WALLABY Peculiar Velocities: Synergies with 2MTF and 6dFGS

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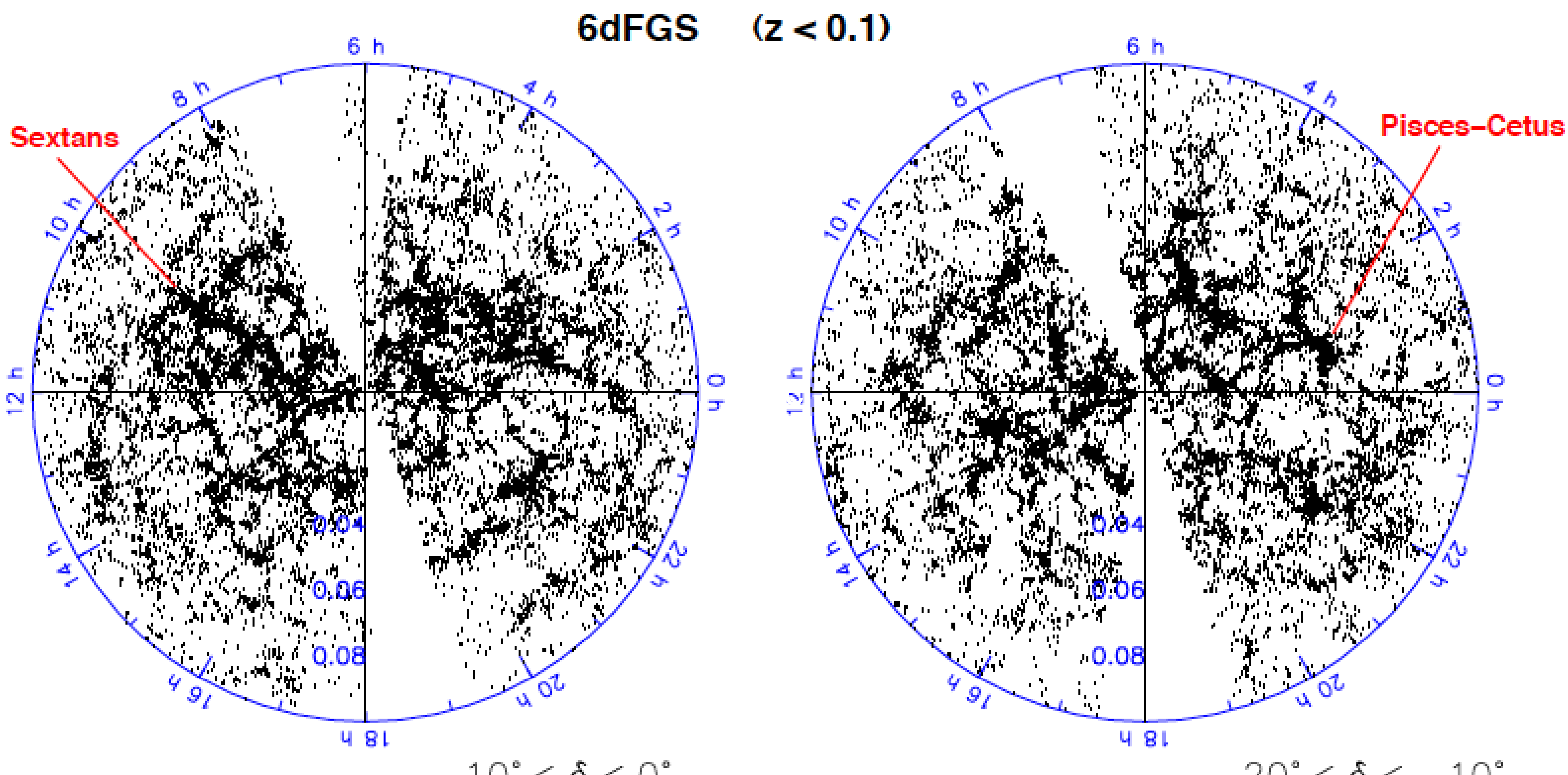


Outline

- 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?
- 2MTF and 6dFGS:
  - Description of the surveys, and how they will feed into WALLABY

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 (late types) and FP (early types) from photometry + spectroscopy can give you peculiar velocities for thousands of galaxies.

