Cosmic Flows via NIR FP Distances to an All-sky Sample of Rich Clusters

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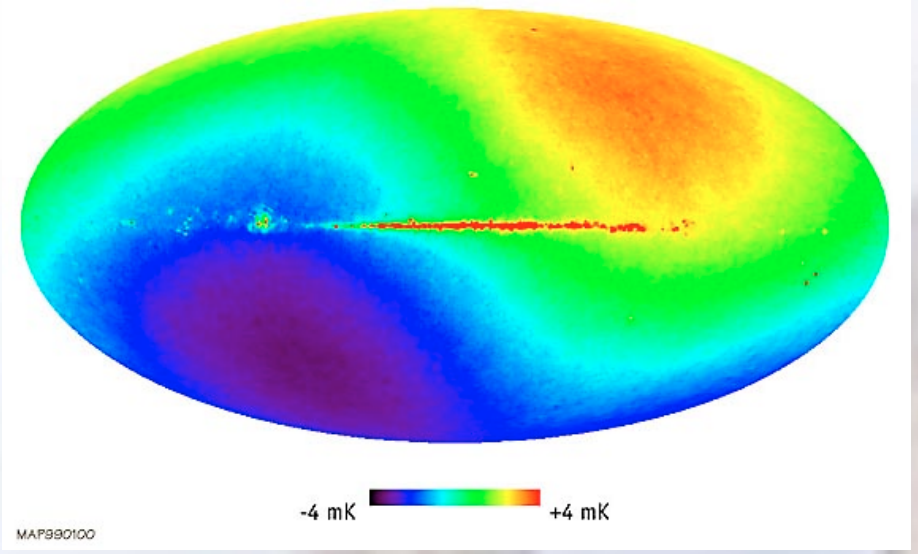
Outline:

- Background
- New Cluster Sample
- The Fundamental Plane Distance Indicator
- Measurement of the FP parameters
- Construction of the Base FP
- Hubble diagrams
- Bulk Flow measurements
- Recovery of the LG motion wrt CMB

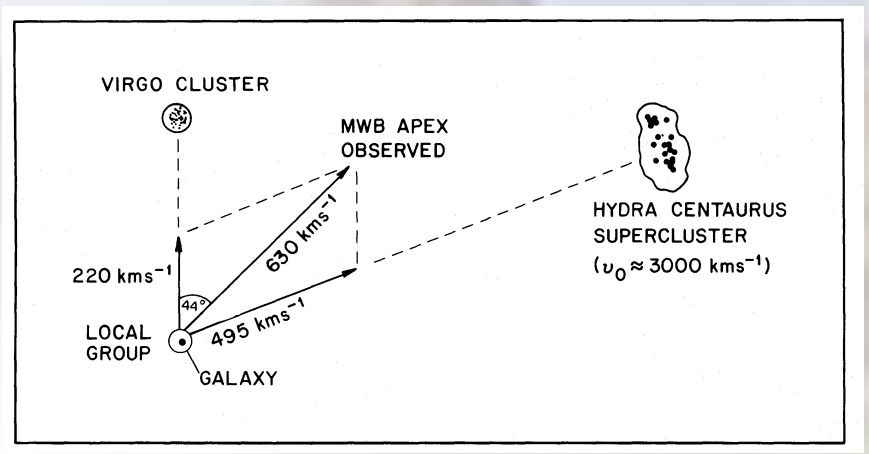
- Future FP prospects

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)



Shaya (1984) first noted the "… substantial motion of the entire (Local Supercluster) roughly towards Hydra-Cen …"

Two very basic questions:

What masses are the source of the LG motion?

What is size of bulk flow on large-scales?

Aaronson et al 1986, ApJ, 302, 536 (Recovery of the LG motion wrt to CMB from NIR Tully-Fisher distances to ten rich clusters)

A DISTANCE SCALE FROM THE INFRARED MAGNITUDE/H I VELOCITY-WIDTH RELATION. V. DISTANCE MODULI TO 10 GALAXY CLUSTERS, AND POSITIVE DETECTION OF BULK SUPERCLUSTER MOTION TOWARD THE MICROWAVE ANISOTROPY

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The final Hubble ratios, based on newly derived cluster redshifts, are found to exhibit a scatter considerably larger than the formal errors, which we show arises from the presence of a Local Group velocity component. Formal solution for the motion yields $V = 780 \pm 188$ km s^{-1} toward $l = 255° \pm 17°$ and $b = 18° \pm 13°$. This vector agrees well in both magnitude and direction with the 3 K dipole anisotropy, for which $V = 600 \pm 30$ km s^{-1} toward $l = 268° \pm 3°$ and $b = 27° \pm 3°$, a velocity which is in turn roughly double the known Local Group motion in the Local Supercluster. Hence, we conclude that the motion giving rise to the 3 K dipole has been positively detected, and consists of two principal components having comparable size; these are Local Group motion within the Supercluster, primarily toward Virgo, and bulk Supercluster motion as a whole, in a direction lying close to that of our next nearest neighbor supercluster, Hydra-Centaurus.

101 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,
has sizeable errors (10 – 20%) and scales with redshift.

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

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

Some Recent Bulk Flow Results

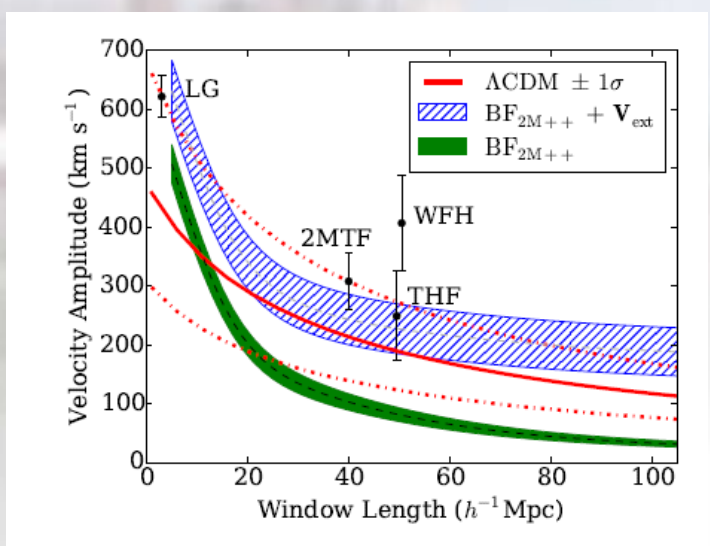
Hoffman, Courtois, Tully (2015) CF2

R [h^{-1} Mpc]	Data	$V_{\rm bulk}$	Galactic (l, b)	$V_{\rm bulk,\,x}$	$V_{\rm bulk,\,y}$	$V_{\rm bulk,\,z}$
40	CF2	274 ± 23	(288°, 19°)	-226 ± 23	102 ± 20	-116 ± 28
	SFI++	333 ± 38	(276°, 14°)	−242	103	−203
50	CF2	250 ± 21	(280°, 18°)	-209 ± 22	90 ± 19	-100 ± 24
	COMPOSITE	243 ± 28	(284°, 18°)	−193	89	−1183
100	CF2	270 ± 23	(283°, 19°)	-211 ± 31	105 ± 23	-131 ± 33
	SFI++	257 ± 44	(279°, 10°)	−198	61	−151
	COMPOSITE	300 ± 33	(282°, 11°)	−240	76	−163

Carrick et al (2015) with the SFI++ & SNIa samples find for R=50, V=230+/- 30 km/s towards (l,b) = (293+/-8, 14+/-10).

Hong et al (2014, 2MTF) 2018 spirals find for R=40, V=331+/-23 km/s towards (l,b) = (292+/-3, 12+/-4).

Scrimgeour et al (2016, 6dFGSv) from ~9k FP distances find R=50, V=248+/-58 km/s towards (l,b) = (318+/-20, 40+/-13)



While only very large datasets reach these levels of uncertainties, new independent distance measurements are always valuable.

New All-Sky FP Cluster Sample

Aim: To provide a new independent measurement of the bulk flow on the large scale and investigate the practical issues with high quality data in preparation for the large forthcoming FP surveys like TAIPAN.

