Measuring the cosmic bulk flow with 6dFGSv

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and the 6dFGSv team

Zeldovich Universe - IAUS 308: June 2014

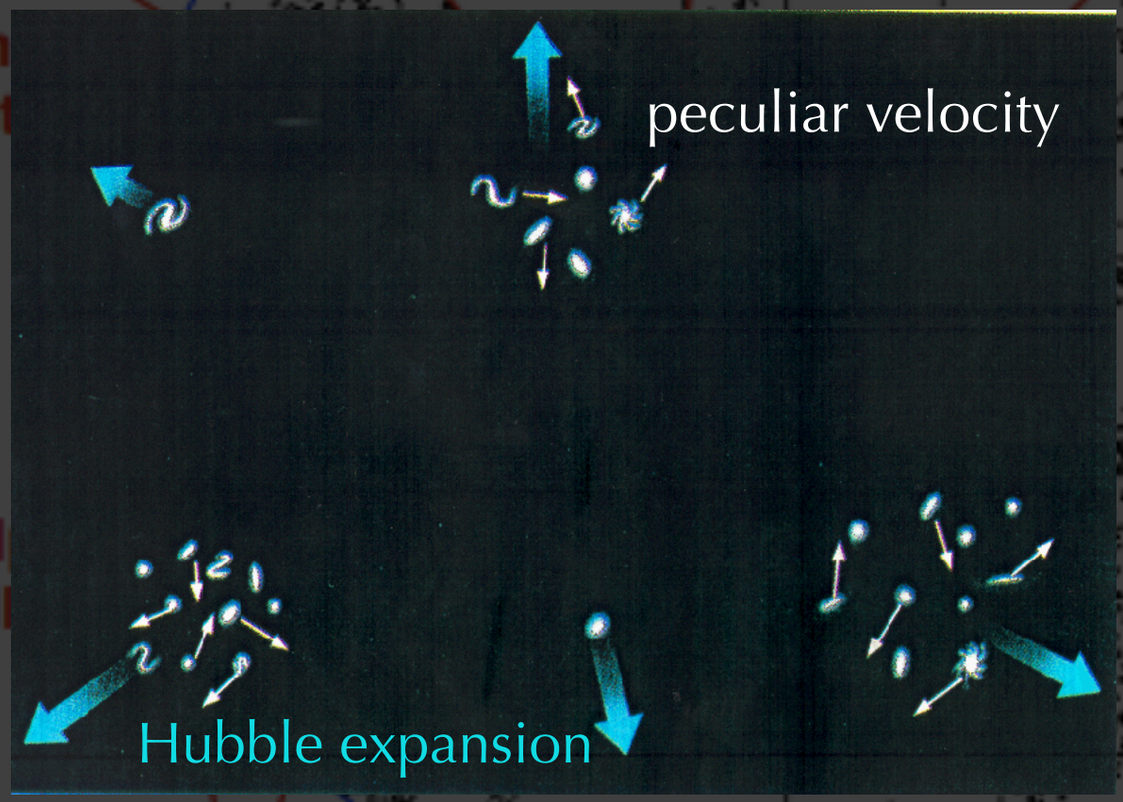
Background Image: C. Fluke

Cosmic Web of Large-scale structure

- Redshift Surveys: 2dFGS, SDSS, ***6dFGS***
  - insight into the formation of structure from gravitational instability
  - non-uniformity in mass distribution produces motions deviating from Hubble Expansion - peculiar velocities!

Peculiar velocity surveys provide:

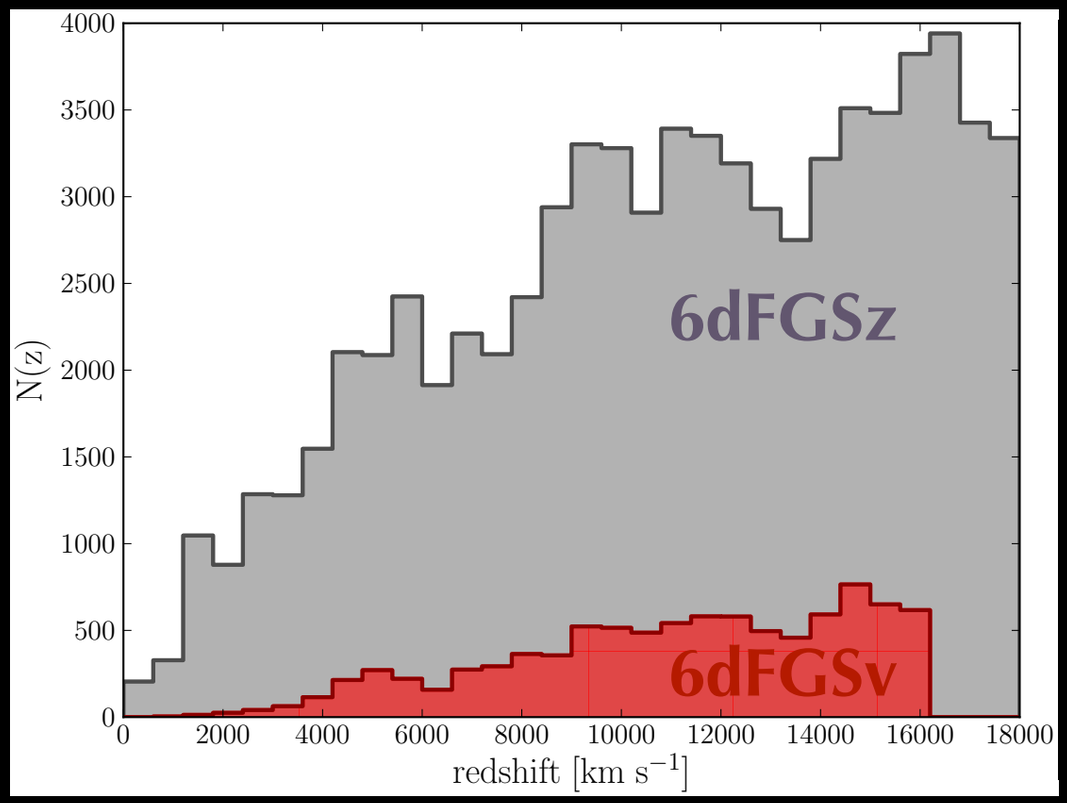
- an **independent probe** of cosmology in the low redshift universe; sensitive to mass fluctuations on the largest scales
- **direct, unbiased** tracer of the distribution of matter

