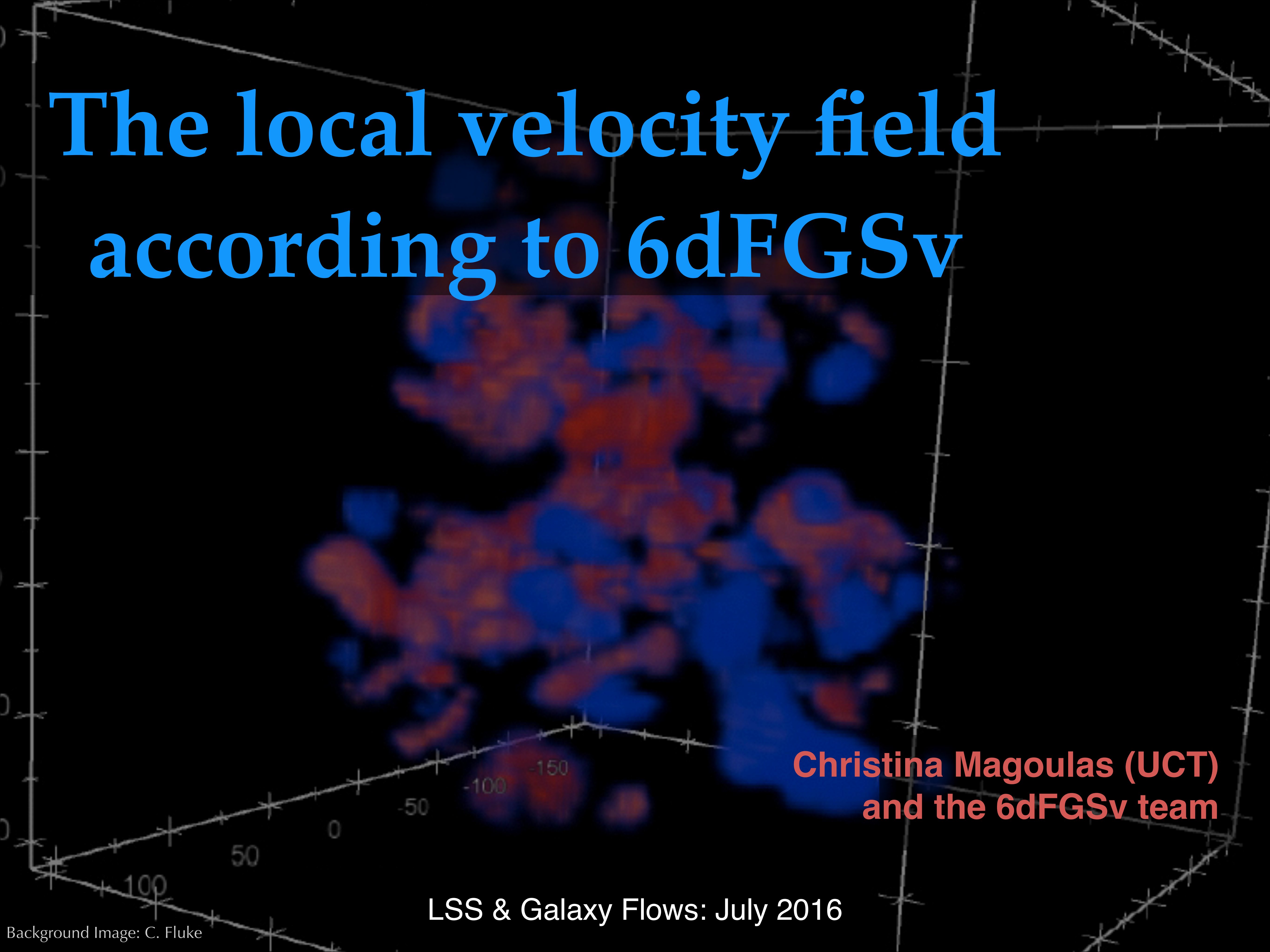
The local velocity field according to 6dFGSv



Christina Magoulas (UCT)
and the 6dFGSv team

LSS & Galaxy Flows: July 2016

Background Image: C. Fluke

6dFGSv: outline

- **6dFGSv: distances and peculiar velocities**
  defining the 6dFGSv sample and the individual peculiar velocity distributions.

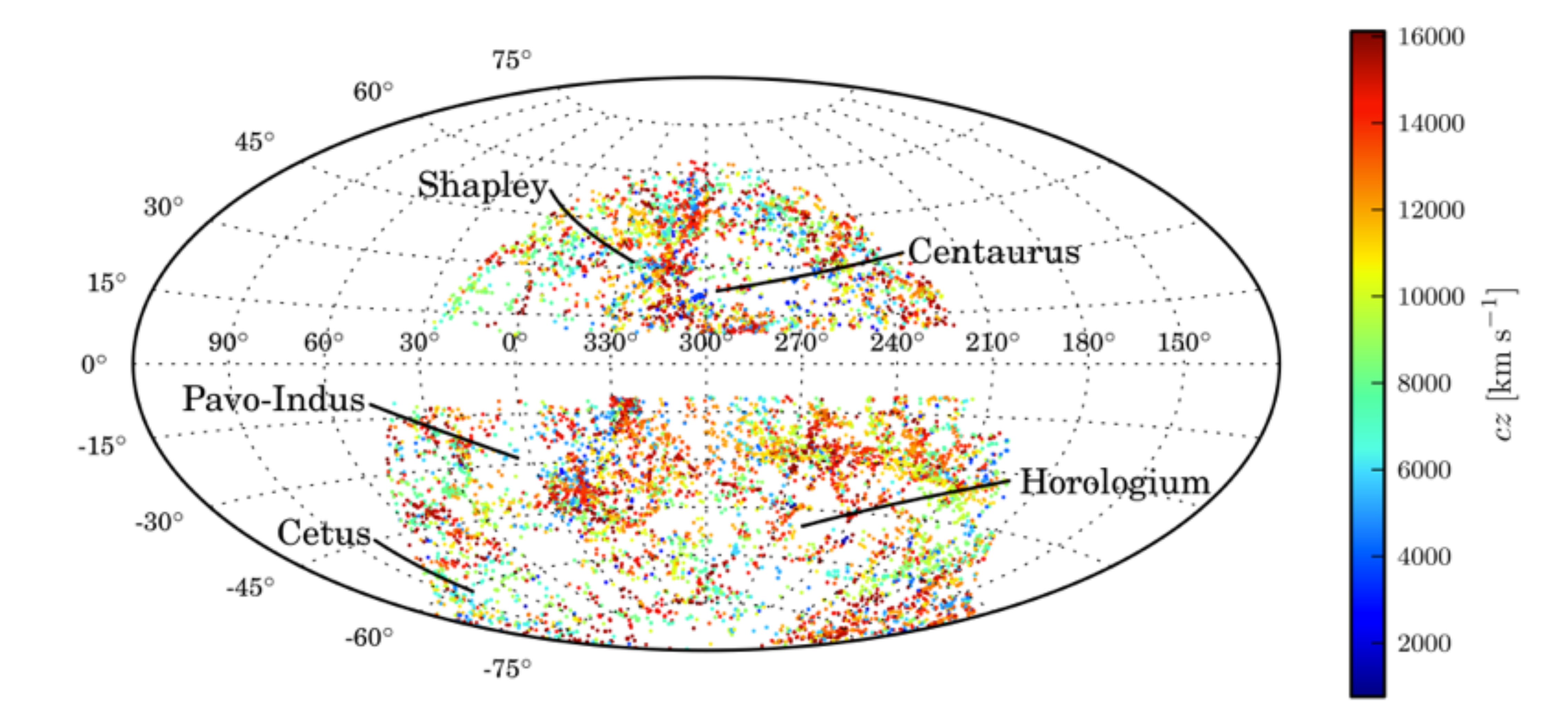
- **6dFGSv: the most recent results**
  cosmological constraints from the velocity power spectrum (Johnson et al. 2014) and MV bulk flow (Scrimgeour et al. 2016).

- **6dFGSv: cosmographic results**
  3D map of the velocity field out to 160 Mpc/h, as traced by 6dFGSv

- **Maximum Likelihood forward fitting of the bulk flow and β**
  Bayesian analysis of the 6dFGSv dataset as a whole

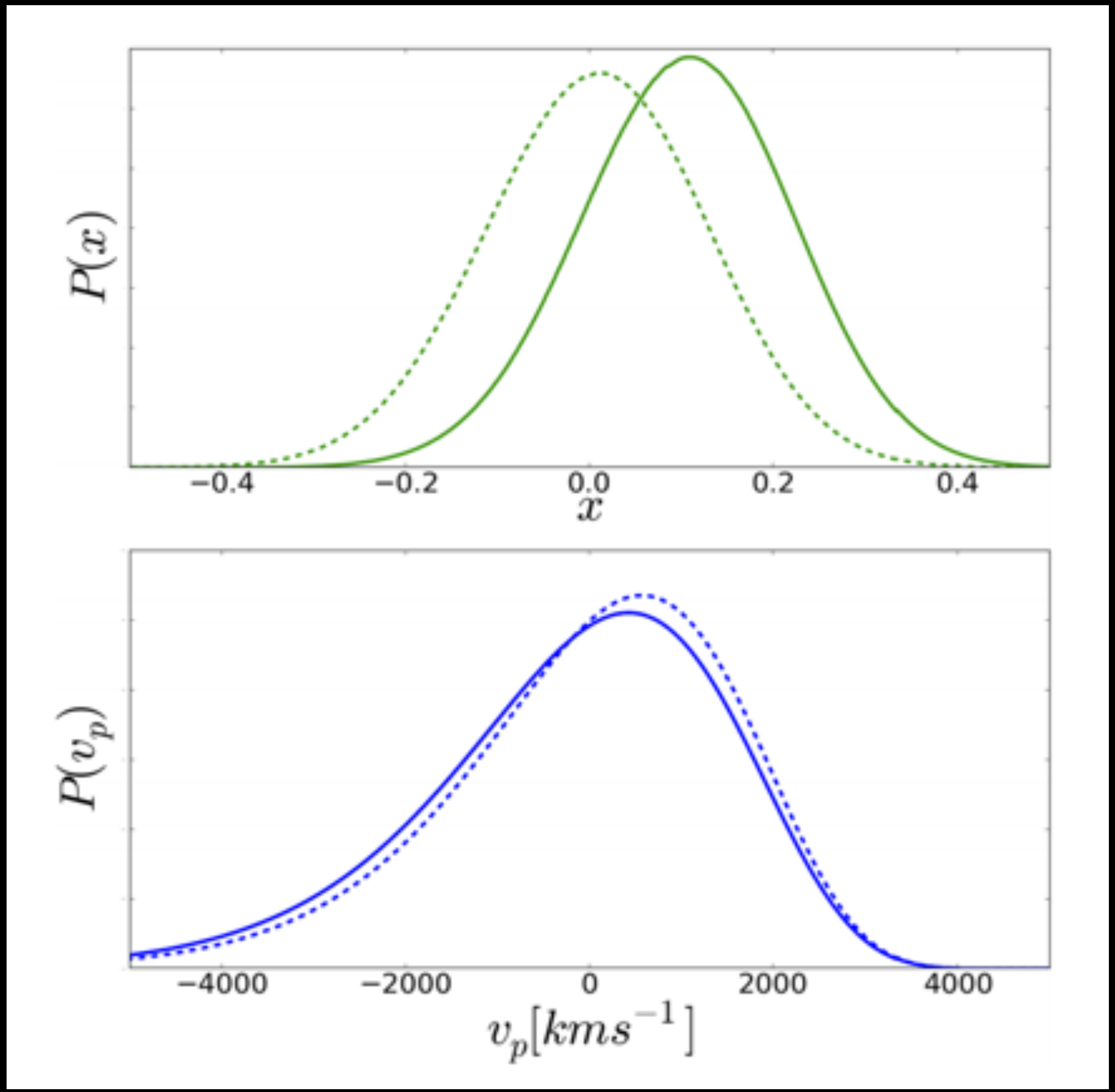
The 6dF peculiar velocity survey (6dFGSv)