Limit cluster redshift range to $0.020 < z < 0.055$

$z < 0.020$ Hydra-Cen-Norma (GA) and Perseus-Pisces SCs dominate.
$z > 0.055$ Random and systematic errors are becoming sizable.

Clusters selected from:

SMAC sample all the “great” well-known clusters.
early-type galaxies from eyeball morphology.

NFPS x-ray selected to be the most massive clusters.
early-type galaxies via (B-R) red-sequence selection.

SDSS using the Tempel et al (2014) cluster catalog.
(g-r) red sequence selection of FP targets

Some clusters in all three surveys.

Use clusters only n > 15 FP galaxies which results in 88 clusters.

Why Clusters?

Used as the pathfinder work. Many early-type galaxies at one common distance which defines the base relation and the first estimate of the intrinsic scatter.

Observing efficiency for imaging
and fibre spectroscopy for sigmas.

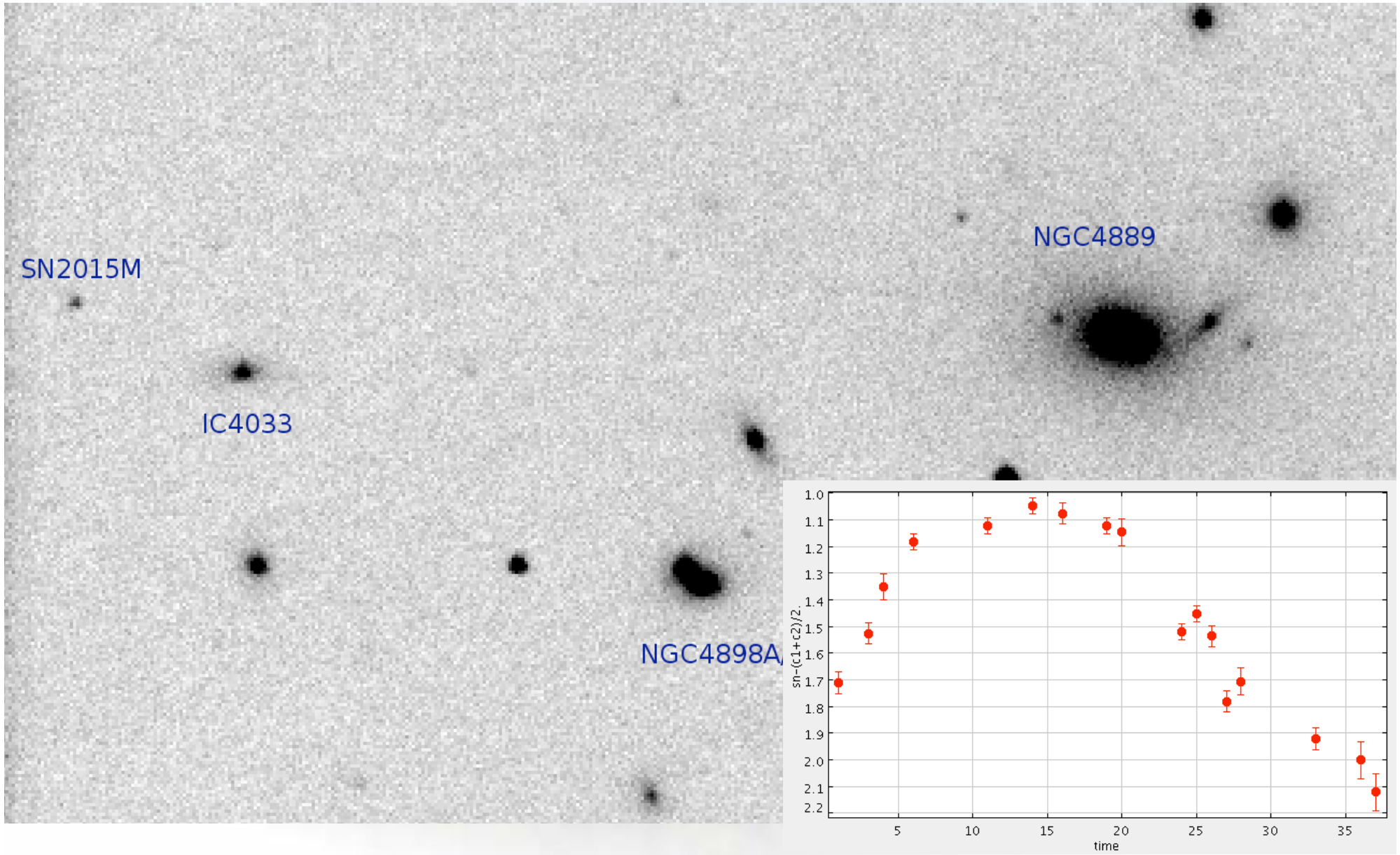
Distance uncertainties reduced by $\sqrt{n}$.

Allowed the quality of the measurements to be assessed
Key to understanding the systematics.

Fully independent techniques can be used to the same clusters, e.g. FP, TF, SBF and SNIa!

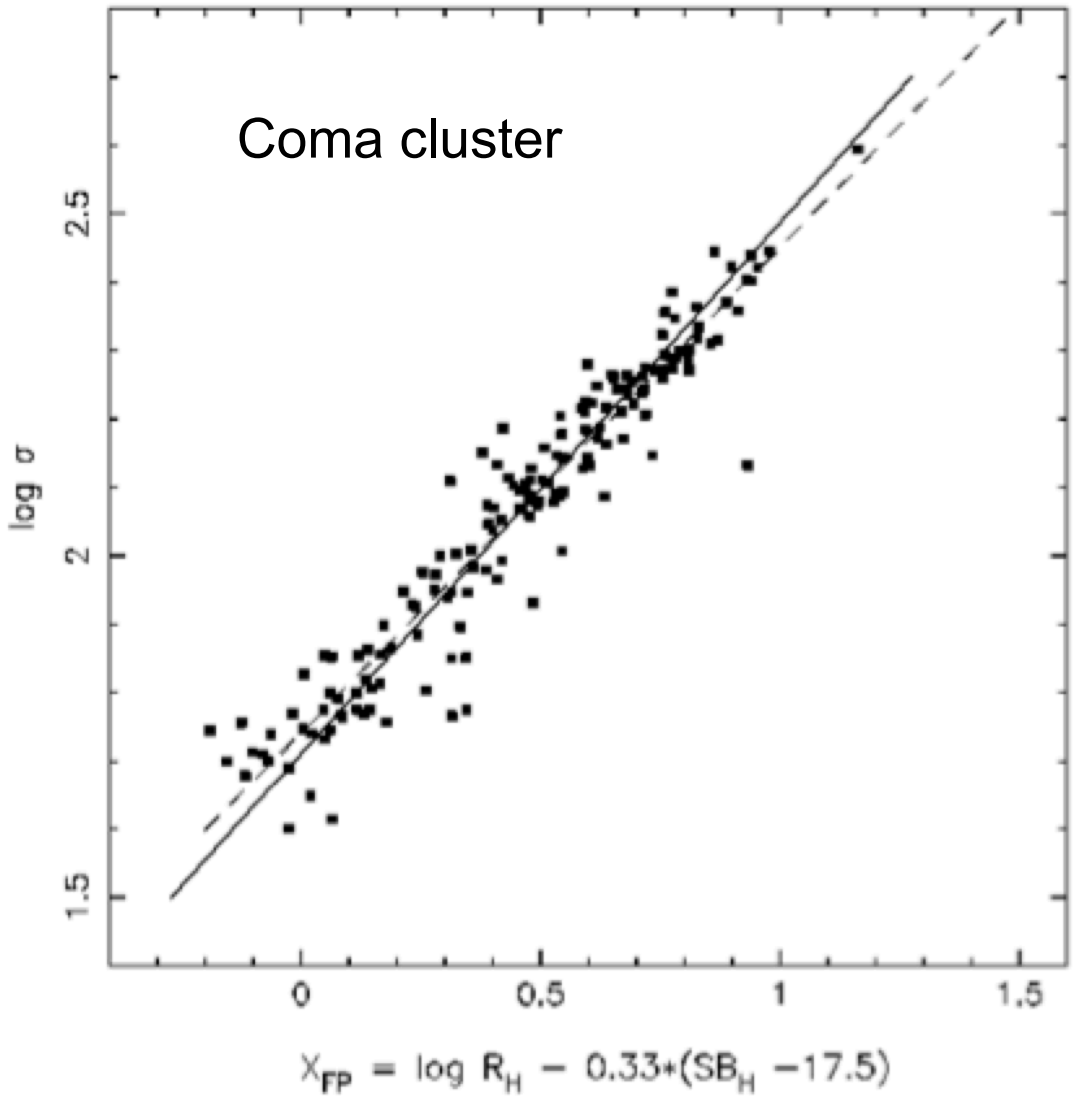

SN2010ai SNIa in the Coma Cluster

SN2015M in the Coma Cluster



The Fundamental Plane

The empirical relation between the central velocity dispersion, the effective (half-light) radius and effective surface brightness. (Dressler et al 1987 (7S, Dn-sigma), Djorgorvski & Davis 1987 "Fundamental Plane").