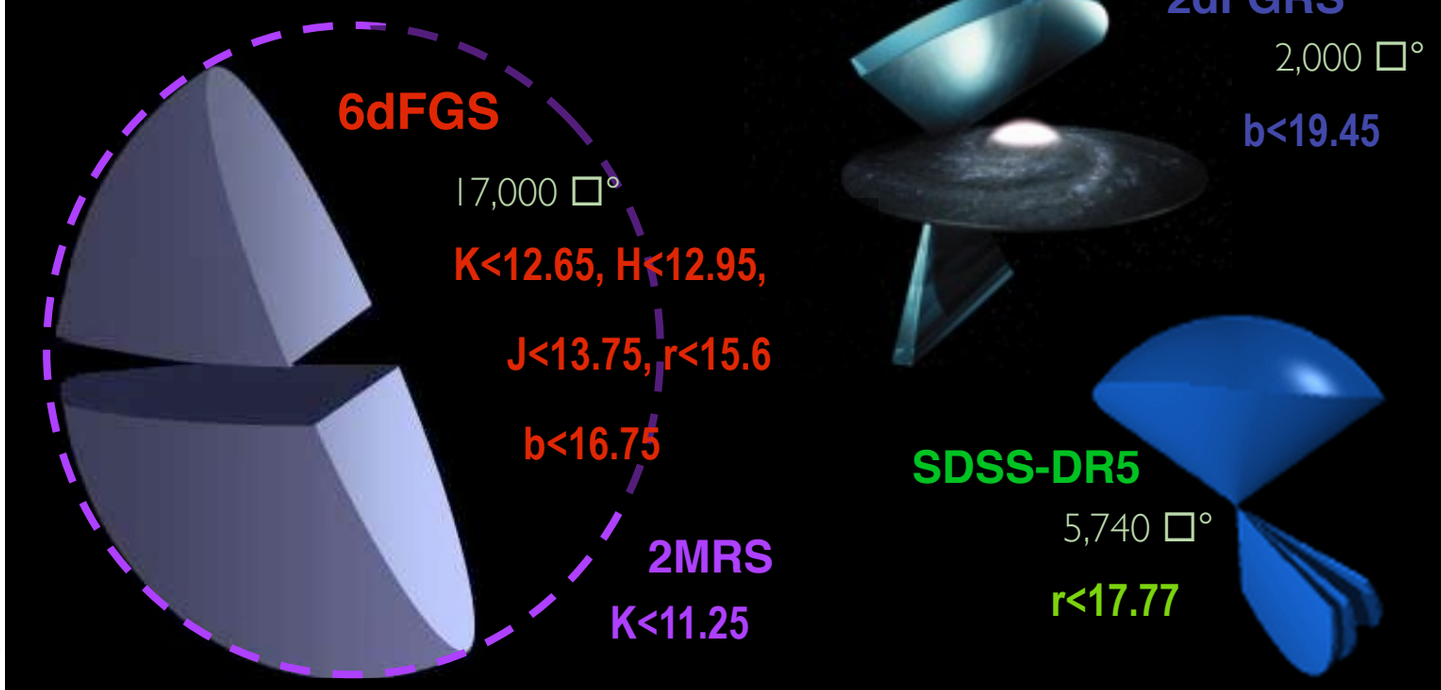


- **6dFGSv** - the (FP) peculiar velocity survey of 6dFGS; series of published papers - Magoulas et al. 2012, Springob et al. 2012, Johnson et al. 2014, Campbell et al. 2014. (submitted/in prep) **Magoulas et al. 2014**, Springob et al. 2014, Scrimgeour et al. 2014

The 6dF Galaxy Survey

- Combined ***redshift (z-) and peculiar velocity (v-) survey*** of the entire Southern Sky on the UK Schmidt Telescope
- 6dF z-survey: 137k spectra, 125k redshifts (Jones et al. 2009)
- 6dF v-survey: ~9000 Fundamental Plane distances and peculiar velocities; out to a redshift of cz < 16,000 km/s. *largest PV survey to date*





Magoulas et al. (in prep.)

Peculiar Velocity Distributions

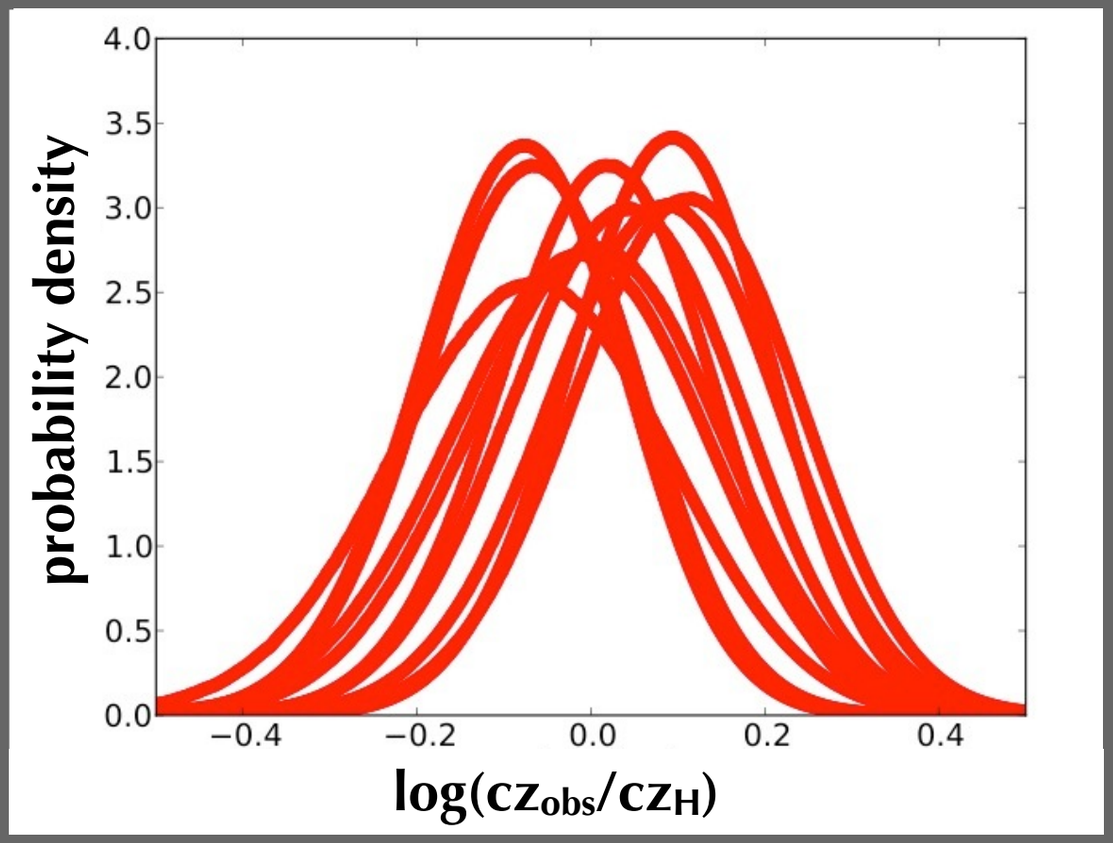
- We analyse the velocity field using two approaches:

[1] Compute a Bayesian posterior probability distribution (below) for the distance/ peculiar velocity of each galaxy. Derive velocity maps and statistics directly. Springob et al., submitted

[2] Do a Bayesian analysis of the observational dataset as a whole, fitting models directly without computing individual peculiar velocities. Magoulas et al., in prep.

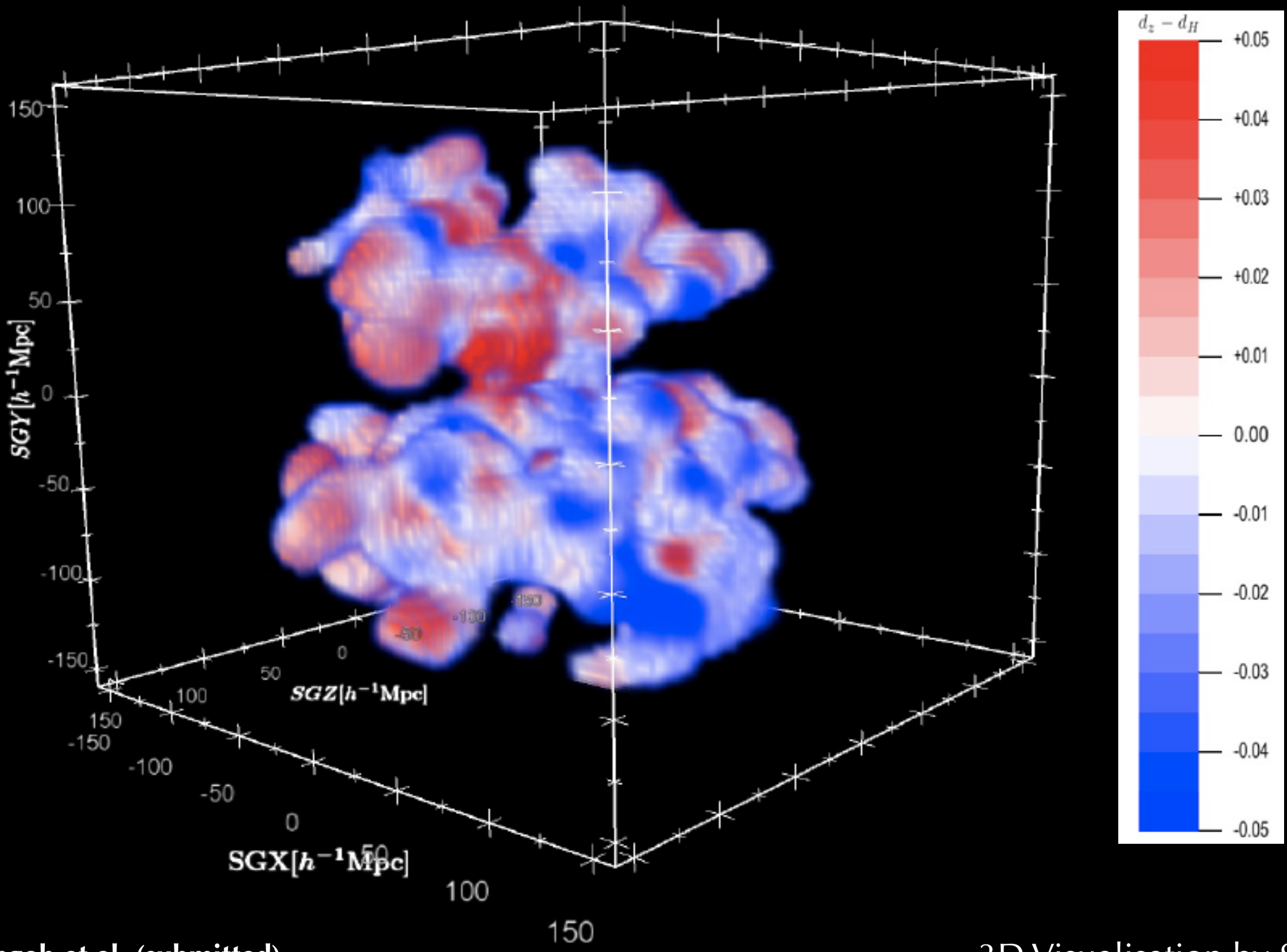
- We fit in log (distance ratio) units where errors are nearly Gaussian, take advantage of fully **forward fitting** (i.e. fitting in "data" space)