- 6dFGS: combined redshift (z-) and *peculiar velocity (v-)* survey of the entire Southern Sky on the UK Schmidt Telescope; large uniformly sampled volume
- 6dFGSv: 9000 peculiar velocities using FP distances out to cz<16000 km s^{-1}
- Largest *homogeneous* velocity survey to date



Peculiar Velocity Distributions

- For each galaxy we determine individual probability distributions in log (distance ratio) units where errors are *Gaussian*, taking advantage of (forward) fitting in "data" space



Johnson et al. MNRAS (2014)

Gaussian distribution in log(distance) space where x = $\log_{10}(D_z/D_H)$

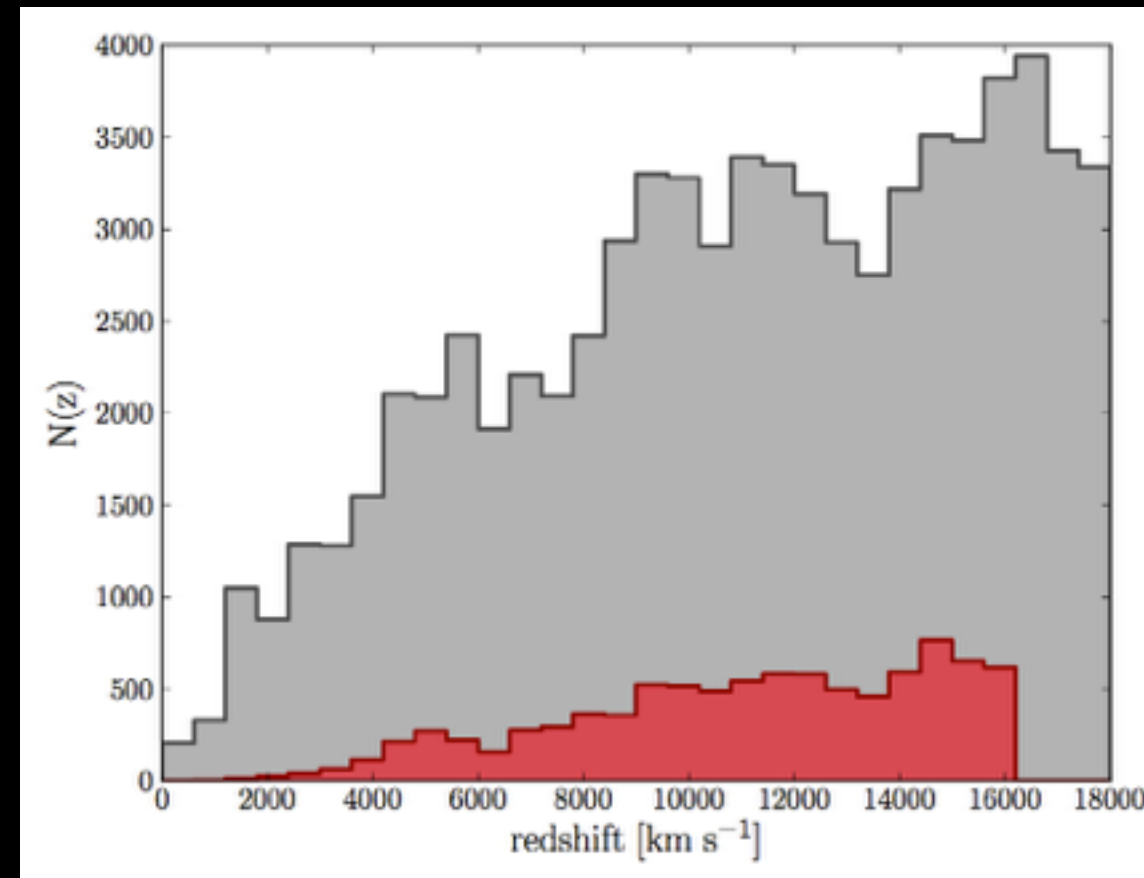
skewed in velocity, v_p, distribution (errors are close to *log-normal*)

6dFGSv distance and velocity data

From Springob et al. MNRAS (2014)

- redshifts (cz), log distance ratios (Δd), and probability distribution variables (ϵ_d, α) available online:

http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=J/MNRAS/445/2677



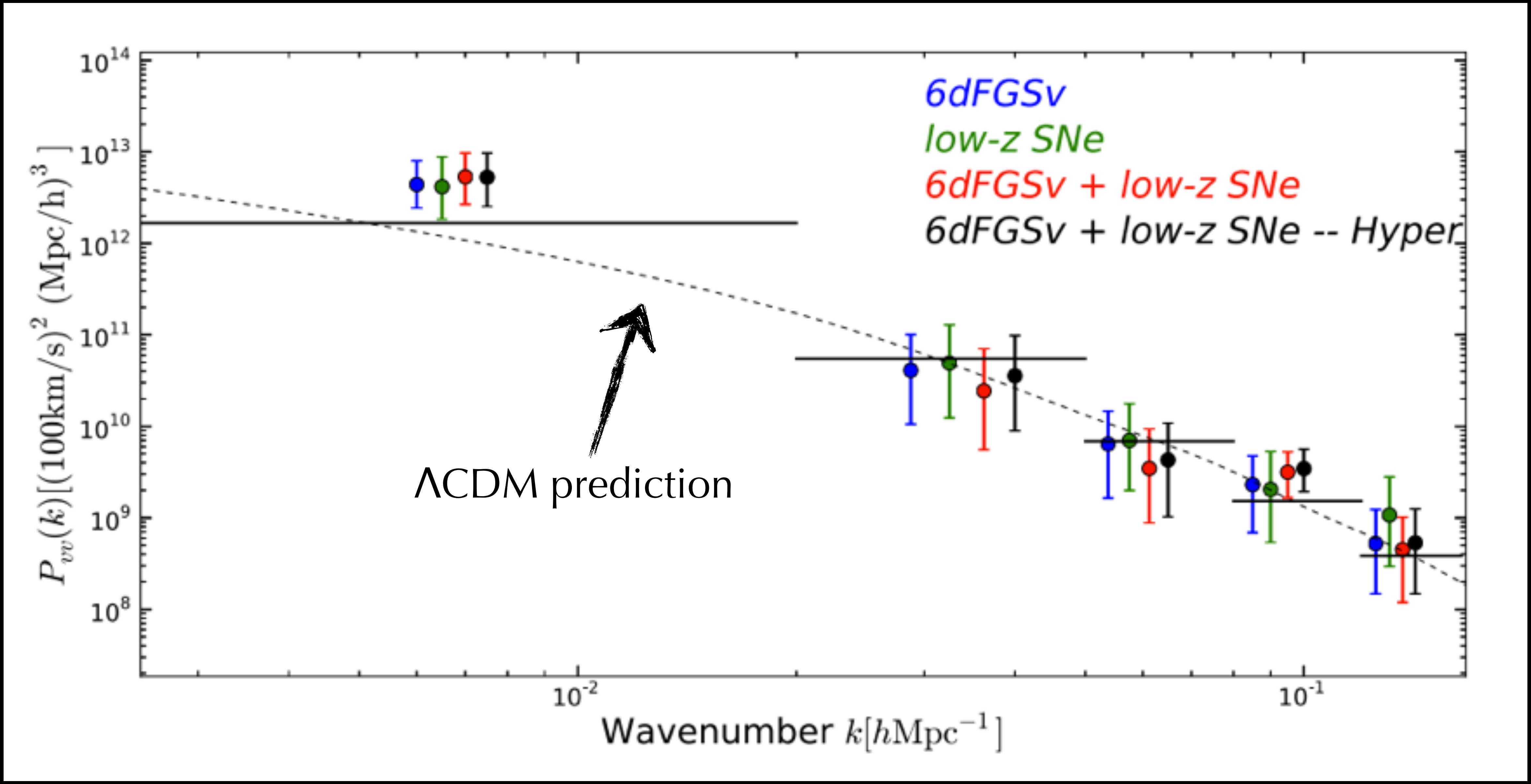
6dFGS name	R.A. (deg.)	Dec. (deg.)	$cz_{\rm gal}$ (km s^{-1})	$cz_{\rm group}$ (km s^{-1})	Group number	$\langle \Delta d \rangle$ (dex)	$\epsilon_{\rm d}$ (dex)	α
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
g0000144-765225	0.05985	−76.8736	15941	−1	−1	+0.1039	0.1296	−0.0200
g0000222-013746	0.09225	−1.6295	11123	−1	−1	+0.0870	0.0954	−0.0066
g0000235-065610	0.09780	−6.9362	10920	−1	−1	+0.0282	0.1073	−0.0116
g0000251-260240	0.10455	−26.0445	14926	−1	−1	+0.0871	0.1065	−0.0111

Springob et al. MNRAS (2014)

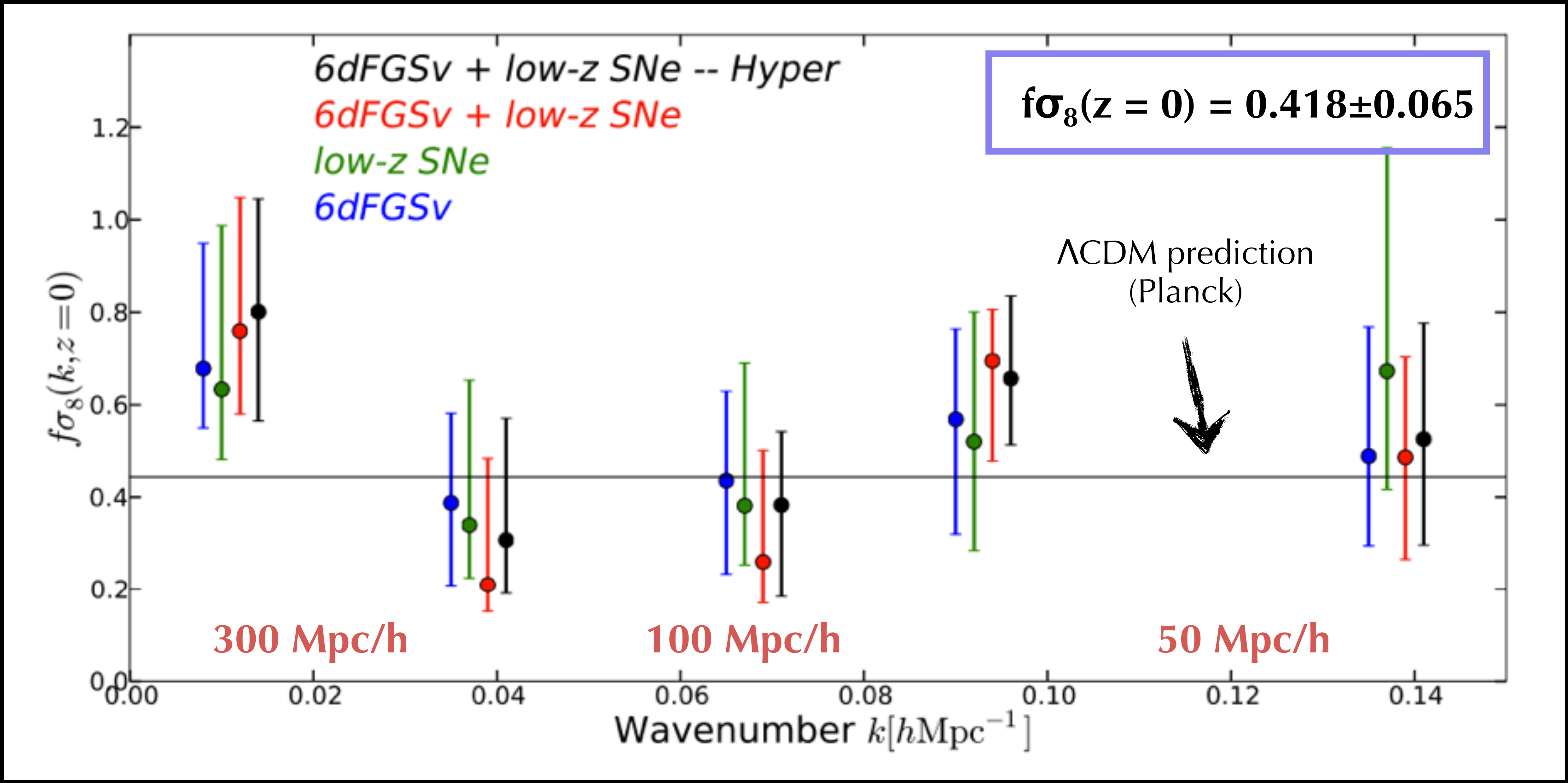
6dFGSv: survey papers

- **Springob et al. 2014:**
  The 6dF Galaxy Survey: peculiar velocity field and cosmography.
- **Johnson et al. 2014:**
  The 6dF Galaxy Survey: cosmological constraints from the velocity power spectrum.
- **Scrimgeour et al. 2016:**
  The 6dF Galaxy Survey: bulk flows on 50-70 h^{-1} Mpc scales.
- **Magoulas et al. (THIS TALK):**
  The 6dF Galaxy Survey: bulk flows and β from fitting the peculiar velocity field