Sample of early-type galaxies

Total magnitude → r_H and SB_H

Central velocity dispersion (sigma)

X_{FP} is effectively an edge-on view.

Distance uncertainties reduced by $\sqrt{n}$.

Clearly this "gain" is only realised if the systematic errors are controlled.

FP photometry parameters (r_H and SB_H) from J-band 2MASS

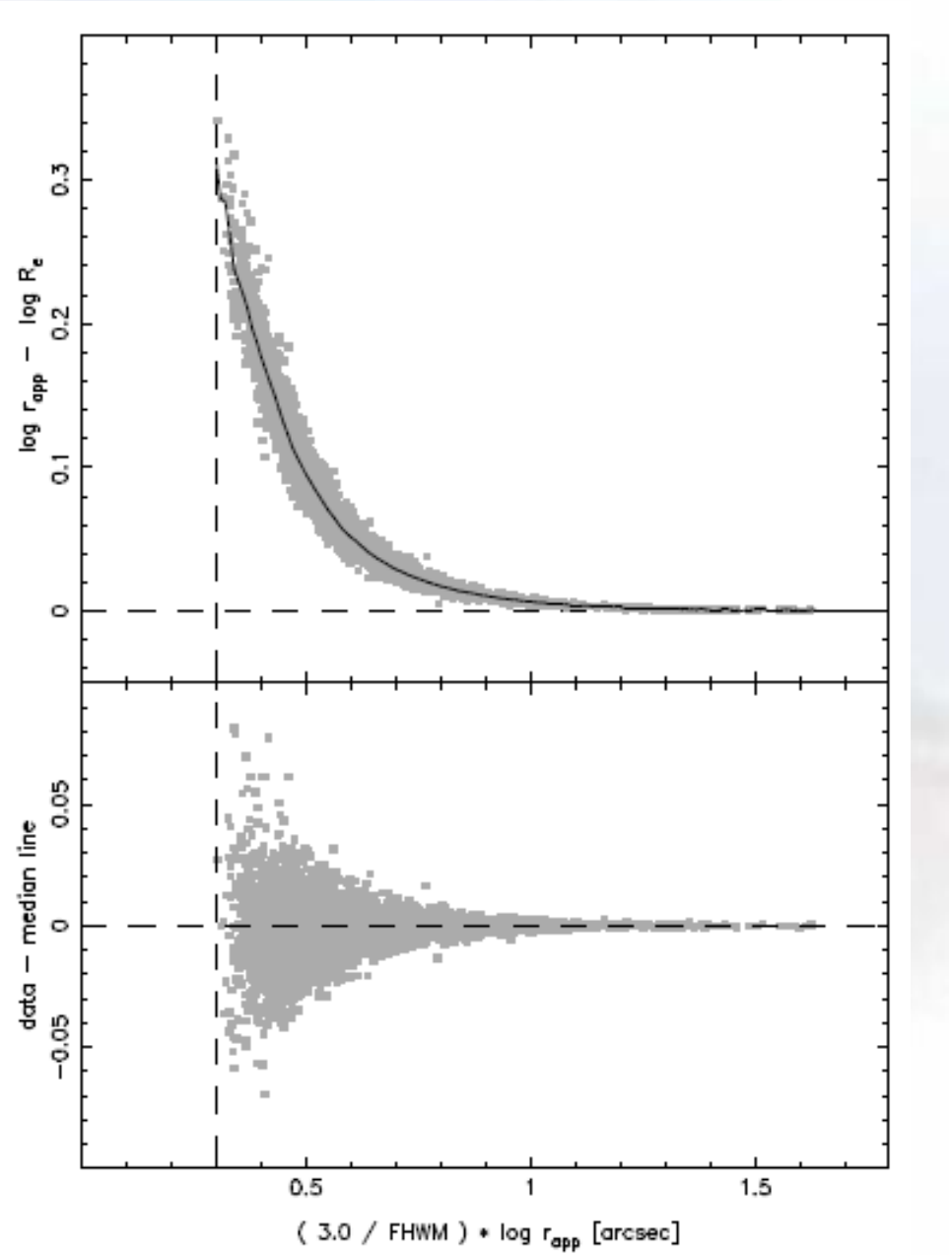
All-sky coverage in J,H,K but a very shallow dataset with PSF ~ 3”. However actually really excellent for FP studies out to z ~ 0.07 provided r_H > 2”.

Follow the 6dFGSv procedure to correct r_H for the 2MASS PSF.

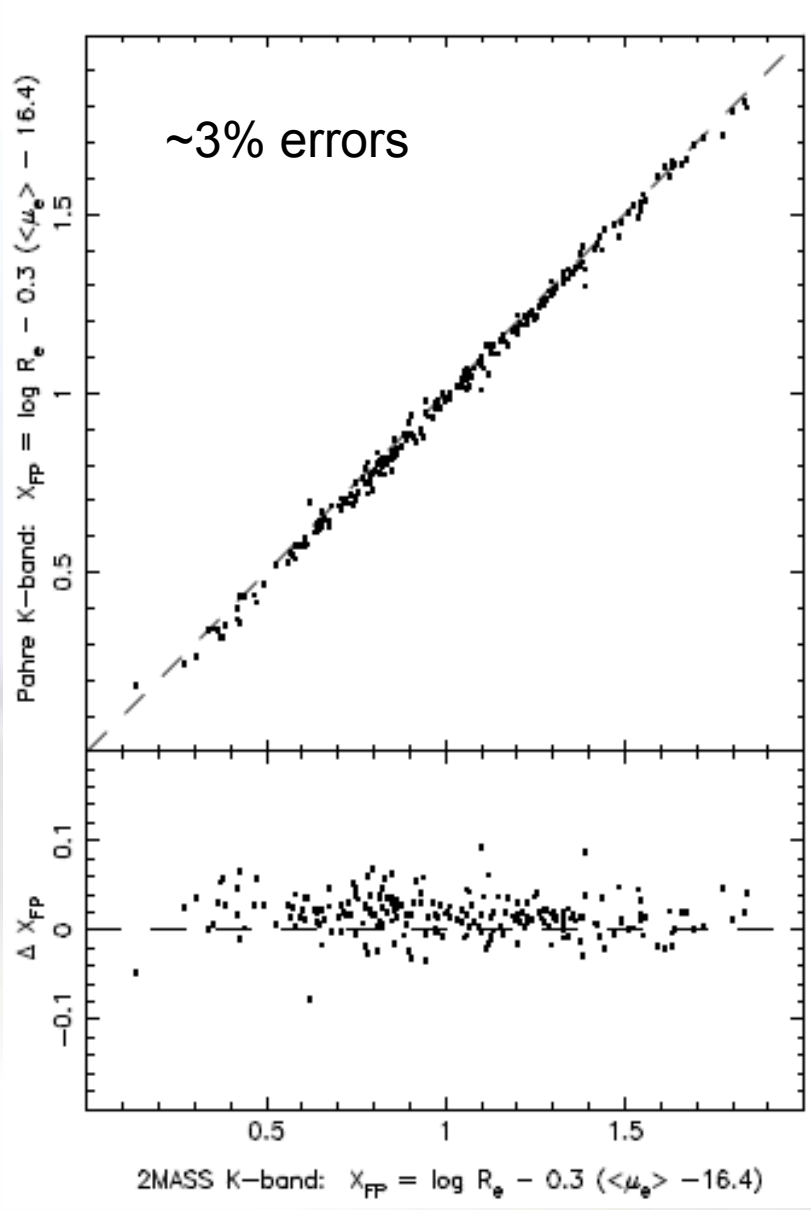
Adopt the listed 2MASS J_ext and use Sersic model with GALFIT to find the required PSF correction.

