6dFGS Peculiar Velocities and All That

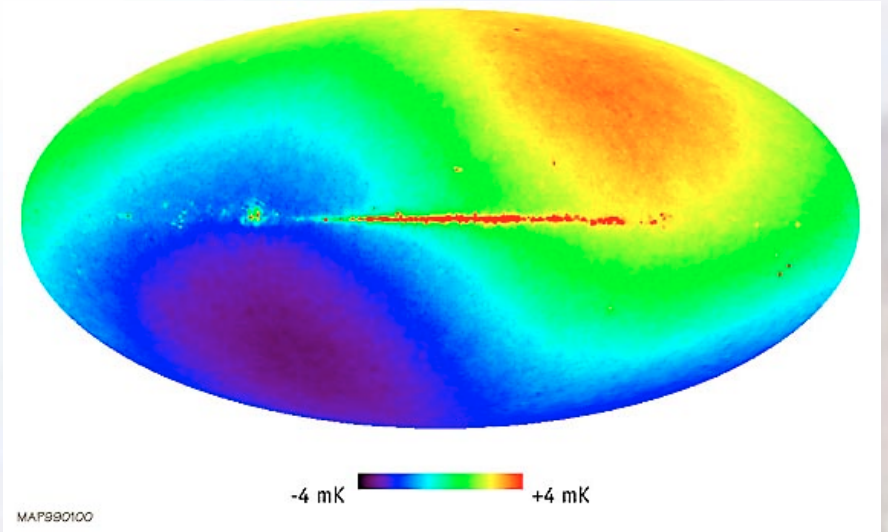
John Lucey (Durham)

$$V_{pec} = cz - H_0 d$$

Outline:

- Background
- The Fundamental Plane
- 6dFGSz and 6dFGSv
- Ongoing FP extensions
- Future prospects with TAIPAN and LoRCA

Key Questions



WMAP: CMB dipole of 3.346 +/- 0.017 mK in a direction of (l,b) = (263.85+/-0.1, 48.25 +/- 0.04)

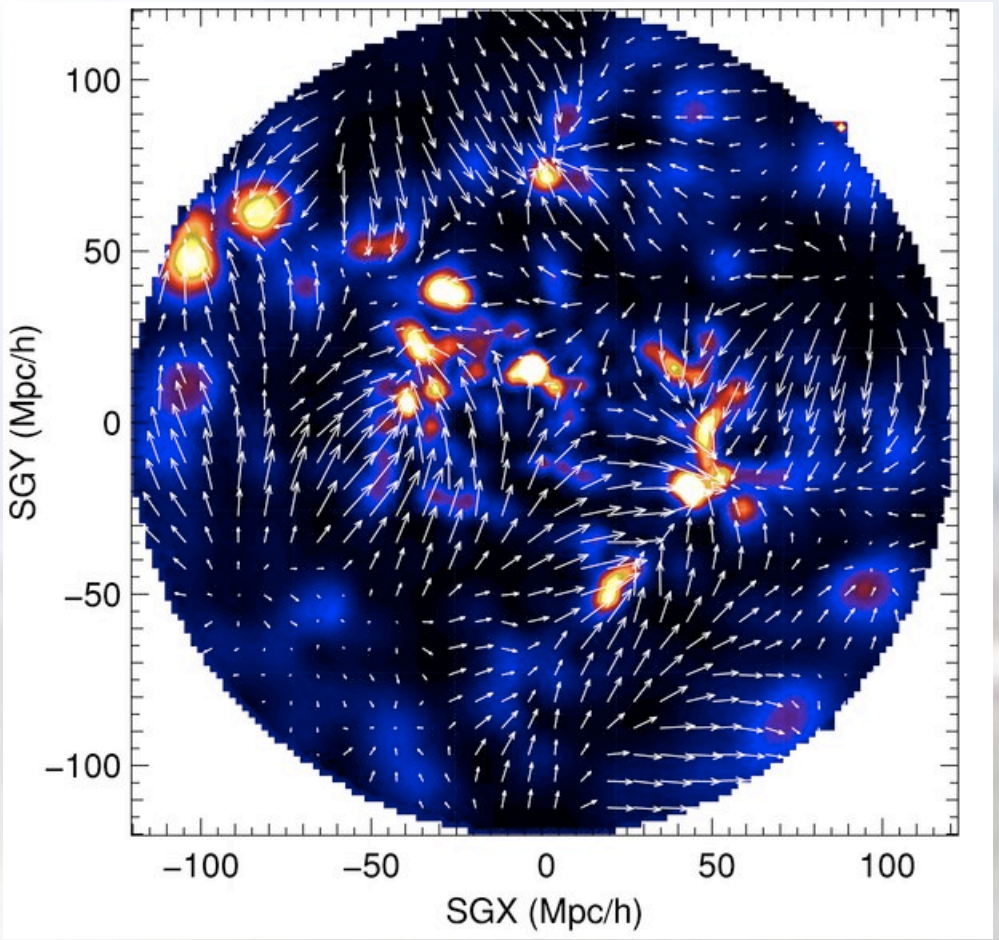
LG velocity wrt CMB is ~620 km/s towards (l,b) = (277,30)

Two very basic questions:

What masses are the source of the LG motion?

What is size of bulk flow on large-scales?

Reconstructions from Redshift Surveys



2MRS Reconstruction (Lavaux et al 2010)

Peculiar velocities arise from inhomogeneities in the large-scale mass distribution.

Redshifts trace the density field and the peculiar velocity field.

Peculiar Velocities

Measured directly via $V_{pec} = cz - H_0 d$

cz is easy and accurate.
$H_0 d$ is always a challenge to measure well
and has sizeable errors (10 – 20%).

Four distance indicators primarily used:
Fundamental Plane (FP),
Tully-Fisher (TF),
Surface Brightness Fluctuations,
type Ia supernova.

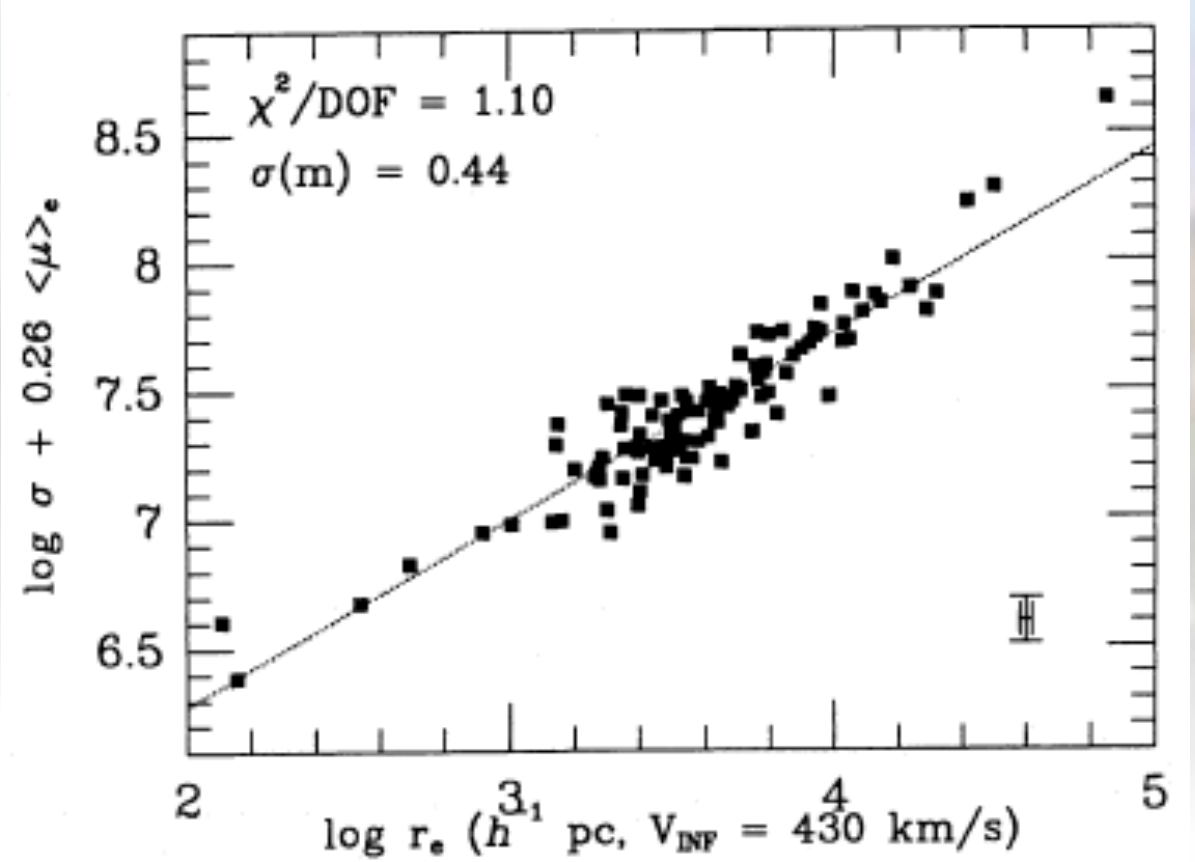
Each method has advantages and limitations, e.g.
numbers of objects,
intrinsic precision,
sensitivity to systematic uncertainties.

