{r}' - \mathbf{r})}{|\mathbf{r}' - \mathbf{r}|^3}$$

$$f \equiv \frac{d \ln D_+}{d \ln a} \simeq \Omega_{\rm m}^{\gamma}$$ Υ=0.55 in flat ΛCDM

WHY PECULIAR VELOCITIES?

- Measure the *matter* power spectrum on very large (~Gpc) scales in the low z Universe : via **bulk flow**
- Measure growth factor ***f*** and σ_8: via **infall**

BULK FLOW

VELOCITIES IN FOURIER SPACE

$$\mathbf{v_k} = Haf(\Omega)\frac{i\mathbf{k}}{k^2}\delta_\mathbf{k}$$

- Note extra power of **k** in denominator

MEASURING THE BULK FLOW

- Bulk flow is the mean velocity of a region, usually spherical.

- Galaxies are sparse samples of this volume: there are optimal ways to do this (Watkins, Feldman, Hudson 2009)

EXPECTATIONS FOR THE BULK FLOW VARIANCE

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

Fourier transform of survey geometry.
Integrand peaks at k ~0.01

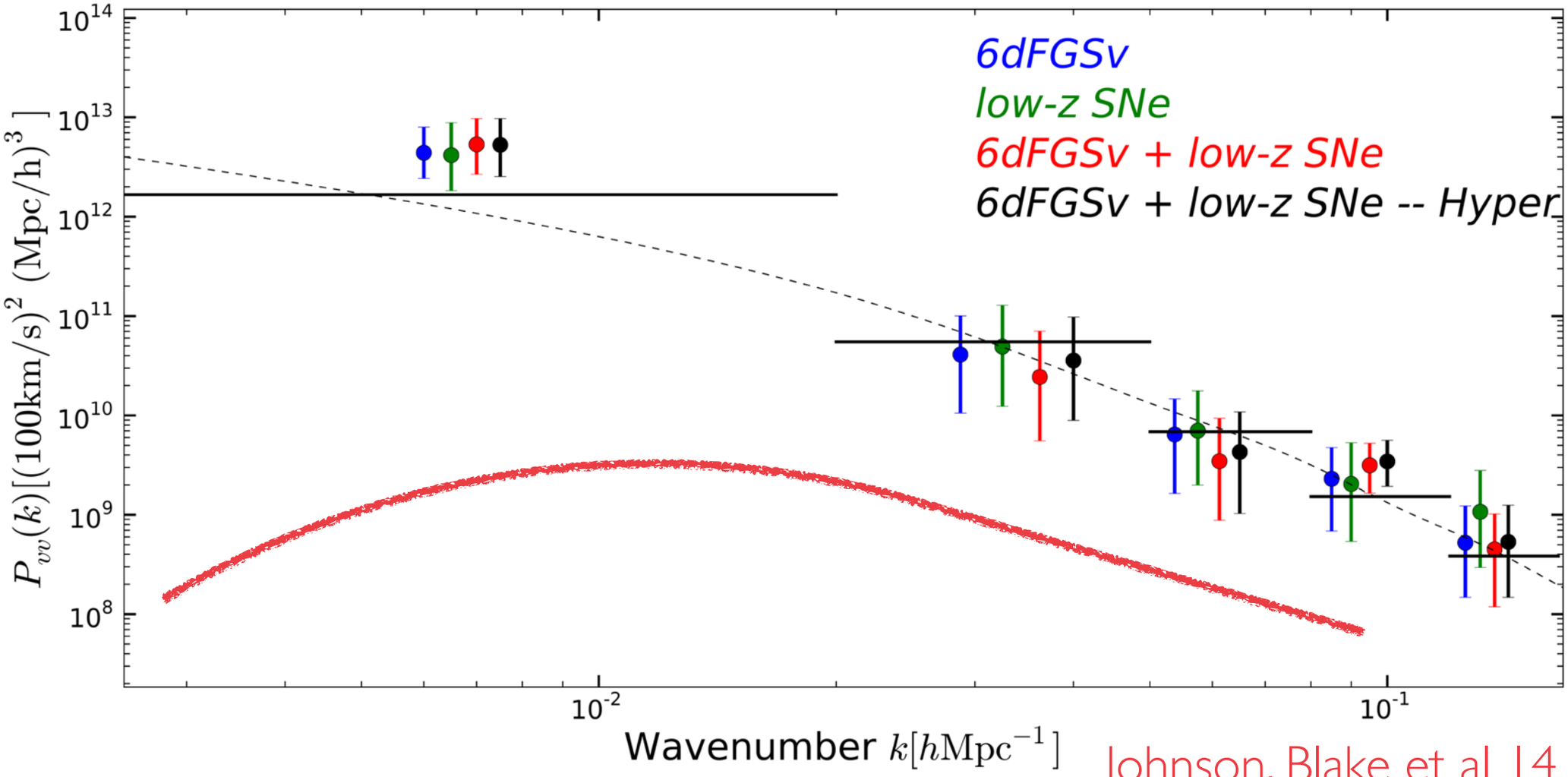
For a Gaussian-shaped window (50 Mpc/h) and ΛCDM:
σ_V ~ 100 km/s for each vector component

Expect ~170 km/s ~300 km/s OK ~400 km/s too unlikely

BULK FLOW MEASUREMENTS

SAMPLE	Flow km/s	Scale Mpc/h	ΛCDM?	Ref
COMPOSITE	407 ± 81	50	2%	Watkins, Feldman & Hudson '09
SNe	249 ± 76	50	OK	Turnbull, Hudson, Feldman et al. '12
CosmicFlows-2	262 ± 60	50	OK	Watkins & Feldman '14
2M Tully-Fisher	325 ± 49	40	OK	Hong, Springob, Staveley-Smith et al. '14
6dFGVS (FP)	257 ± 56	70?	OK?	Scrimgeour, Davis, Blake et al. '14
NFPS	175 ± 115	~80	OK	Lucey, Hudson et al., *in prep.*
CosmicFlows-3	300 ± 25?	70	~1%	Watkins & Feldman, *in prep.*