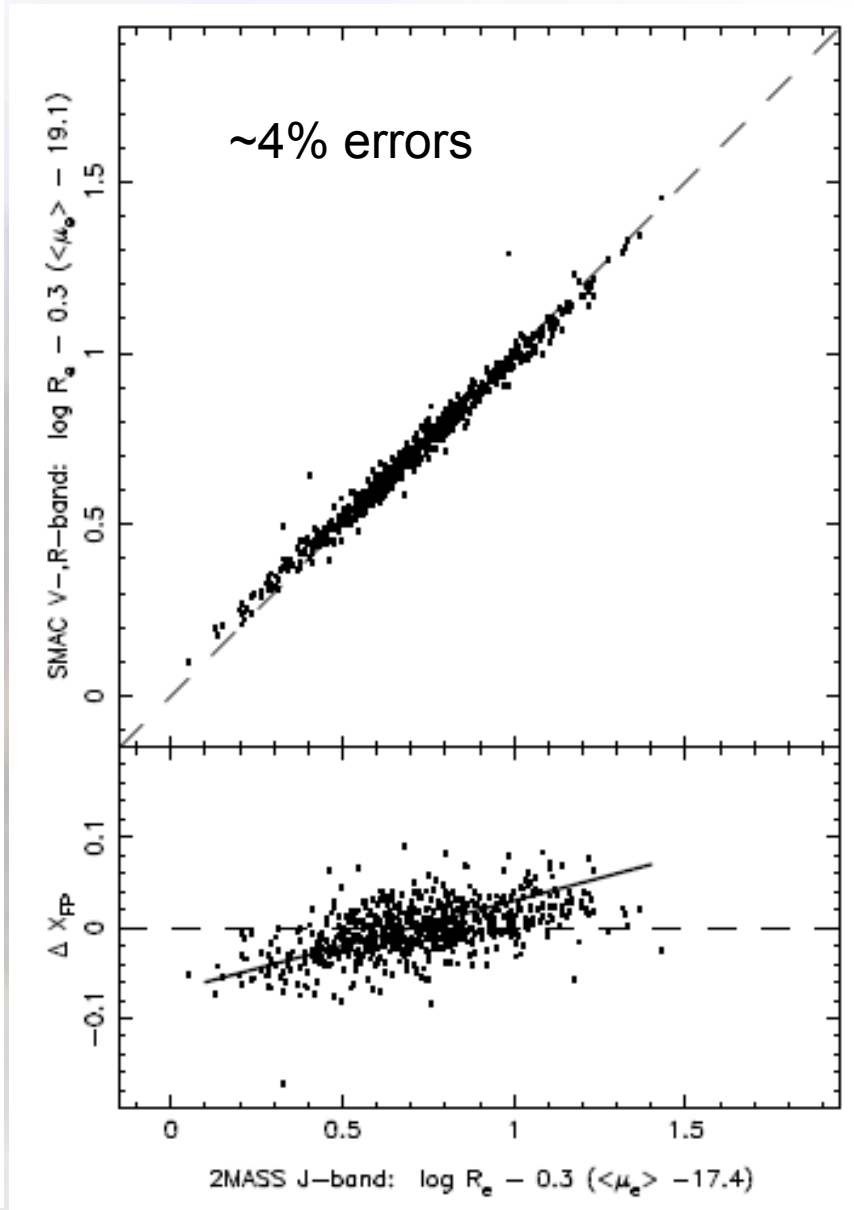
Very well-behaved (expected).

Usual corrections applied for
(i) galactic extinction (SF11)
(ii) (1+z)^4 SB dimming
(iii) k-correction
(iv) evolution-correction



