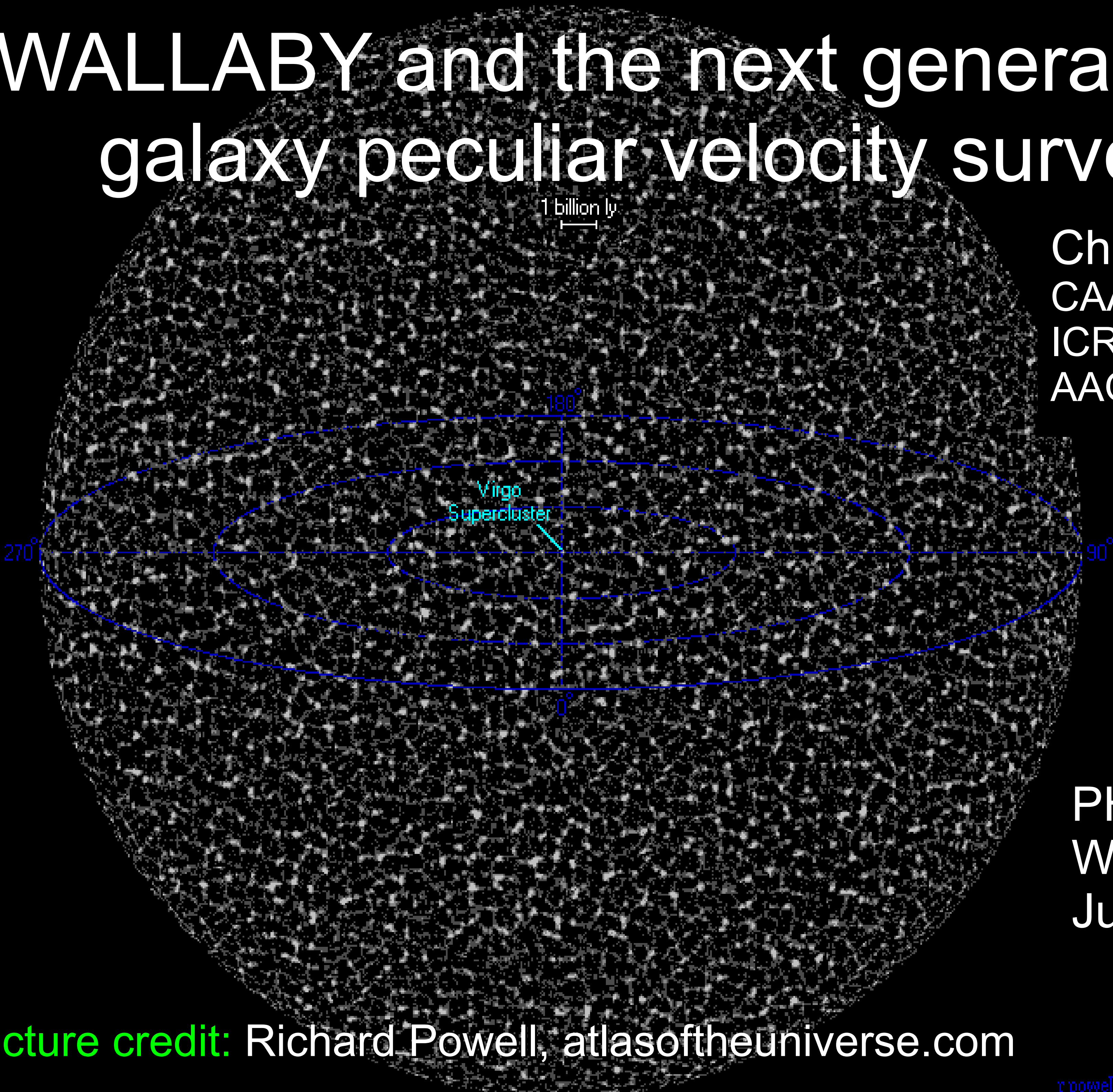
WALLABY and the next generation of galaxy peculiar velocity surveys



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PHISCC
Workshop
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picture credit: Richard Powell, atlasoftheuniverse.com

Outline

- Background on galaxy distances and peculiar velocities and why they're interesting
- Redshift independent distance indicators
  - Tully-Fisher & Fundamental Plane: The workhorses of redshift-independent distance indicators
- Overview of current and future galaxy peculiar velocity surveys—where does WALLABY fit in?
- Other surveys: TAIPAN
- Building peculiar velocity models from all-sky redshift surveys

Measuring large scale motions

- peculiar velocity—the velocity of a test particle (galaxy) *separate from its velocity due to the overall Hubble expansion*
  - caused by the gravitational attraction of nearby matter overdensities
- Given the *peculiar velocity field* **v(r)**, can infer matter density field, which gives you cosmological parameters

Measuring peculiar velocities = measuring distances

- How do you measure peculiar velocities?
  - Use a redshift independent distance indicator:

$$cz_{obs} = H_0 r + v_{pec}$$

Cosmology from galaxy peculiar velocities

- One advantage over redshift surveys alone:
  - Comparison between density field (from redshift surveys) and velocity field: “cancelling cosmic variance”

Burkey & Taylor (2004) MNRAS 347, 255

- Derive a method for using the combination of the z-survey and v-survey to estimate the following cosmological parameters:
  - the amplitude of the galaxy power spectrum, which is related to the amplitude of the mass power spectrum by the bias parameter $A_g = bA_m$
  - the power spectrum shape parameter $\Gamma = \Omega_m h$
  - the redshift space distortion parameter $\beta = \Omega_m^{0.55} / b$
  - the correlation coefficient between luminous and dark matter r_g

Bulk flow: Is it larger than predicted by ΛCDM?