- In velocity units, errors are close to log-normal distribution



Gaussian distribution in log(distance) space

Smoothed 3D 6dFGSv velocity field

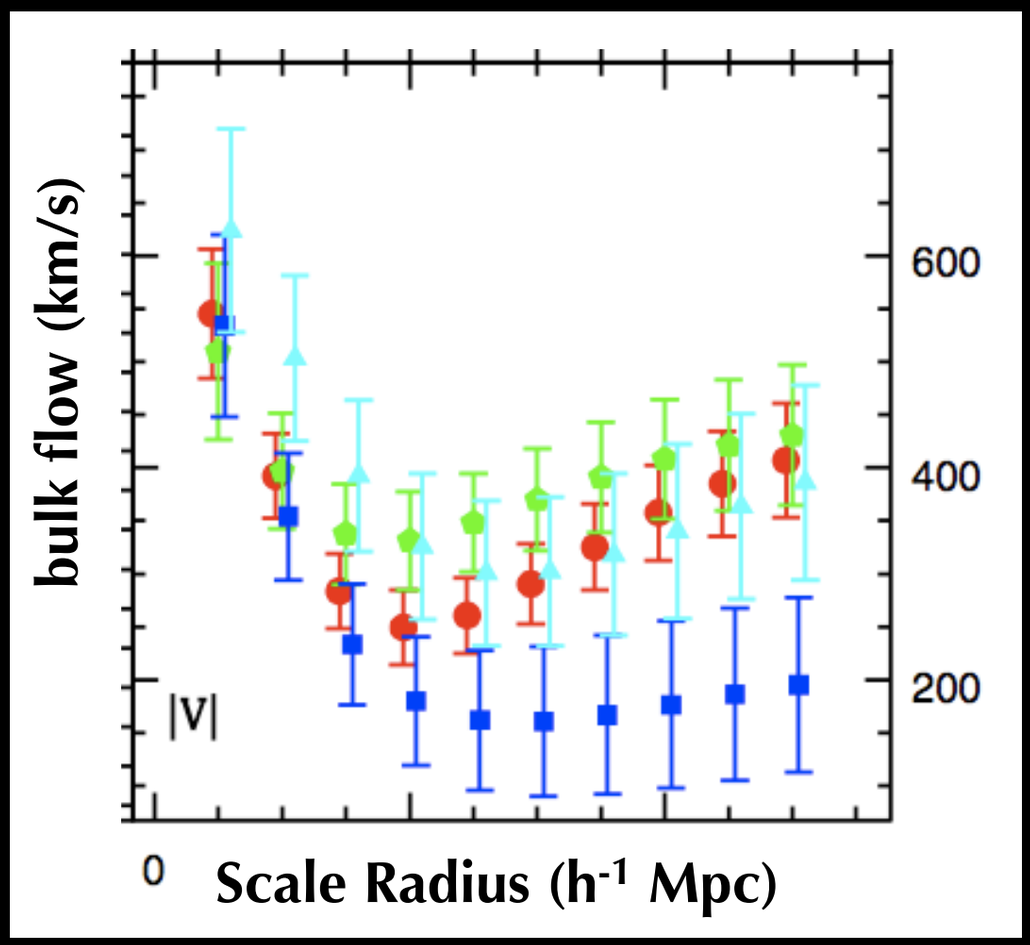


Springob et al. (submitted)

3D Visualisation by S2PLOT

Cosmic bulk flow

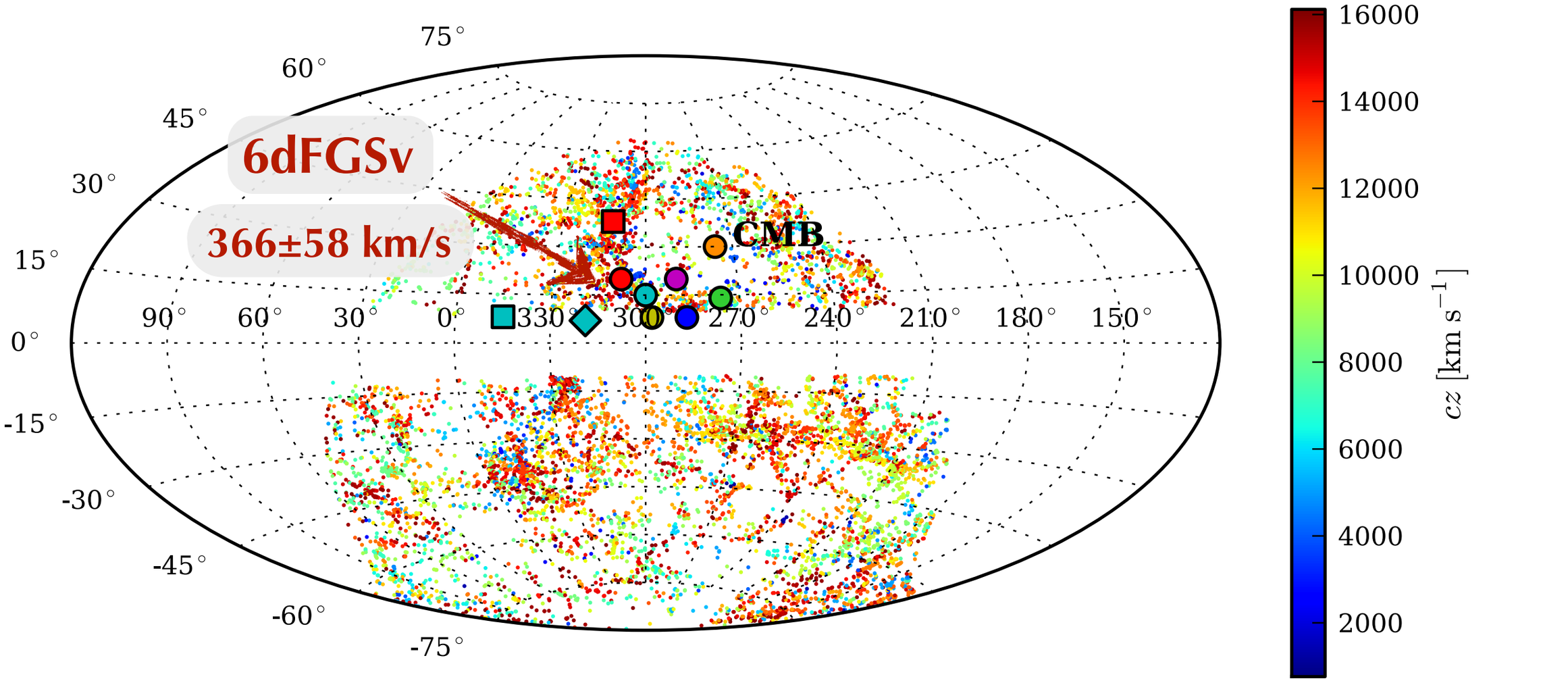
- The standard cosmological model (ΛCDM) predicts our bulk motion should converge to the Hubble Flow at large distances; convergence scale and consistency with ΛCDM is still a topic of debate!
- Watkins, Feldman and Hudson (2009) - compiled all major peculiar velocity surveys into a ***Composite*** catalogue