FP-photometry Parameters External Comparisons

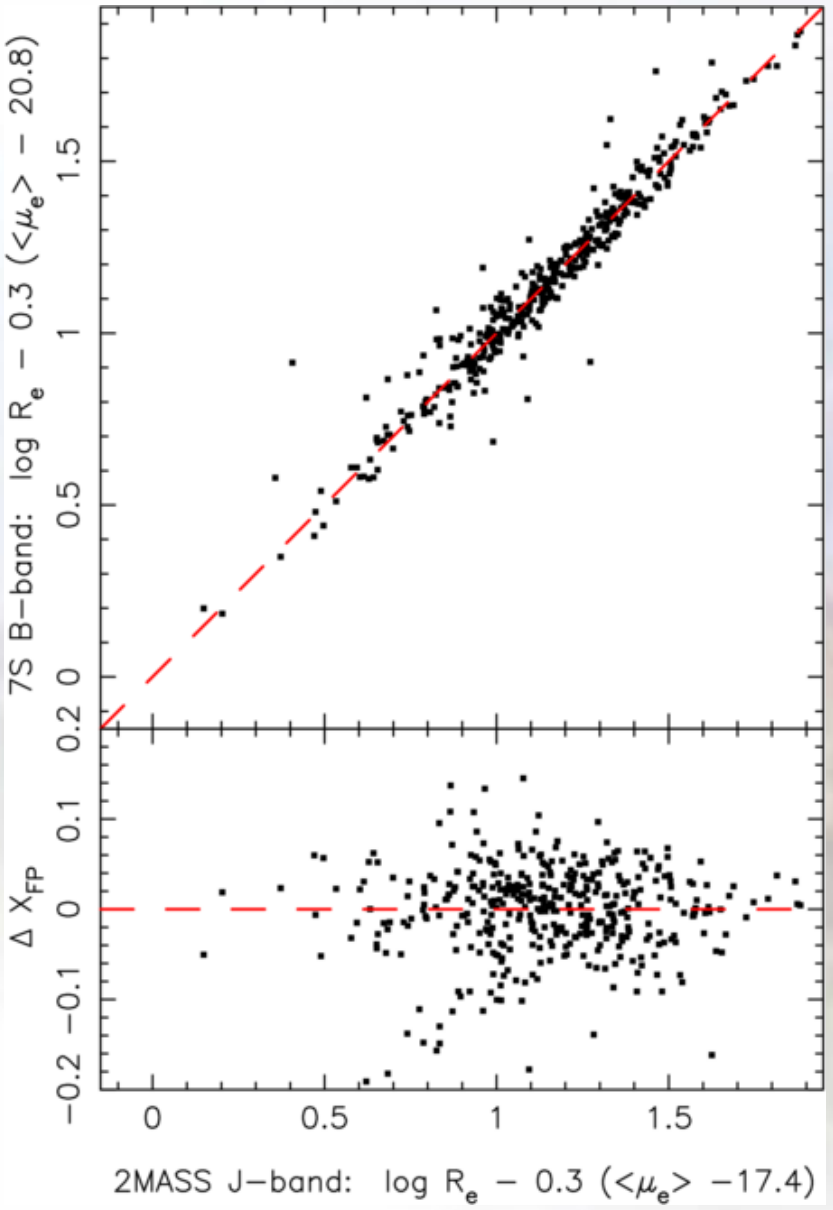




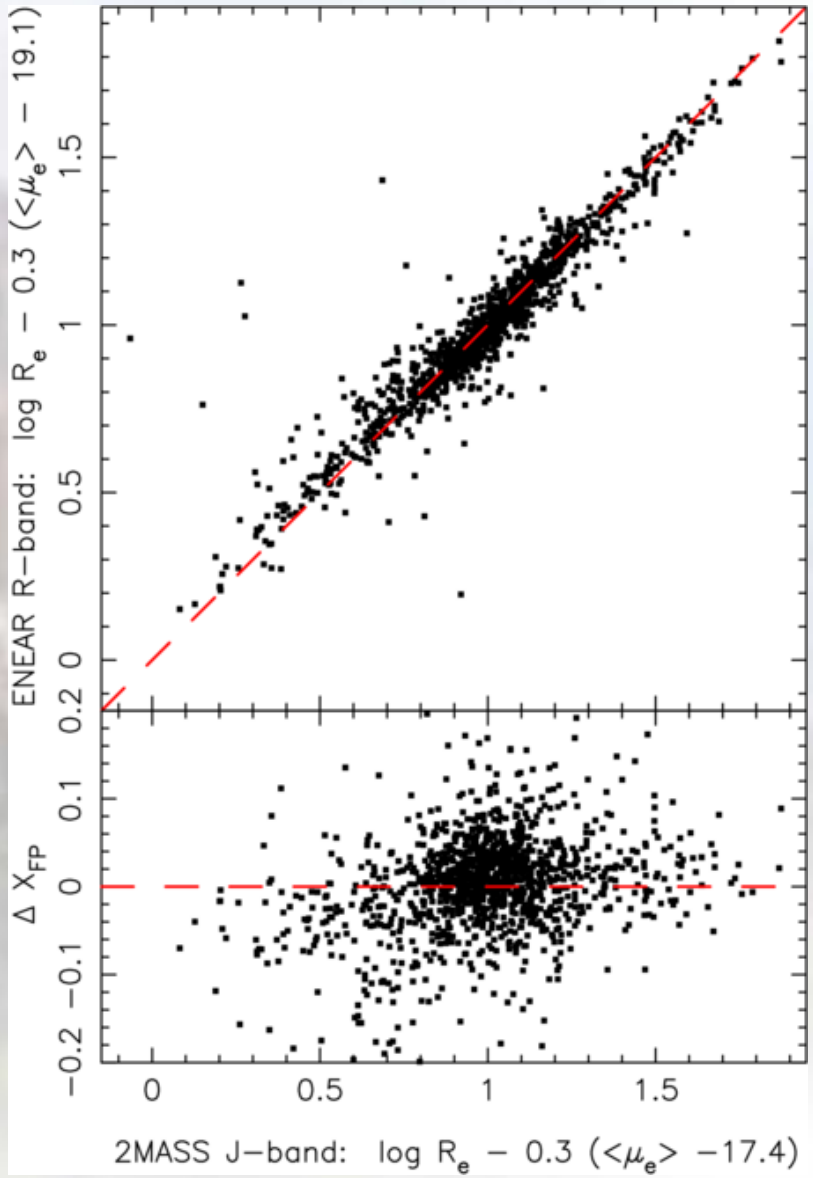
Pahre (1998) K-band values

SMAC V/R-band

2MASS FP Parameters comparison with older datasets



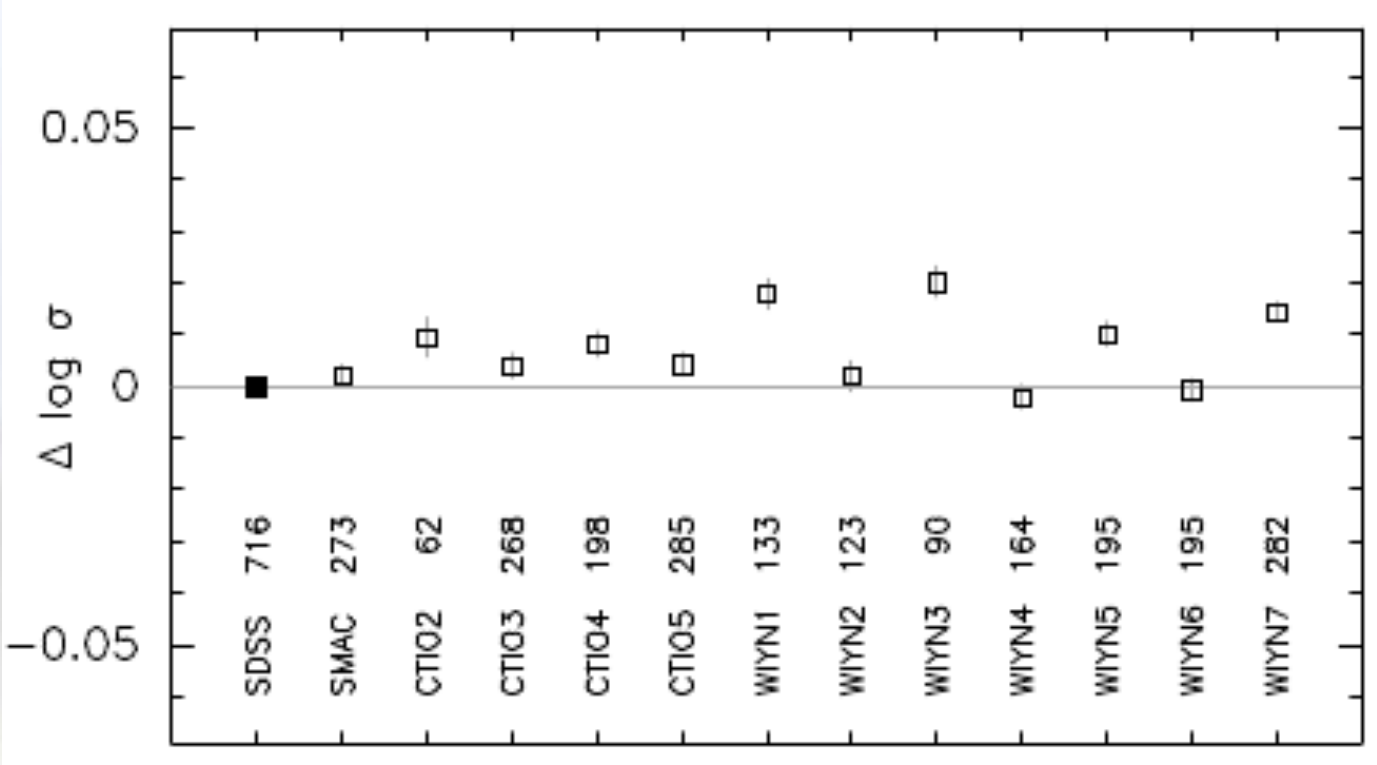
7S B-band



ENEAR R-band

Velocity Dispersion Measurements

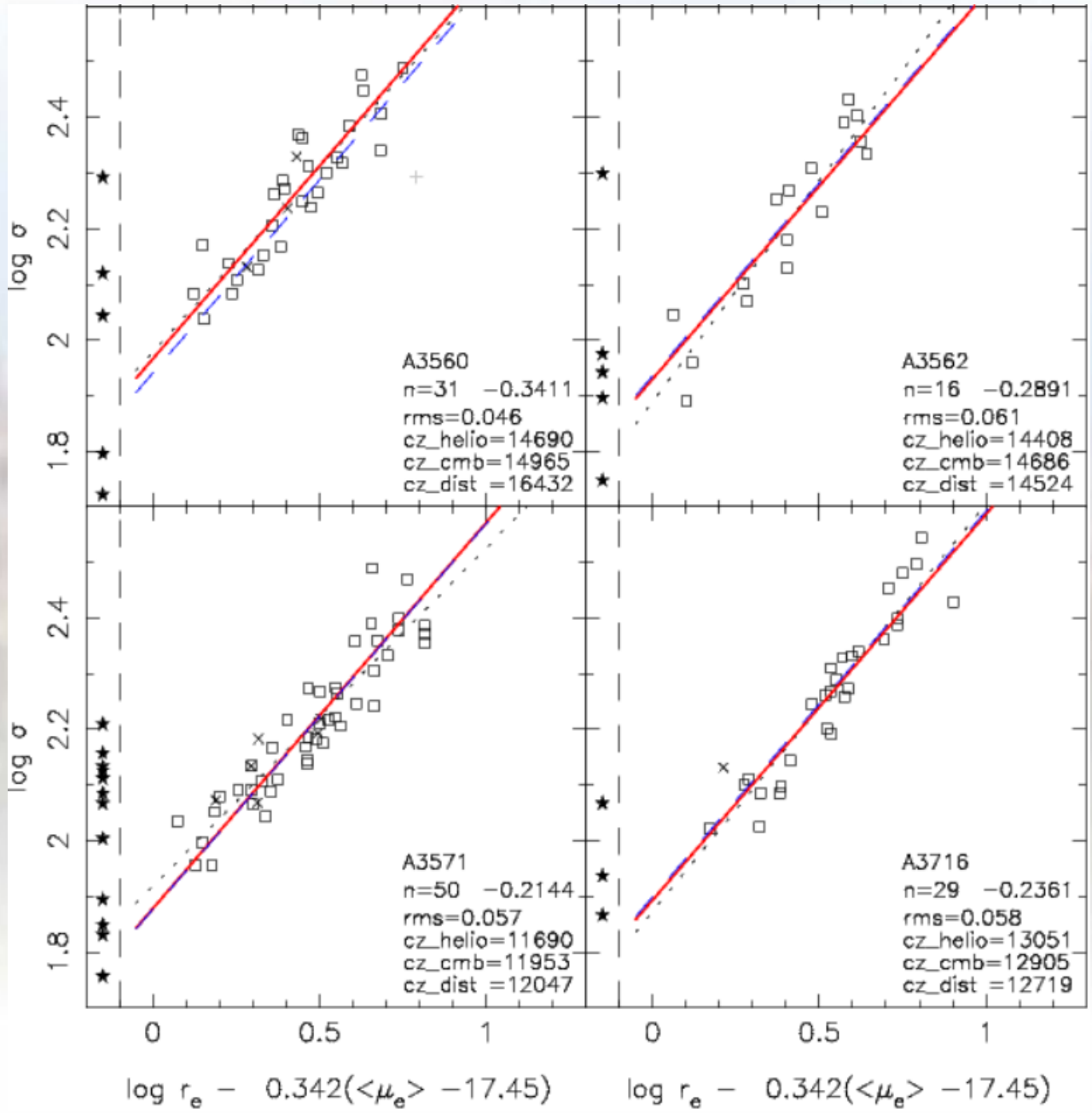
Adopted published values from SMAC, NFPS and SDSS to provide a high quality sigma dataset. Aperture corrected and match to a standard system from the large number of common objects.