- Davis, Nusser: Existing datasets (minus 6dFGS) show mean motion within ~50 Mpc/h consistent with ΛCDM
- Watkins, Feldman, Hudson: Existing datasets (minus 6dFGS) show mean motion within ~50 Mpc/h higher than predicted by ΛCDM (~97.5% probability that a random observer would see a lower value)

Measuring distances: primary vs. secondary distance indicators

- Primary distance indicators: distance measurement doesn't require calibration by another method
  - Variable stars (Cepheids, RR Lyrae stars)
  - Tip of the Red Giant Branch
  - Eclipsing binaries
- Secondary distance indicators: distance measurement must be calibrated by the distance scale derived from primary distance indicators
  - Surface brightness fluctuations
  - Type Ia supernovae
  - **Tully-Fisher relation**
  - **Fundamental Plane relation**

Only TF (spirals) and FP (ellipticals) from photometry + spectroscopy can give you peculiar velocities for <u>thousands</u> of galaxies.

What's the optimal survey design for a peculiar velocity survey?

- Largest possible number of galaxies
- Smallest possible distance / peculiar velocity errors
- Widest possible sky coverage
- Largest possible survey volume

“Current” generation peculiar velocity surveys

- Tully-Fisher surveys
  - SFI++: Masters et al. (2006); Springob et al. (2007) – ~4000 galaxies
  - 2MTF: Masters, Huchra, & Springob (2008)....now Hong, Springob, Staveley-Smith... – ~2000 galaxies
  - Cosmic Flows: Courtois & Tully 2012 – ??? galaxies (mostly cz<6000 km/s)
- Fundamental Plane surveys
  - 6dFGS: Magoulas et al. (2012); Springob et al. (in prep.) – ~9000 galaxies, southern sky only
  - SDSS: George, Schlegel – ~80,000 galaxies to 30,000 km/s, but only in 1/4th of the sky

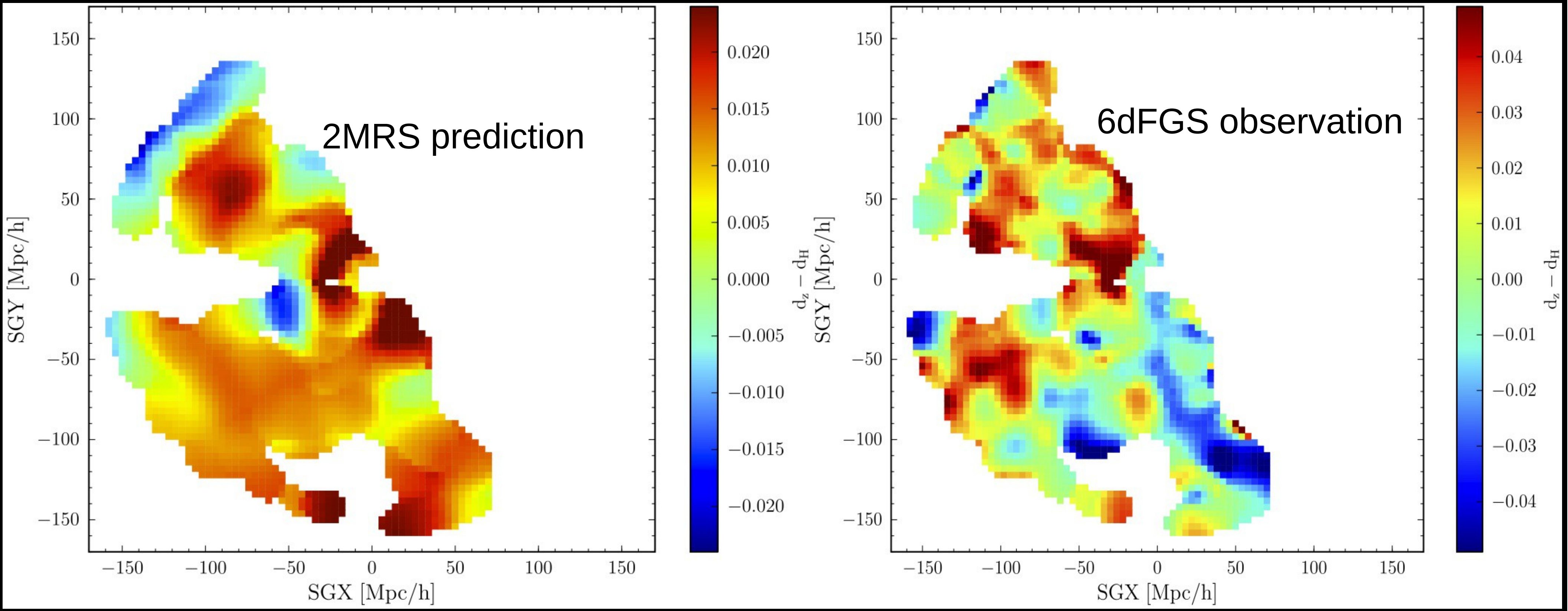
6dFGS bulk flow (Magoulas PhD 2012)

- Total bulk flow = 337+/-66 km/s on scale of ~160 Mpc/h in Southern Hemisphere
- Residual from 2MRS prediction = 273+/-45 km/s

[Does not account for uneven sampling of survey. See Scrimgeour PhD thesis (in prep).]