Tully-Fisher (TF) relation: Scaling relation for spirals

- Bigger, more luminous galaxies rotate faster --> For spiral galaxies, $L \sim v_{rot}^{\alpha}$, where $3 < \alpha < 4$
  - magnitudes, redshifts, and rotational velocities (from spectral line widths—optical or HI 21 cm line) --> distances and peculiar velocities

Fundamental Plane (FP) relation:

Scaling relation for early type galaxies

Effective radius ~ (velocity dispersion^{a}) * (surface brightness^{b})

$\log(R_e) = a \log(\sigma) + b \log(I_e) + c$ where.....

- R_e = half-light radius (physical units, not angular units)
- σ = velocity dispersion
- I_e = surface brightness
- *a*, *b*, *c* = parameters of the plane

As with TF, you need both photometry and spectroscopy

What you might want from an ideal survey

- Large number of objects, homogeneous sampling over as large a fraction of sky as possible
- Redshift range.....you're stuck with ~20% distance errors or more for both TF and FP
  - Larger survey volume is better, but distance errors swamp the peculiar velocities very quickly when you get to cz~20,000 km/s or more

TF / FP peculiar velocity surveys including ~5000 galaxies or more

Published:

TF = blue
FP = red

- **SFI++**: Masters et al. 2006, Springob et al. 2007
  - ~5000 galaxies, all sky, <cz>~5000 km/s

In prep:

- **2MASS Tully-Fisher (2MTF)**
  - ~5000 galaxies, all sky, <cz>~5000 km/s, $|b| > 5$ degrees
- **“Cosmic Flows”**
  - eventually, ~10,000 galaxies, all sky, cz < 6000 km/s
- **6 degree field Galaxy Survey (6dFGS)**
  - ~10,000 galaxies, southern sky, <cz>~12,000 km/s

In prep.*:

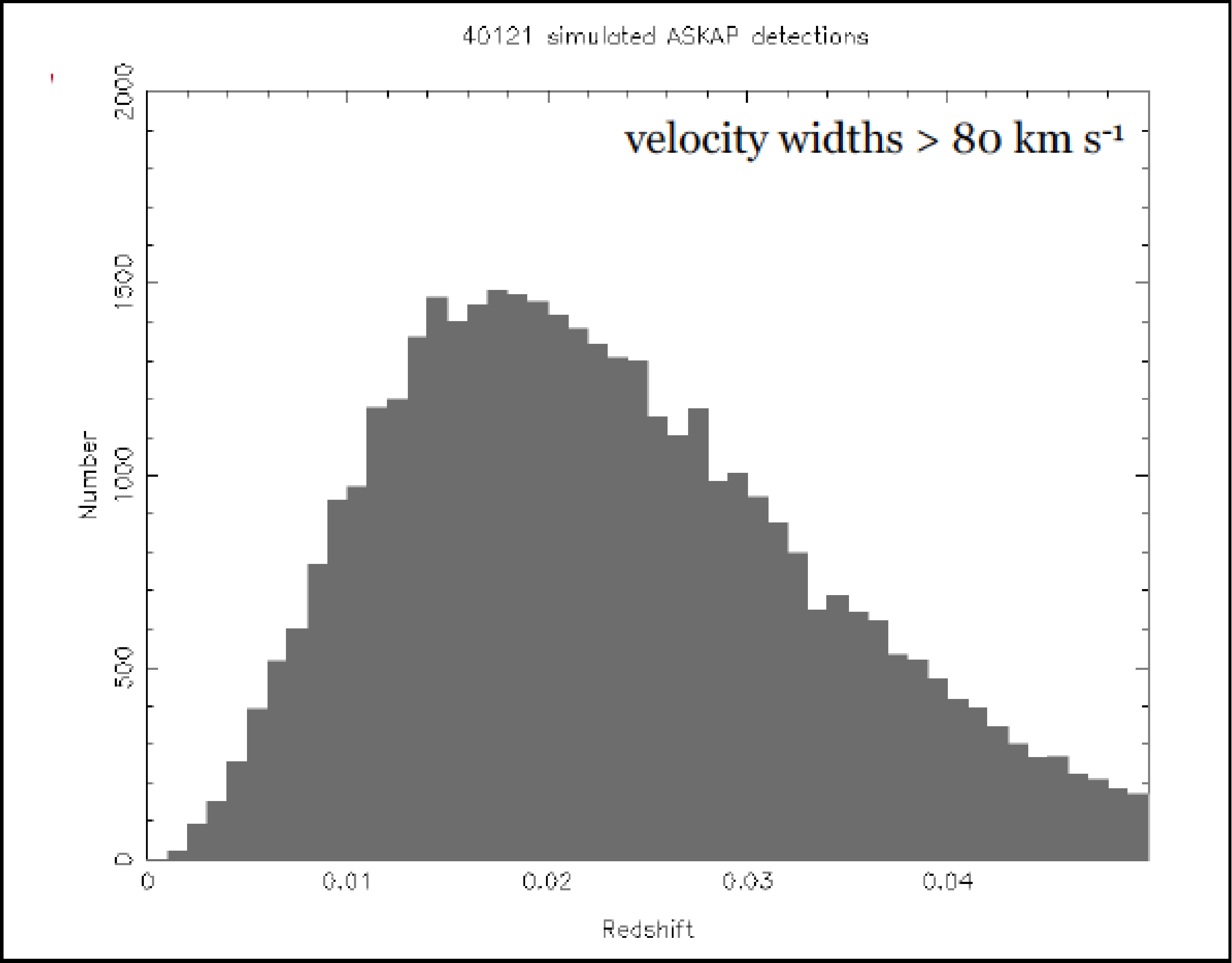
- 6dFGS + SDSS + NFP
  - ~20,000 galaxies? all sky, <cz> = 10,000 – 15,000 km/s?