- **Johnson et al. 2014:** Constraining the growth rate of structure using a *velocity power spectrum* analysis of 6dFGSv and SNe data



Johnson et al. MNRAS (2014)

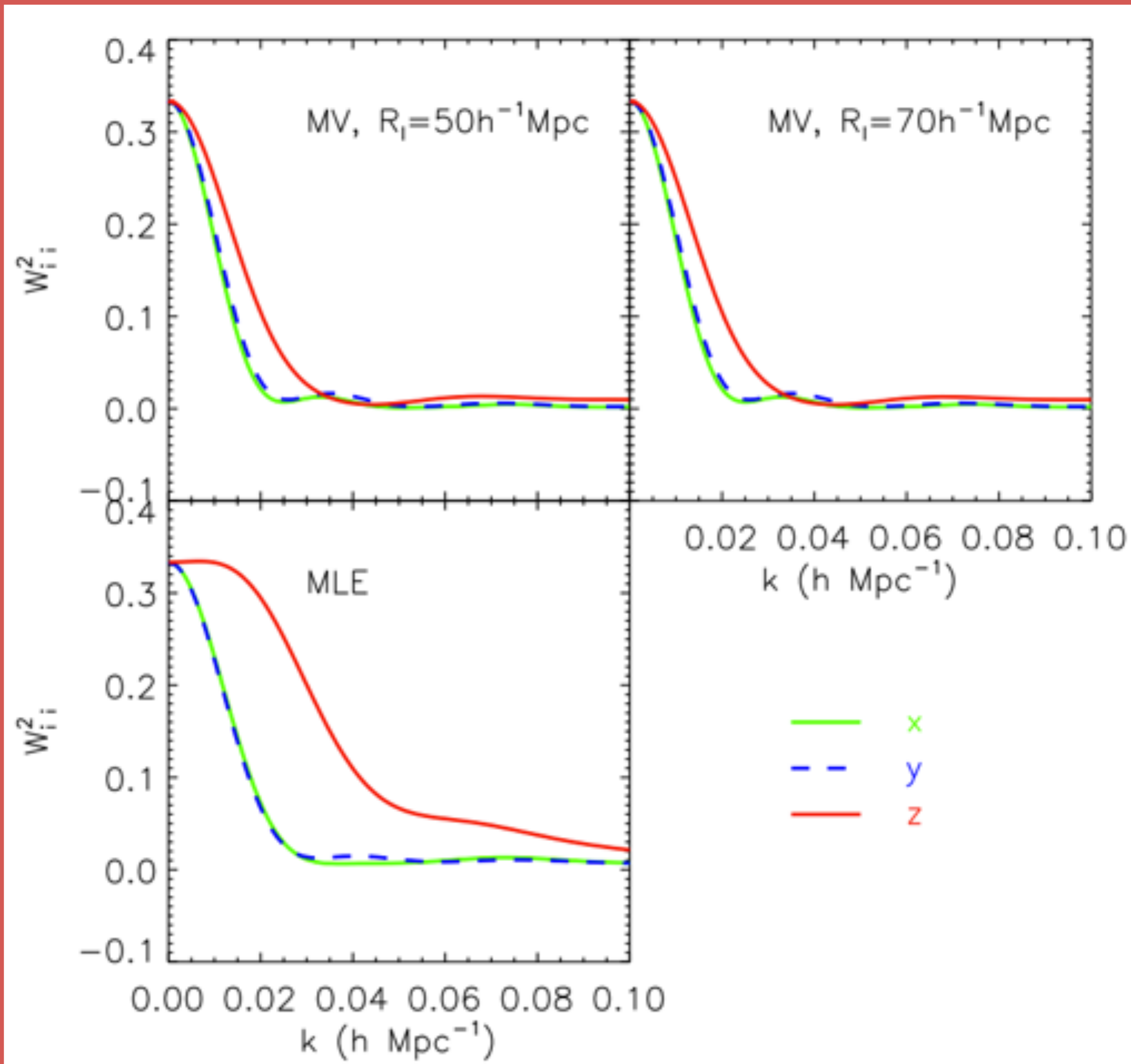


Johnson et al. MNRAS (2014)

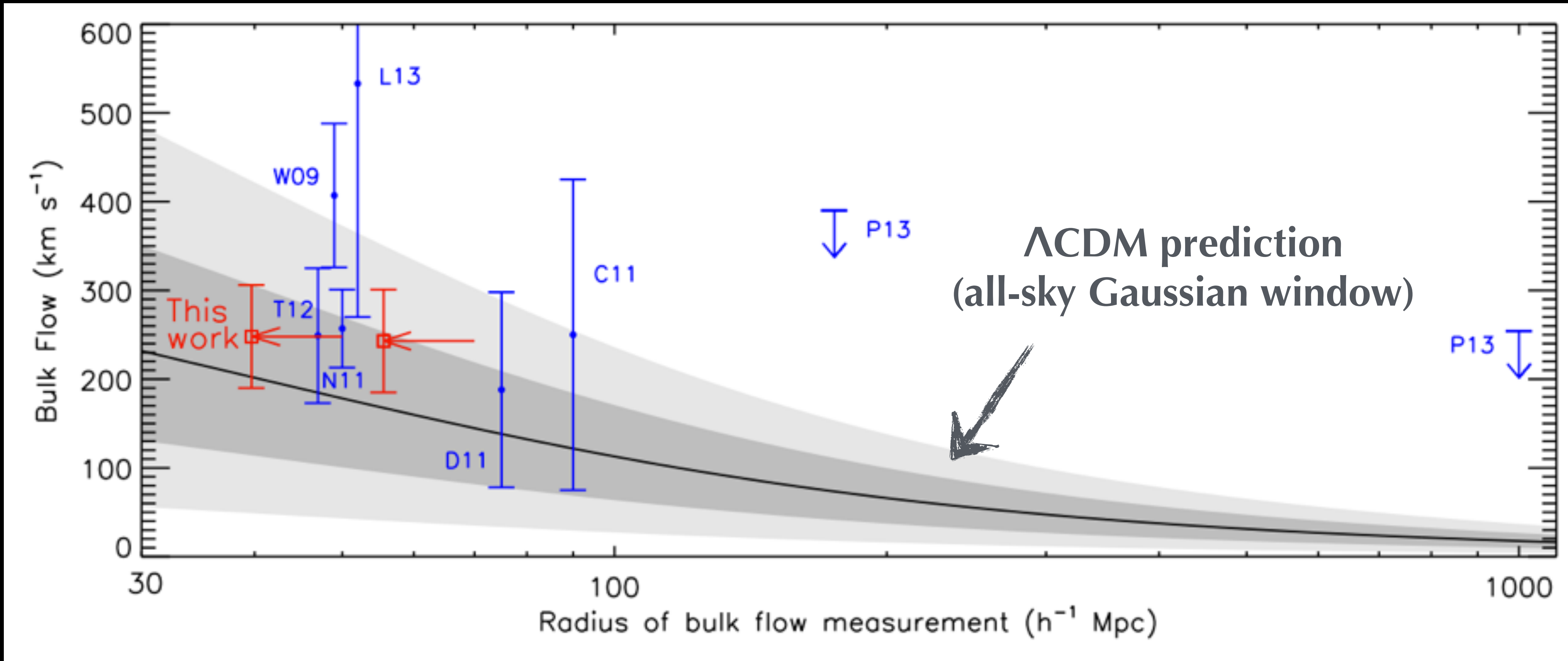
- Redshift zero measurement of the growth rate that is independent of galaxy bias and accurate to ~15%
- sensitive to largest scales; consistent with fiducial Planck cosmology

See also Howlett talk tomorrow

- **Scrimgeour et al. 2016:**
using a minimum variance method to measure the 6dFGSv bulk flow in Gaussian spheres of R_I=50 and 70 h^{-1} Mpc



- At R_I=50 h^{-1} Mpc:
|U| = 248±58 km s^{-1}
(l,b) = (318°±20°, 40°±13°)
- At R_I=70 h^{-1} Mpc:
|U| = 243±58 km s^{-1}
(l,b) = (318°±30°, 39°±13°)
- Largest discrepancy in z-direction when compared to MLE method (reflects difference in weighting schemes)



Scrimgeour et al. MNRAS (2016)

- Scrimgeour (2016) bulk flow in agreement with recent measurements: Turnbull et al. (2012), Feindt et al. (2013), Hong et al. (2014)
- Somewhat higher bulk flow than ΛCDM prediction on these scales, implying a high value of σ_8, but consistent with Planck results within 2σ

Peculiar Velocity Fitting Method

- We have two choices:

[1] **Forward-fitting** (Magoulas et al. in prep.)

Fitting model to the data and compare in “data space”.

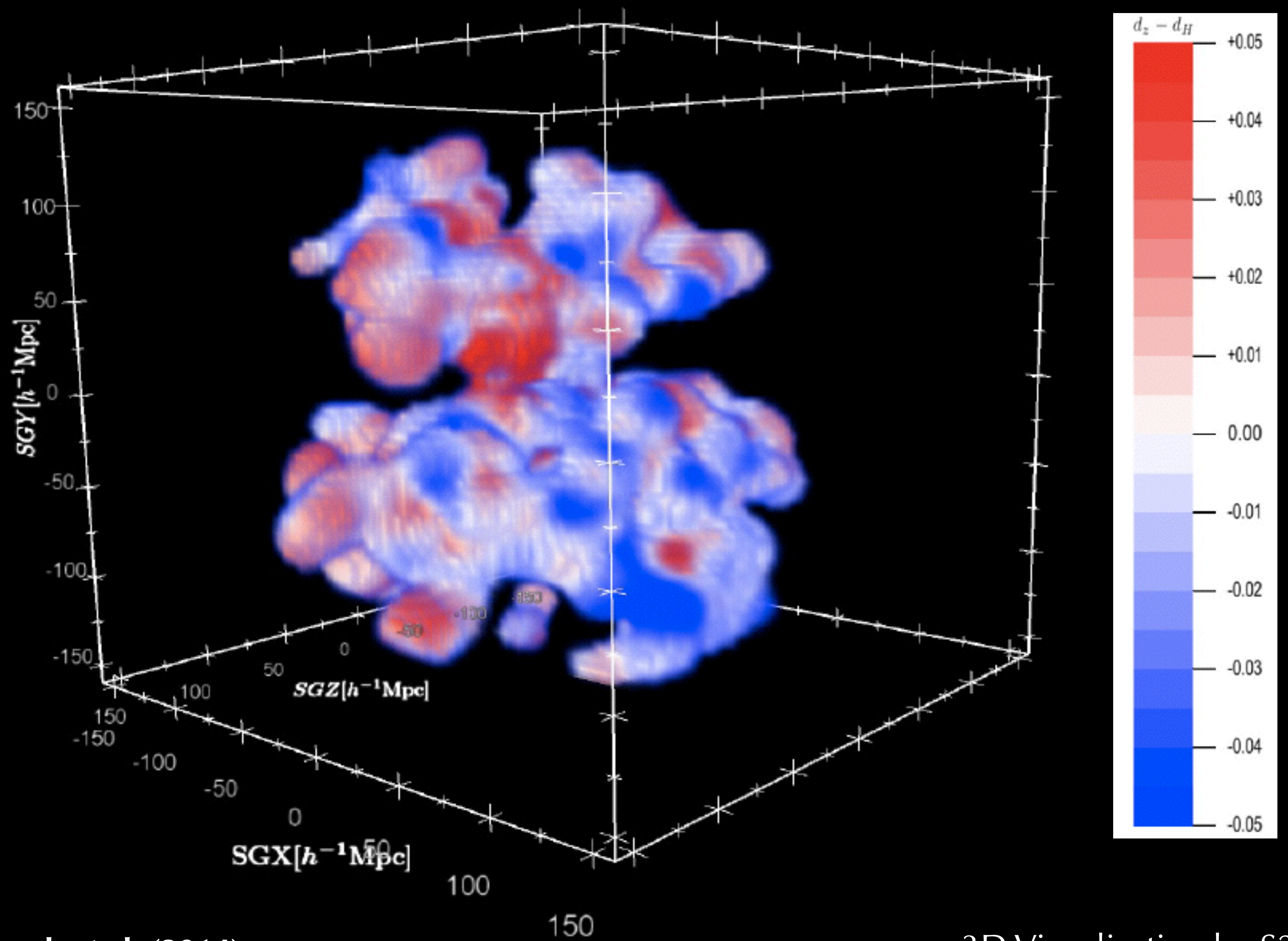
Do a Bayesian analysis of the observational data set as a whole (in r-s-i space), without computing individual peculiar velocities.