Watkins et al. (2009)

- Watkins et al. used **minimum variance estimate** to measure bulk flow on specific scales; on 50 Mpc/h scale found ~400 km/s flow (left) in direction of Shapley
- This disagrees with ΛCDM cosmology with 98% confidence - but, see Nusser and Davis (2011) who find consistency with ΛCDM using inverse TF method

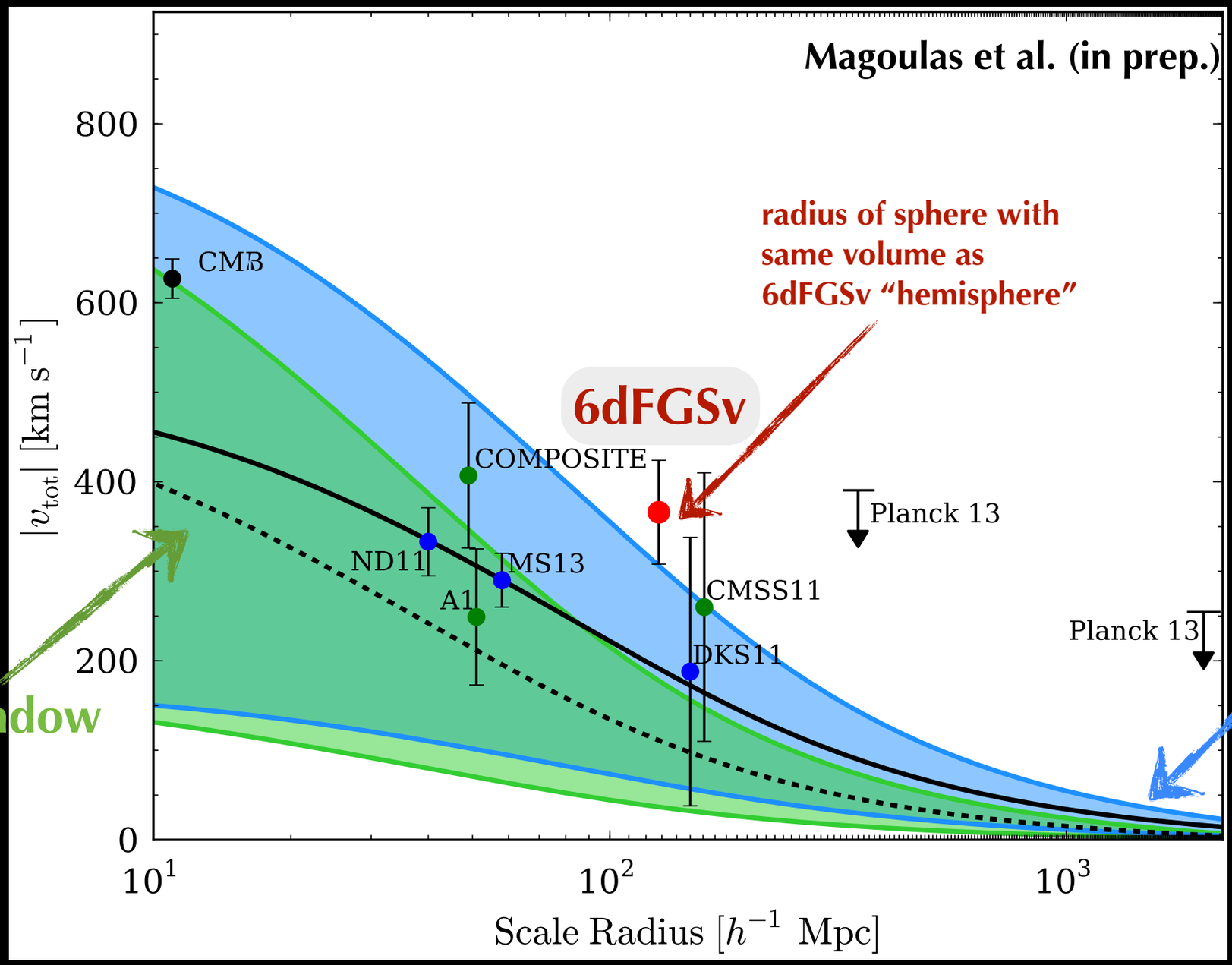
6dFGSv bulk flow



6dFGSv (total)	Turnbull et al. 2012 (total - ML)	Colin et al. 2011
6dFGSv (residual)	Turnbull et al. 2012 (residual)	Dai et al. 2011
Watkins et al. 2009	Turnbull et al. 2012 (total - MV)	Nusser & Davis 2011