6DF PECULIAR **VELOCITY** POWER SPECTRUM



Johnson, Blake et al 14

COSMOLOGICAL PARAMETERS

USING THE GALAXY DENSITY FIELD

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ASSUME GALAXY DENSITY TRACES MASS

$$\delta_{\mathrm{g}} = b\, \delta_{\mathrm{m}}$$

β

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

Directly measurable from data

β

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

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

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

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

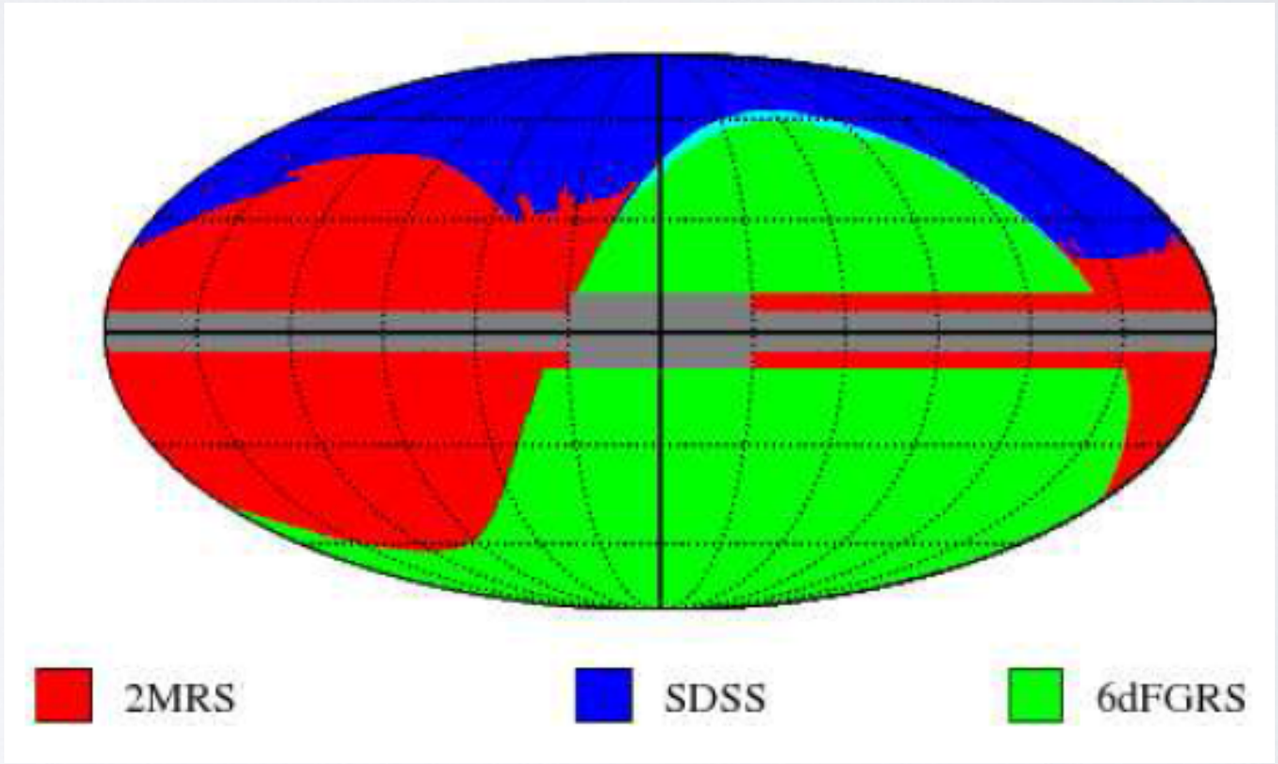
$$f\sigma_8 = \beta\sigma_{8,g}$$

Measurable