Future:

- TAIPAN?
  - UK Schmidt Telescope survey, details TBD
- WALLABY + WNSHS
  - ~40,000 galaxies?, all sky, <cz> = 8000 km/s?
  - Could potentially exceed all previous peculiar velocity surveys over the relevant redshift range

WALLABY + WNSHS

Redshift histogram of ~40,000 galaxies estimated to be suitable TF galaxies in WALLABY + WNSHS



Two current galaxy peculiar velocity surveys with significant Australian involvement

- 2MTF (Tully-Fisher)

Observations (mostly) completed; data reduction underway

- 6dFGS (Fundamental Plane)

Observations completed; data reduction completed; derivation of peculiar velocities underway

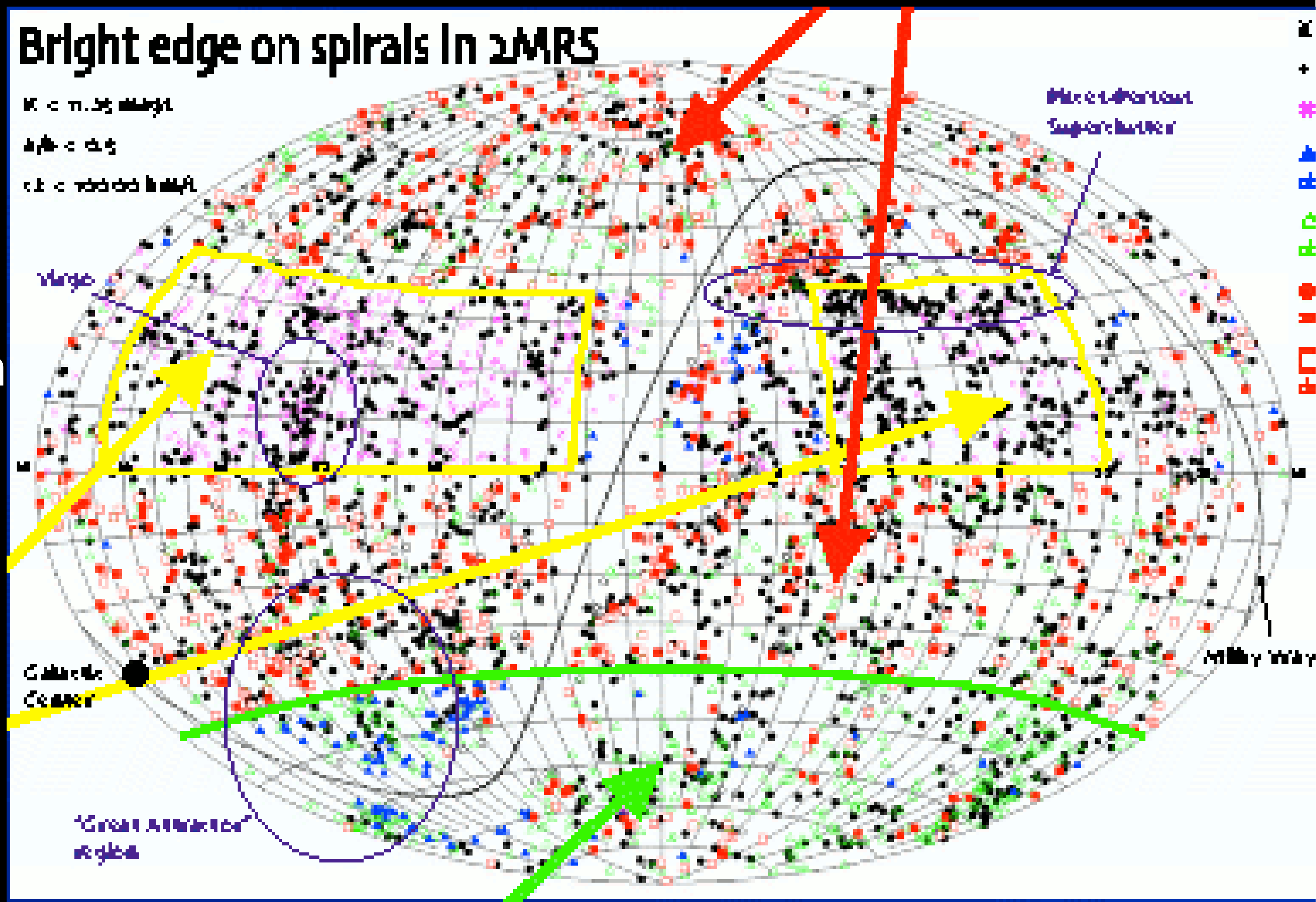
2MASS TF Survey (2MTF)