Early FP Studies

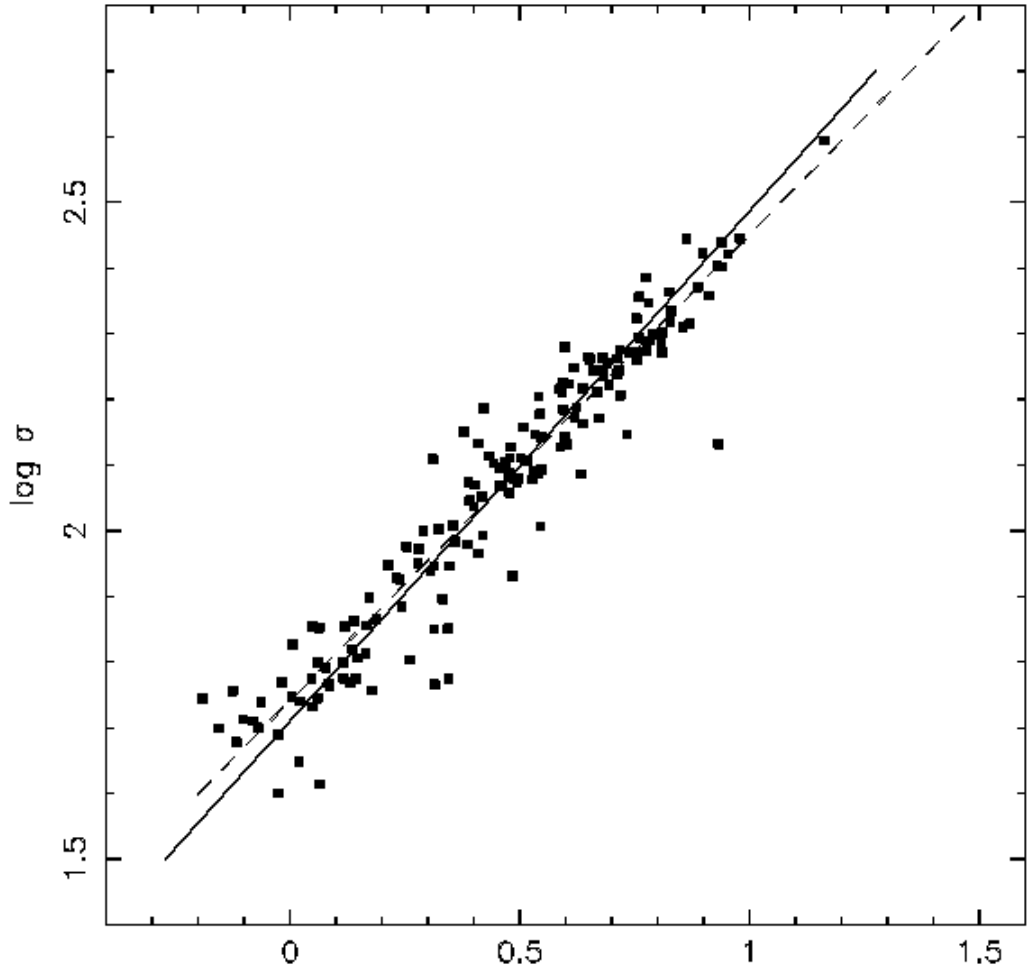
Dressler et al 1987 (7S) Six clusters (Dn-sigma)

Djorgorvski & Davis 1987 “Fundamental Plane”

The empirical relation between the central velocity dispersion, the effective (half-light) radius and effective surface brightness.



FP for Early-Type Coma cluster Galaxies



$$X_{FP} = \log R_H - 0.33*(SB_H - 17.5)$$

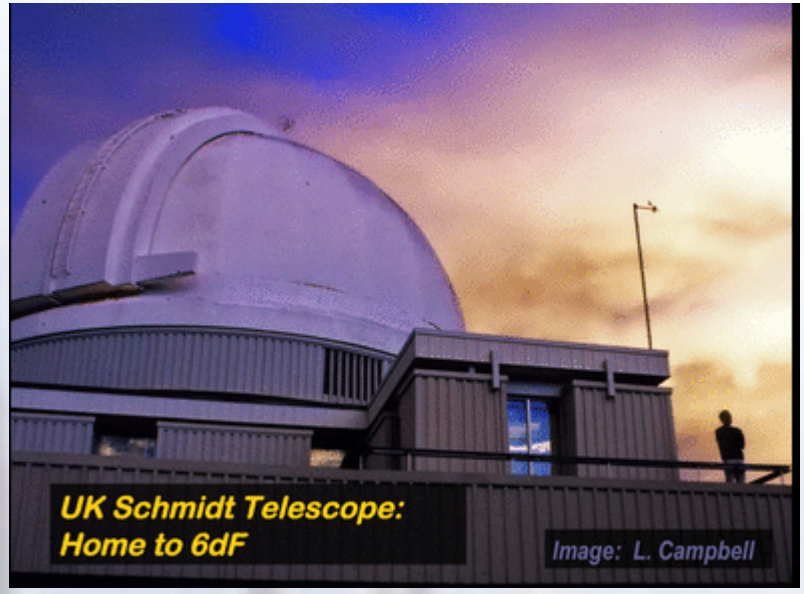
FP Peculiar Velocity Studies: Long/Ancient History!

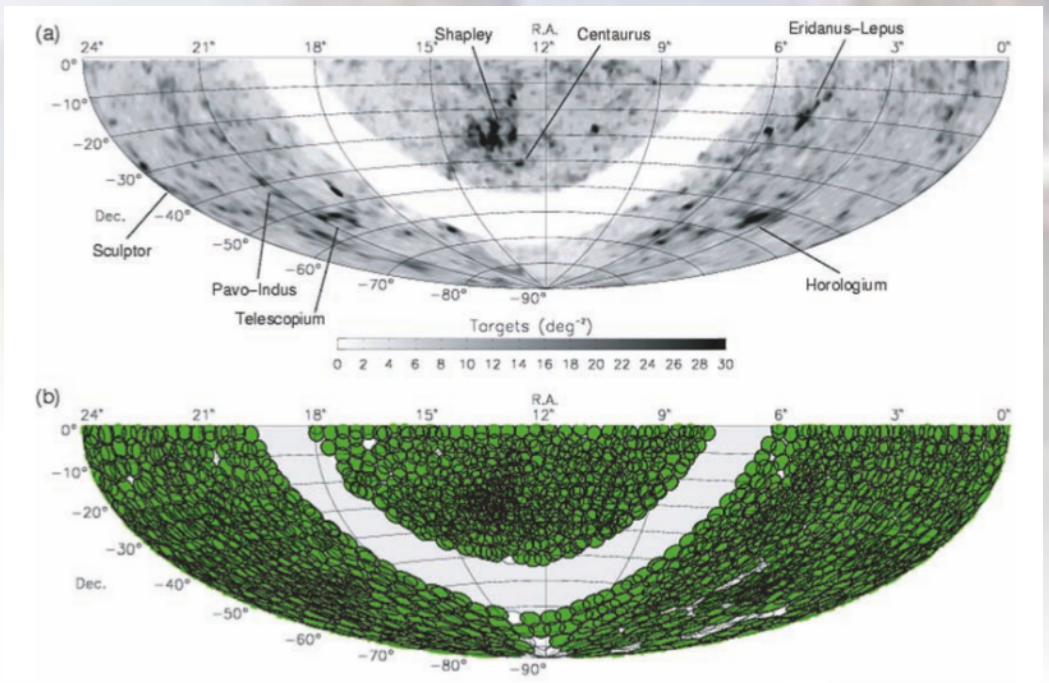
7S 1987-1989	All sky sample of ~400 early-types
Lucey & Carter 1988	Five southern clusters (Dn-sigma) first fibre sigma measurements
Lucey et al 1991	Coma: radial trends
Jorgensen et al 1993	Coma: Dn-sigma vs FP
Jorgensen et al 1995	Ten clusters
Pahre et al 1995	K-band FP for five clusters
Hudson et al 1997	Perseus-Pisces
Hudson et al 1999	SMAC
Colless et al 1999	EFAR (Cor-Bor, Per-Pis-Cetus)
Mobasher et al 1999	K-band Coma
Bernardi et al 2002	ENEAR
Blakeslee et al 2002	FP vs SBF
Bernardi et al 2003	SDSS FP
Smith et al 2004	NFPS
Magoulas et al 2012	6dFGSv

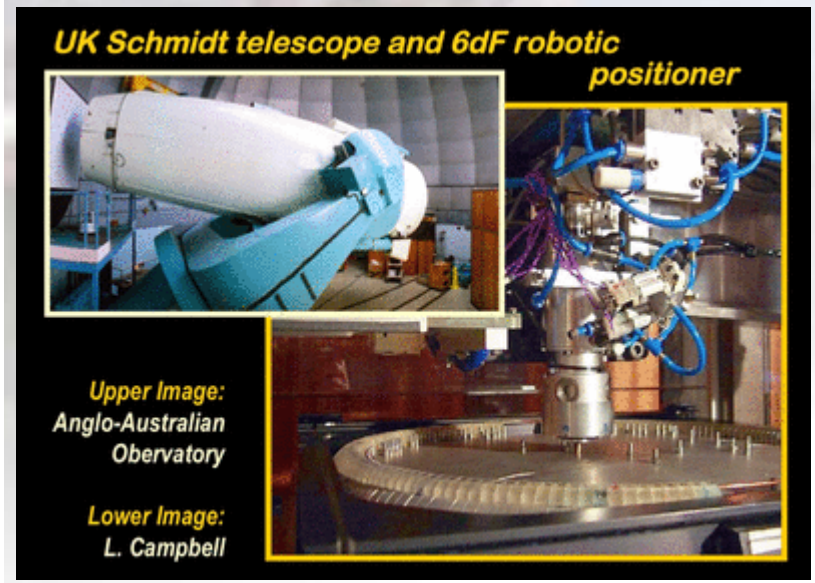
6df Technical Overview

1.2-metre UK Schmidt Telescope.

150 fibre buttons over 5.7 degree-diameter FoV.
100 micro (6.7 arcsec) fibres.
Wavelength: 3900-5600A and 5400-7500A.
FWHM resolution 5-6A in V and 9-12 A in R.
Adaptive tiling of the fields.
Dec < 0 deg and | b | > 10 deg.
Primary sample has K_tot < 12.75 mag.
Median redshift 0.053.