Getting cosmology out of cosmography:

If bulk flow is large, is it because Λ-CDM needs revision, or because we happen to live in a region with unusually large superclusters / voids that induce the large bulk flow?



Above: smoothed predicted velocity field from 2MRS (left) and observed velocity field from 6dFGS (right) for a slice through the supergalactic plane (-20 < SGZ < +20 Mpc/h). Redder colors correspond to more positive peculiar velocities; bluer colors to more negative peculiar velocities.

WALLABY – Wideband ASKAP L-band Legacy All-sky Blind SurveY

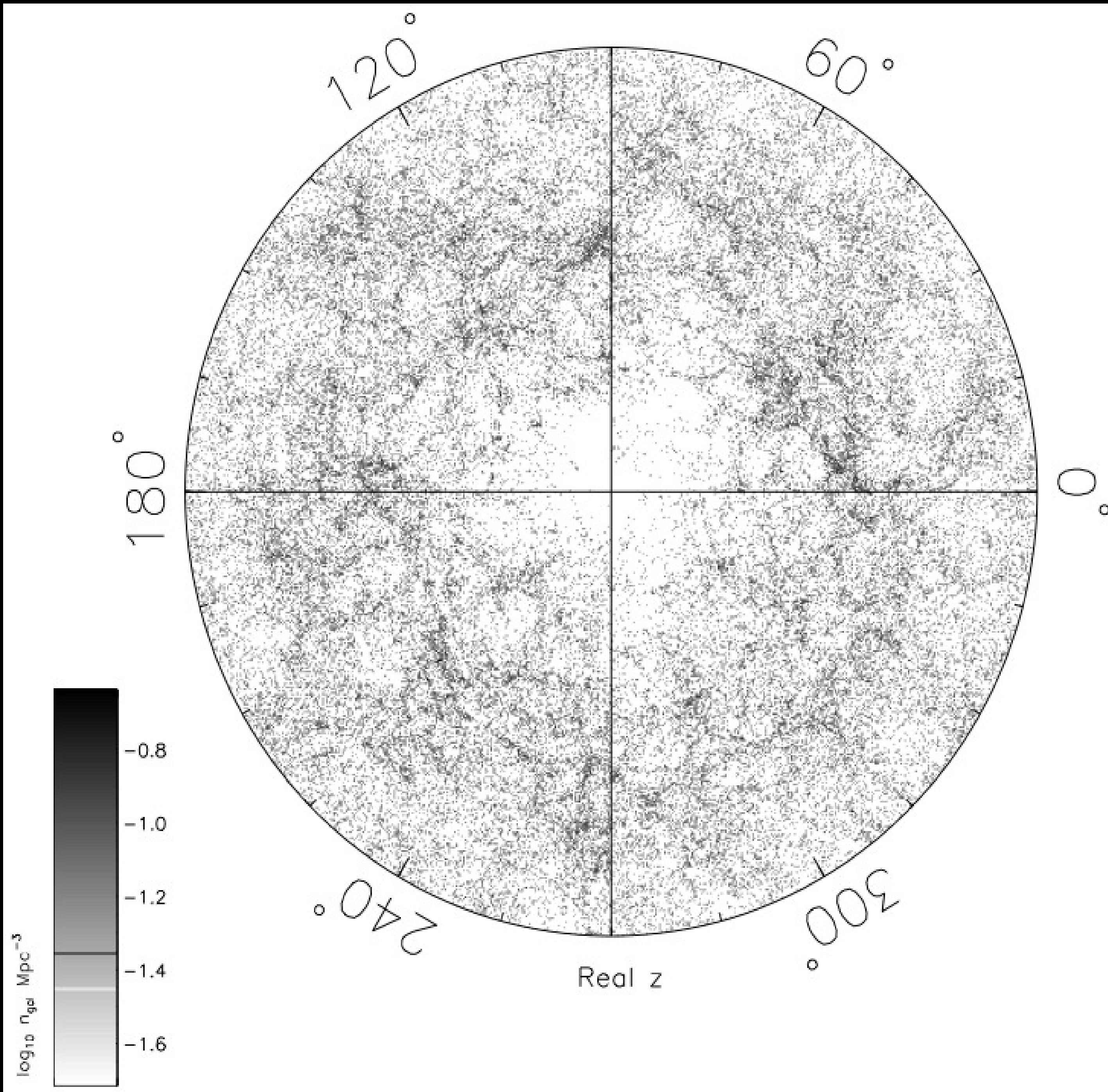
- Integration time 9600 hrs
- Angular resolution: ~30 arcsec
- Area: 3 pi (decl. < +30 degrees)
- Bandwidth: 300 MHz (z = 0 to 0.26)

PIs: Baerbel Koribalski, Lister Staveley-Smith

A next generation all-sky TF survey

- WALLABY: HI widths for galaxies south of decl = +30 degrees
- Westerbork Northern Sky HI Survey (WNSHS) =northern hemisphere WALLABY counterpart conducted with the Westerbork Synthesis Radio Telescope; provides coverage north of +30 degrees.
- SkyMapper + PanSTARRS = source of photometric data

Duffy et al. (2012): WALLABY / WNSHS simulation



Left: Simulated sky distribution of detected galaxies with cz<12,000 km/s.