- TF distances for ~5000 bright (m_k=11.75) edge-on spirals in 2MRS
- Photometry from 2MASS; spectroscopy from three radio telescopes: Arecibo, GBT, Parkes
- Advantages over SFI++:
  - Homogeneous selection criteria
  - Homogeneous photometry
  - HI spectroscopy only, so smaller width errors
  - Will extend deep into ZOA (b=|5°|)

2MTF Current Status

Outside Arecibo dec. range, HI observations are done...though data reduction is still ongoing

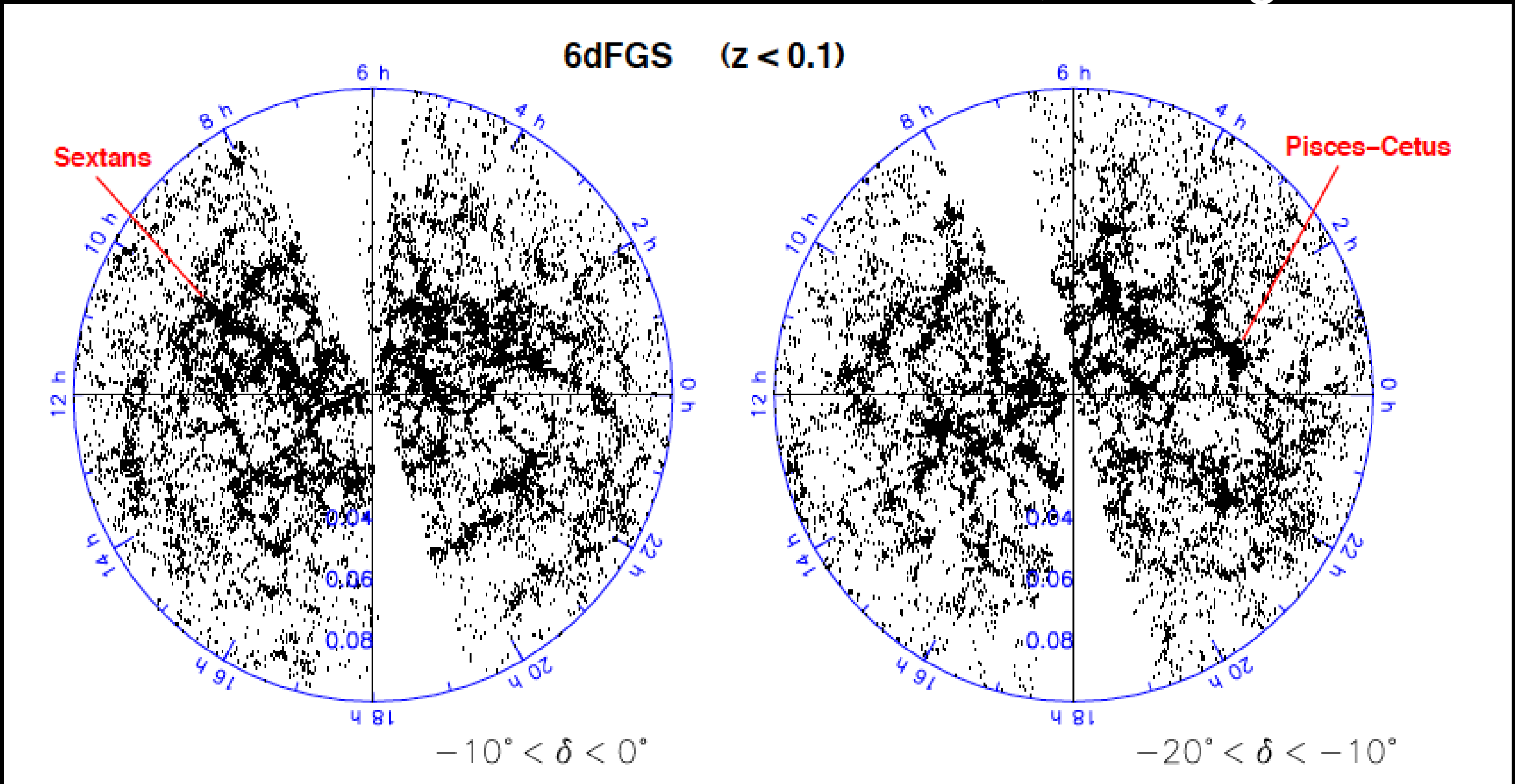
Within Arecibo dec. range, we rely on ALFALFA survey, which goes through 2012?