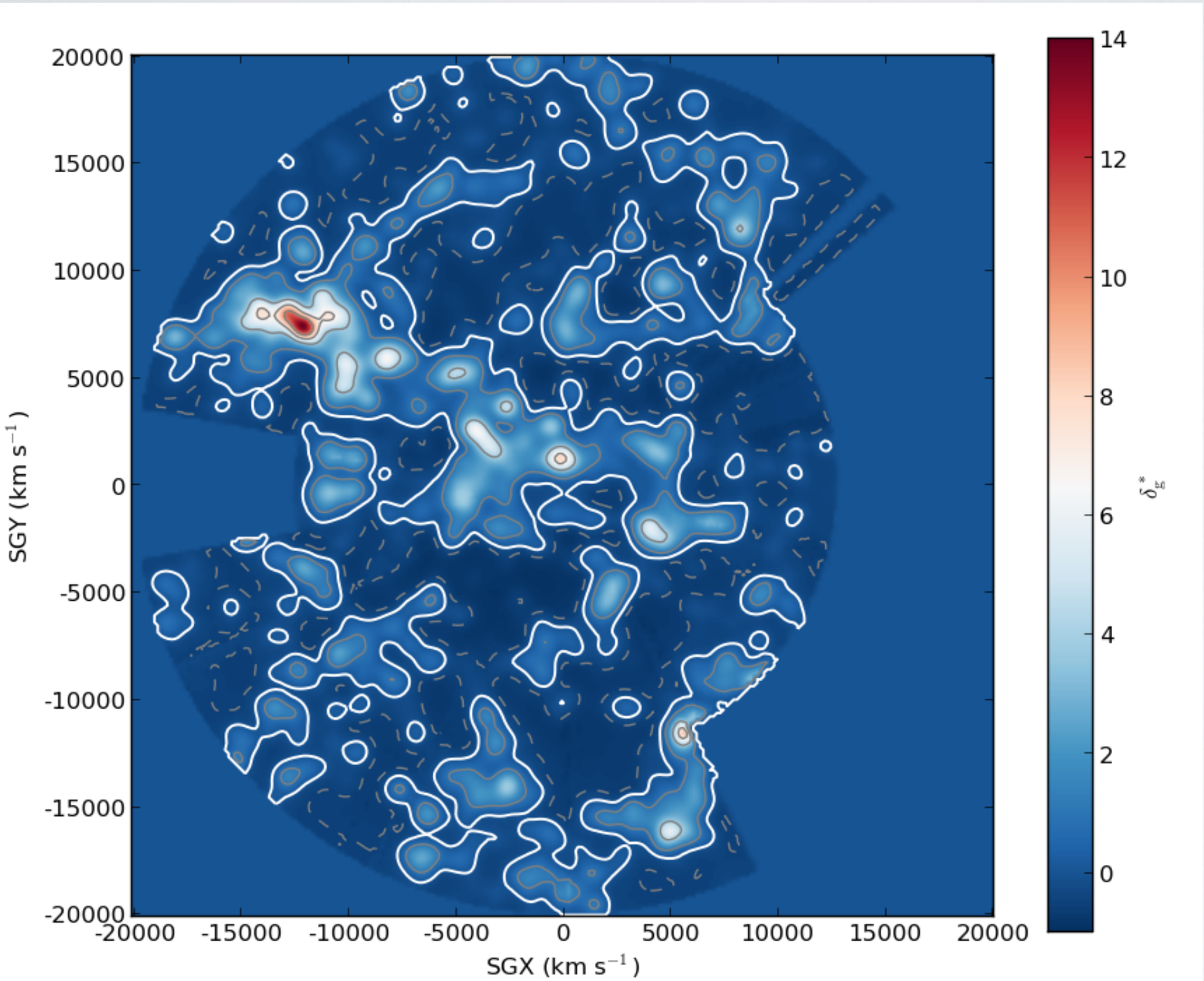
2M++

Lavaux & Hudson 2011, MNRAS, 416, 2840

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

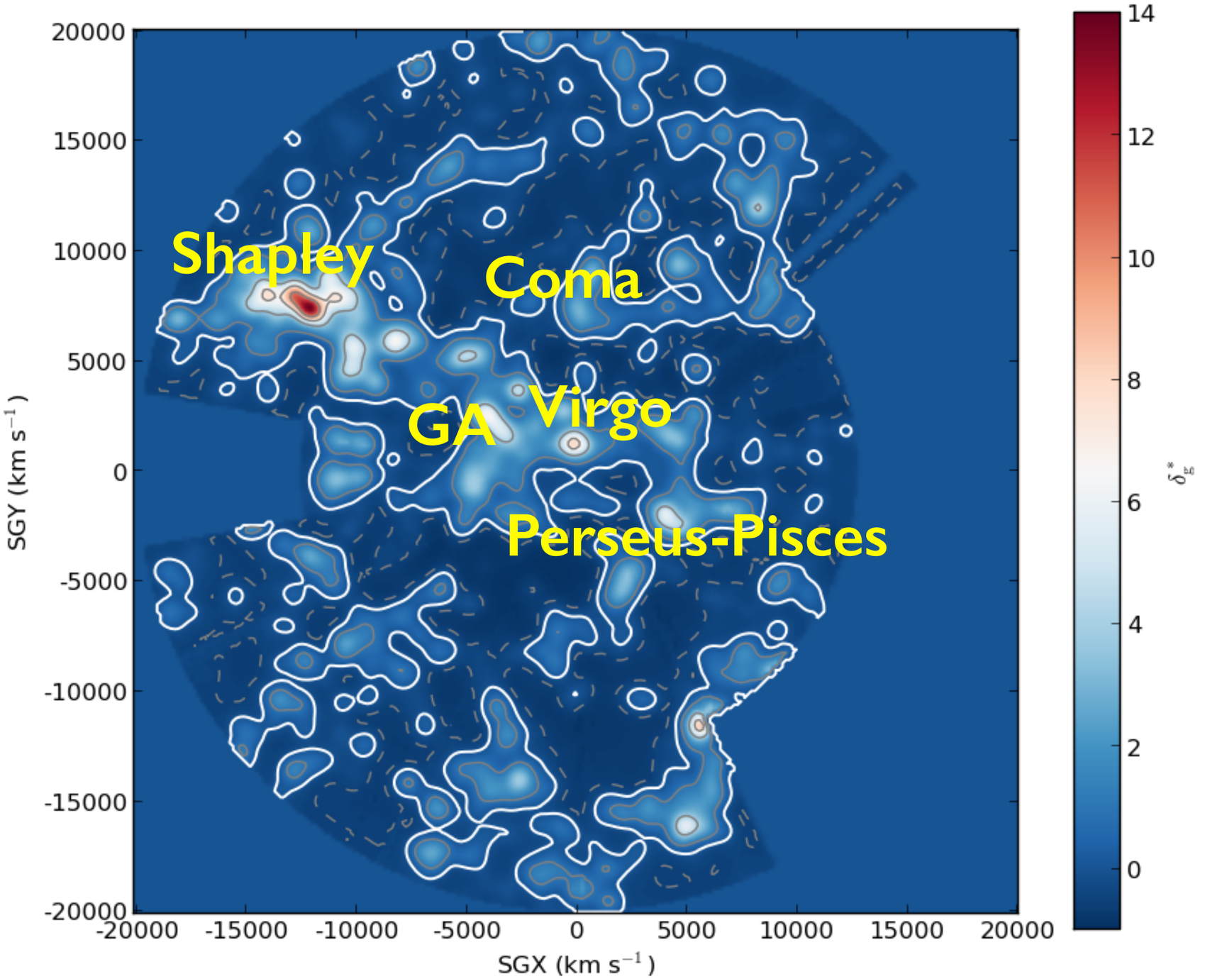


2M++ RECONSTRUCTION



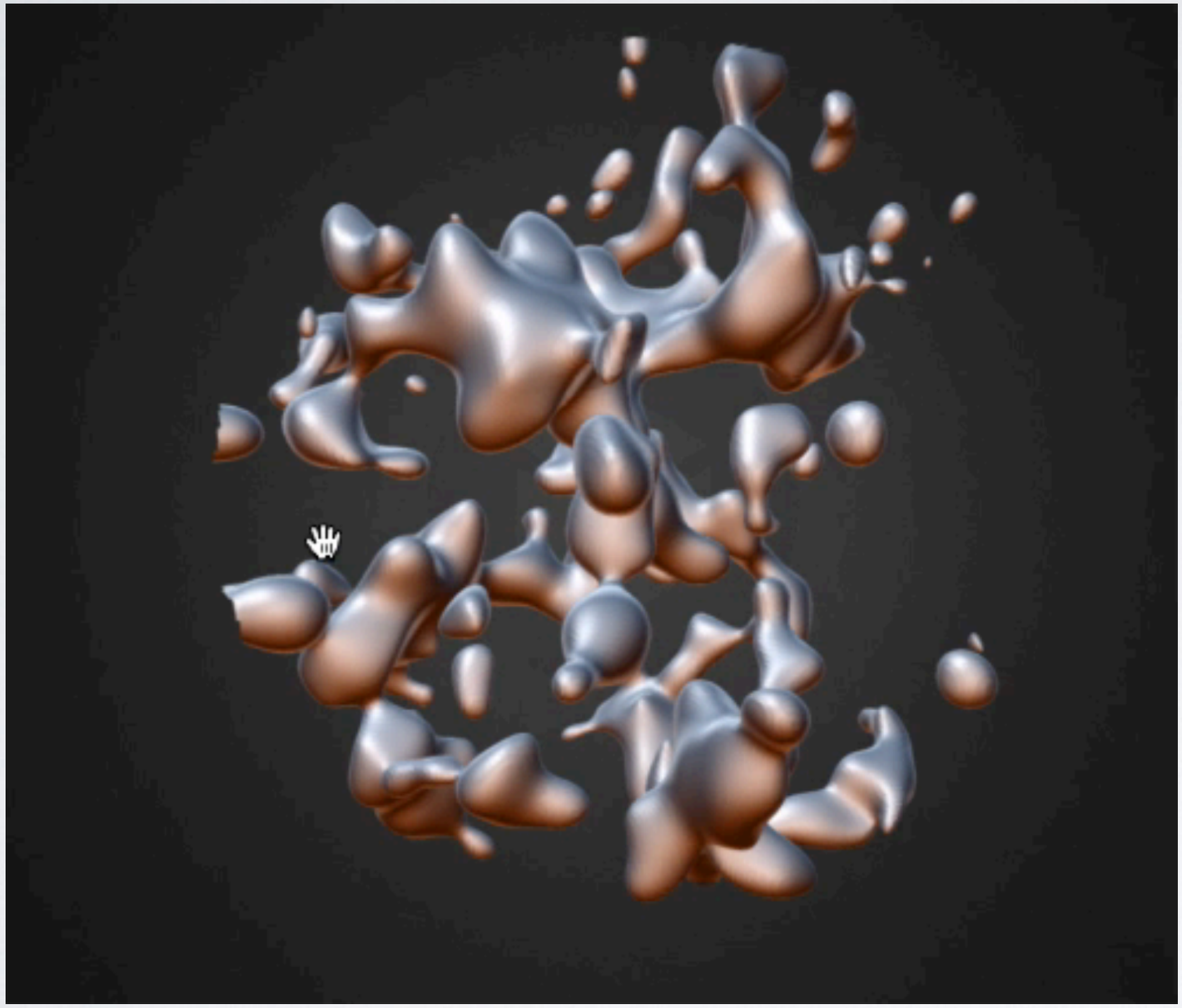
Carrick et al 15, MNRAS, 450, 317

2M++ RECONSTRUCTION



Carrick et al. 15, MNRAS, 450, 317

NOW IN 3D!