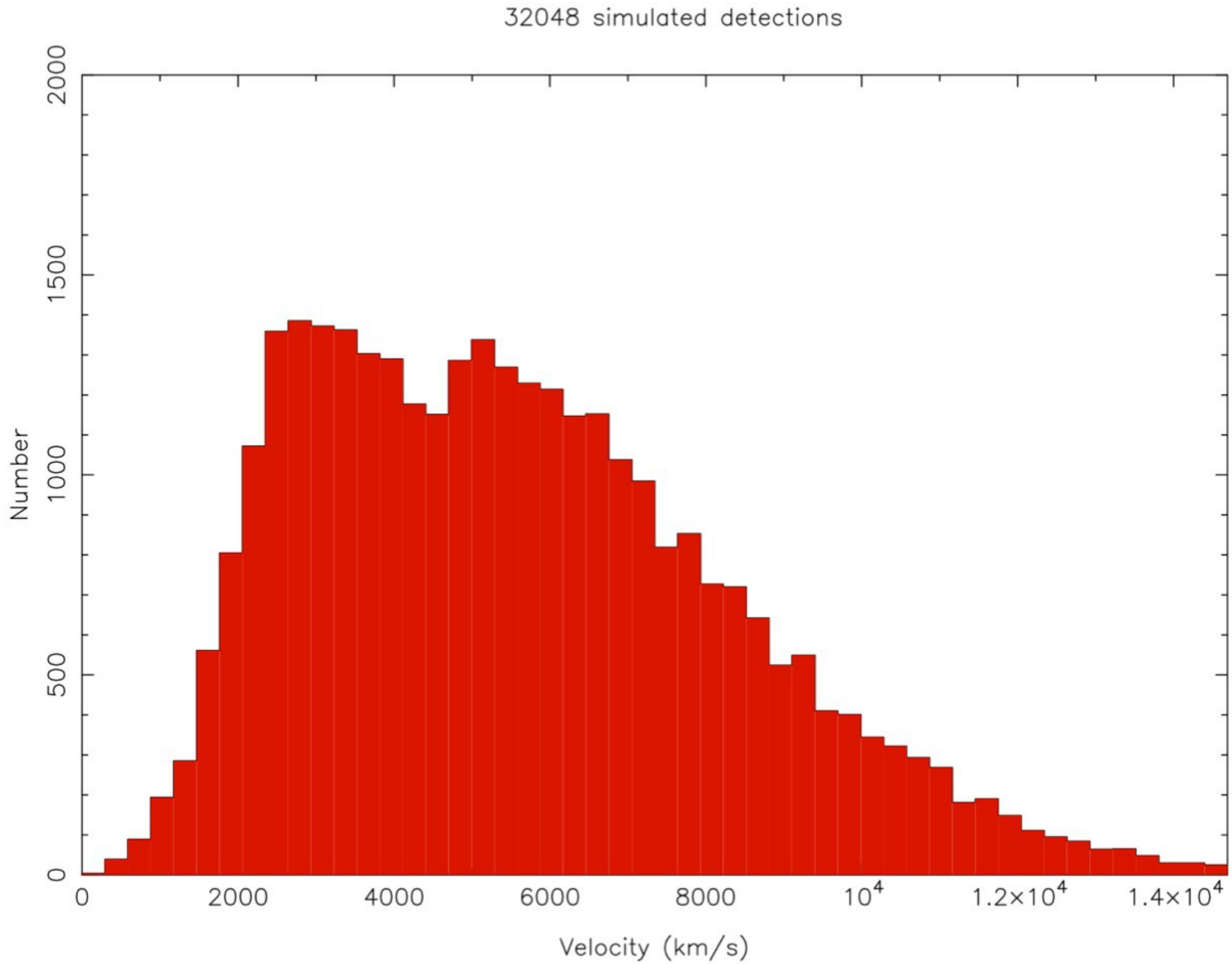
Expected total (out to z=0.26):

S/N>5: 825k gals

S/N>10: 249k gals

Mock TF velocity sub-sample

S/N>7 in 10 km/s bins; i>30 deg; W>80 km/s



TAIPAN – Transforming Astronomical Imaging-surveys through Polychromatic Analysis of Nebulae

- Survey w/ the UK Schmidt Telescope at Siding Spring, following in footsteps of 6dFGS, using 300 “starbug” fibre probes
- All southern sky multi-object spectrographic survey, ~500,000 galaxies
- ~50,000 FP peculiar velocities? (Magoulas simulations)