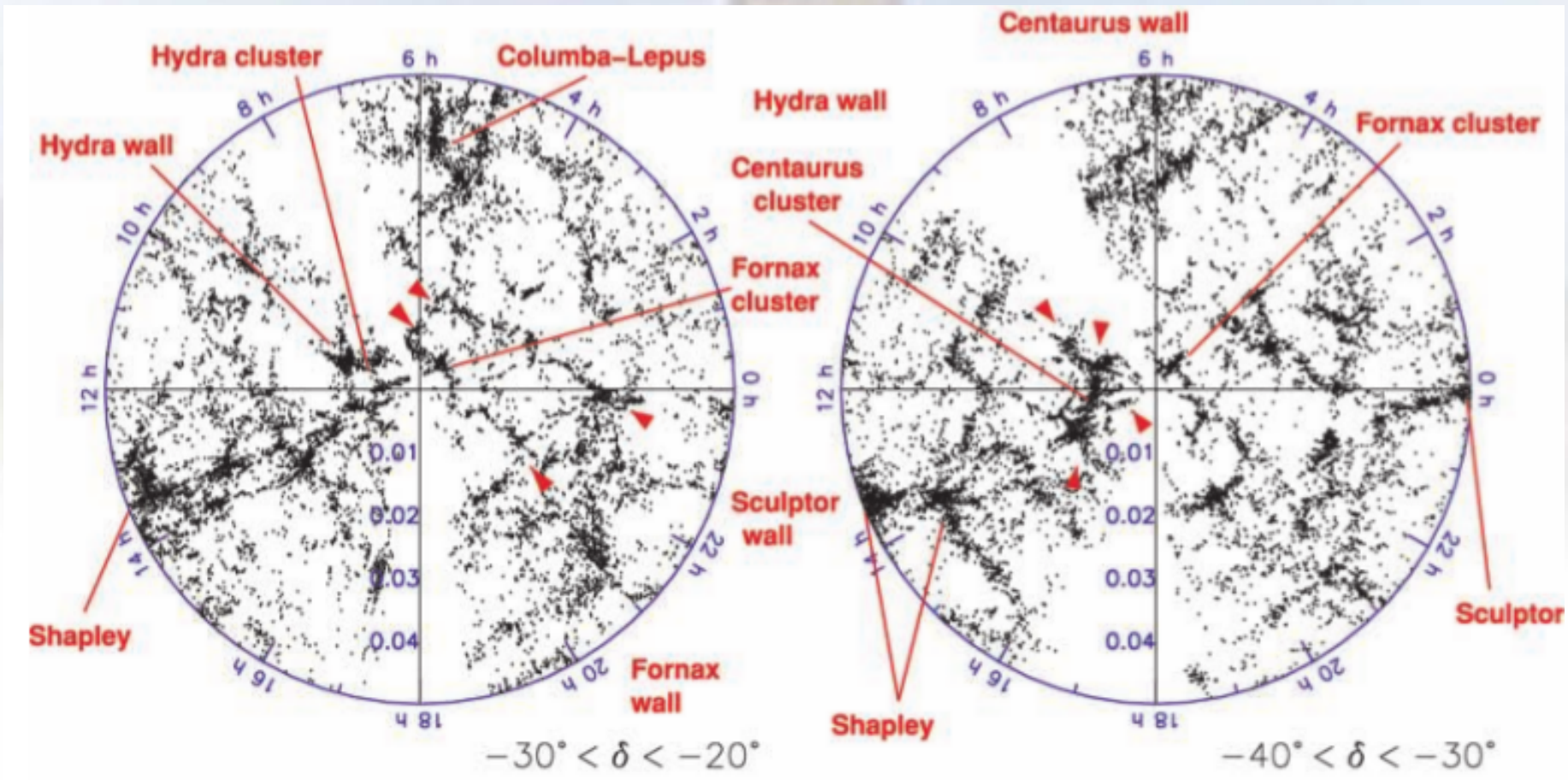




6dF Galaxy Survey (6dFGSz)

Matthew Colless, Heath Jones, Lachlan Campbell, Jeremy Mould, Tom Jarrett, John Lucey, Pirin Erdogdu, Chris Blake, Andrew Johnson, Morag Scrimgeour, Tamara Davis, Chris Fluke Alex Merson …

Map the southern cosmography with ~110 k redshifts .
Probes the Great Attractor region and the mighty Shapley.



The 6dF Galaxy Survey: Fundamental Plane Data

Lachlan A. Campbell[1], John R. Lucey[2⋆], Matthew Colless[1,3], D. Heath Jones[1,4], Christopher M. Springob[1,5,6], Christina Magoulas[1,7] Robert N. Proctor[8], Jeremy R. Mould[7,9], Mike A. Read[10], Sarah Brough[1], Tom Jarrett[11,12], Alex I. Merson[2,13], Philip Lah[3], Florian Beutler[5,14], Michelle E. Cluver[1,11], and Quentin A. Parker[1,15]

Velocity dispersions for 11k galaxies.

FP photometry parameters from measurement of the JHK 2MASS tiles.

Morphologically culled to provide an FP sample of ~9k “early-type” galaxies.

FP Photometric Parameters from 2MASS

2MASS

Excellent all-sky coverage in J,H,K

Very shallow dataset : 7.8s only with1.3m telescopes

Best S/N in J-band, PSF: ~3” FWHM

Excellent all-sky photometric calibration (0.02 mag).

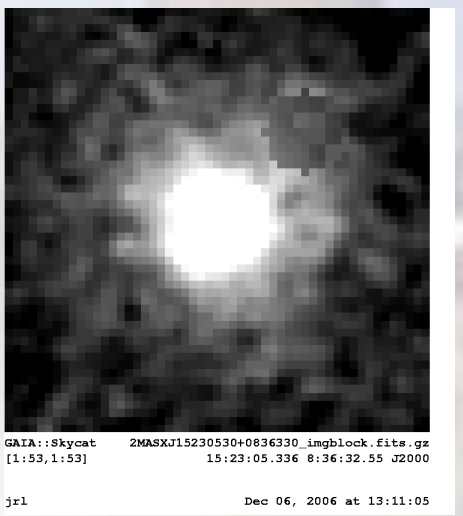
Extended Source Catalogue has 1.6 million objects
and lists 389 parameters for each.
(But not PSF-corrected!)

Superb dataset for FP peculiar velocity studies.

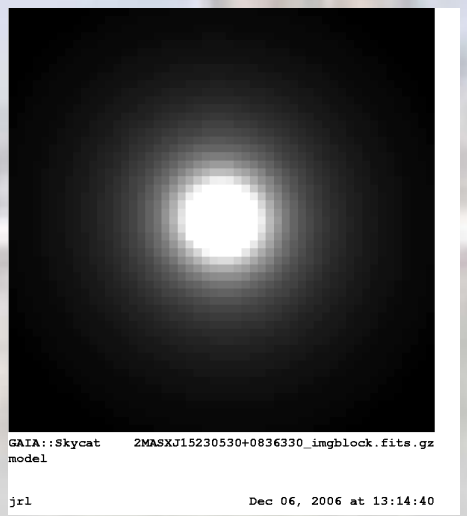
Measuring FP photometric parameters from 2MASS

Take 2MASS postage stamps
Measure the PSF from stars on the image tile
Use Chein Peng's GALFIT 2-D image fitting (Sersic)

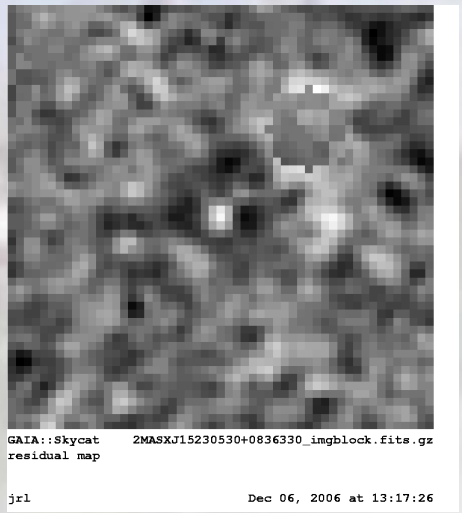
RAW



MODEL x PSF



DIFFERENCE



Use GALFIT to measure PSF-correction only!

PSF correction to the effective (half-light) Radii

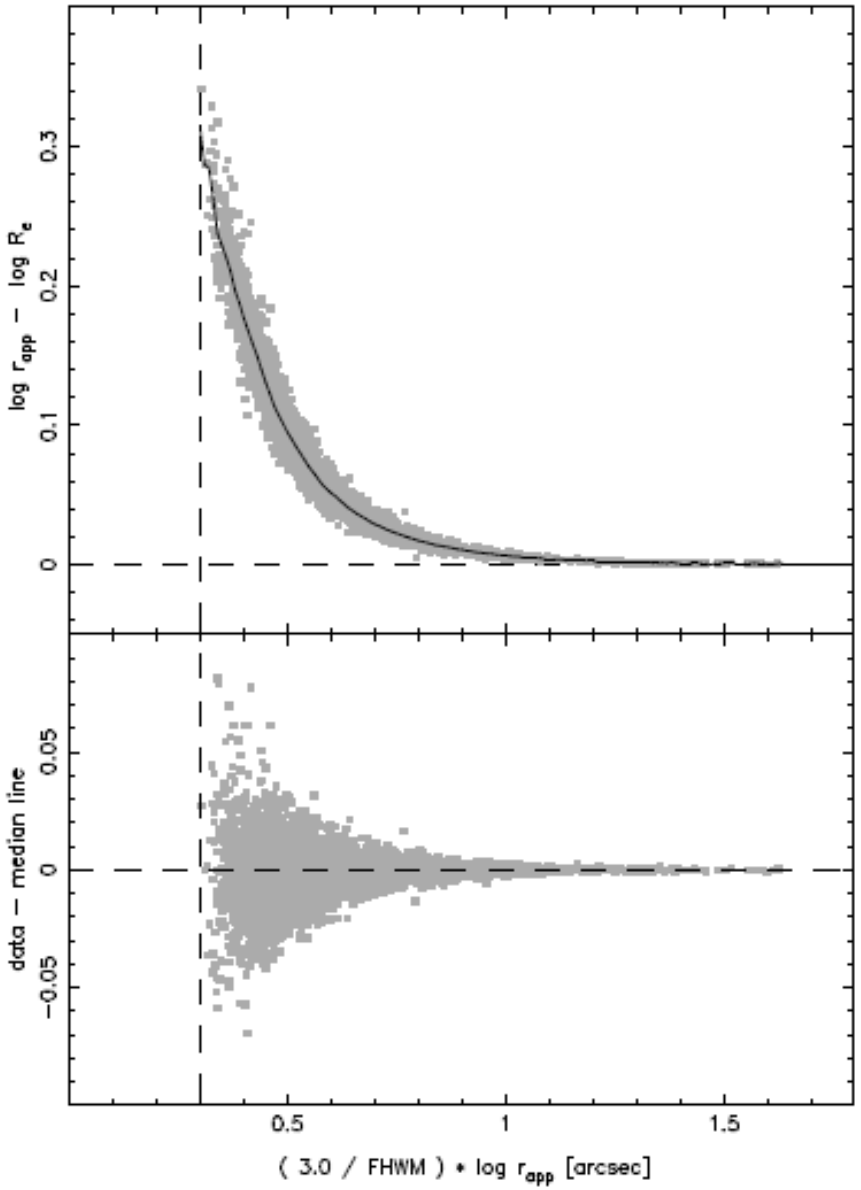
Adopt 2MASS J_ext.

Find r_e (apparent).