[2] **Reverse-fitting** (Springob et al. 2014)

Fitting data to the model and compare in “model space”.

Compute a Bayesian posterior probability distribution for the distance/peculiar velocity of each galaxy, rather than a single velocity.

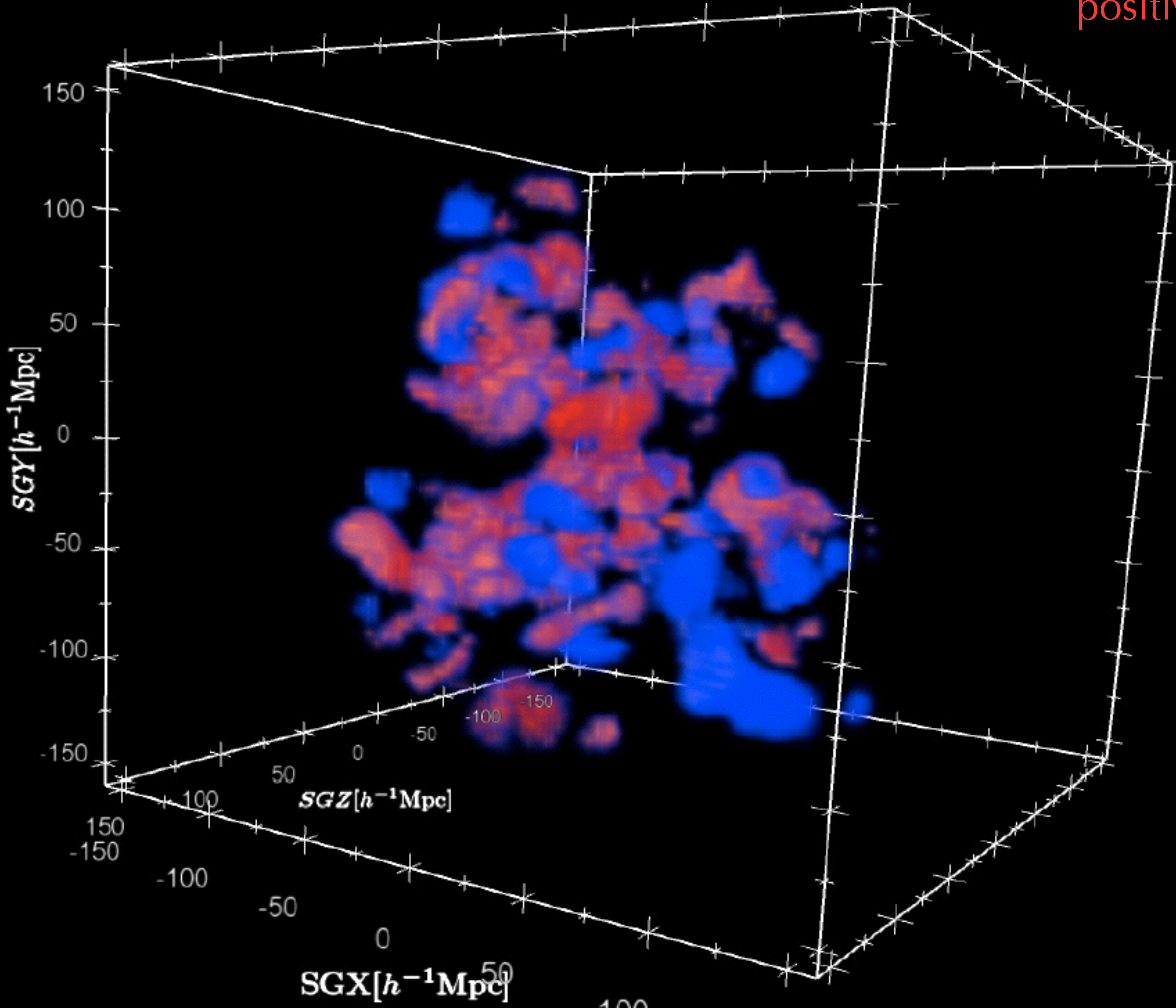
Smoothed 3D 6dFGSv velocity field



Springob et al. (2014)

3D Visualisation by S2PLOT

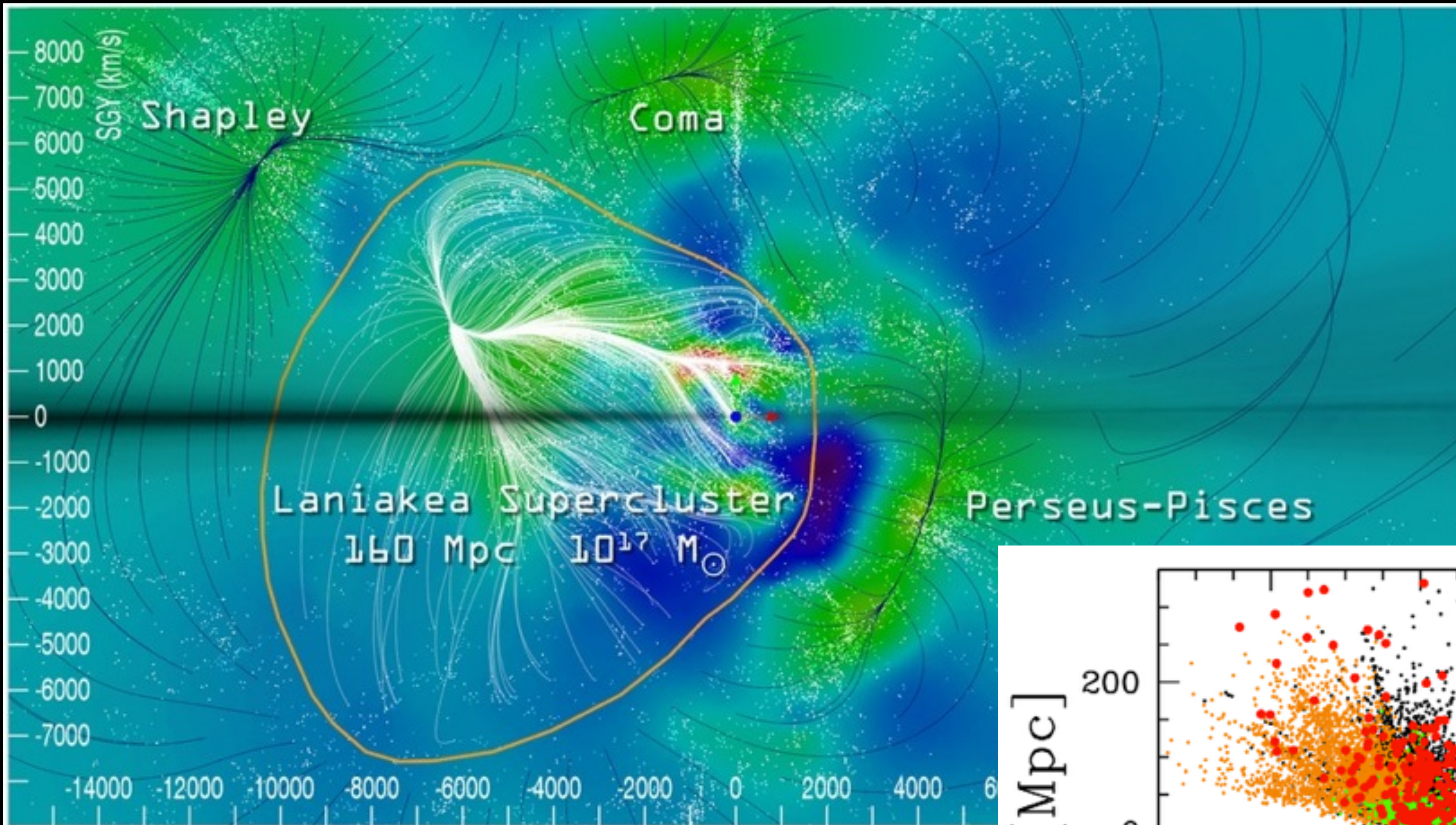
3D map of 6dFGSv velocity field (smoothed)
showing only those regions with largest
positive/negative velocities



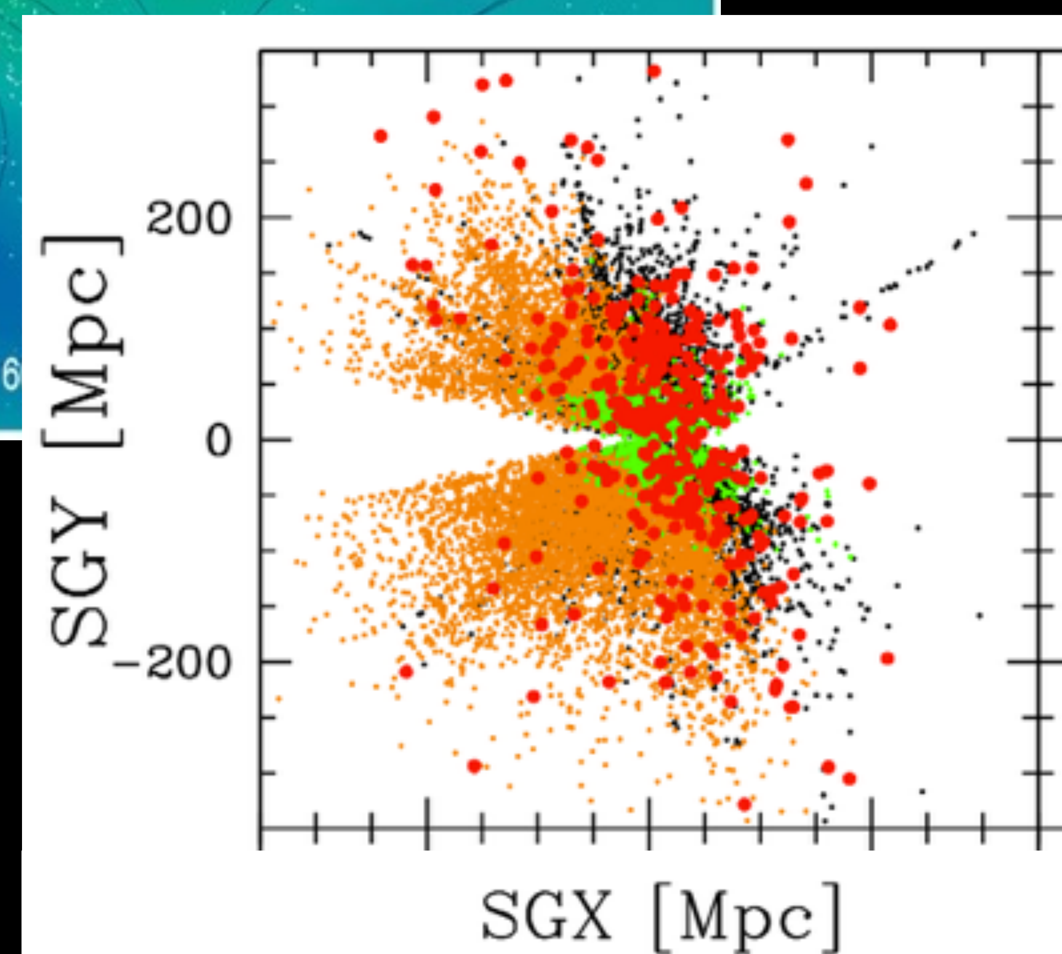
Springob et al. (2014)