Model velocity fields as derived from redshift surveys

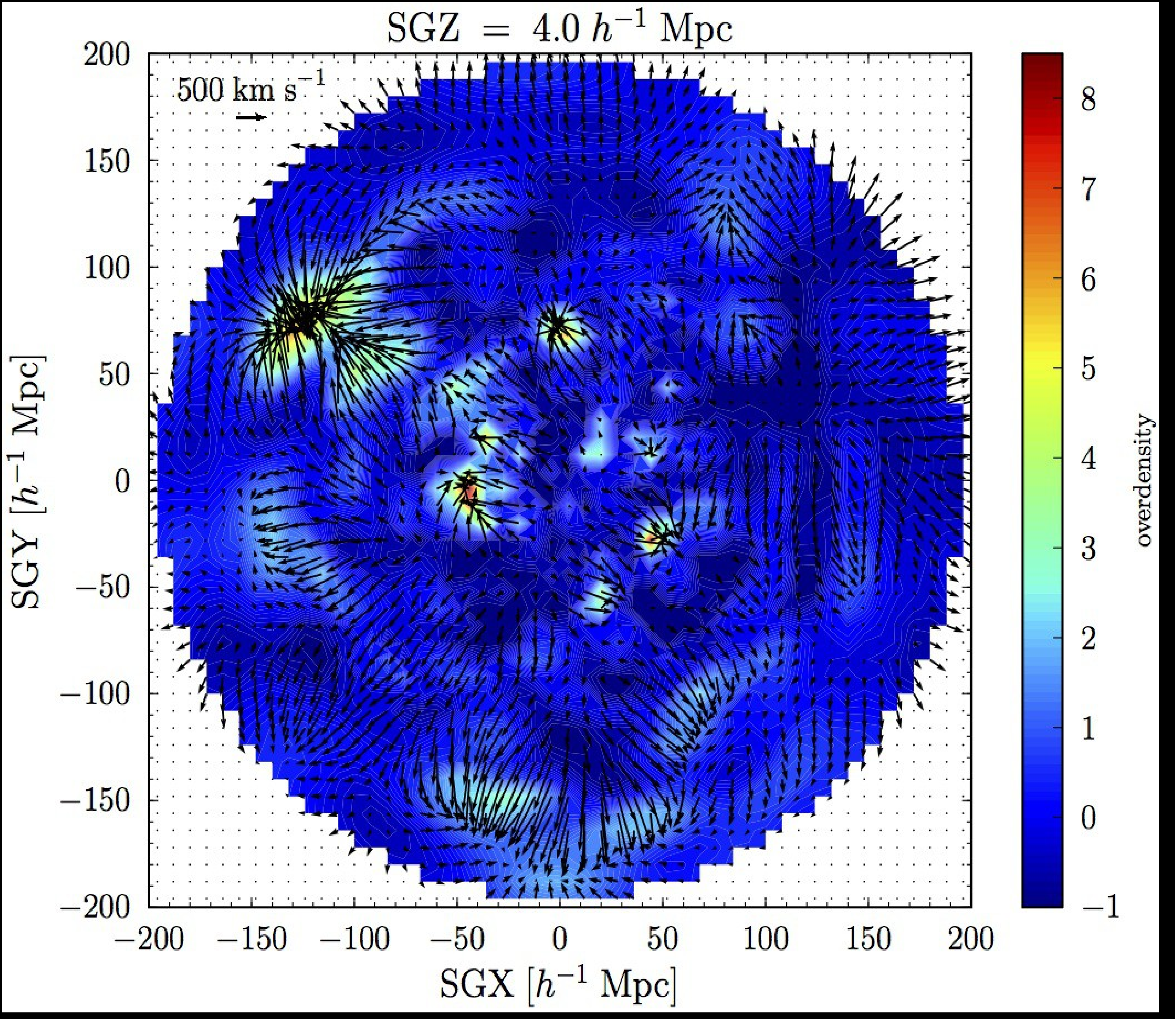
- Take an all-sky redshift survey:
  - Reconstruct the predicted peculiar velocity field, assuming galaxy distribution traces matter distribution, and $b=\delta_{gal}/\delta_{mass}$
  - Some of the cosmological analysis comes from analyzing the *observed* peculiar velocities on their own, but some analysis involves comparing to the *predicted* peculiar velocity field.

The 2MRS velocity field

Erdogdu et al. (submitted)

3D reconstruction of densities and velocities from 2MRS, out to ~200 Mpc/h

Right: The reconstructed peculiar velocity field for 2MRS (11.75 mag. limit sample.).



All sky redshift survey....can we do better?

Table 1
Large Redshift Surveys of the Nearby Universe to Date

Survey	Sky Coverage (% 4π sr)	Depth[a] (z)	Selection (band, flux)	No. of Gals. ($\times 10^3$)	Reference
CfA1	30%	0.03	$B = 14.5$ mag	2.4	de Lapparent et al. (1986)
ORS	60%	0.03	$B = 14.0$ mag	8.5	Santiago et al. (1995)
SSRS2+	60%	0.04	$B = 15.5$ mag	23.6	da Costa et al. (1998) and
CfA2					Huchra et al. (1999)
IRAS PSCz	85%	0.08	$60\ \mu\text{m} = 0.6$ Jy	16.1	Saunders et al. (2000)
LCRS	1%	0.17	$R = 17.5$ mag	25.3	Shectman et al. (1996)
2dF	8%	0.19	$b_J = 19.5$ mag	245.6	Colless et al. (2001)
SDSS[b]	35%	0.33	$r = 17.5$ mag	943.6	Aihara et al. (2011)
6dFGS	40%	0.10	$K_s = 12.65$ mag	124.6	Jones et al. (2004, 2005, 2009)
2MRS11.25	83%	0.04	$K_s = 11.25$ mag	20.6	Huchra et al. (2005)
2MRS	91%	0.05	$K_s = 11.75$ mag	43.5	This work

Notes.
[a] 90 percentile redshift value in catalog.
[b] DR8 main galaxy sample.