Green Bank
Arecibo
Parkes

The 6dF Galaxy Survey

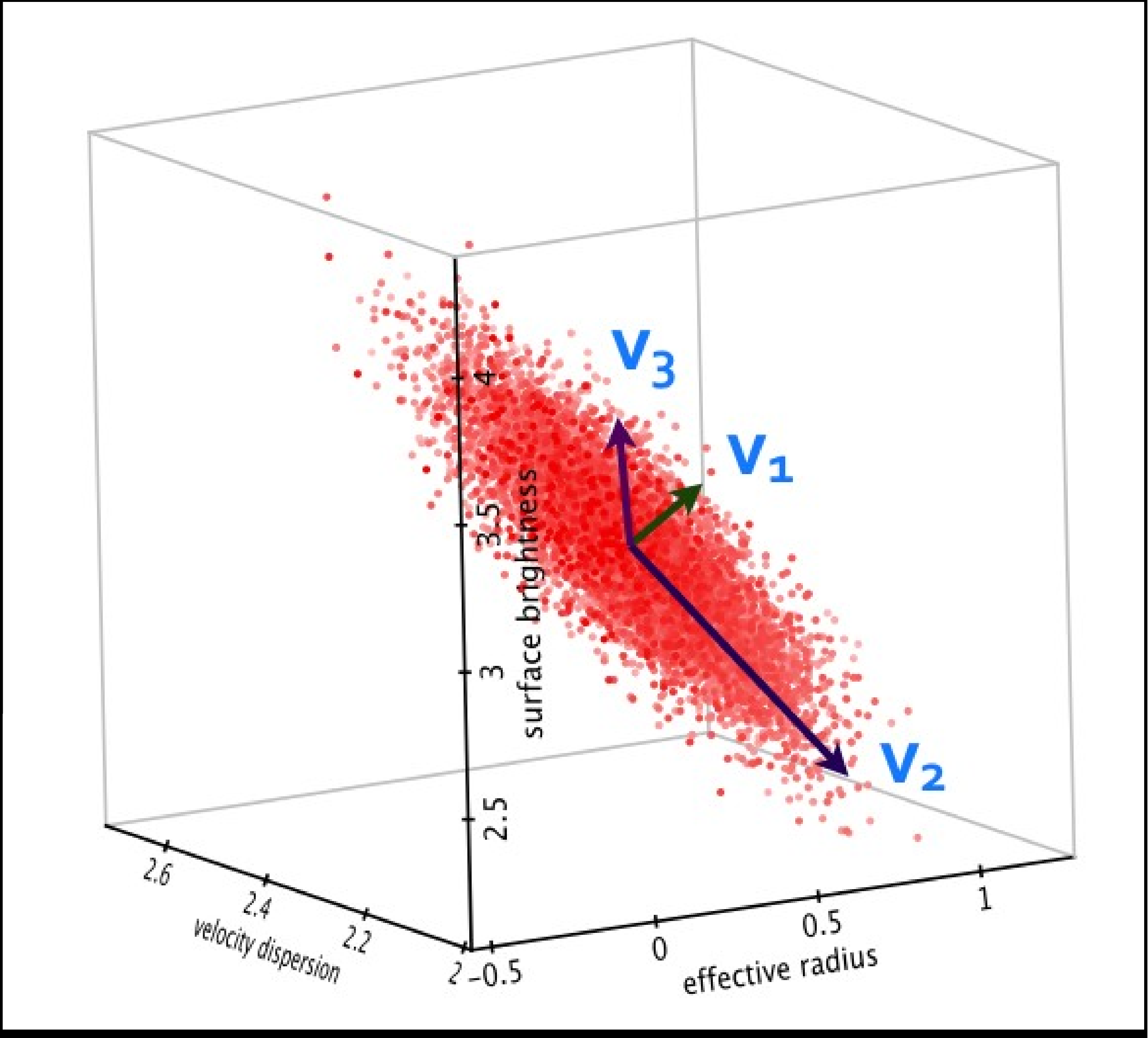
- Spectroscopic survey of southern sky with $|b|>10°$ (17,000 deg^2) from AAO's UK Schmidt Telescope at Siding Spring
- The 6dFGS is both a redshift (z-) and a peculiar velocity (v-) survey
- 2MASS photometry + 6dFGS spectroscopy: FP distances and PVs for ~10,000 early-type galaxies
- Observations & data reduction done; working on deriving distances