3D Visualisation by S2PLOT

Cosmicflows-2 > 3: slice in the Supergalactic equatorial plane



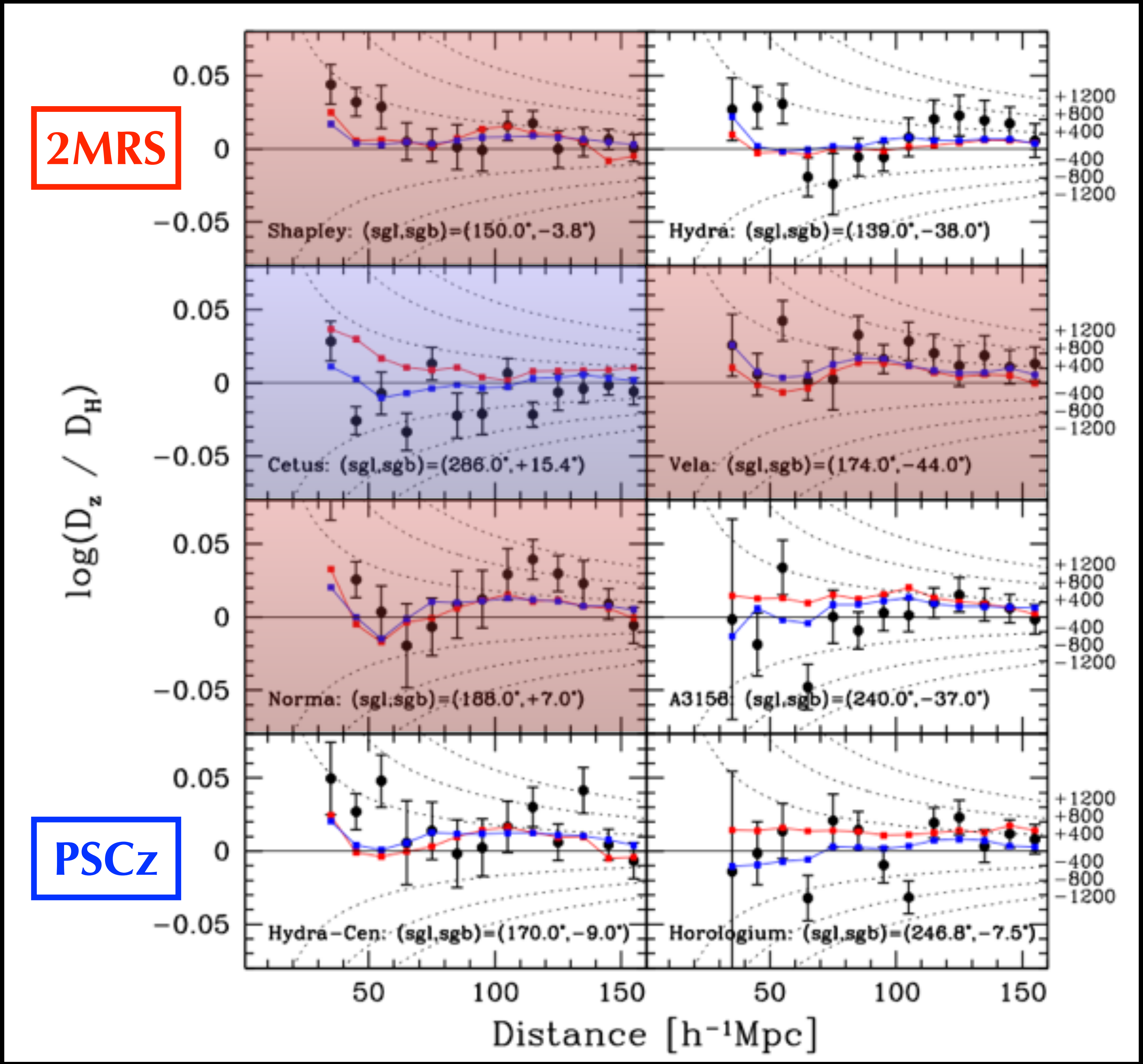
CF-2: Tully et al. (2014)



Addition of 6dFGSv (orange) is significant fraction of the South

CF-3: Tully et al. (submitted)

- Distance ratio along LOS within 30° of local structure compared with models of 2MRS and PSCz

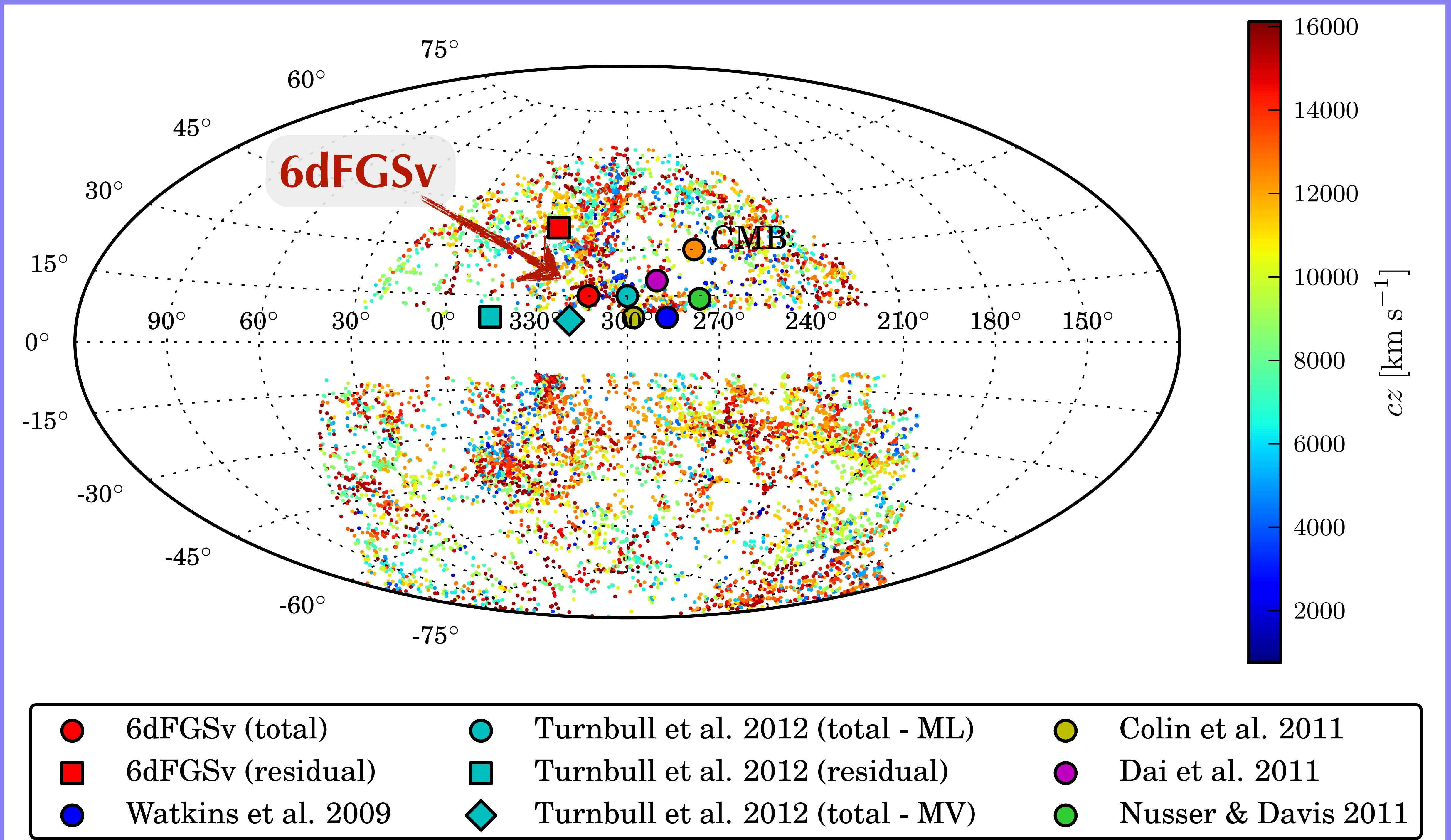


Springob et al. (2014)

- Systematically ***positive*** peculiar velocities in vicinity of Shapley (as well as Norma and Vela Supercluster)

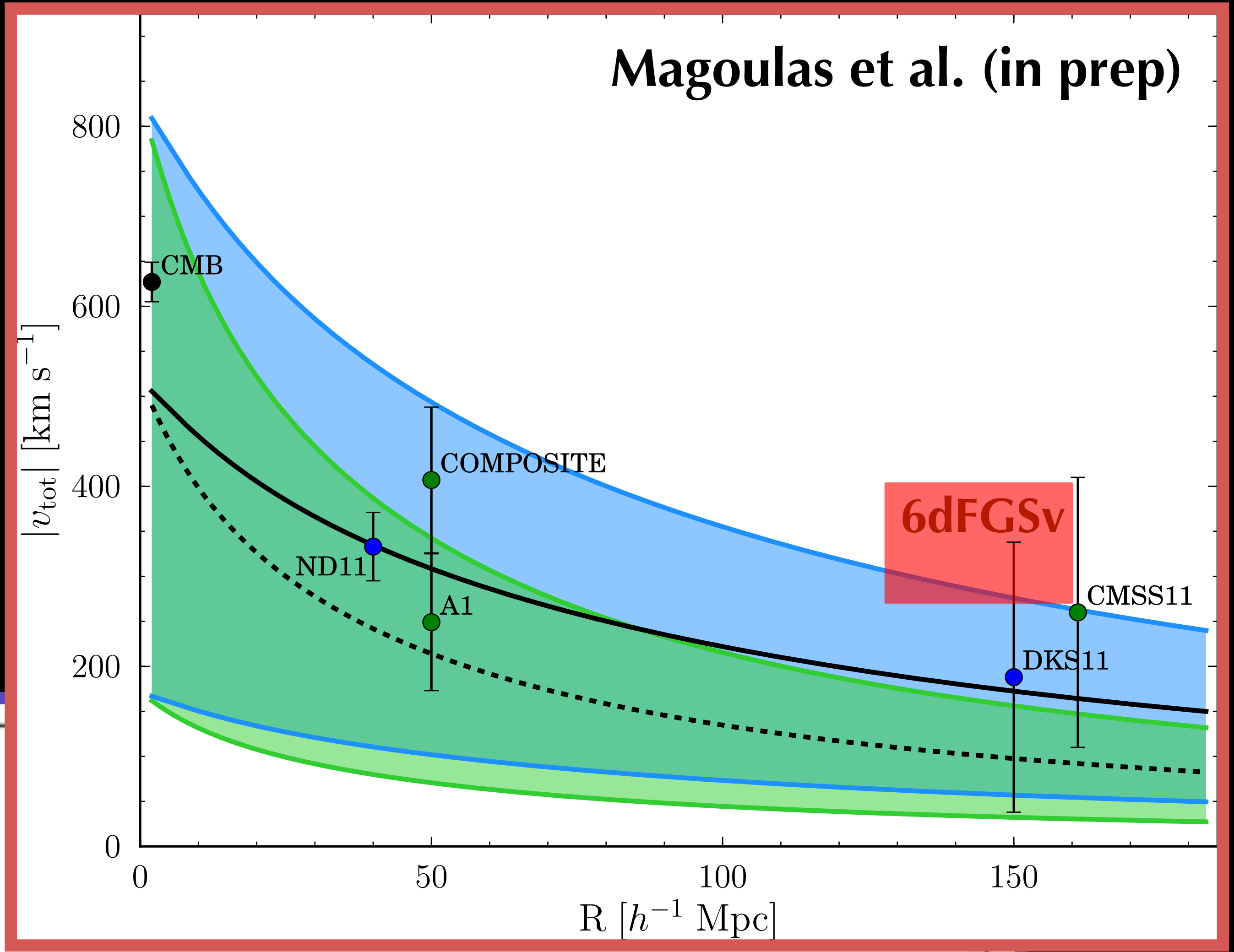
- Offset by more ***negative*** than expected peculiar velocities in the direction of Pisces-Cetus Supercluster, (~130° away)