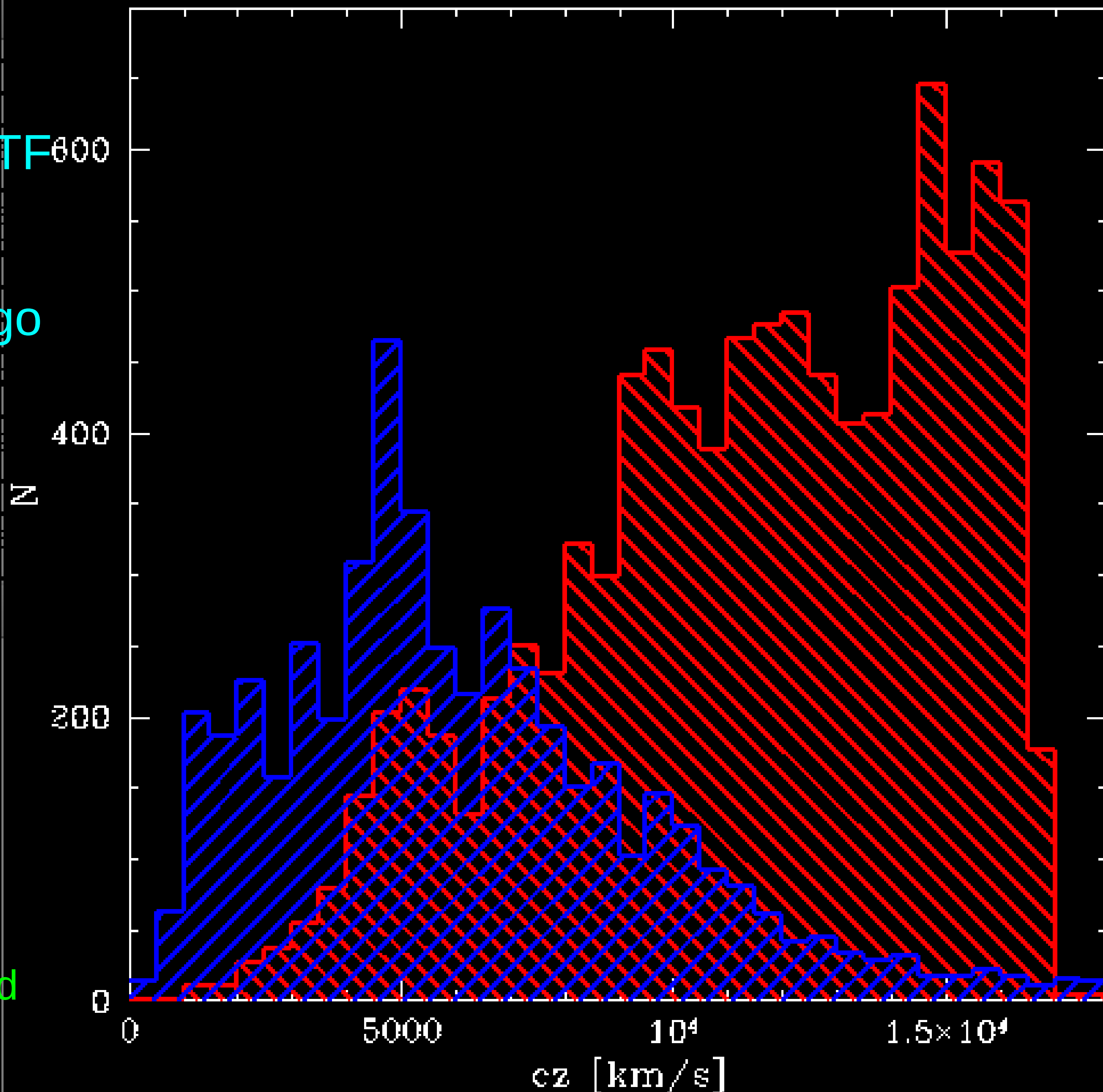
Source: Huchra et al. (2011) Table 1.

Conclusions

- Current generation of galaxy peculiar velocities each have ~3000 to ~10,000 galaxies—with WALLABY and TAIPAN, we can grow this by an order of magnitude
- WALLABY & TAIPAN, as peculiar velocity surveys, will be complementary—the former giving us peculiar velocities for the spirals, and the latter for ellipticals
- The redshifts from WALLABY will also be useful to peculiar velocity studies, in that one can reconstruct predicted peculiar velocity field models from redshifts alone.