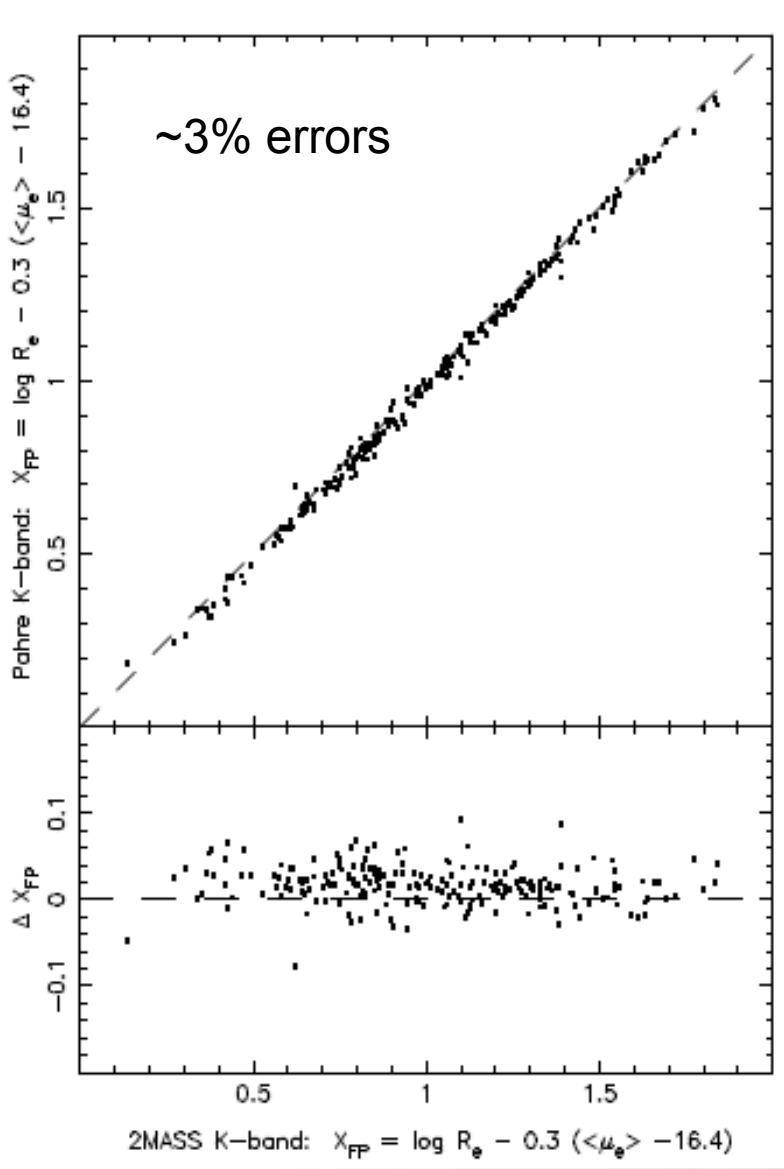
Sersic model with GALFIT to find the required PSF correction.

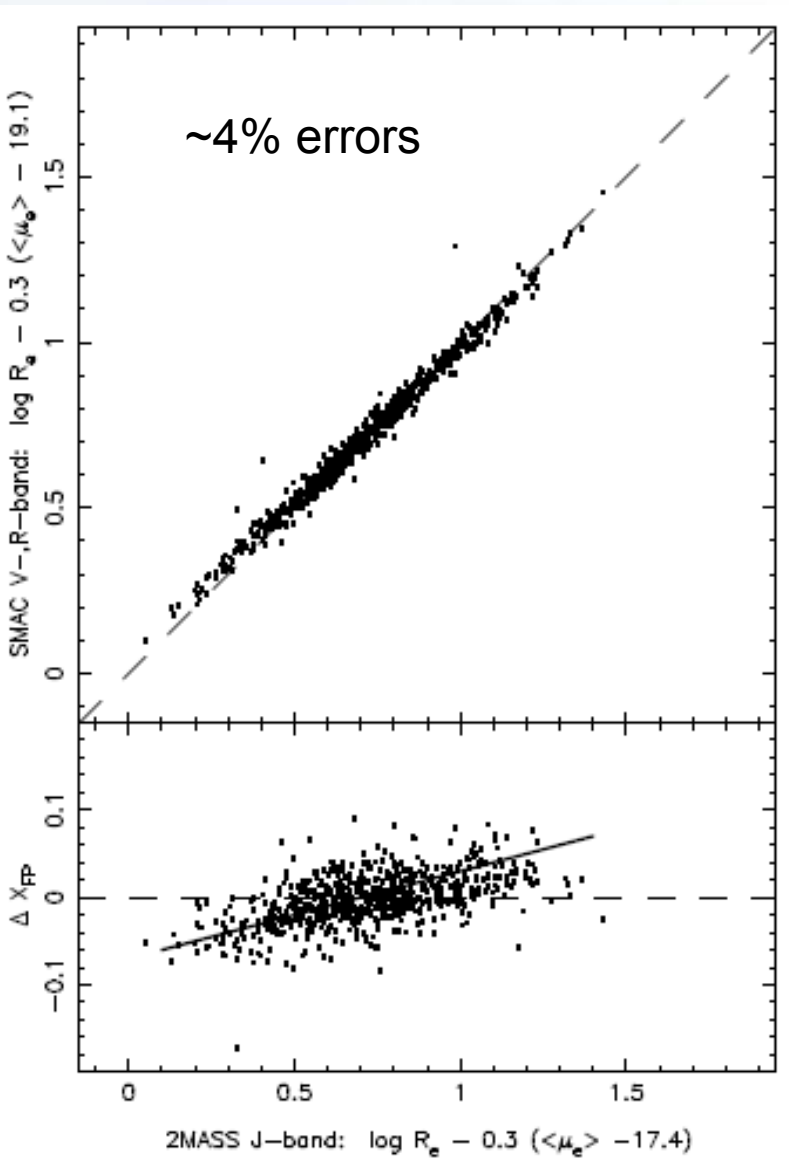
Very well-behaved!
(expected)

Run independently for the J-, H-, K-band images.



FP-photometry Parameters External Comparisons

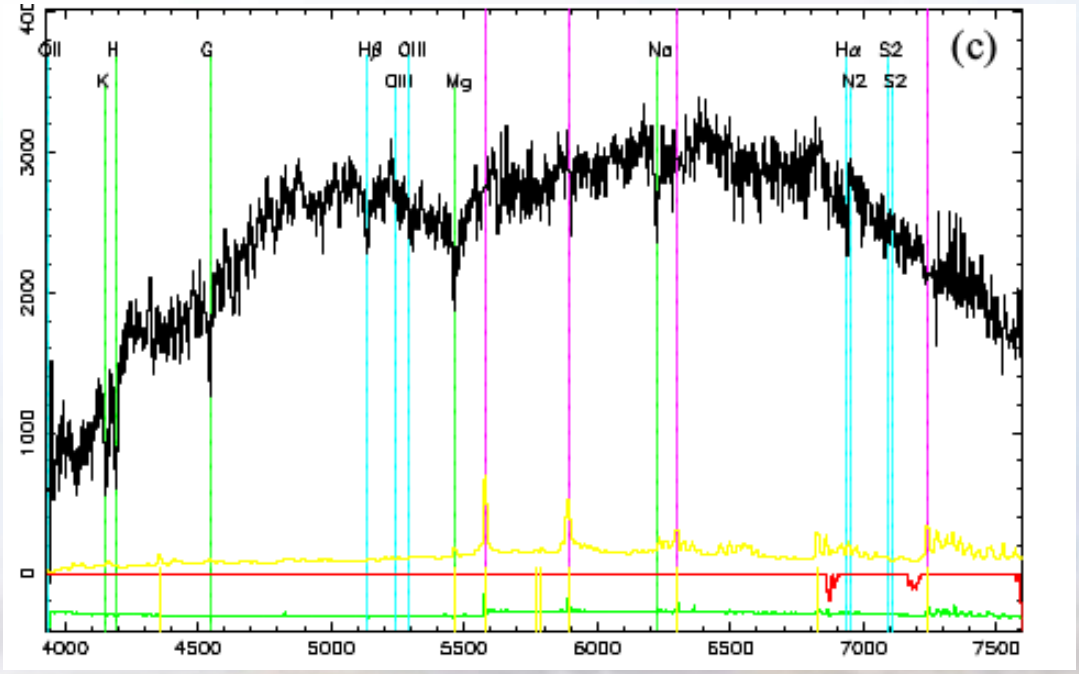


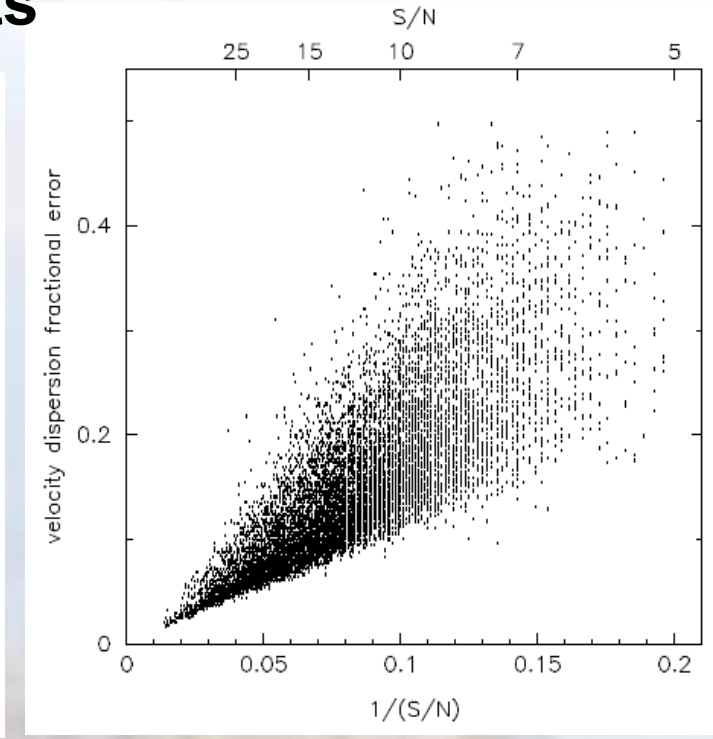


Pahre K-band

SMAC V/R-band

Velocity Dispersion Measurements

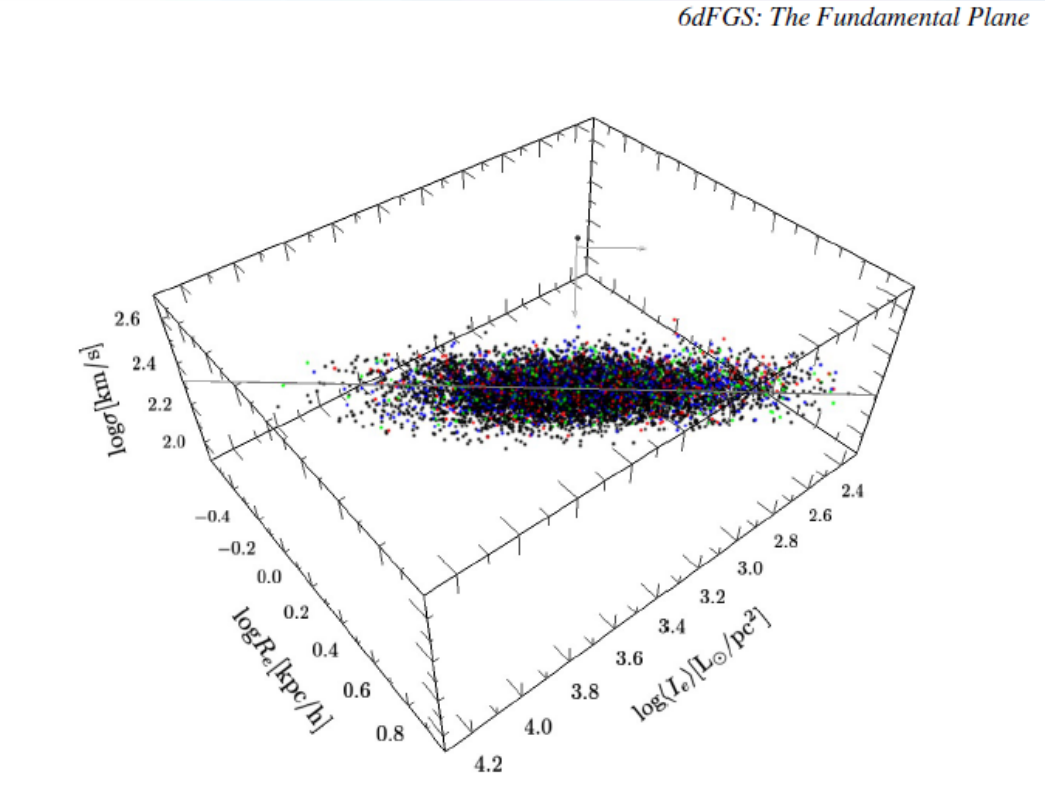




Spectral resolution (1-sigma) ~140 km/s, average errors ~12%
Small corrections ~10 km/s for fibre differences.
Sigma measured from 4000 to 5570A range.
Average S/N of ~13 per A. Individual errors via bootstrap resampling.
“Reasonable” agreement with external sources
but limited by S/N.