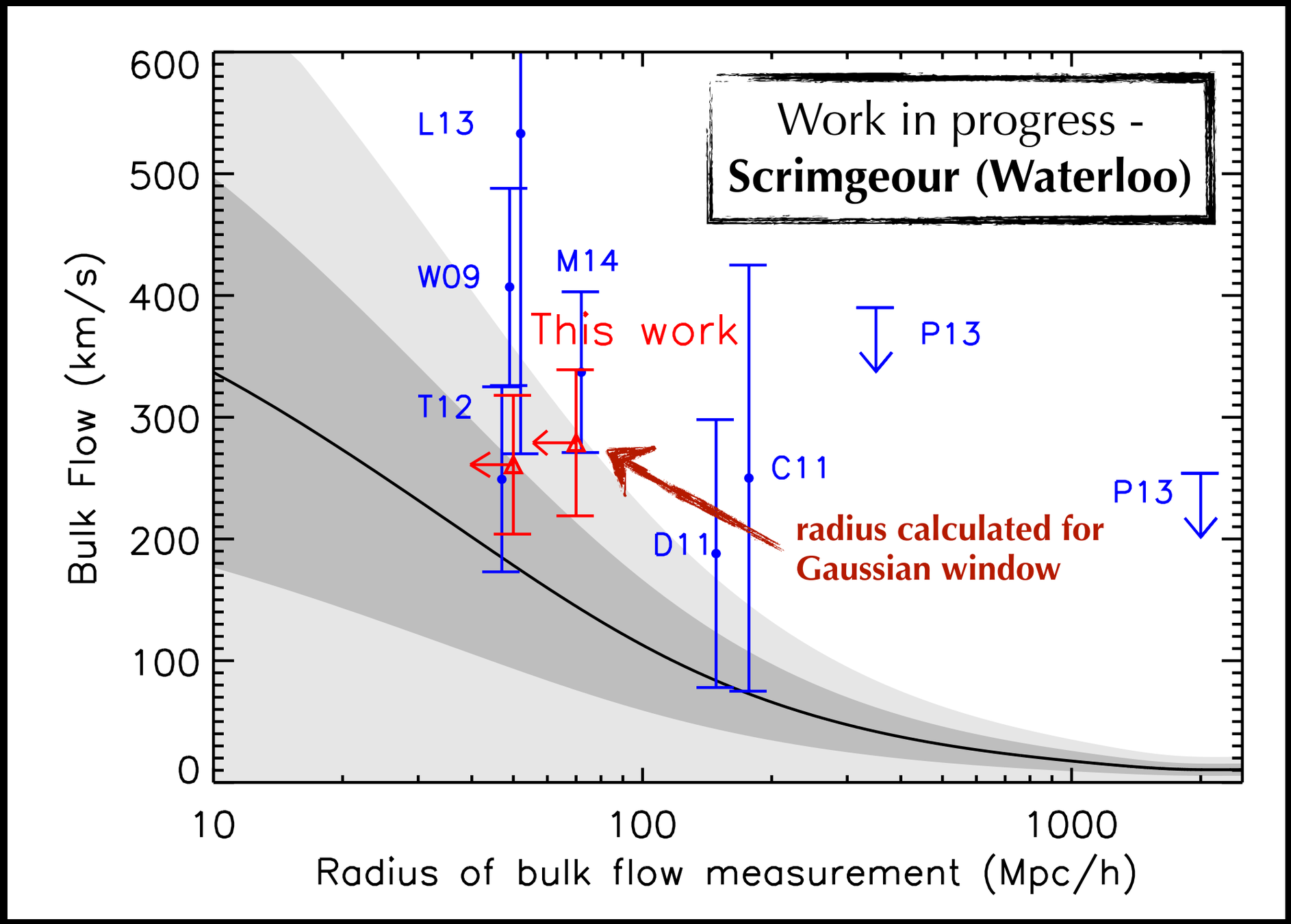
- The 6dFGSv total bulk flow is 366 km/s towards (l,b)=(308°, 20°) in the direction of Shapley.
- In general, direction of flow is located in a narrow 10° wide strip, parallel to the ZoA (shallow surveys reflect LG motion, deeper surveys show motions due to the most massive structures).

6dFGSv flow as a function of scale



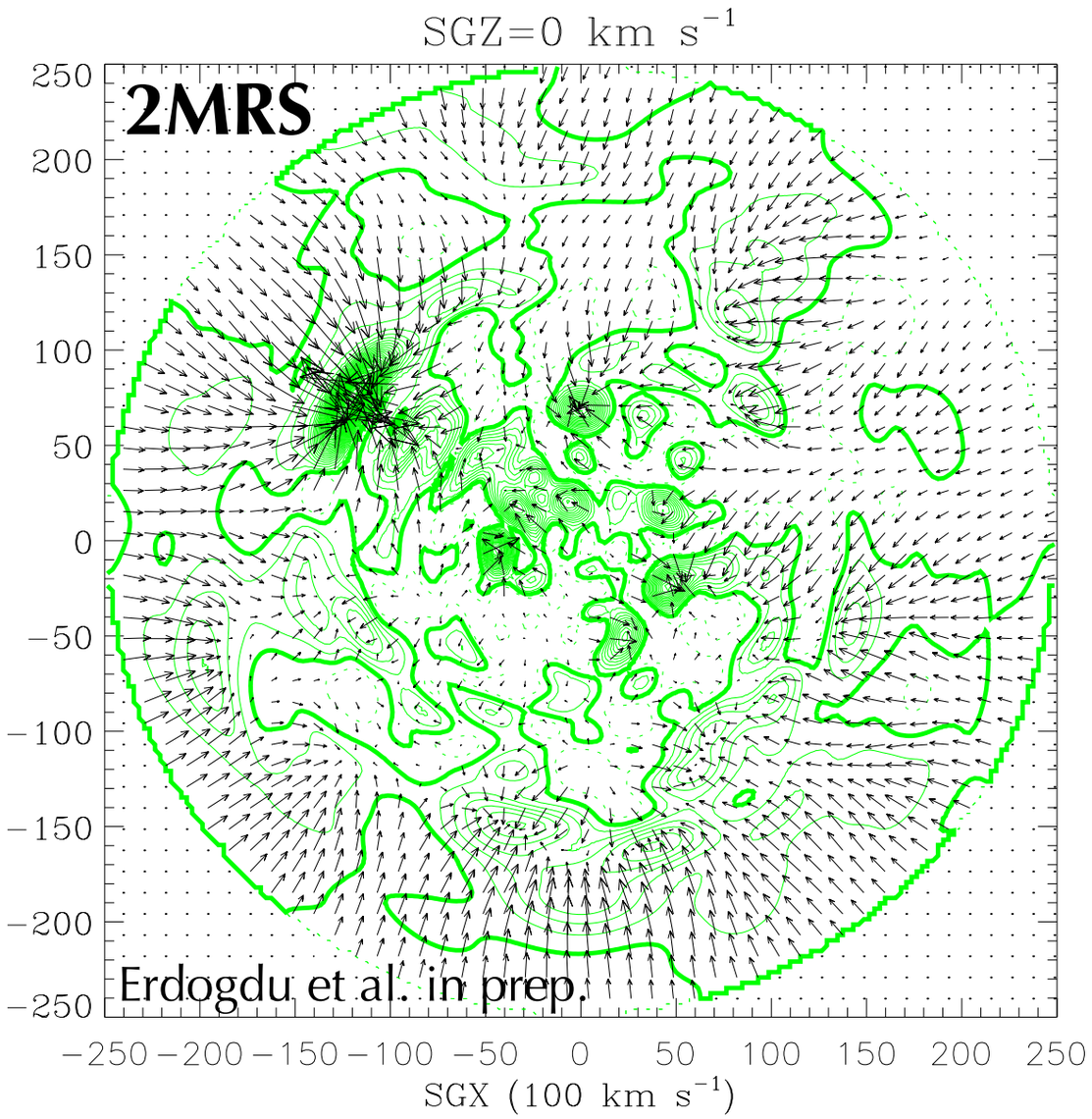
- We compare 6dFGSv to top-hat (blue) window function
- Caveats: neglects the differences in survey volume (hemisphere vs all-sky) and sky coverage (shallow/dense vs deep/sparse).