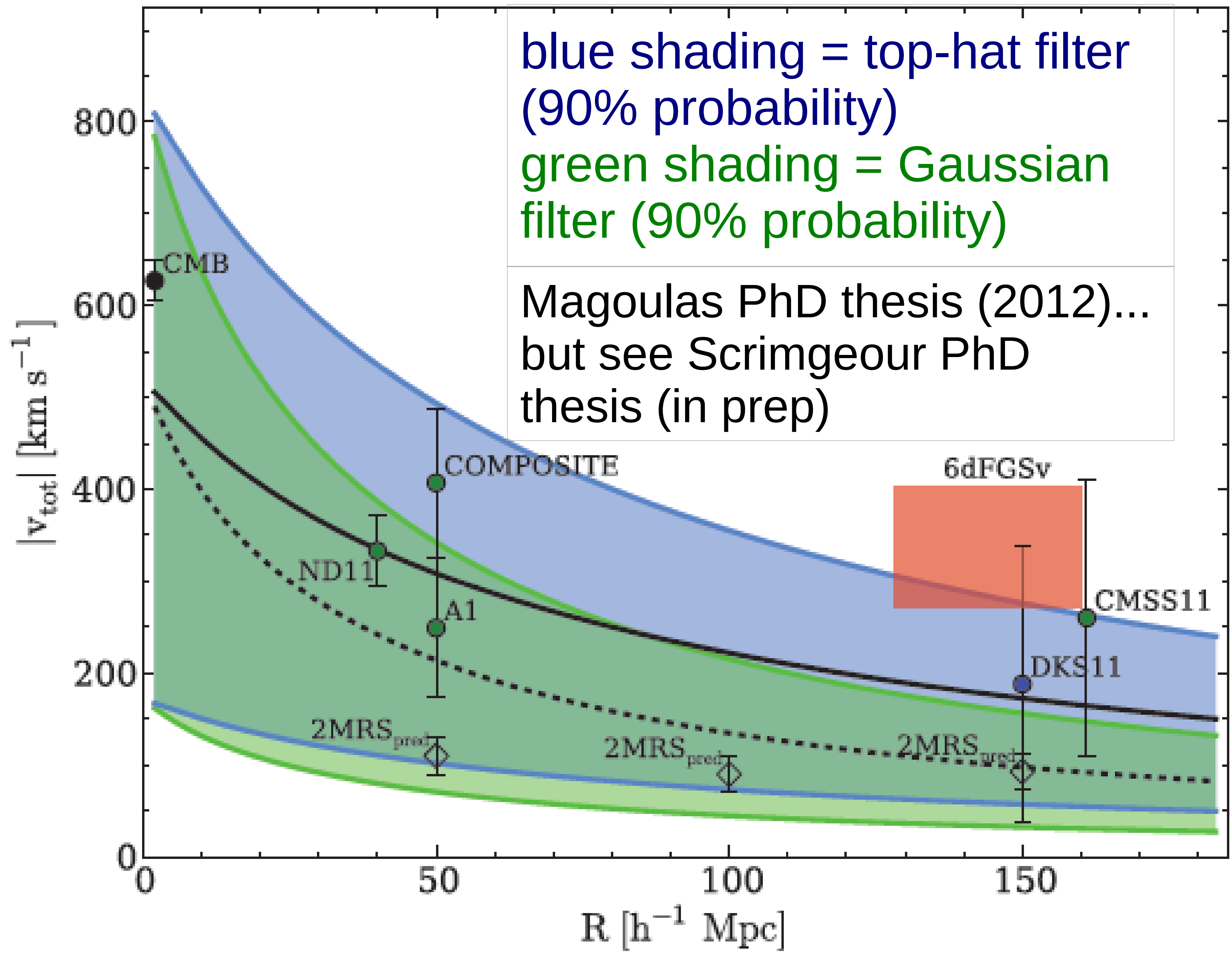
Extra slides

There are more TF galaxies in the universe, but FP surveys tend to go deeper.



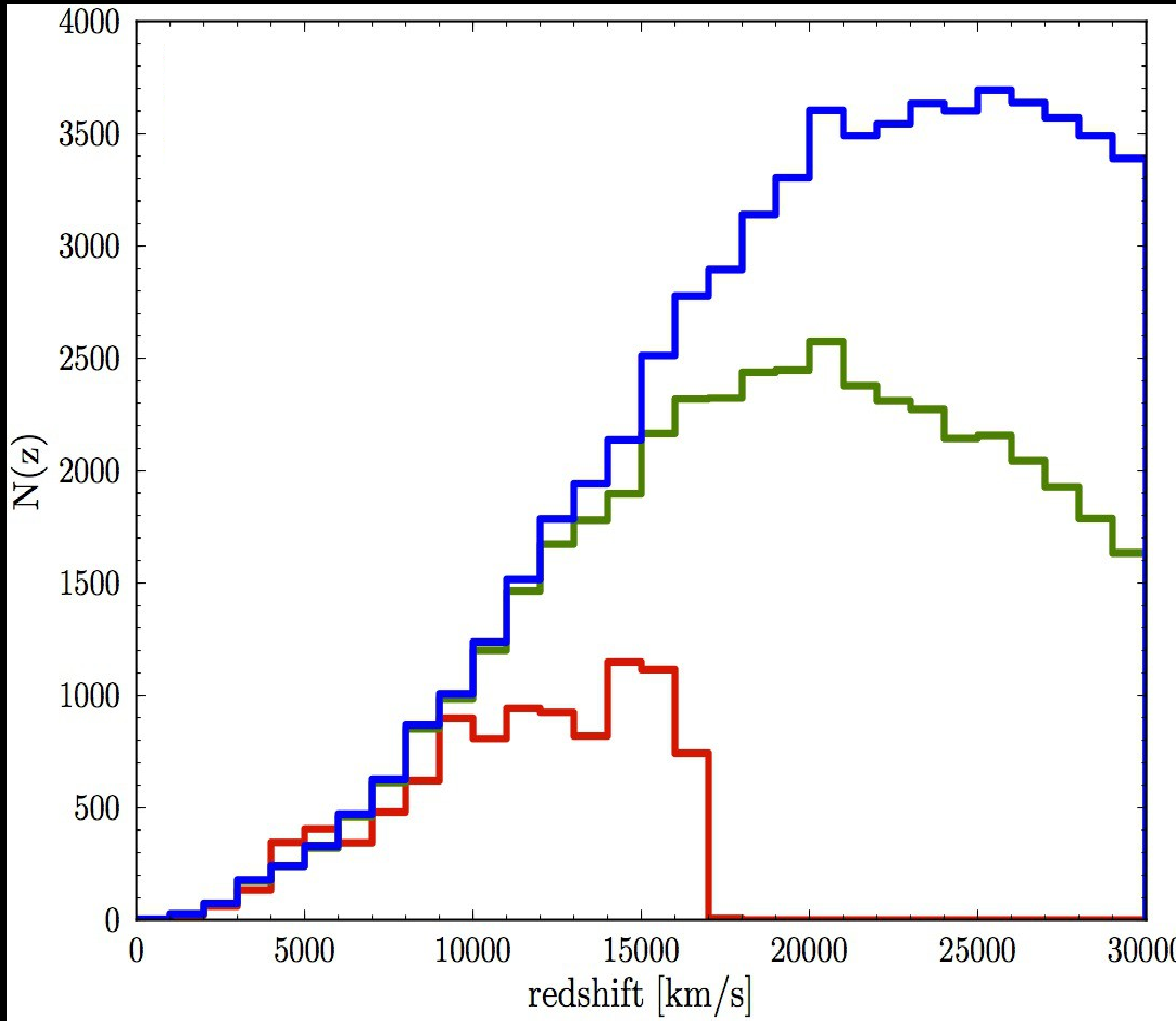
Redshift histogram for SFI++ (blue) and 6dFGS (red).