The quality of the velocity dispersions limit the FP peculiar velocity measurements.

6dF Fundamental Plane Results

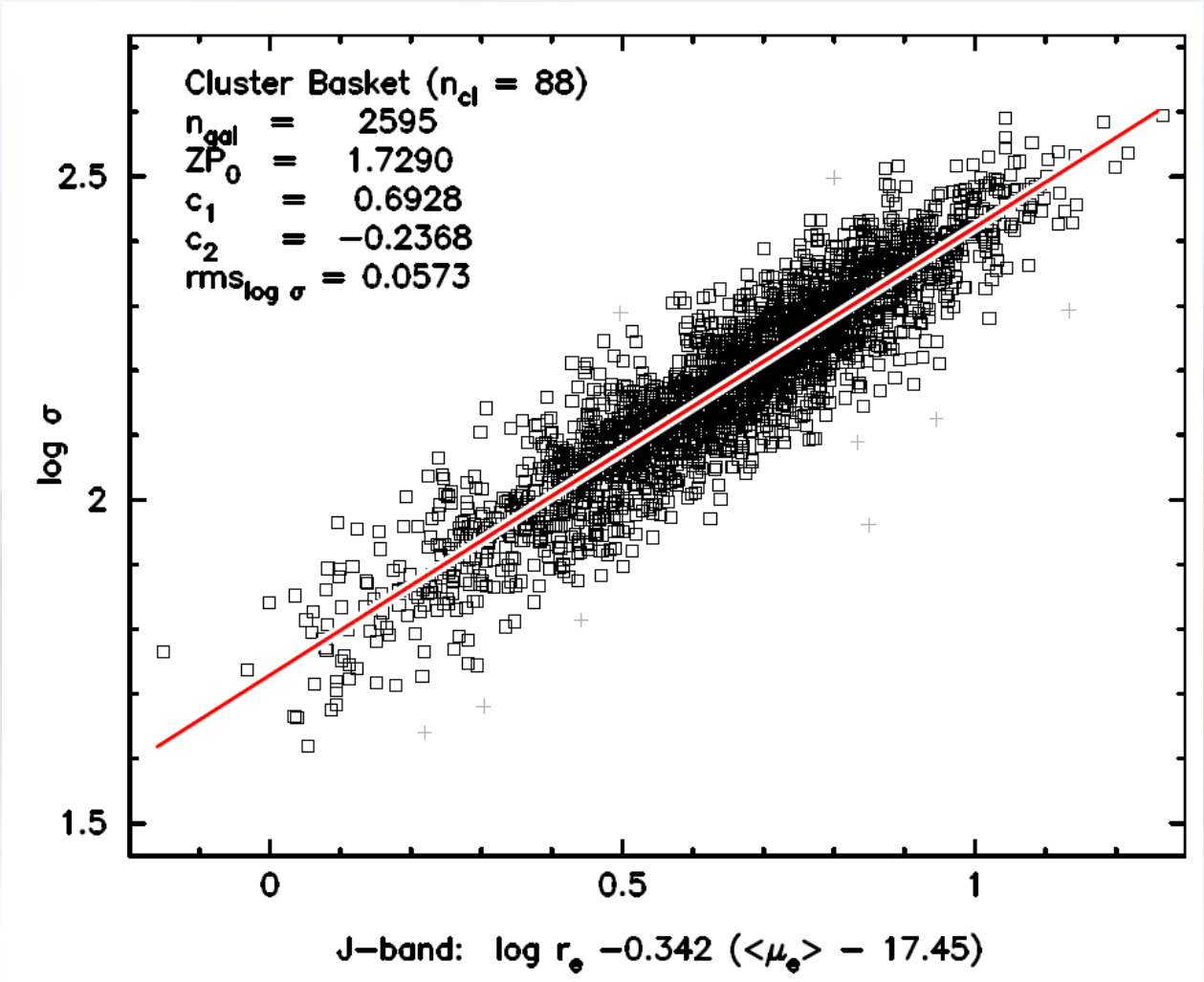


Extensive model of the FP.
Distance errors
of ~26% per galaxy.

Magoulas et al 2012	Construction and characterisation of the FP
Springob et al 2012	Stellar population trends on the FP
Springob et al 2014	Bayesian-based peculiar velocity measurements
Johnson et al 2014	Cosmological constraints
Scrimgeour et al 2016	Bulk flow determination

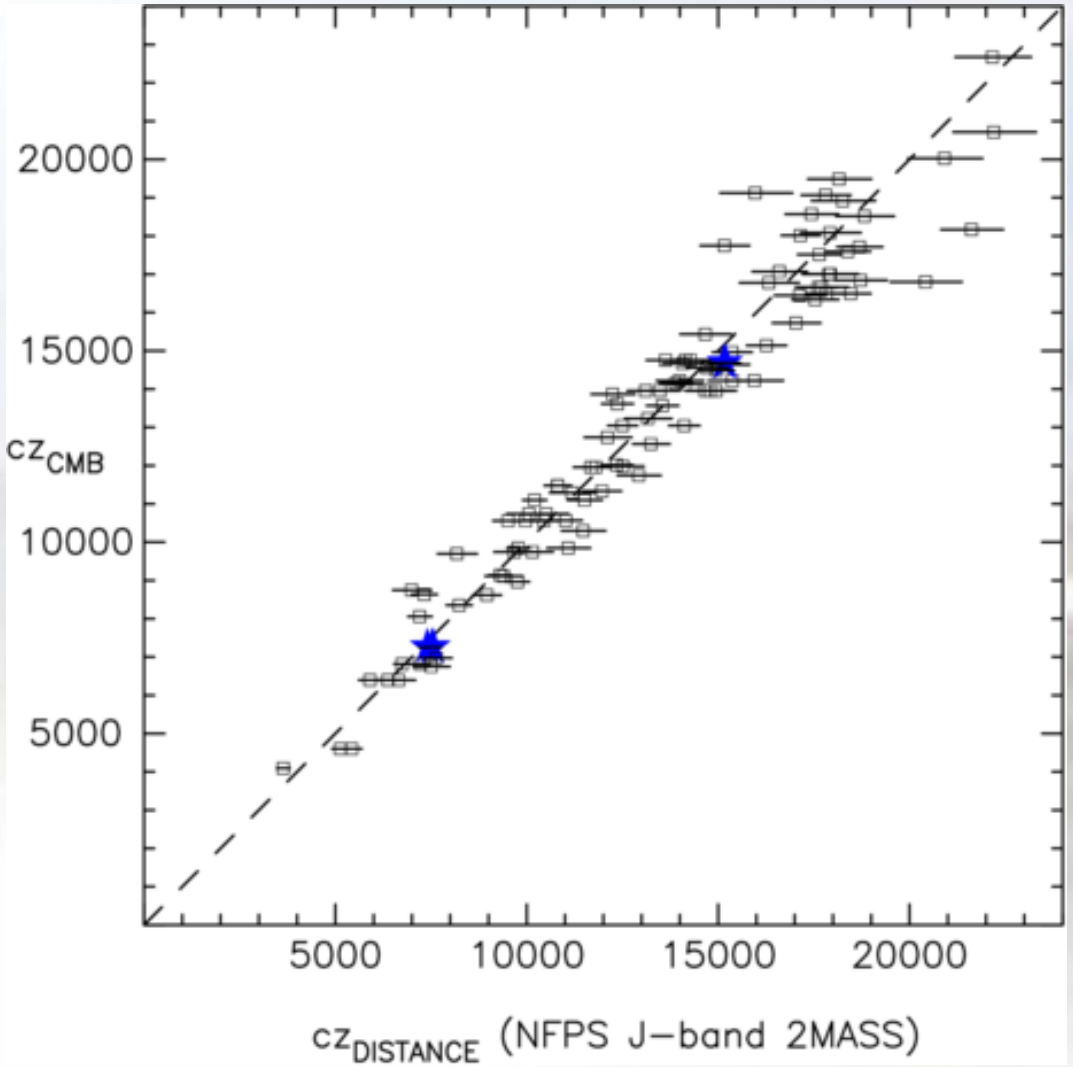
What is the intrinsic scatter of the J-band FP?

Cluster galaxy sample with high quality velocity dispersions.