6dFGSv flow: minimum variance method



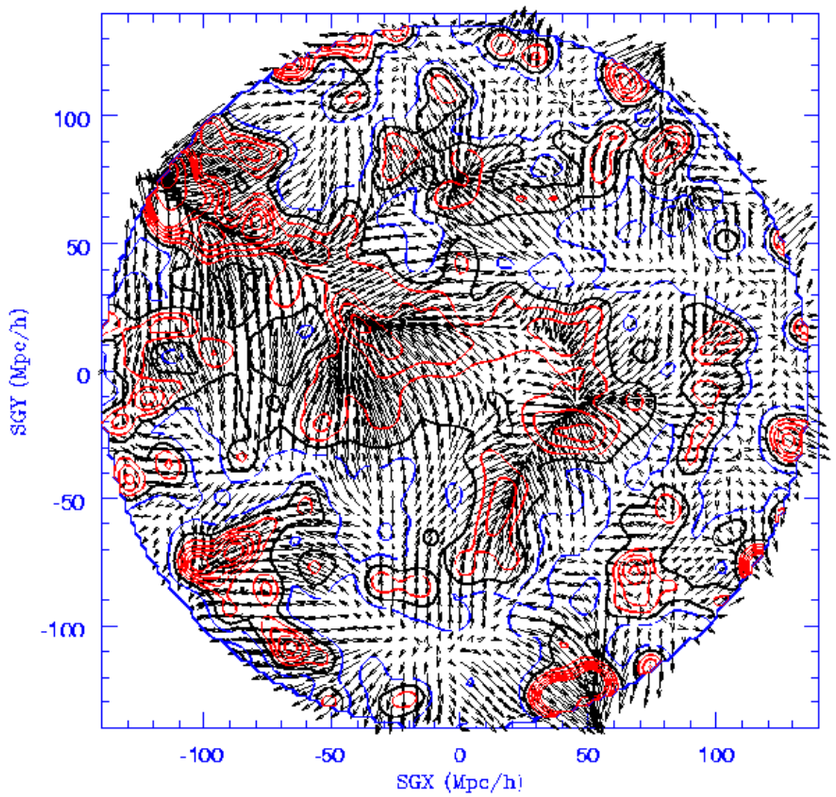
- An *alternative* analysis of the bulk flow applied to 6dFGSv which accounts for sparse sampling following the method of Watkins, Feldman & Hudson (2009).

Velocity Field Reconstructions



Erdogdu et al. in prep.