Slices of 6dFGS at -20 < decl. < 0°, out to z = 0.1.

Maximum likelihood fitting of 3-d Gaussian model

- The Fundamental Plane is fit by performing maximum likelihood fit to a 3d gaussian distribution.
- More robust than doing a least squares regression fit on one parameter.



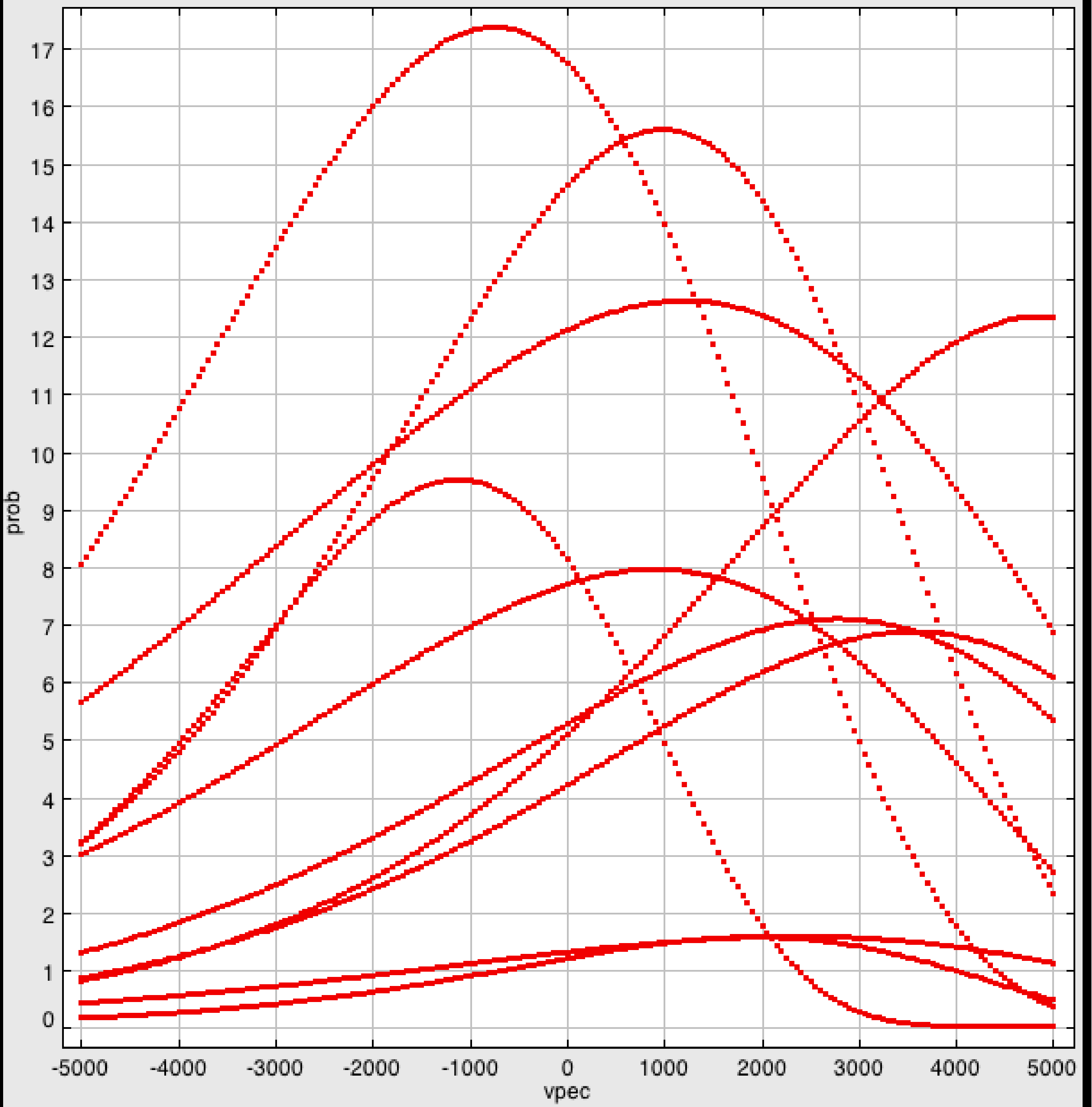
Bayesian peculiar velocities

$$P(v_i|D,M) = \frac{P(v_i|M) * P(D|v_i,m)}{P(D|M)}$$

- M = model parameters (fixed by Maximum Likelihood FP fitting)
- D = the data
- $P(D|M)$ = Normalization (of data)
- $P(v_i|M)$ = Prior
- $P(D|v_i,M)$ = Likelihood of galaxy (given our model)

From $P(v_i|D,M)$ we calculate a posterior probability distribution of peculiar velocities for each galaxy

Bayesian peculiar velocities



Likelihood distribution of peculiar velocities for 10 galaxies in 6dFGS.

Specific synergies and crossover applications from 2MTF and 6dFGS to WALLABY

- 6dFGS & WALLABY are complementary, as they probe (almost) mutually exclusive samples of galaxies in the same cz range
- Each peculiar velocity survey provides an independent check on the velocity field
- 2MTF and 6dFGS as testing ground for WALLABY: building up expertise on large peculiar velocity surveys in Australia
- New tools developed w/ existing surveys:
  - maximum likelihood fitting
  - Bayesian peculiar velocities
  - peculiar vels + redshifts (Burkey & Taylor 2004)