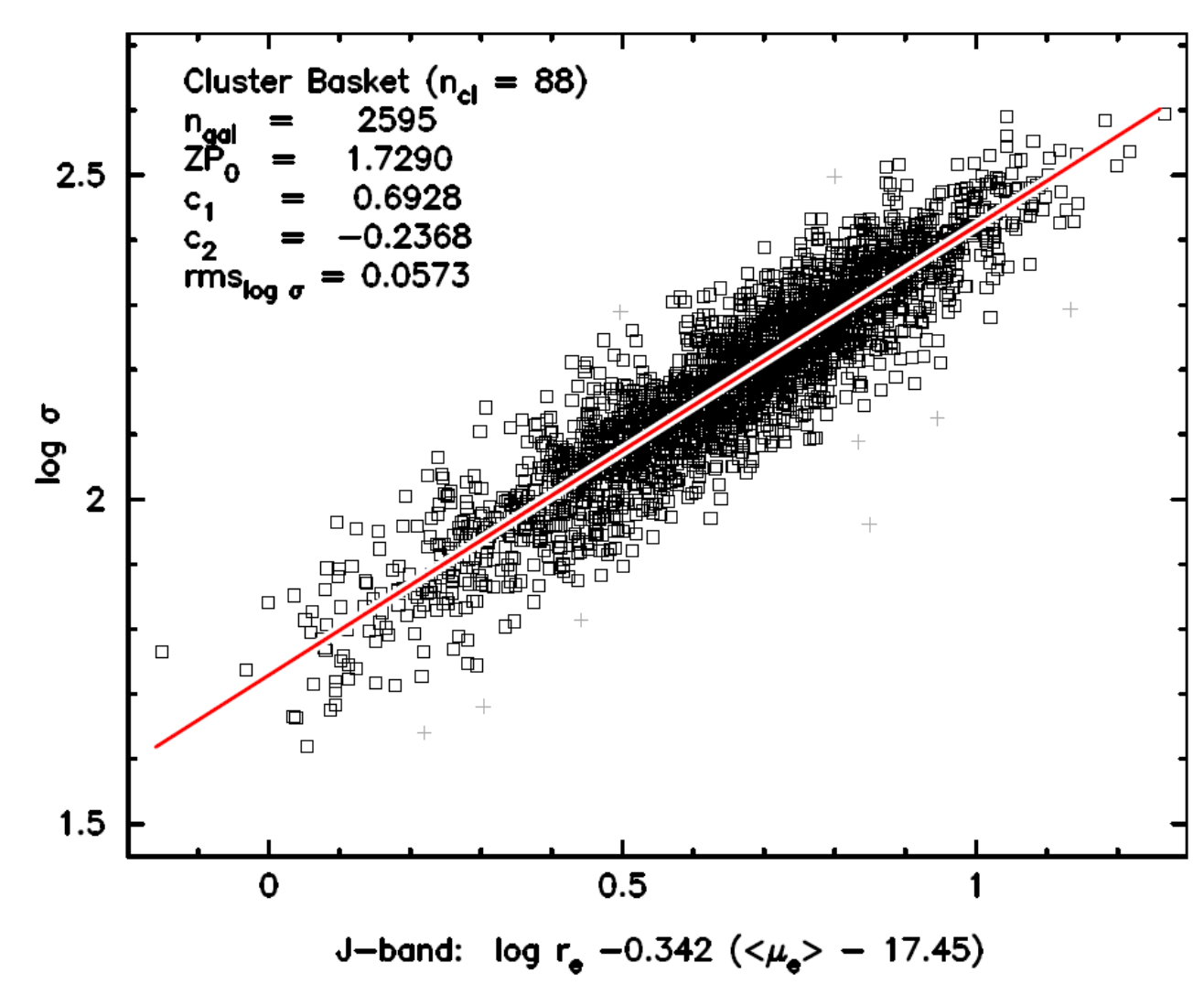
“Nominal” uncertainty in matching is ~0.3%.

This is always the potential bugbear for FP studies particularly for fibre-based sigmas. Homogeneity of SDSS measurements?