PSCz



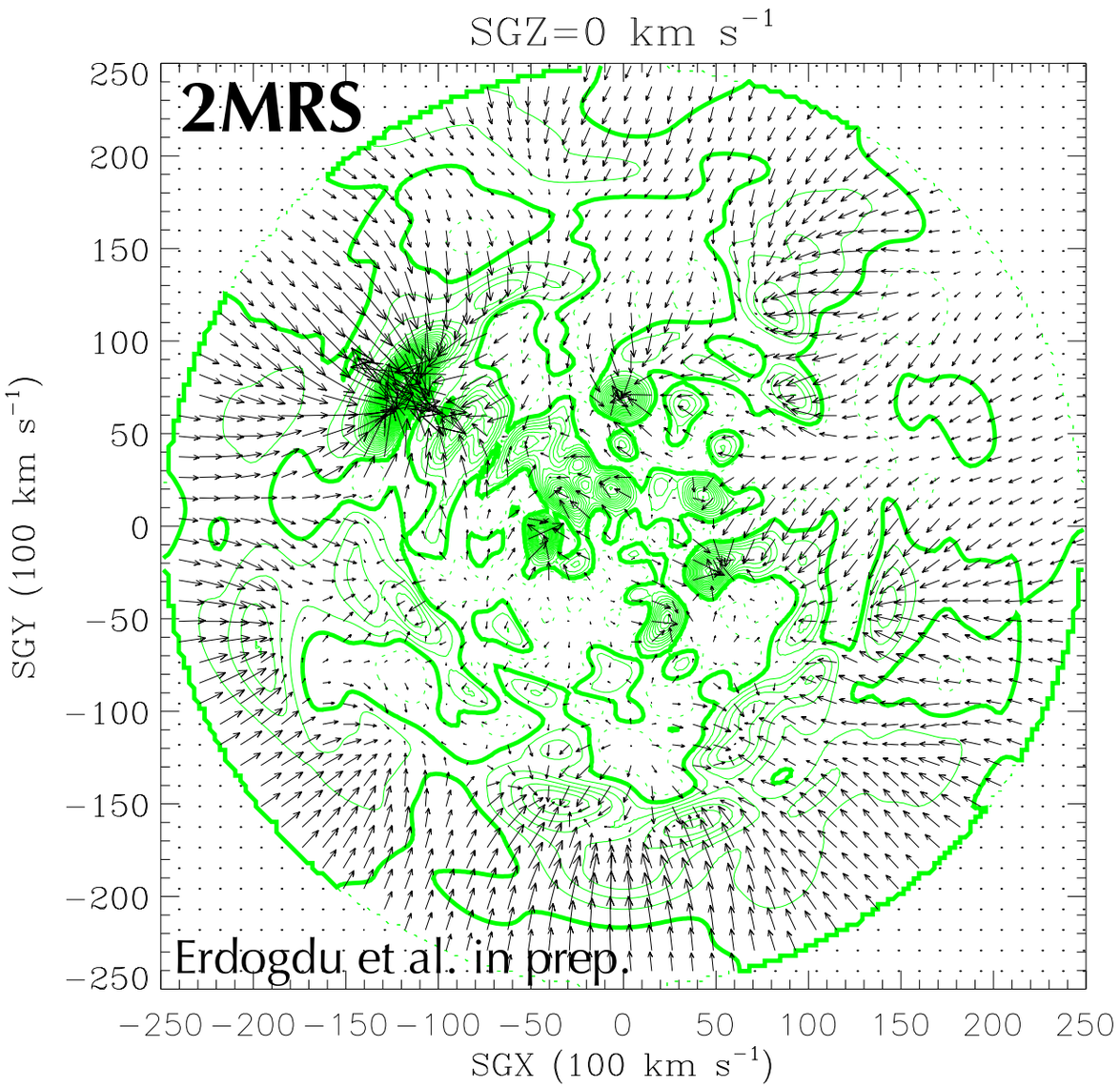
Branchini et al. 1999

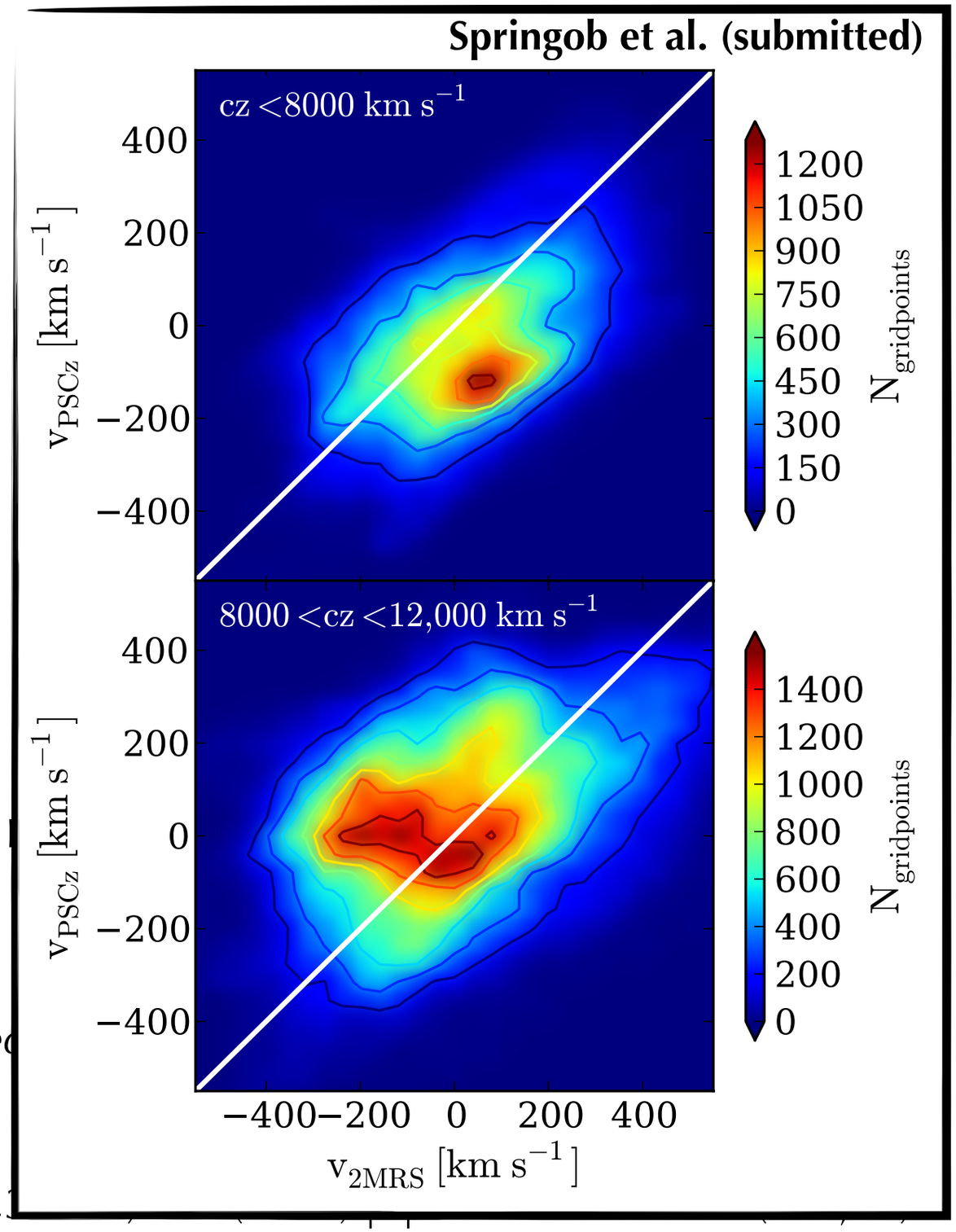
- Comparison of the 6dFGSv *observed* and 2MRS *predicted* velocity fields: $\beta(\equiv\Omega_m^{0.55}/b_{2MRS})$**=0.27±0.07**
- Comparison with PSCz: $\beta(\equiv\Omega_m^{0.55}/b_{PSCz})$**=0.58±0.11**

Residual flow (2MRS) - |u|=319±41 towards (312±20,38±12) and (PSCz) |u|=289±48 towards (319,23)

- BUT at large distances, models disagree. Need better agreement between predicted velocity fields!

Velocity Field Reconstructions





- Comparison of the 6dFGSv *observed* and 2MRS *pred*
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Summary

[1] The 6dFGS peculiar velocity survey (6dFGSv) provides ~9000 early-type galaxies for studying the Fundamental Plane & mapping the local velocity field.

[2] Using peculiar velocity distributions from 6dFGSv, we map the velocity field in the nearby universe and compare to the density field derived from redshift surveys. We then forward-model the velocity field and 3D FP Gaussian simultaneously using a Bayesian analysis of the dataset as whole in order to determine β.

[3] This leads to new constraints on the redshift distortion parameter of **β=0.27±0.07 (2MRS)** and **β=0.58±0.11 (PSCz) with 20% error** (depending on model prediction), in agreement with previous studies.

[4] We recover a total bulk flow for 6dFGSv within ~160 Mpc/h of **366±58 km/s** towards (l,b) = (308°±9°, 20°±11°) suggesting **coherent motion towards Shapley**. However, we also recover a **residual bulk flow** of ~300 km/s (after subtracting the fitted 2MRS or PSCz predicted velocity field), implying that a substantial fraction of the total flow is not modelled by 2MRS/PSCz or originates outside the volume

Future Work: combine 6dFGSv (south) with velocity dispersions from SDSS (north) and 2MASS photometry to obtain a homogeneous *all-sky* velocity field sample