Conclusions

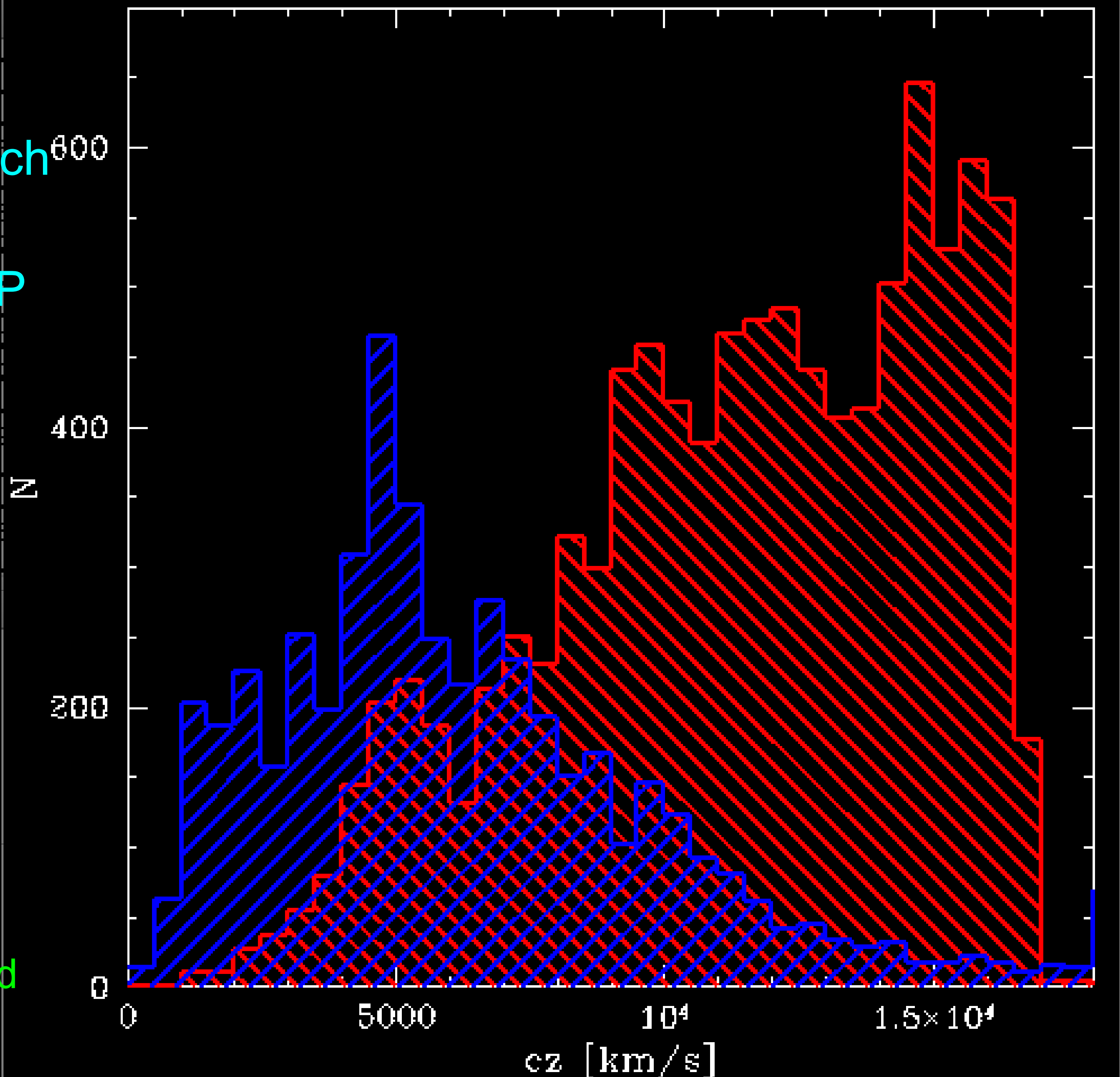
- We're on the cusp of making major new steps forward in galaxy peculiar velocity surveys, and the Australian community is involved in most of the new surveys
    - 2MASS Tully-Fisher (2MTF)
    - 6dFGS
    - WALLABY + WNSHS may potentially be largest galaxy peculiar velocity survey ever upon completion
        - should provide significant advances in our understanding of large scale flows and the large scale distribution of matter
    - 2MTF and 6dFGS can help lead the way for WALLABY, as they allow us to build up expertise in Australia, and get a jump start on some of the challenges with such datasets

Comparison of surveys

Not as deep as SDSS, but broader sky coverage.

	6dFGS	2dFGRS	SDSS-DR7
Magnitude limits	$K \leqslant 12.65$ $H \leqslant 12.95$ $J \leqslant 13.75$ $r_F \leqslant 15.60$ $b_J \leqslant 16.75$	$b_J \leqslant 19.45$	$r \leqslant 17.77$ (Petrosian)
Sky coverage (sr)	5.2	0.5	2.86
Fraction of sky	41%	4%	23%
Extragalactic sample, N	125 071	221 414	644 951
Median redshift, $z_{\frac{1}{2}}$	0.053	0.11	0.1
Volume V in $[0.5z_{\frac{1}{2}}, 1.5z_{\frac{1}{2}}]$ $(h^{-3}\,\mathrm{Mpc}^3)$	2.1×10^7	1.7×10^7	7.6×10^7