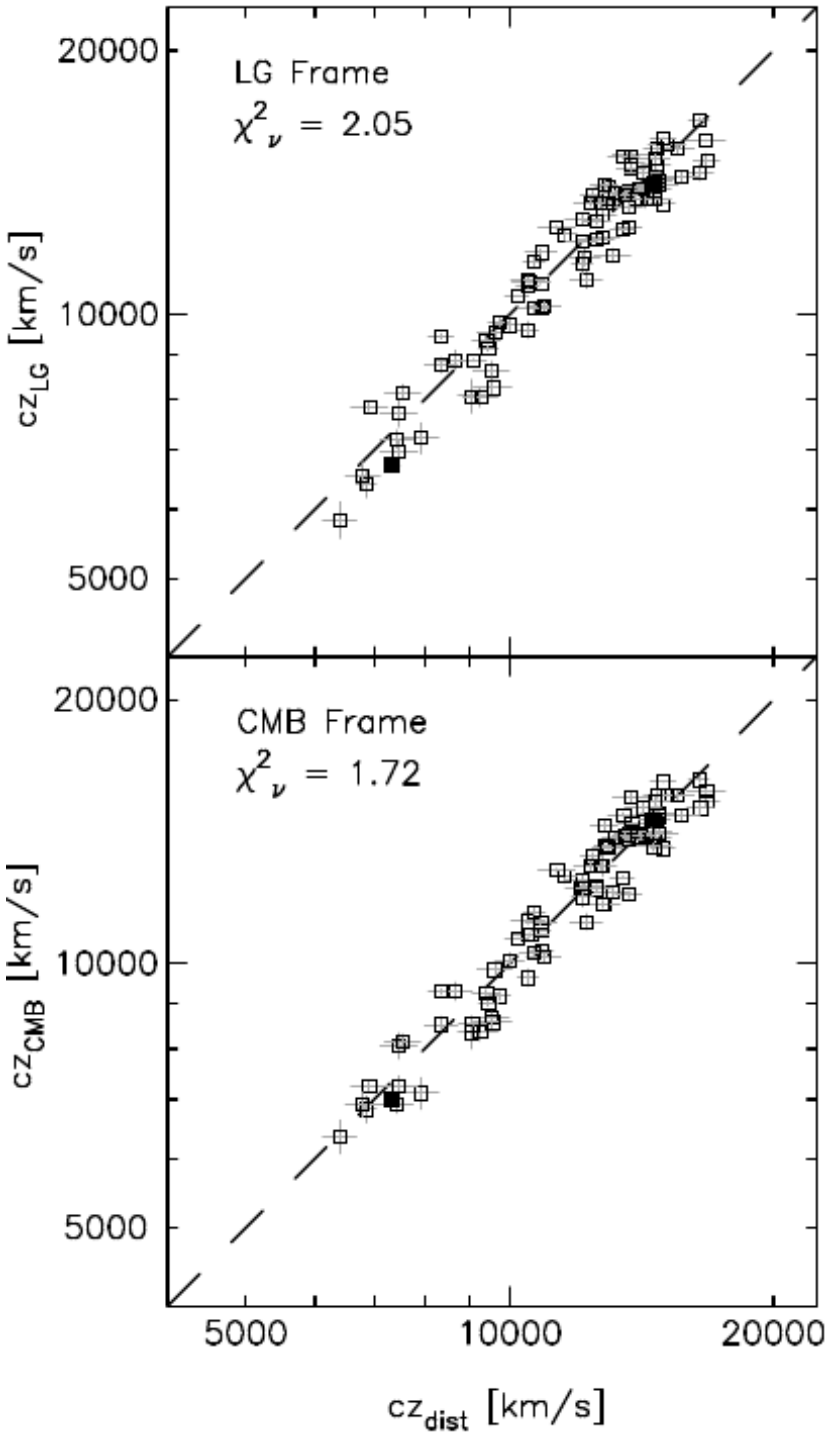
Example Cluster FPs



Base FP Relation from 2595 Galaxies in the 88 Clusters



Distance error per galaxy of ~19%.
Mean cluster distance error is 4%.



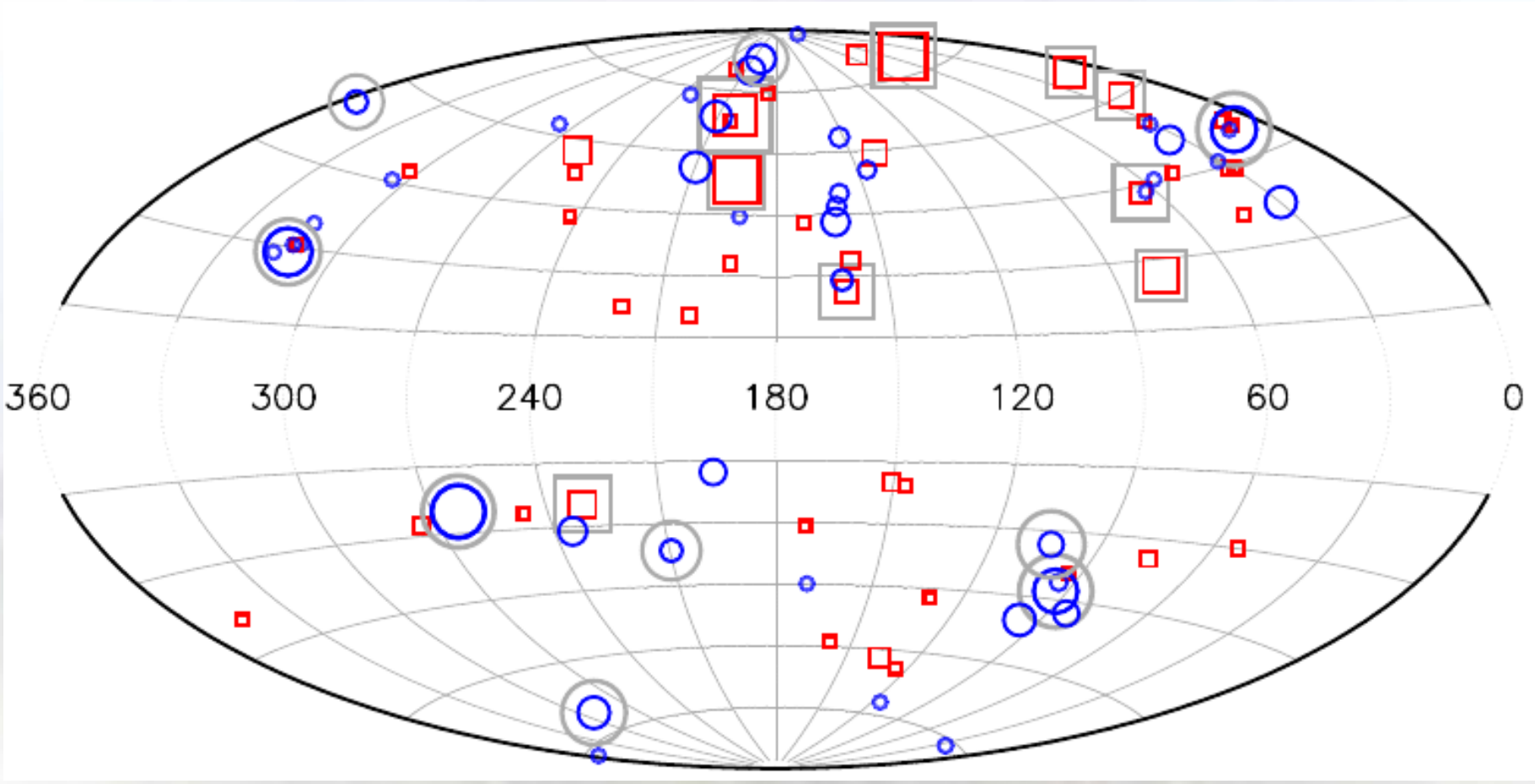
Hubble Diagrams

Lower chi-squared in CMB frame than the LG frame, i.e. 1.72 vs 2.05.

Need to have an rms cluster peculiar velocity of 500 km/s or increase the measurement errors by 50% to get a reduced chi-squared of 1.

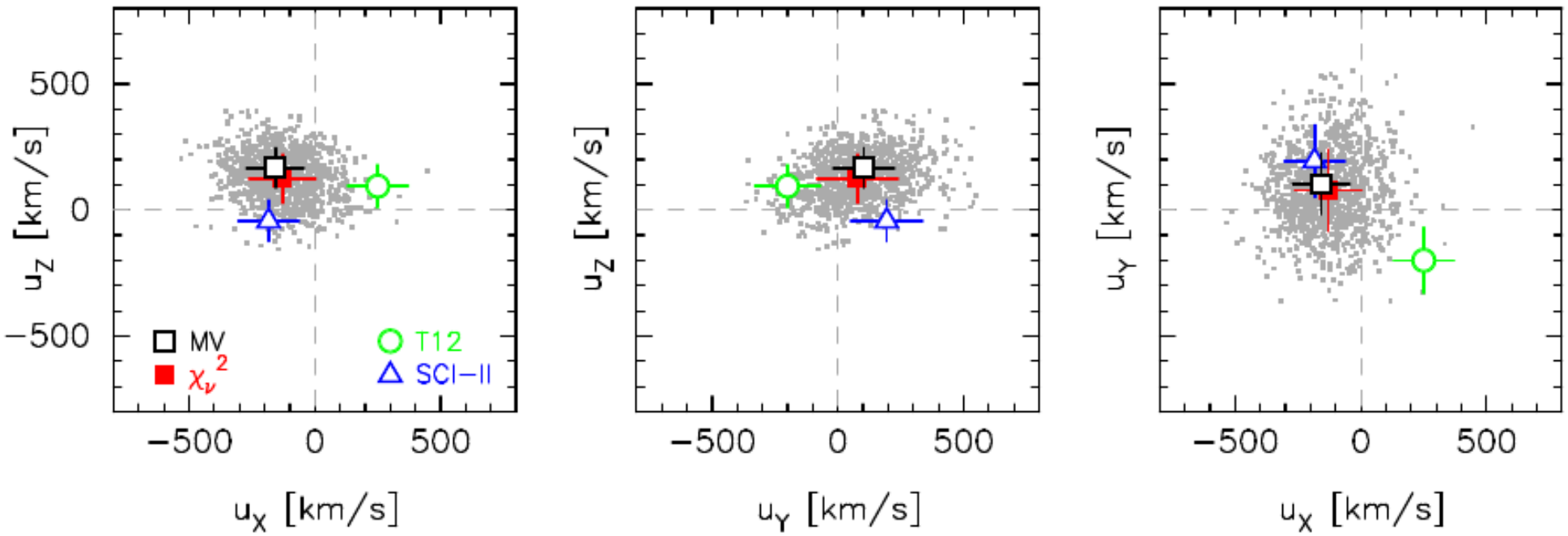
Hidden systematic errors in ~5% of fibre-based sigma measurements ????