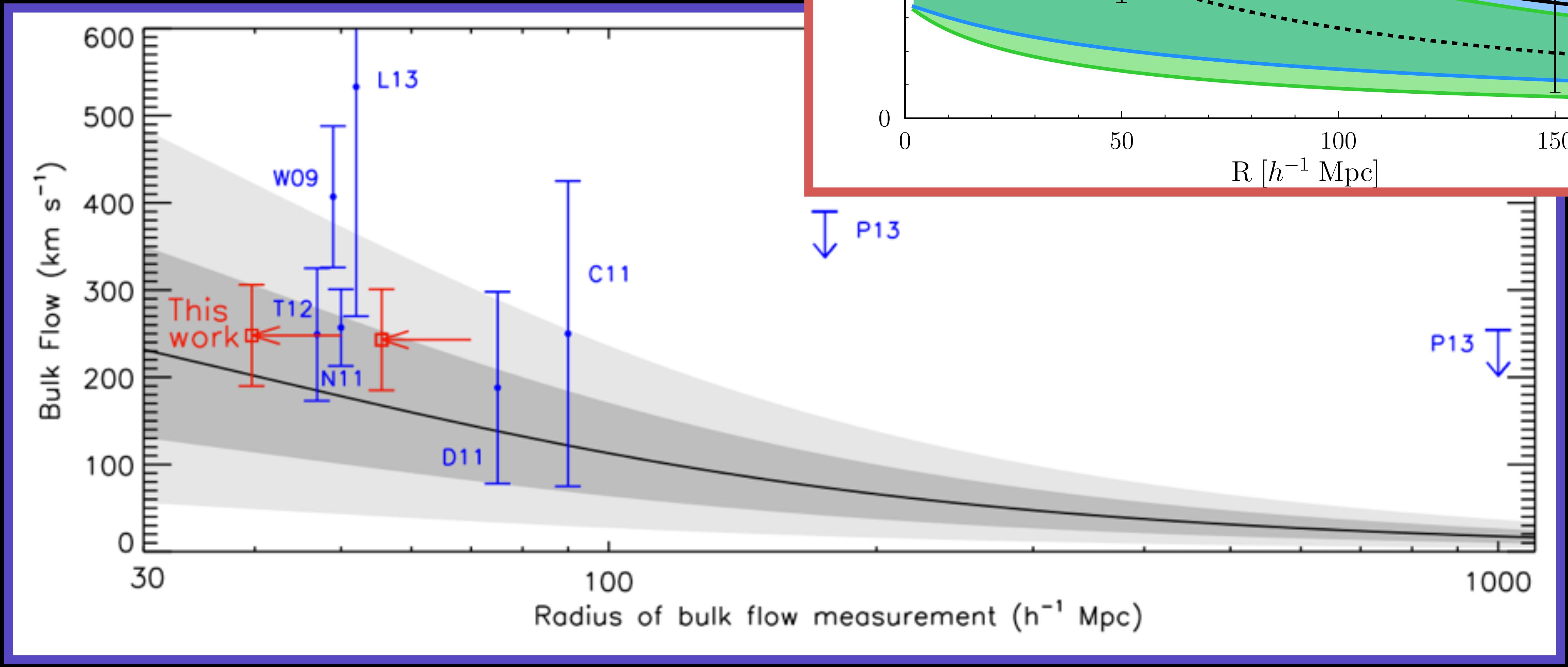
- The 6dFGSv bulk flow is 395±64 km s^{-1} in the direction (l,b) = (318°±20°, 40°±13°) using ML forward modeling approach



6dFGSv flow as a function of scale

- Different surveys have different window functions; hard to compare with each other or predictions.
- Selection function reduces the effective volume of the survey



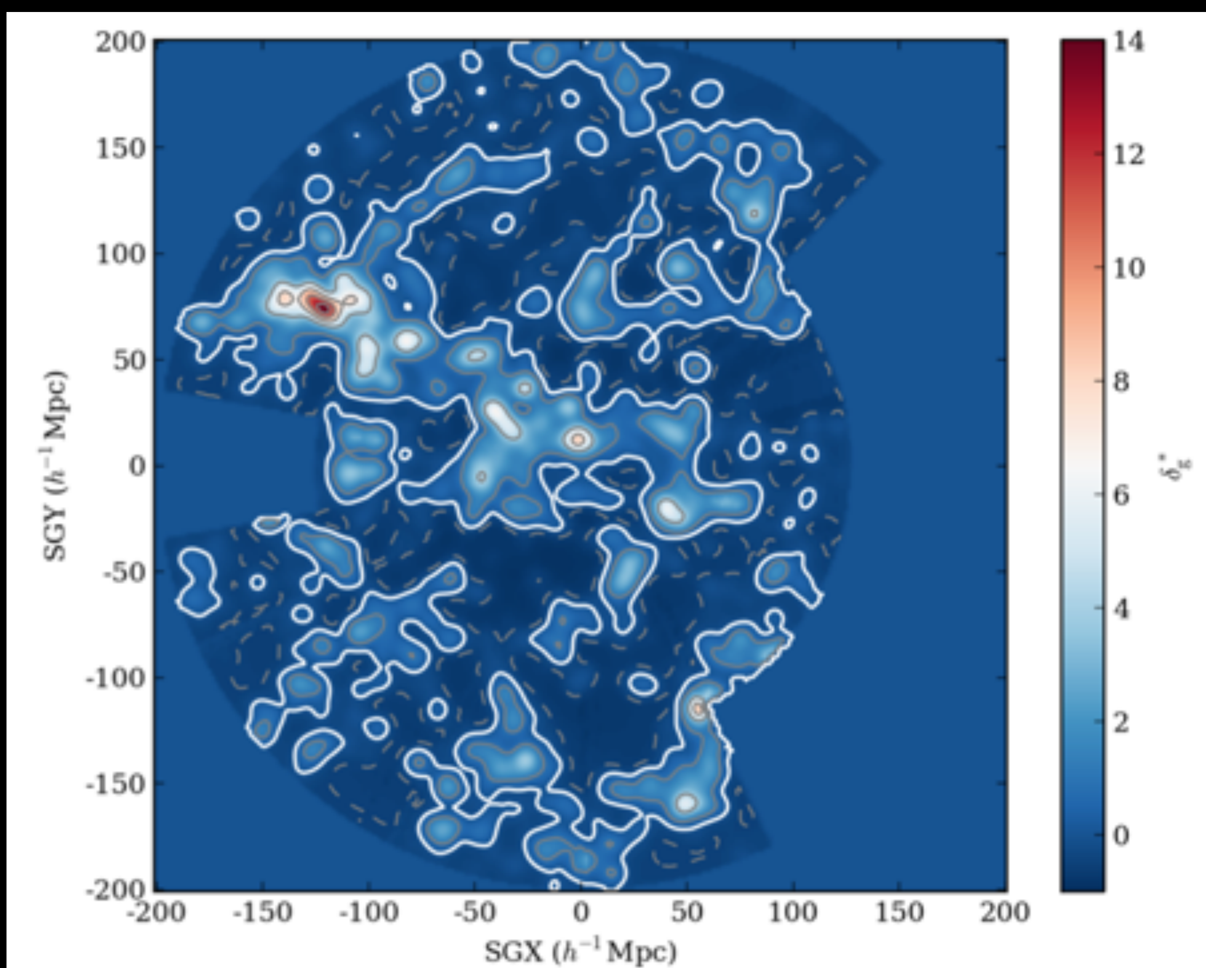


Scrimgeour et al. MNRAS (2016)

Velocity model reconstruction

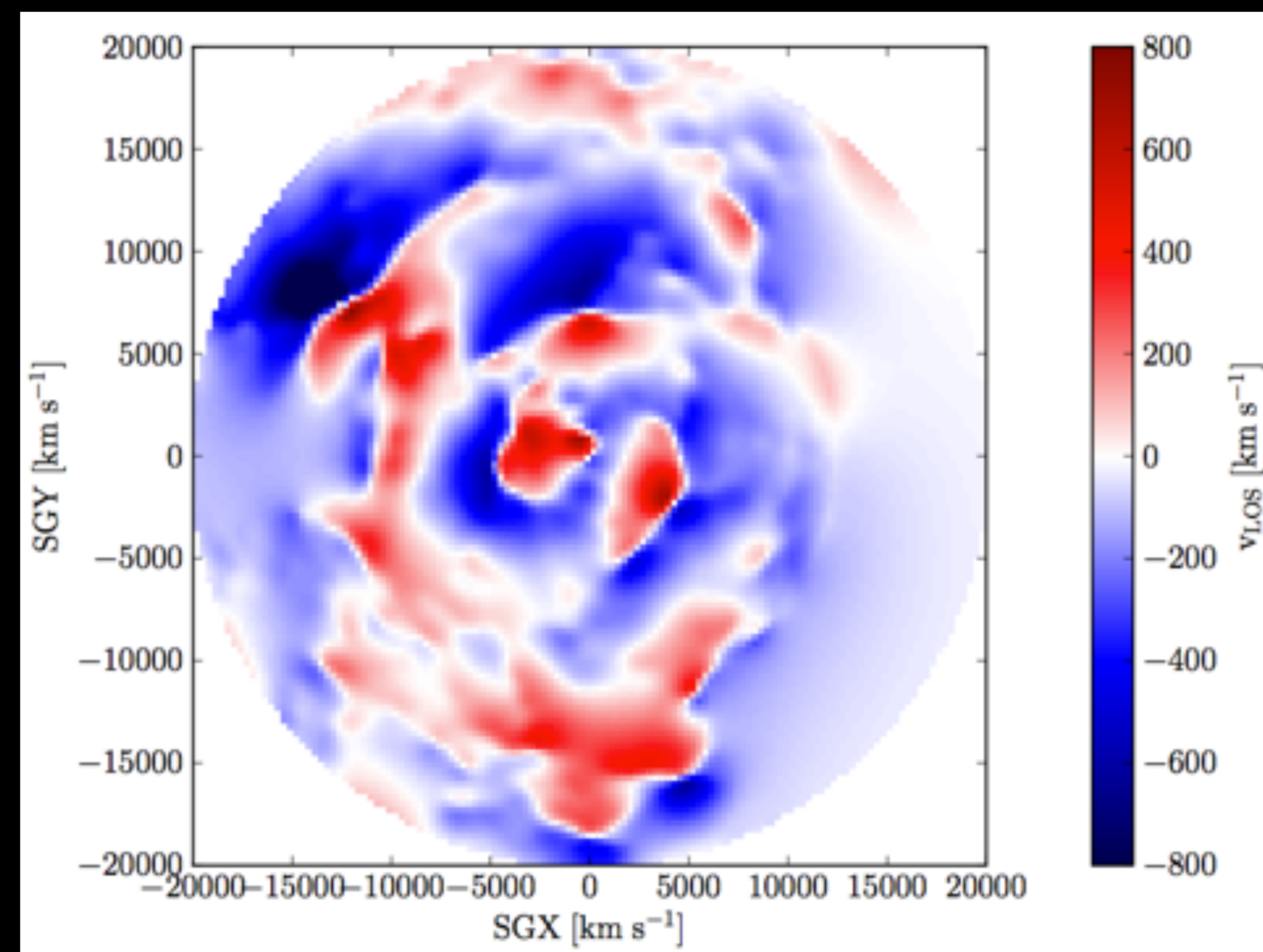
- Reconstruction of the density and velocity field (following the linear theory method of Carrick et al. 2015) within 200 h^{-1} Mpc; based on the all-sky 2M++ redshift catalogue (mostly 6dF in the South)

2M++ density field



Carrick et al. 2015

2M++ velocity field



Carrick et al. 2015, Magoulas et al. in prep.