https://skfb.ly/Iy7R

PECULIAR VELOCITY DATA

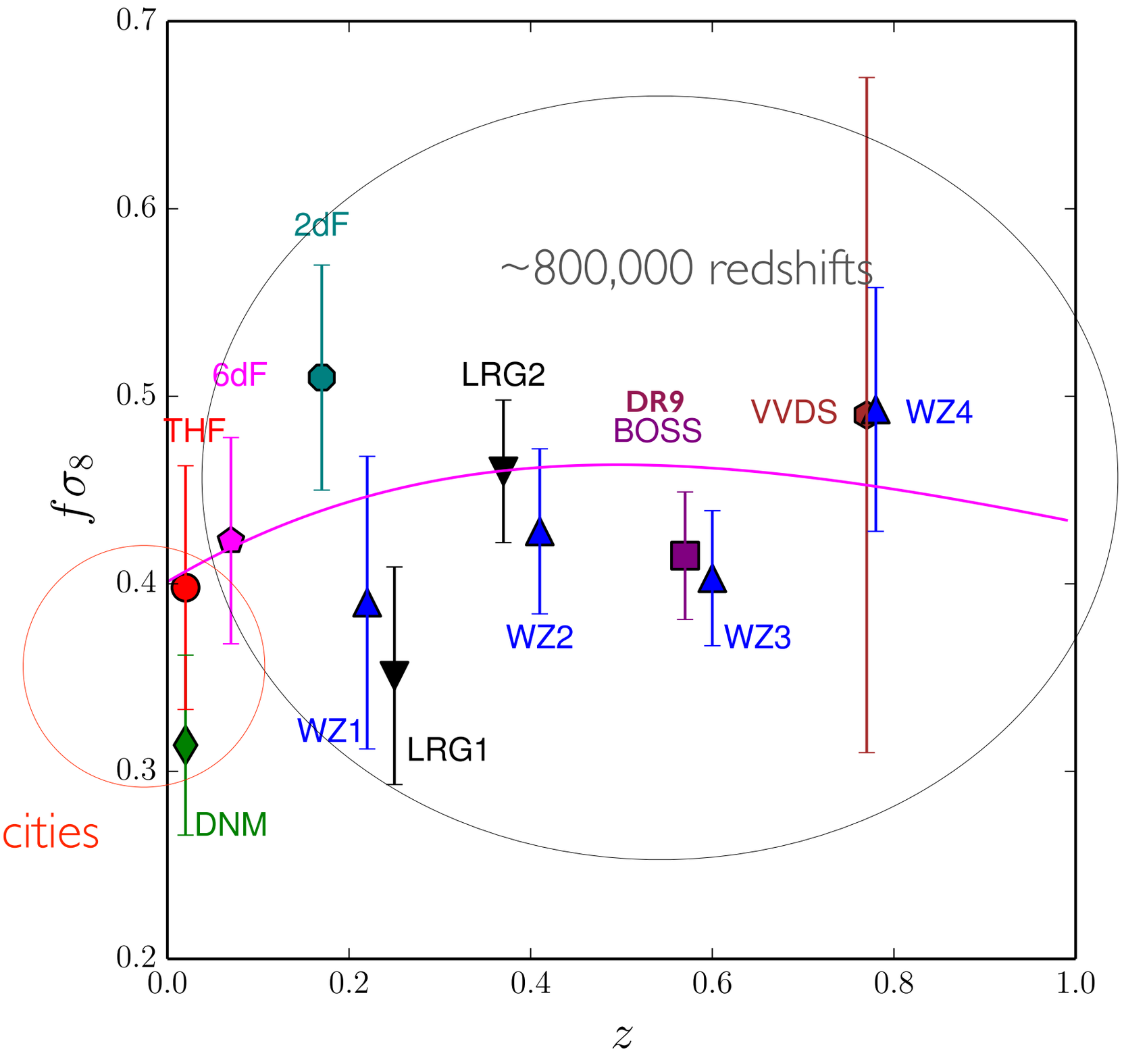
- **SFI++** (Spiral TF Field I-band, ~2500)
  - Masters et al 2006, Springob et al 2007
  - Cut to exclude faint, low linewidth galaxies (similar to Davis et al)
- **"First Amendment" SNe** (245)
  - Compiled by Turnbull et al 2012

COSMOLOGICAL PARAMETERS

Combined with galaxy clustering measurements, peculiar velocities yield:

$$f\,\sigma_8 = 0.401 \pm 0.024 \text{ (6\%!)}$$

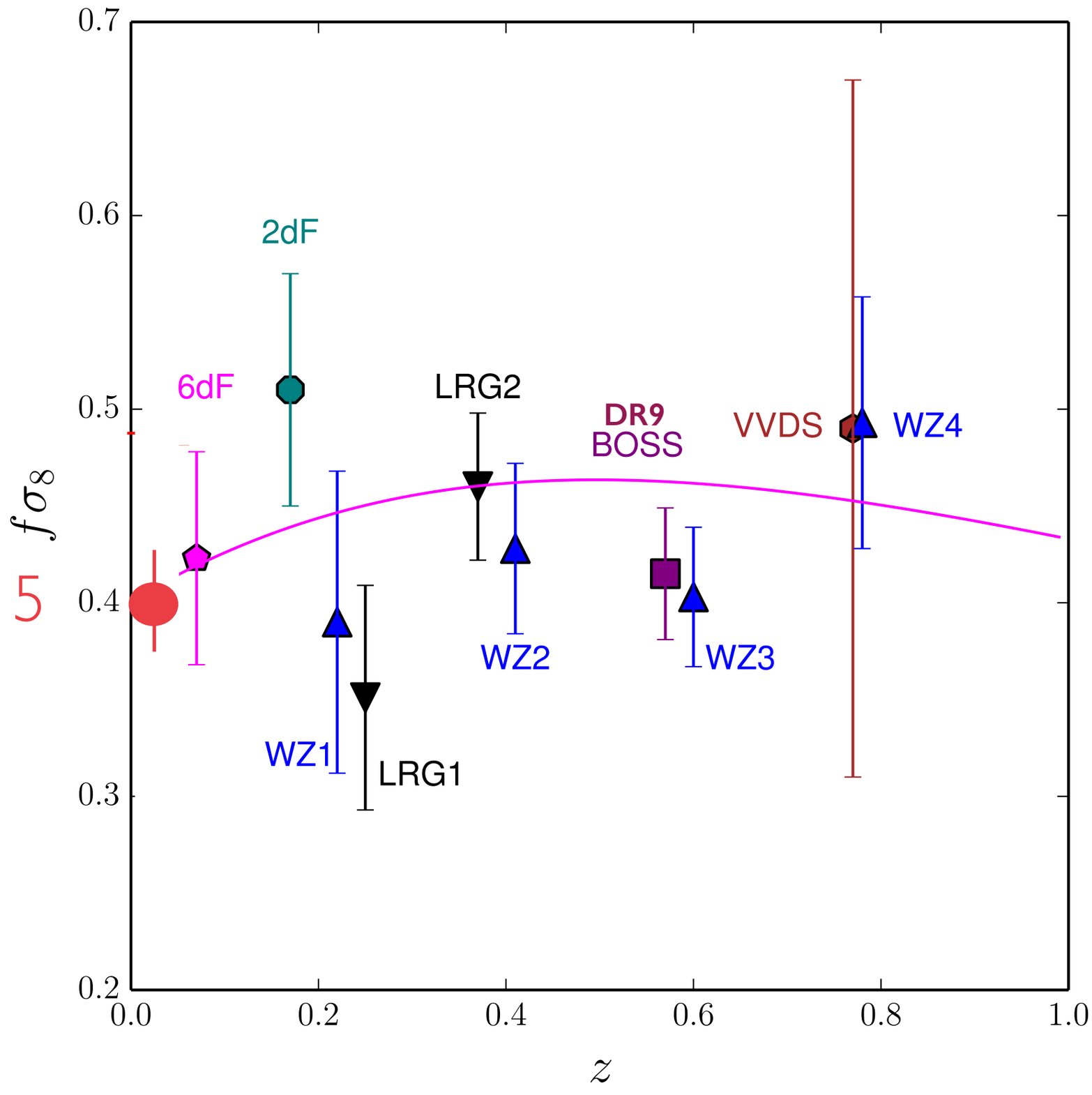
Peculiar velocities are consistent with other cosmological probes on small (~20 Mpc/h) scales.