Distance error per galaxy of ~19%

2MASS-based FP cluster distances
(NFPS sigma measurements)



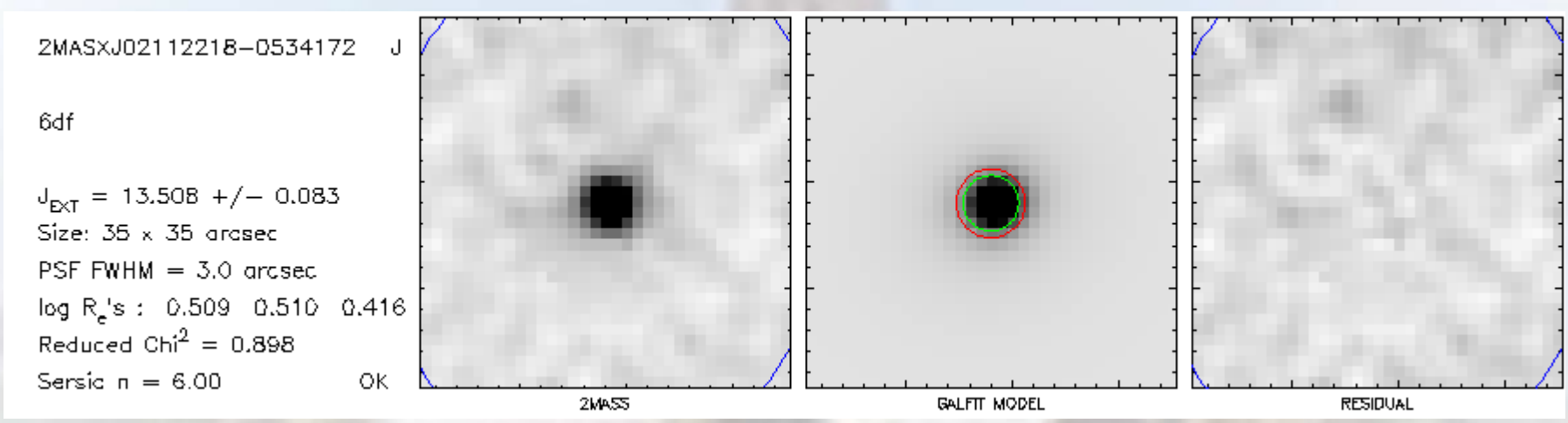
2MASS J NFPS

For clusters z < 0.05,
Ngal > 9

V= 242 +/- 125 km/s
l = 194 +/- 40 deg
b = 51 +/- 23 deg

Other Ongoing Work

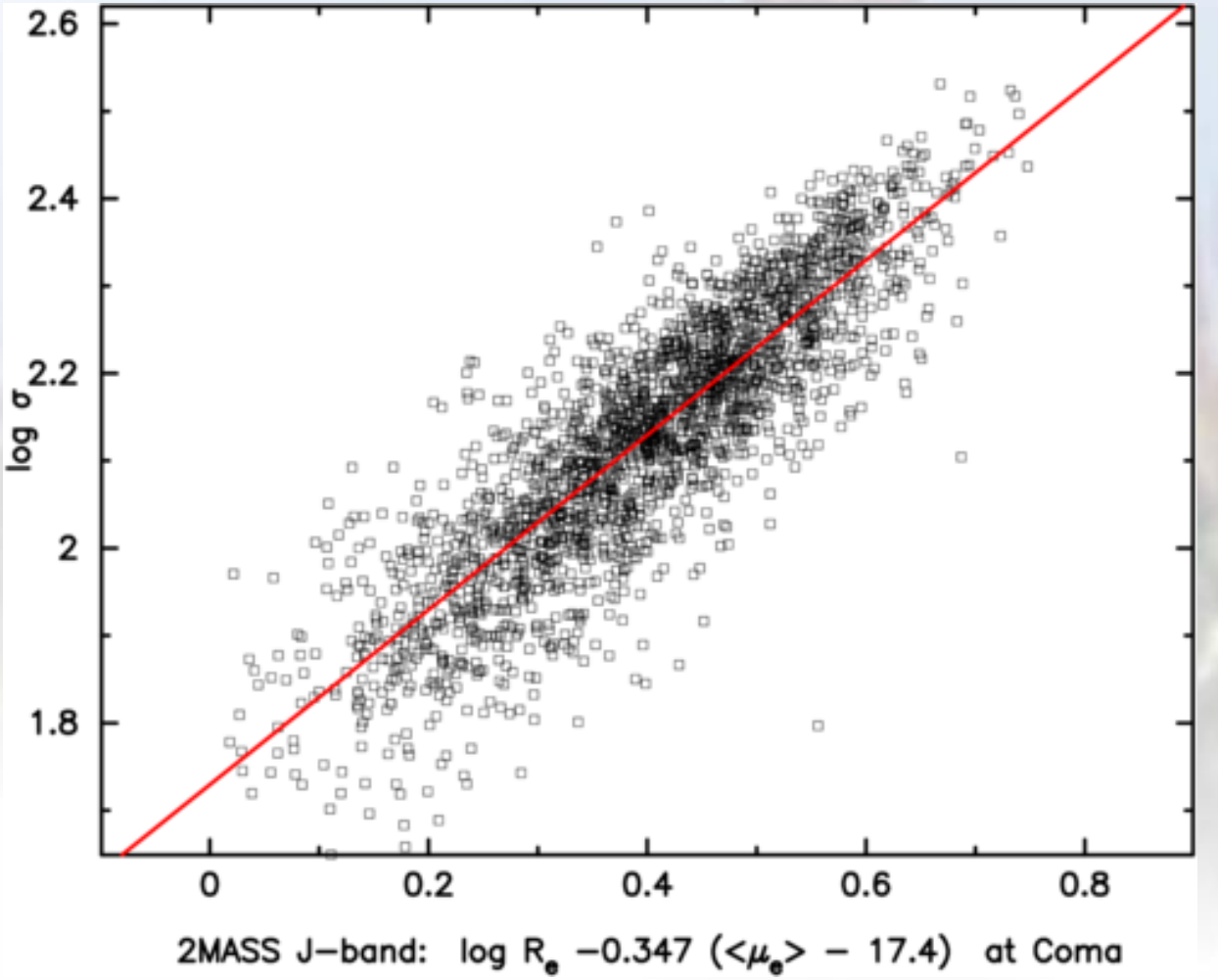
2MASS-based FP photometric measurements all-sky.
(400 k 2MASS XSC object brighter than J = 14 mag.)



Other Ongoing Work

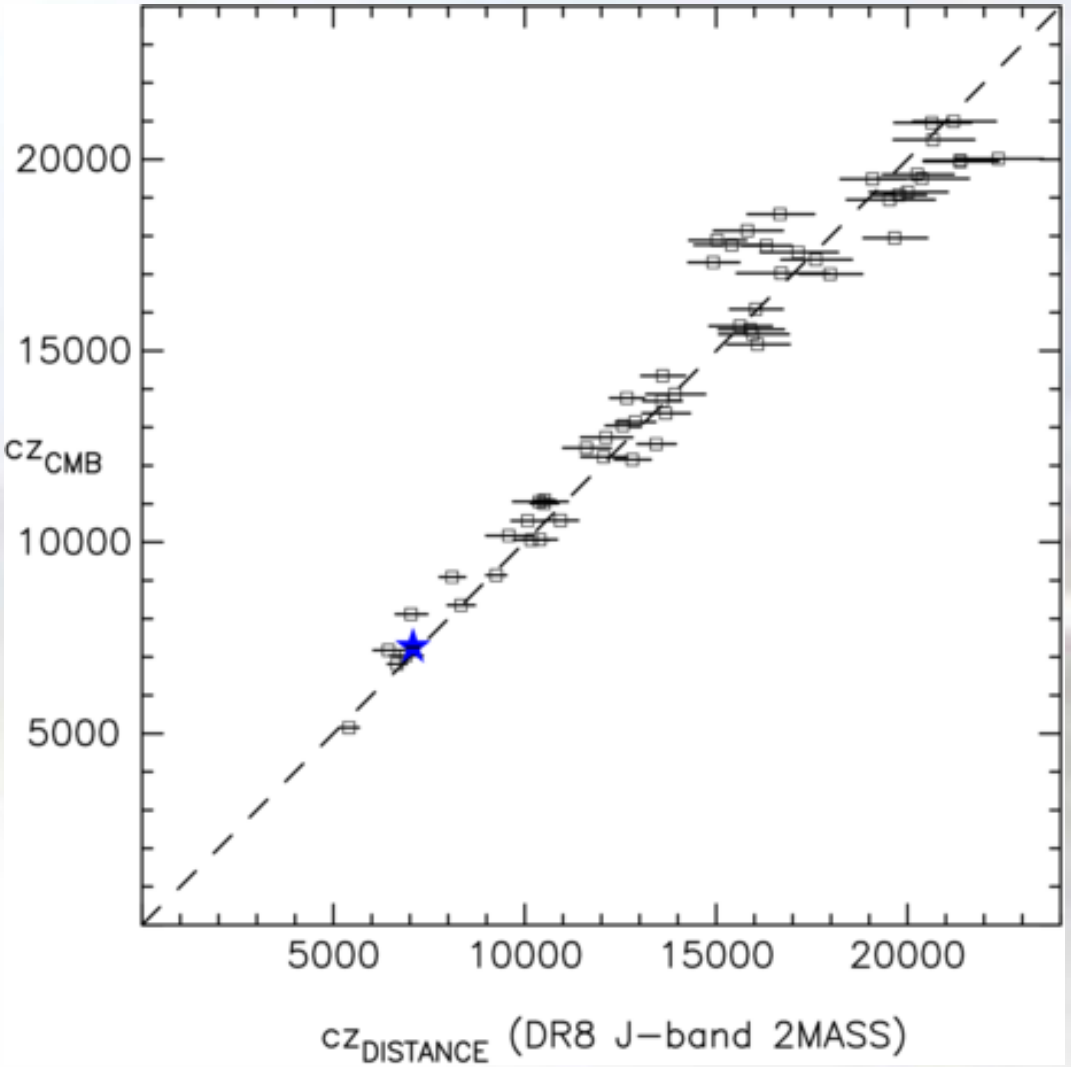
2MASS-based FP plus SDSS sigma measurements

~2500 SDSS “early-type” galaxies with 0.04 < z < 0.05



rms ~ 0.10 dex

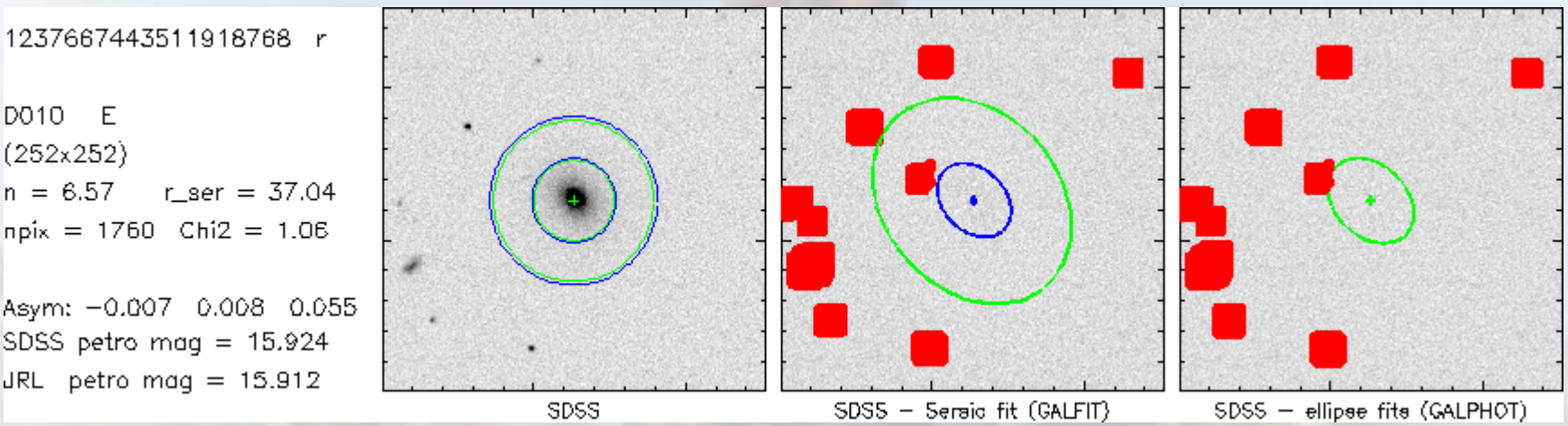
2MASS-based FP cluster distances
(SDSS sigma measurements)