Sampling density at $z_{\frac{1}{2}}$, $\bar{\rho} = \frac{2N}{3V}$ $(h^3\,\mathrm{Mpc}^{-3})$	4×10^{-3}	9×10^{-3}	6×10^{-3}
Fibre aperture ($''$)	6.7	2.0	3.0
Fibre aperture at $z_{\frac{1}{2}}$ $(h^{-1}\,\mathrm{kpc})$	4.8	2.8	3.9

6dFGS goes much deeper than any previous large FP or TF survey.



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

Lessons learned on TF errors

- How to minimize peculiar velocity errors
  - Grouping information: group distance error decreases by sqrt(N)
  - In TF, velocity width error is much bigger than magnitude error....however galaxy inclination error (from the photometry) is major contributor to this
  - Morphological types: early spirals and late spirals follow somewhat different TF relations

6dFGS Fundamental Plane current status

- All observations are complete
- All data is completely reduced
- Have derived half-light radii, surface brightnesses, velocity dispersions, and uncertainties on each of those parameters
- Have developed a code that fits a 3d gaussian (and hence, a plane) to the data via Maximum Likelihood algorithm
- Have derived “first cut” peculiar velocity measurements for each galaxy, however....
- Still developing the method for making all of the bias corrections on the peculiar velocities, and checking results