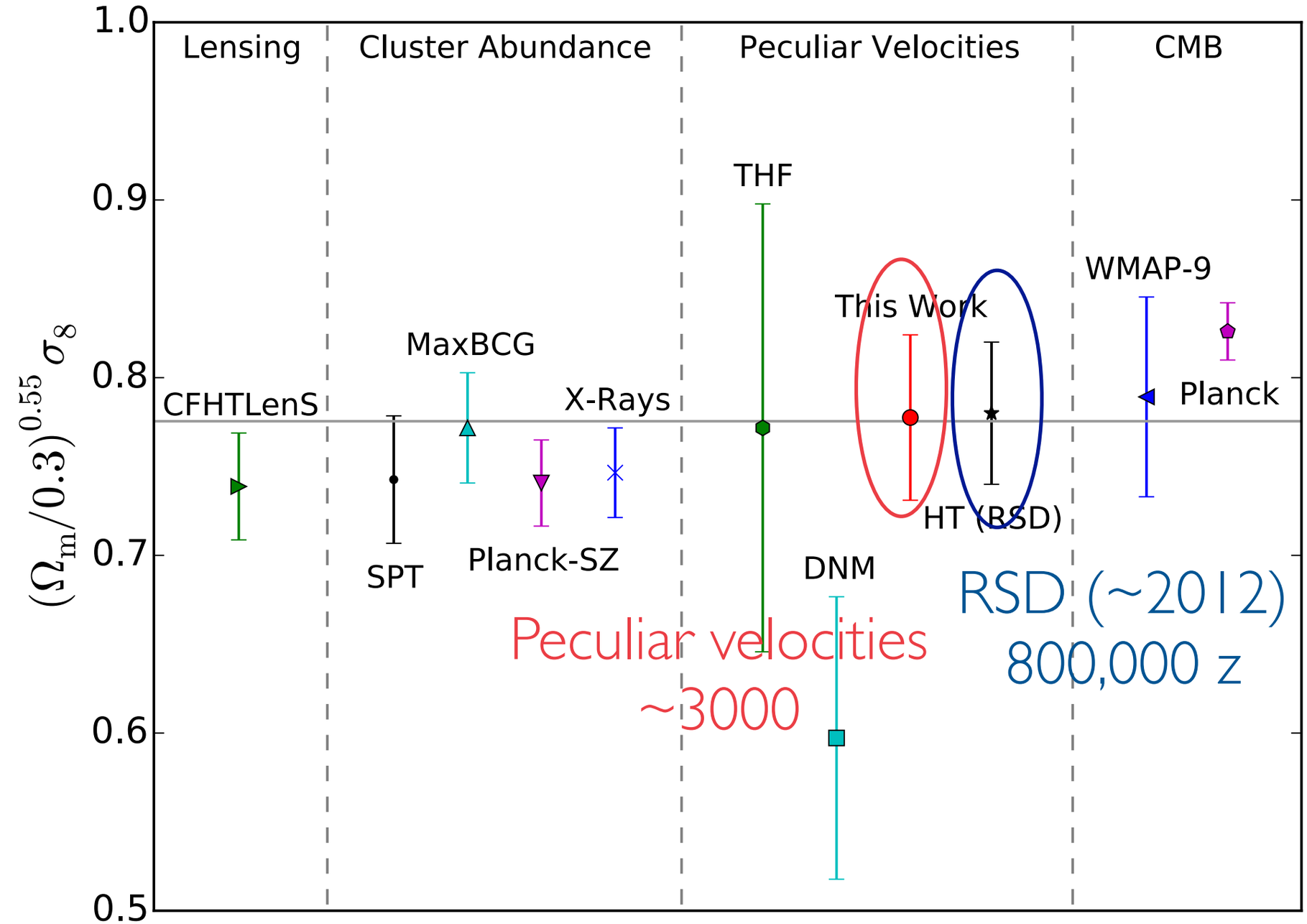


~3000 peculiar velocities

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

Carrick et al 15





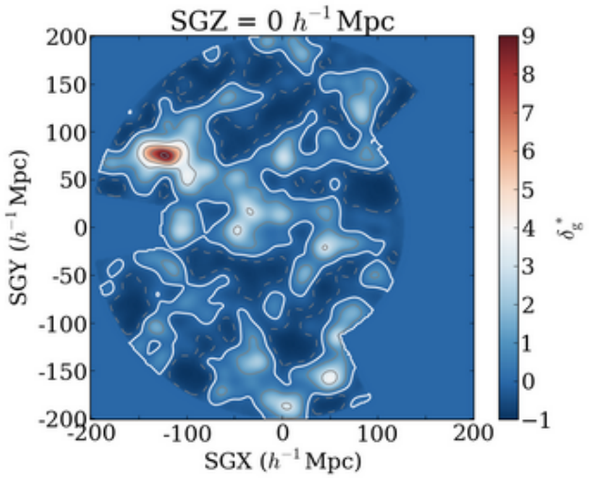
$f\sigma_8$ from different probes

Carrick et al 15

Cosmic Flows

Density and Peculiar Velocity Fields in the Nearby Universe

We present a model for the density and predicted peculiar velocity fields within 200 Mpc/h. This model can be used to estimate the density within a depth of 200 Mpc/h. It can also be used to calculate predicted peculiar velocities within the same volume. These predictions can also be used to correct observed redshifts for the effects of peculiar motions restoring them to the Hubble flow. This has applications for SNe and measurements of the Hubble constant.



The density field in the Supergalactic Plane, smoothed with a 10 Mpc/h Gaussian

Data

The density field is based on the 2M++ redshift compilation, which in turn is based on the 2MRS, 6dF and SDSS redshift surveys. Self-consistent distances to all galaxies are calculated consistent with their observed redshifts and linear perturbation theory.

Download

From the download page, you can obtain the density and peculiar velocity fields in ASCII or numpy format.

Distances to galaxies and clusters

Coming soon! Stay tuned for updates.

How to acknowledge

Please citing the following papers:

- "Cosmological parameters from the comparison of peculiar velocities with predictions from the 2M++ density field", Carrick J., Turnbull S., Lavaux G. & Hudson M. J., MNRAS, 2015. (ADS, MNRAS, arXiV)

A BiBTeX file with the above references can be downloaded here.

Register for updates

We plan to update this site with new features and data sets in the future. Please register here so that we can send you (infrequent) emails announcing these improvements as they are implemented. (We promise not to use your email for any other purpose!)