- Velocity field determined by the linear redshift-space distortion parameter, $\beta(=\Omega_m^{0.55}/b)$.

Beta and external dipole results

Model	v_n	$\langle M_\beta \rangle$ [-]	$\langle \beta \rangle$ [-]	$\langle u_x \rangle$ [km s^{-1}]	$\langle u_y \rangle$ [km s^{-1}]	$\langle u_z \rangle$ [km s^{-1}]	$\lvert \boldsymbol{v_{tot}} \rvert$ [km s^{-1}]	SGL °	SGB °
(1) β	2MRS	0.79±0.19	0.32±0.08	-	-	-	-	-	-
(2) β, $\boldsymbol{u_{ext}}$	2MRS	0.63±0.14	0.25±0.06	-258±69	173±47	-29±50	324±45	145±13	-5±9
(1) β	PSCz	1.15±0.23	0.58±0.12	-	-	-	-	-	-
(2) β, $\boldsymbol{u_{ext}}$	PSCz	0.68±0.19	0.34±0.10	-282±66	92±53	-10±48	308±53	161±13	-1±9
(1) β	2M++	0.31±0.13	0.13±0.06	-	-	-	-	-	-
(2) β, $\boldsymbol{u_{ext}}$	2M++	0.41±0.11	0.18±0.05	-393±71	83±48	-100±52	420±65	167±9	-13±7
(3) $\boldsymbol{u_{tot}}$	-	-	-	-362±74	107±51	-81±52	395±64	162±10	-12±7

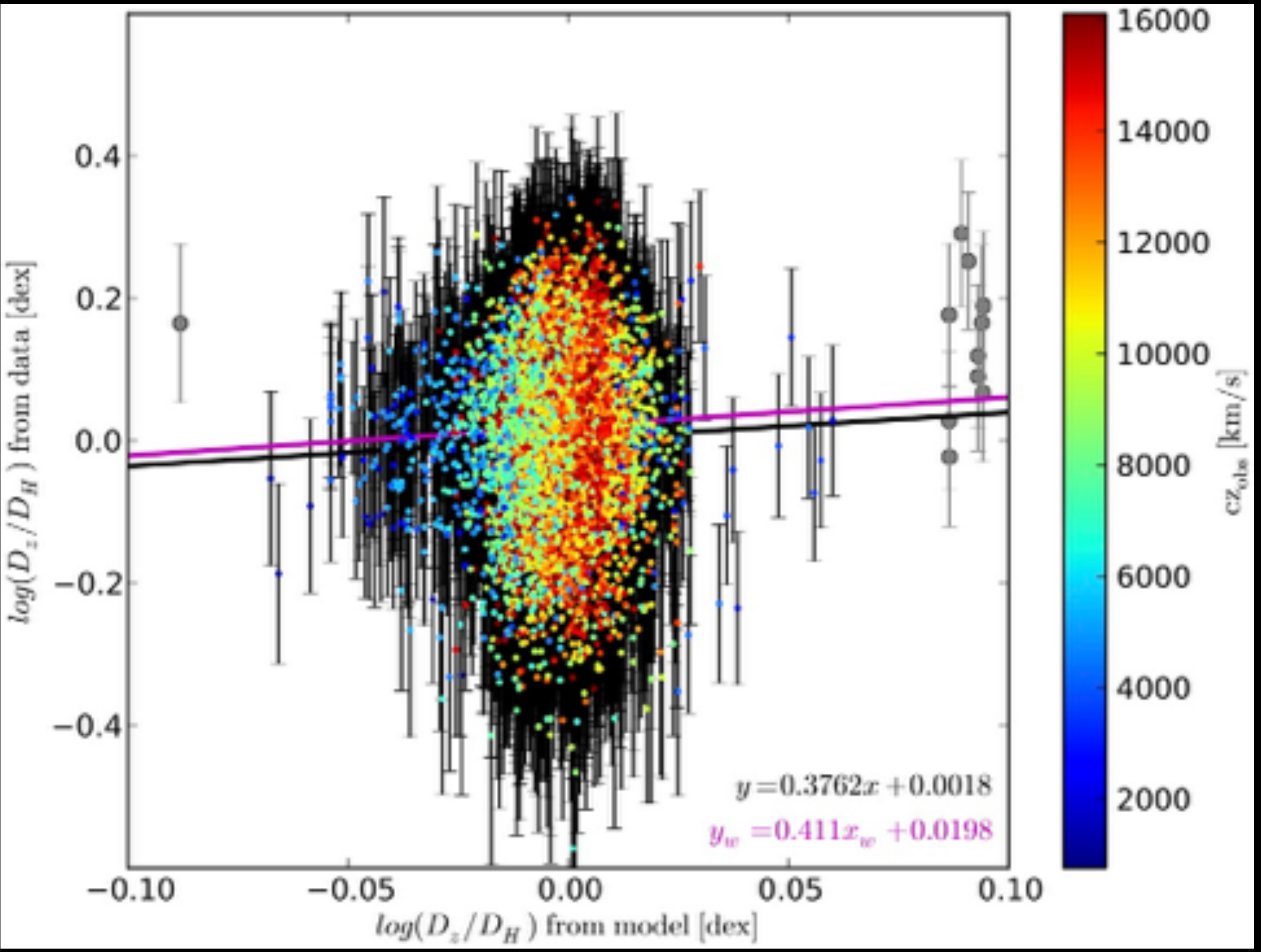
- The beta parameter is consistent with recent results when 6dFGSv is compared to 2MRS (β_{fid}=0.4) and PSCz (β_{fid}=0.5), but low when compared to 2M++ (β_{fid}=0.43)
- We measure *large* **external bulk flows** (assuming matter follows the galaxy distribution of the model reconstruction) but largest with comparison to 2M++ 420±65 km/s with a very low β=0.18±0.05;
  - amplitude is not too much smaller than total flow! (u_{tot}=395±64).

v-v chi-squared fitting

- Simple linear regression (χ^2) to individual $\log_{10}(D_Z/D_H)$ ratios as an independent check to 2M++ (doesn't account for sample selection, distance weighting, zero-point calibration)

- From this method, best-fit of β = 0.13 is consistently close to the value fitted by the full ML forward modeling (cf. β = 0.14±0.06) and suggests usual fitting method is robust.

- Hence there still exists a large discrepancy between the observed 6dFGSv and predicted 2M++ velocities.



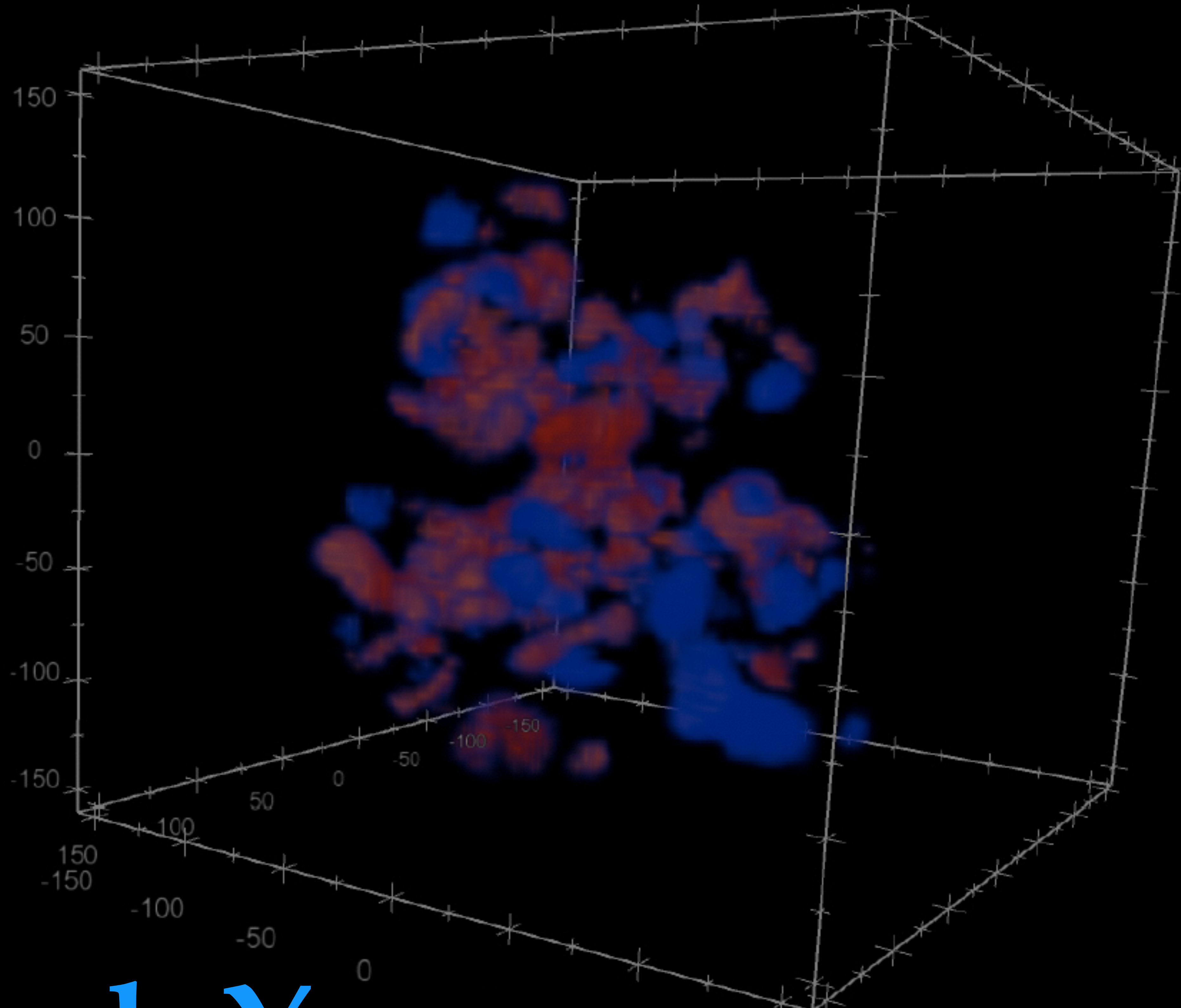
Summary

- 6dFGSv provides the largest homogenous sample of galaxy peculiar velocities to date.

- We model the velocity field and 3D FP Gaussian simultaneously using a Bayesian analysis of the dataset as whole. Using 6dFGSv, we map the velocity field in the nearby universe and compare to the density field derived from redshift surveys.