2MASS J SDSS

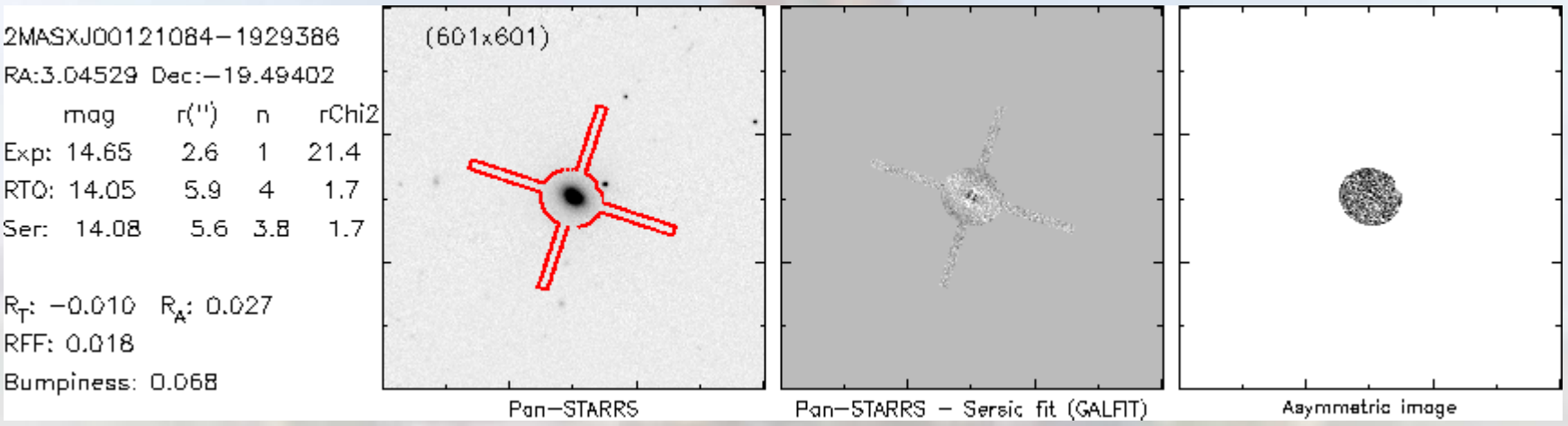
Other Ongoing Work

Links to SDSS image data



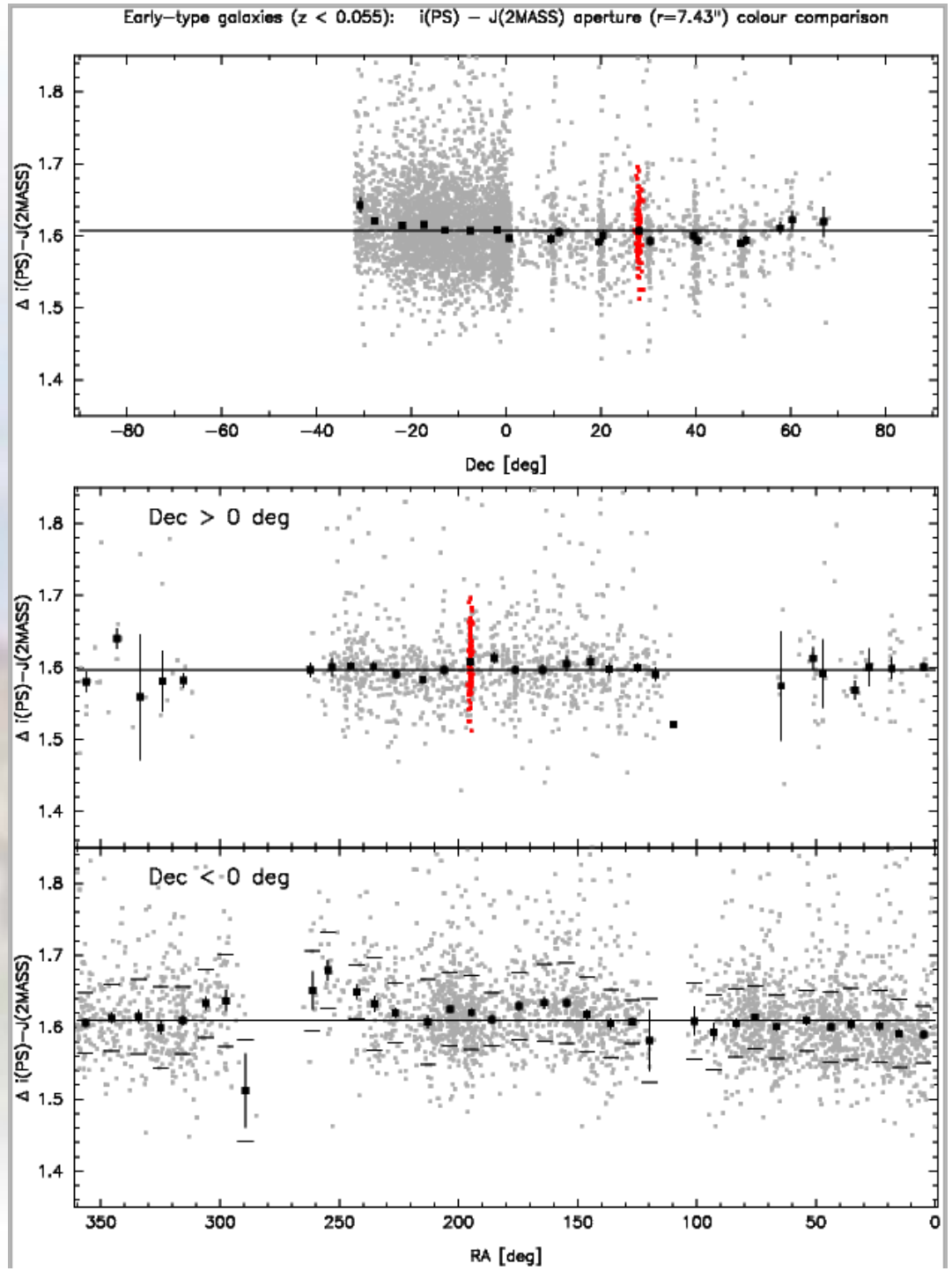
Other Ongoing Work

Links to Pan-STARRS image data

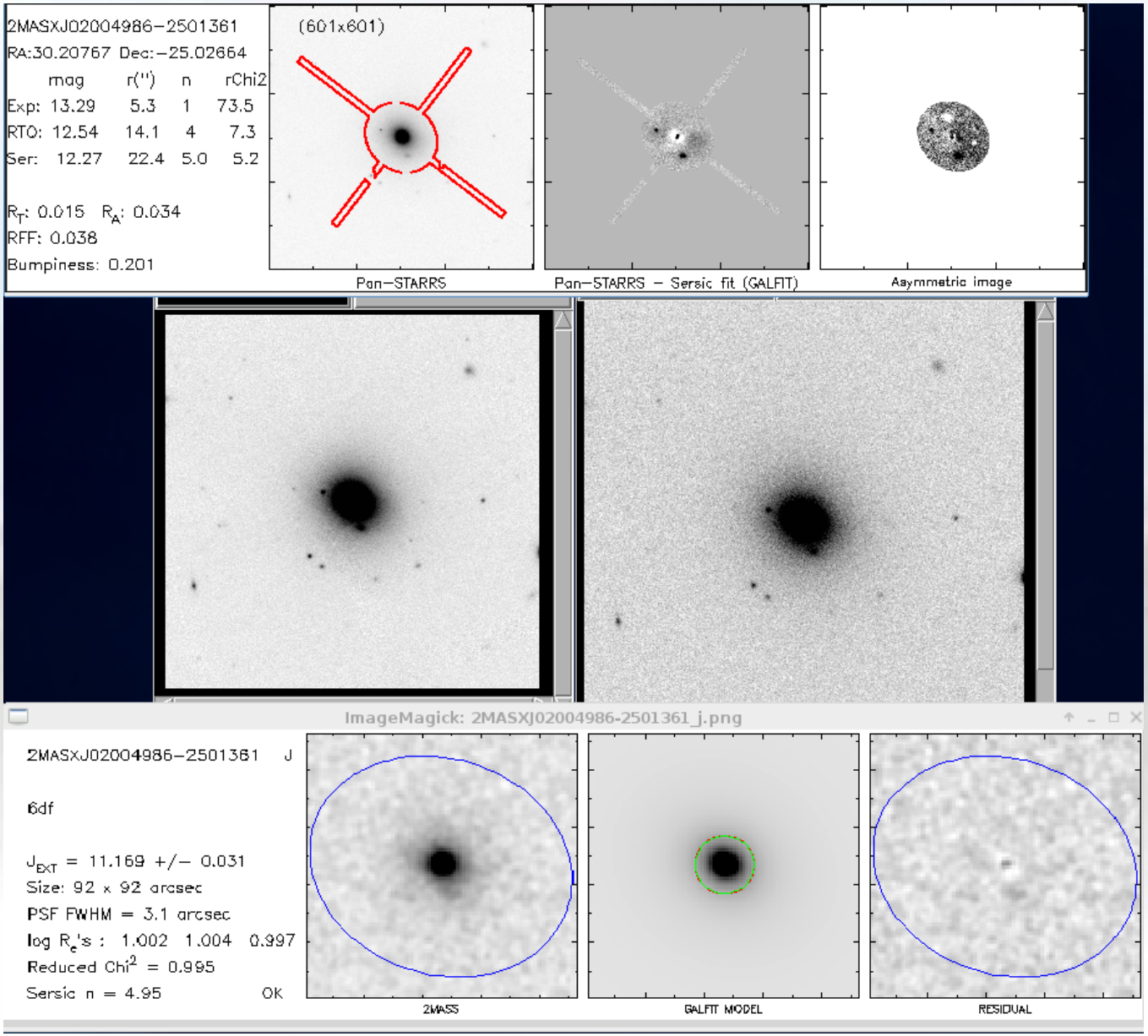


Other Ongoing Work

Linking Pan-STARRS data to 2MASS,
e.g. (i-J) aperture colours.