cosmicflows.uwaterloo.ca or cosmicflows.iap.fr

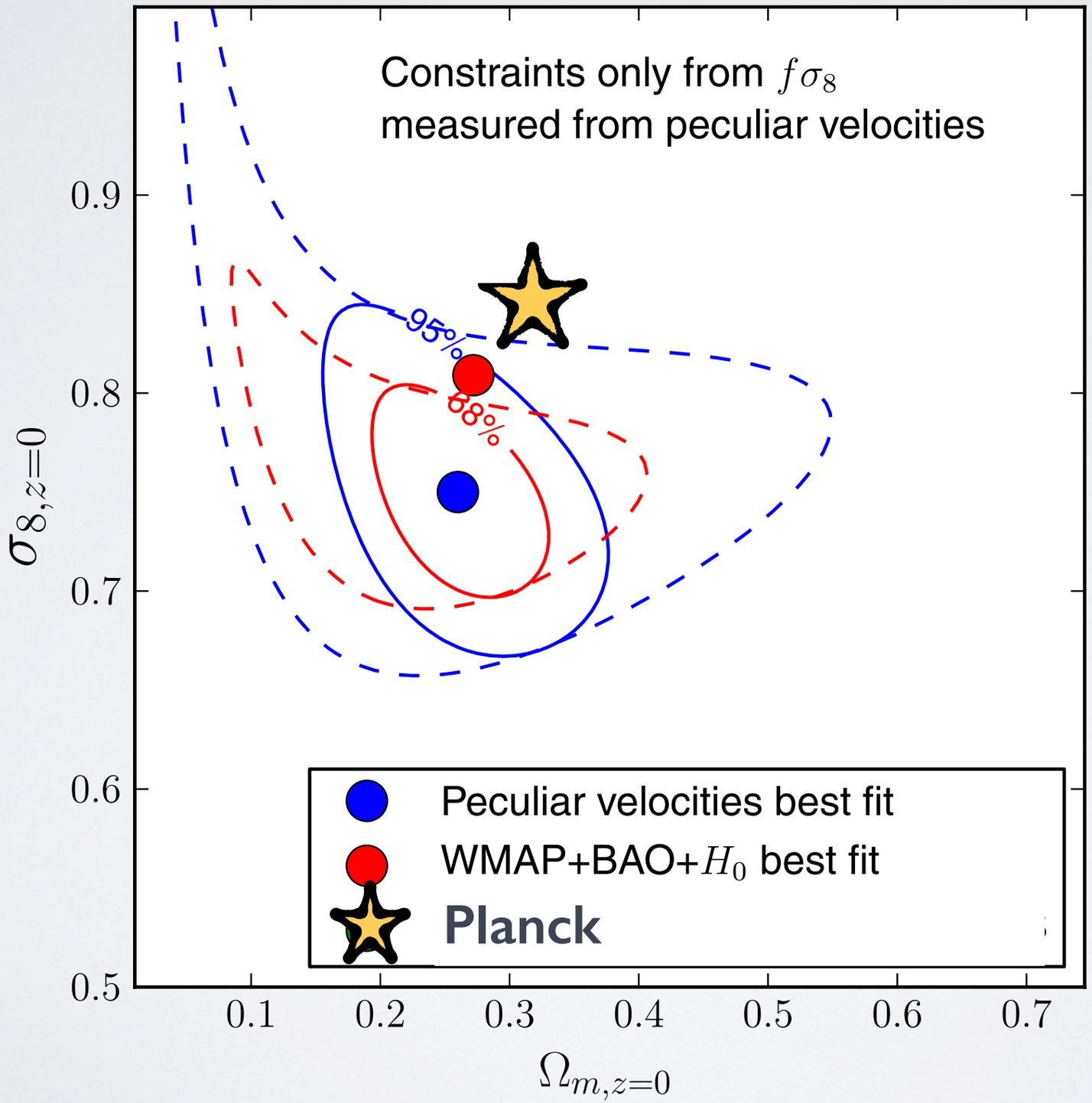
GROWTH OF STRUCTURE

- Both f and σ_8 depend on z

- Using 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

PECULIAR VELOCITIES ONLY



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

TESTING GRAVITY

- ΛCDM: γ=0.55

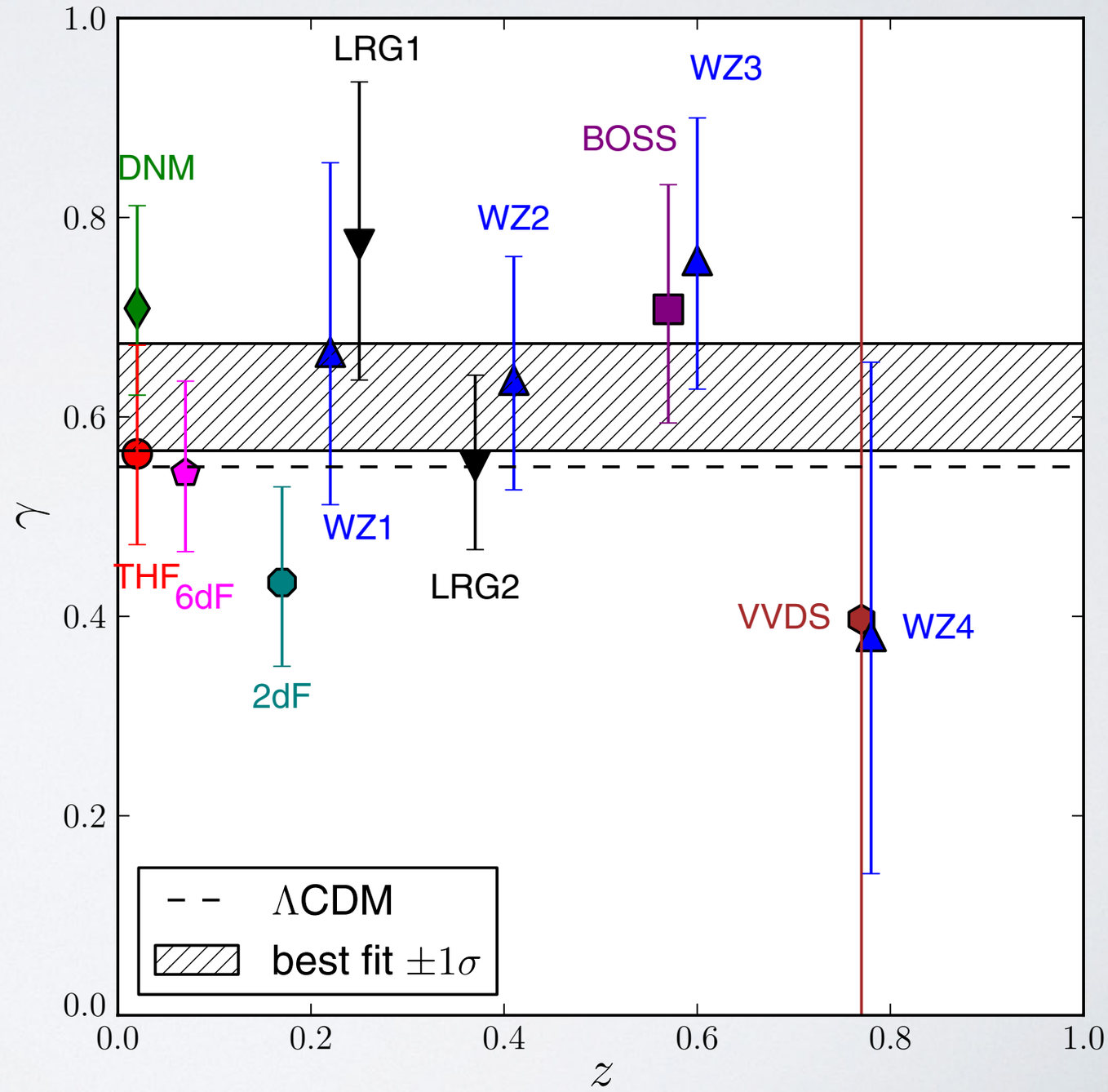
- DGP: γ=0.68

- Fix σ_8 at the time of the CMB (WMAP)

GROWTH INDEX

MH and Turnbull '12:
0.62 ± 0.06

cf. Howlett et al '14:
0.64 ± 0.09



FUTURE

Better DATA:

- Deeper ***all-sky*** redshift surveys (TAIPAN + WALLABY + WNSHS + ? ...): better density field

- *New* large peculiar velocity datasets from FP (6dF +NFPS+TAIPAN…), TF (WALLABY), more SNe.
    - *But need to control systematics to <1%*

- kSZ should allow improved probes particularly of very large scales.

TAKE HOME MESSAGES

- Bulk flows on largest scales: still hints of "tension" with ΛCDM.
- Only ~3000 peculiar velocities give competitive constraints on $f\sigma_8$.

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