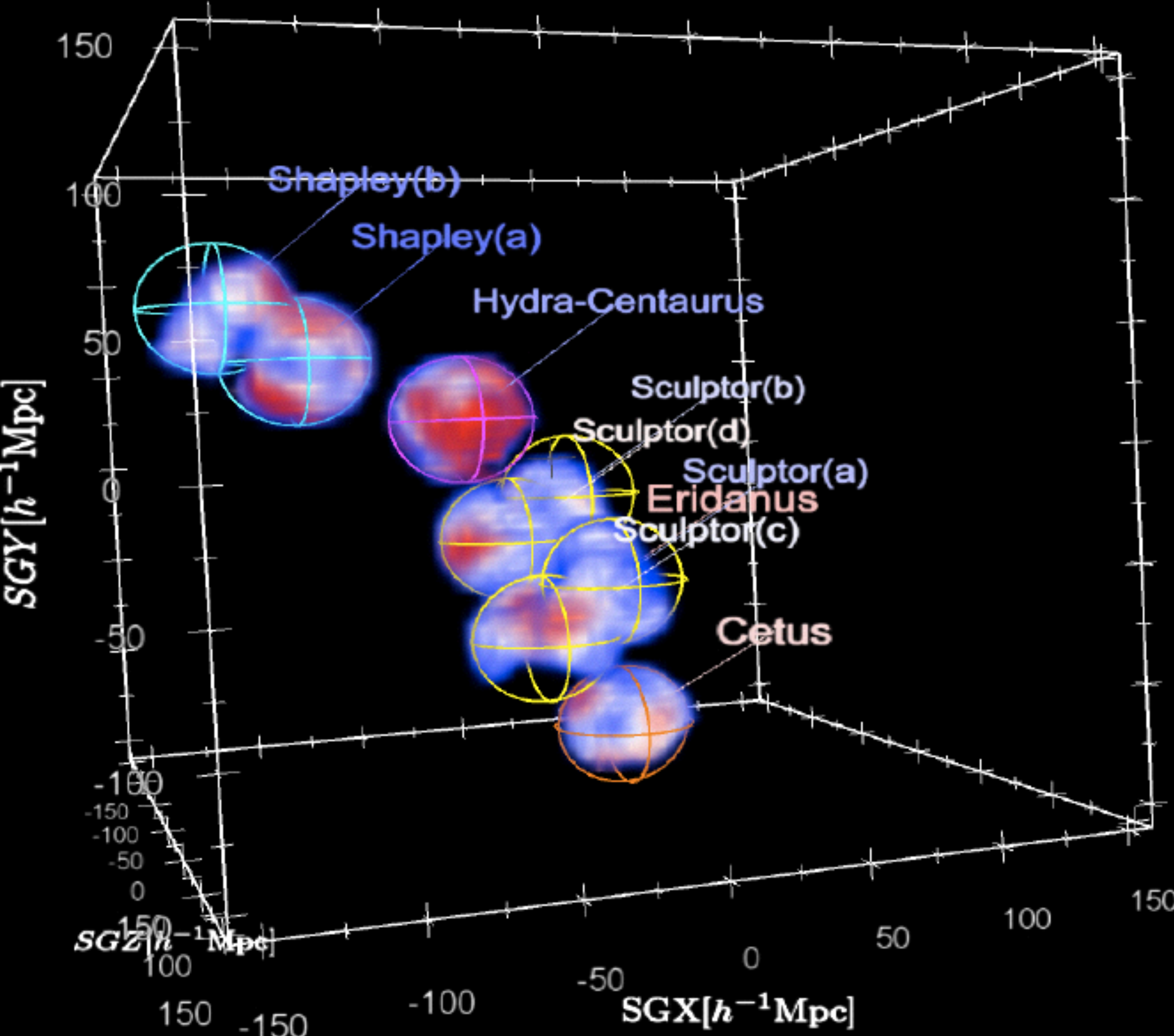
- This leads to new measurements on the redshift distortion parameter with some discrepancies: $\beta=0.32\pm0.08$ (2MRS), $\beta=0.58\pm0.12$ (PSCz) and $\beta=0.13\pm0.06$ (2M++)

- We recover a total bulk flow for 6dFGSv within ~160 Mpc/h of **395±64 km/s** towards $(l,b) = (318^\circ\pm20^\circ, 40^\circ\pm13^\circ)$ meaning the 6dFGSv volume has a substantial **coherent motion towards Shapley**.



Thank You

6dFGSv velocity field in 30 Mpc/h spheres
around local overdensities



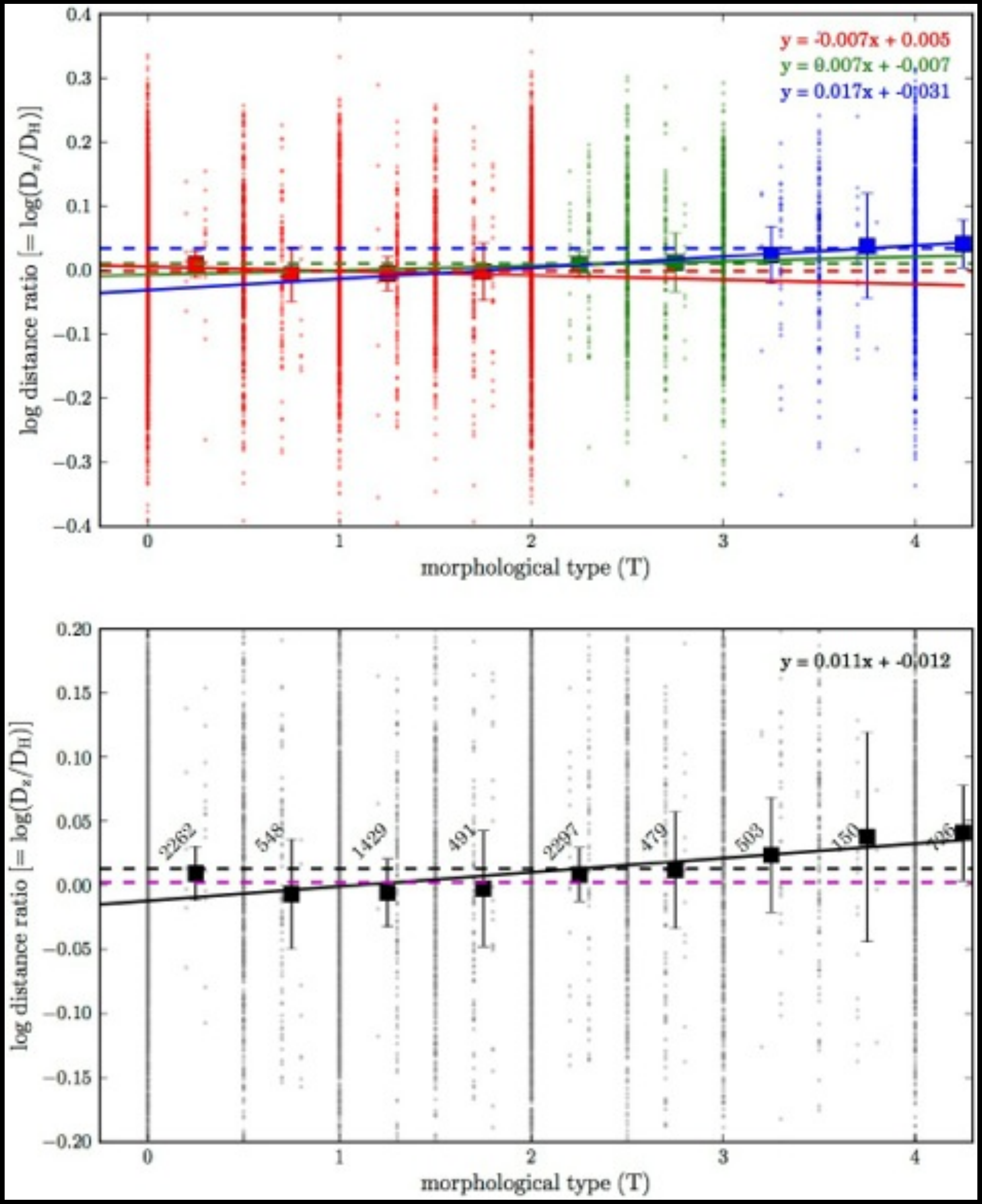
Springob et al. (2014)

3D Visualisation by S2PLOT

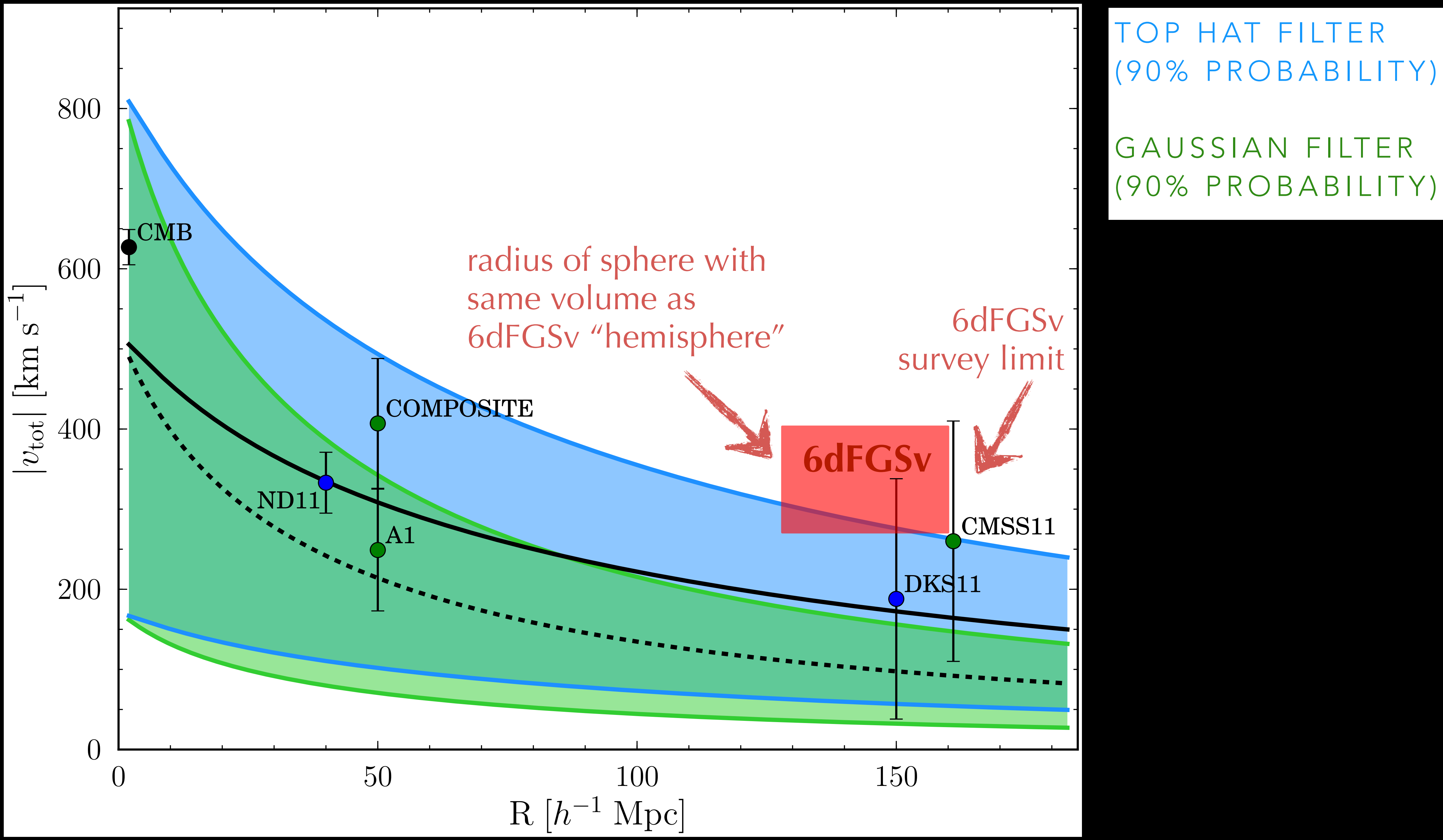
morphology outliers

- Log distance ratio versus morphological type separated by morphological subsamples (top; early types in red, intermediate types in green, late types in blue) and full sample (bottom).

- The median bins (with rms error bars) indicate that a cut of T > 3 removes the most discrepant outliers,



6dFGSv flow as a function of scale



- There is still disagreement between surveys at similar scales (Watkins 2009; Nusser & Davis 2011) and with standard model predictions (Colin 2011, Watkins 2009)