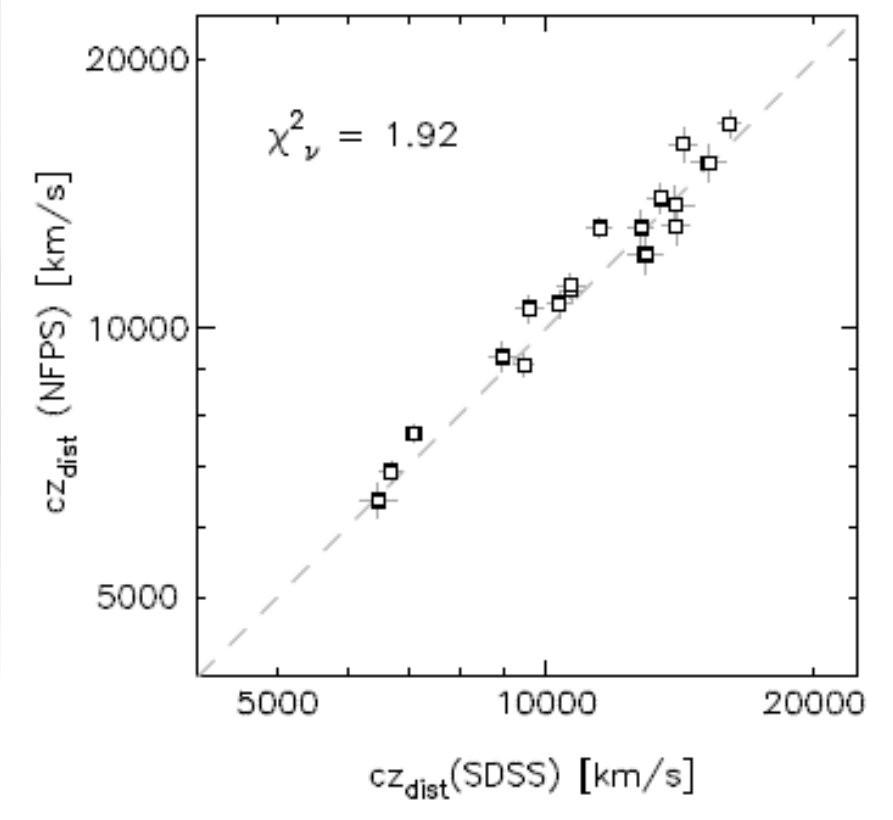
Pan-STARRS, VST ATLAS, 2MASS



Systematics in the Velocity Dispersion Measurements

Always needs to controlled with repeat measurements!!!!!!!!!!!

Extra noise in the peculiar velocities.



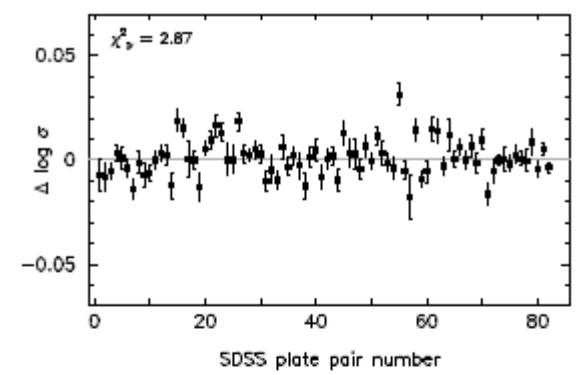


Figure 1. SDSS plate-to-plate sigma offsets

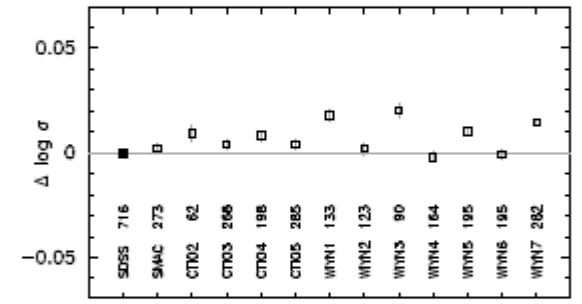


Figure 2. Run-to-run sigma system offsets

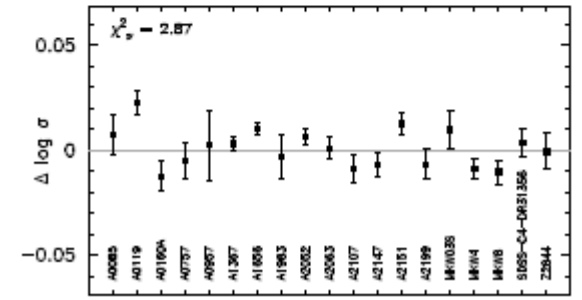
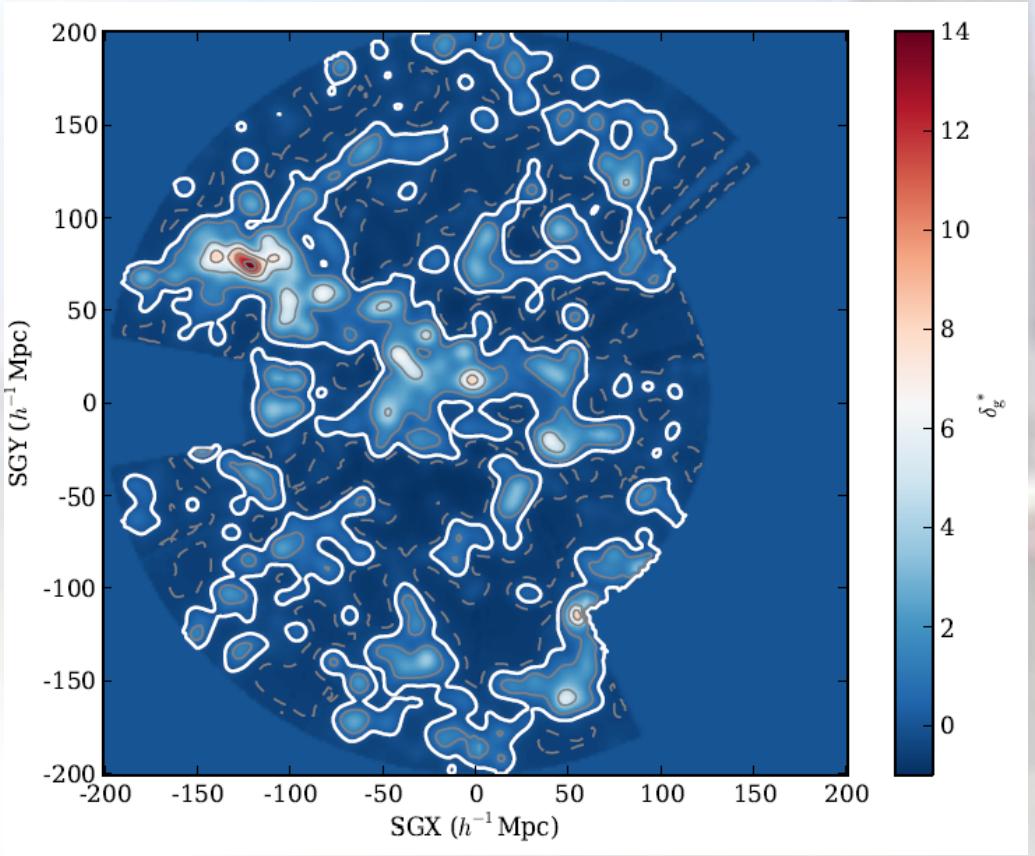
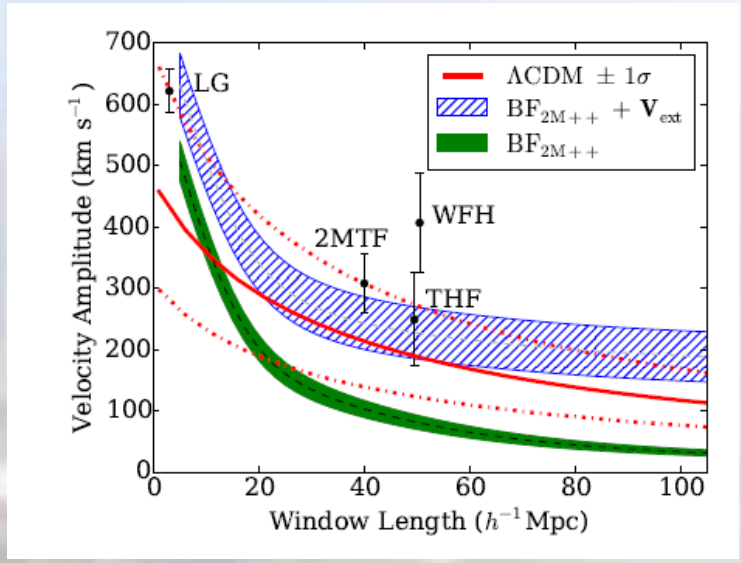


Figure 3. Cluster sigma offsets

Peculiar Velocities

While considerable progress has been made in recent years, see e.g. Tully et al 2013 Cosmicflow-2, 2M++ Carrick et al 2015, there is still much work to be done.





Carrick et al 2015

Heron Island Workshop on
Peculiar Velocities in the Universe
17-21 July 1995

http://www.mso.anu.edu.au/~heron/

Concluding remark by Paul Schechter
“Don’t do better statistics … do better experiments”
Ernest Rutherford

Future Prospects

New measurement of velocity dispersions from
TAIPAN and LoRCA plus links to existing surveys, i.e.
SDSS, 6dFGSv, NFPS, ENEAR, SMAC, etc
will enable a high quality all-sky sigma catalogue to be constructed.

Extensive reliable multi-band photometry is now becoming available, e.g.
igrizw Pan-STARRS (north of Dec = -30 deg),
re-calibrated ugriz SDSS,
ugriz VST ATLAS,
YJHK VHS (coupled to JHK 2MASS),
Skymapper, etc.

Multi-colour red sequence selection coupled with ~1 arcsec images will result in a very homogeneous morphologically clean FP data set over the entire sky within z=0.07 which will be a powerful tool for peculiar velocity studies.

Conclusions

The intrinsic scatter of the NIR FP is ~20% hence this is a great tool to map the peculiar velocity field out to z~0.07.

The extensive multi-band photometry now becoming available means that very reliable FP photometric parameters can be measured for large all-sky sample of early-type galaxies.

TAIPAN and LORCA supplemented by existing work like SDSS are essential to provide the velocity dispersions.

The prospects over the next few years to construct a high quality FP dataset for ~100k early-type galaxies for peculiar velocity studies are excellent.

The main lesson learnt (and re-learnt many times) in FP studies is that velocity dispersion measurements of high quality with low systematic errors are the key to success.