6dFGS results



TAIPAN mock redshift distribution

Right: Simulated redshift histogram for TAIPAN FP, assuming a J-band magnitude limit of 15.15 (blue) and 14.65 (green). Also shown is the actual redshift histogram for 6dFGS FP (red).

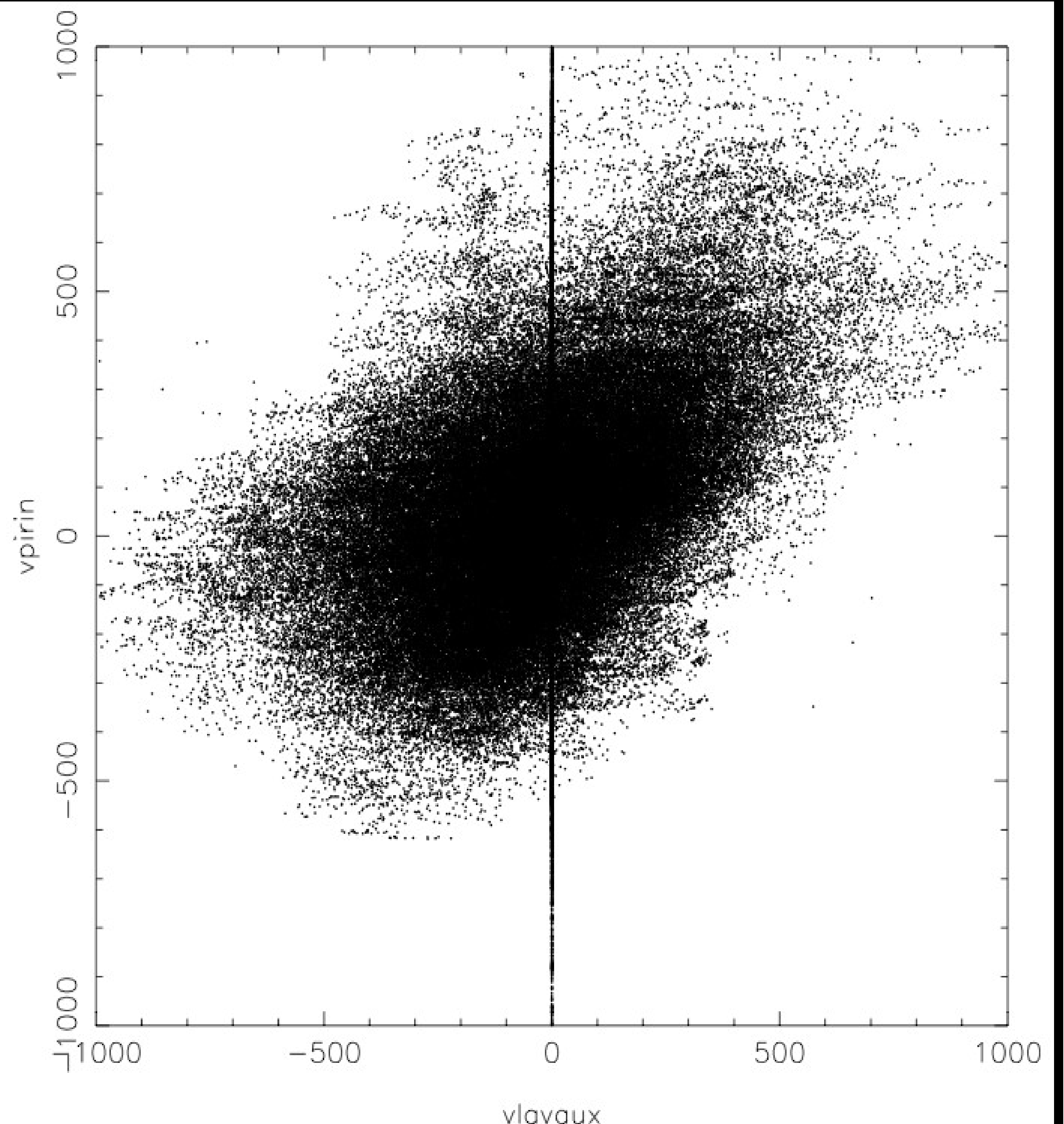


Galaxy peculiar velocities

Can be used for:

- Cosmology
- Cosmography

Different velocity field reconstructions agree with each other in terms of gross features, but disagree in the details, and do not reproduce CMB dipole.



- you assume that the matter density field is a homogeneous background, with small perturbations on large scales: the linear approximation to gravitational instability theory

$$\mathbf{v}(\mathbf{r}) = \frac{f(\Omega)}{4\pi} \int d^3\mathbf{r}' \frac{\mathbf{r}' - \mathbf{r}}{|\mathbf{r}' - \mathbf{r}|^3} \delta_{mass}(\mathbf{r}')$$

where $f(\Omega) = \sim \Omega_m^{0.55}$

$_{mass}(r)$=mass overdensity

Evolution of density field with time:

$$(x,t) = {}_0(x)f(t)$$

density grows “self-similarly”

v_{pec} field gives us present-day mass field, which is the same as initial density perturbations!