Cluster Sky Distribution



Superclusters apparent.

Bulk Flow Measurements in the CMB frame



MV V=174 +/- 115 km/s towards (l,b) = (147+/-35, 42+/-25)

Sample/test	$n_{cluster}$	Raw km s^{-1}	Amplitude km s^{-1}	l°	b°	V_X km s^{-1}	V_Y km s^{-1}	V_Z km s^{-1}	χ^2_ν
NIR-FP base MV solution	88	252	174 ± 115	147 ± 35	42 ± 25	−158 ± 113	+103 ± 121	+167 ± 78	-
NIR-FP base χ^2_ν solution	**88**	220	**< 0**	**-**	**-**	**−149 ± 131**	**+82 ± 160**	**+143 ± 105**	**1.73**
exclude A2593	87		< 0	-	-	−144 ± 133	+128 ± 155	+112 ± 100	1.65
exclude also A1213	86		< 0	-	-	−115 ± 130	+135 ± 157	+87 ± 99	1.57
Cluster redshifts	88								
$0.020 < z < 0.041$	44		< 0	-	-	−45± 194	+151 ± 245	+284 ± 121	1.43
$0.041 < z < 0.055$	44		213 ± 192	152 ± 31	+8 ± 20	−373± 212	+195 ± 226	+56 ± 163	1.80
×1.01 FP zero-point	88		< 0	-	-	−122 ± 145	+46 ± 156	+82 ± 97	1.77
×0.99 FP zero-point	88	295	173 ± 143	146 ± 39	+44 ± 22	−177 ± 145	+117 ± 156	+203 ± 97	1.77
$b > 0^\circ$	60		< 0	-	-	−178 ± 166	+200 ± 212	+118 ± 108	1.67
$b < 0^\circ$	28		< 0	-	-	−104 ± 305	−21 ± 250	+169 ± 224	2.12

Recovery of the LG Motion wrt the CMB

CMB dipole plus the solar motion wrt to the LG centroid implies the LG motion is
621 +/- 22 km/s towards (l,b) = (272+/-3, 28 +/- 2).

Relative to our sample of 88 clusters we find a LG motion of
589 +/- 151 km/s towards (l,b) = (285+/-13, 15+/-10).

Hence we detect the expected reflex motion of the LG.

Conclusions

Using an all-sky set of 88 rich clusters with $0.020 < z < 0.055$ we find:

- The observed rms of the NIR cluster FP is 19%. With the number of galaxies per cluster ranging from 15 to 100 the average uncertainty on the measured cluster distance is ~4%.

- In the CMB frame the cluster sample has a bulk flow of 174 +/ 115 km/s, i.e. a non-detection.

- We recover the expected LG motion with respect to the CMB at a significance of ~4-sigma.

Future FP Prospects

New measurement of velocity dispersions from

TAIPAN (aka 6dF++ on the UKST)
LoRCA (Low Redshift survey at Calar Alto, Comparat et al 2016)
DESI from 2019?

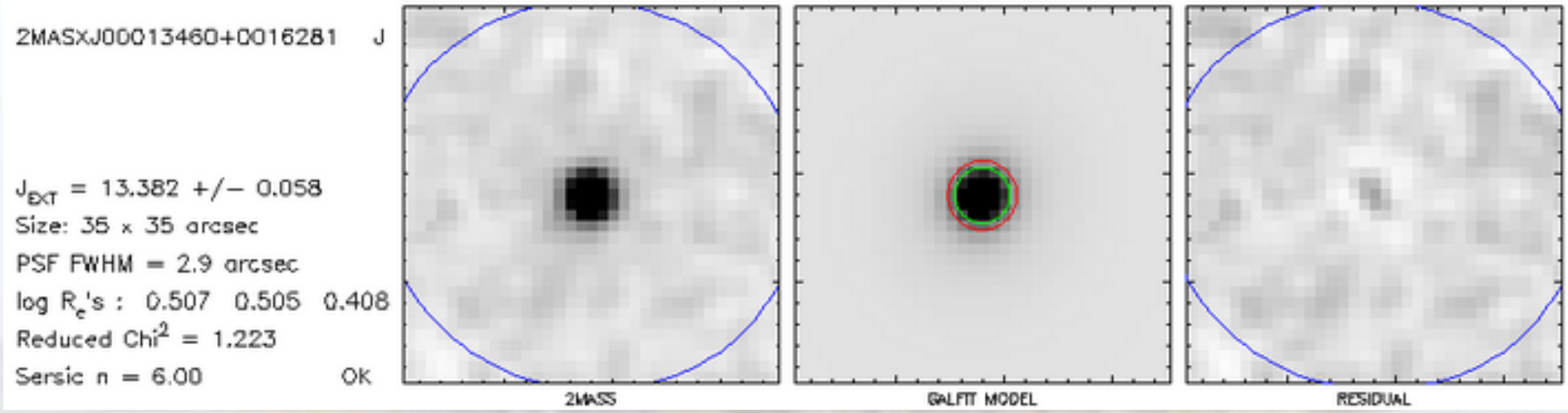
plus better linking to existing surveys, i.e.
SDSS, 6dFGSv, NFPS, ENEAR, SMAC, etc
will enable a high quality all-sky sigma catalogue to be constructed.

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

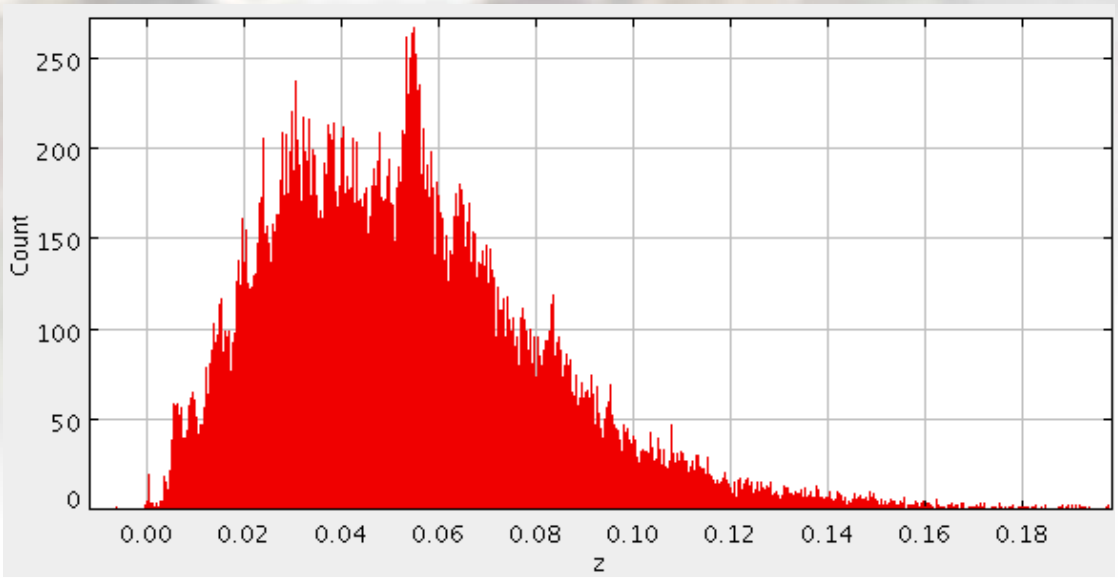
Multi-colour red sequence selection coupled with ~1 arcsec images will result in a very homogeneous morphologically clean FP data set over the entire sky within z ~ 0.07.

2MASS-based FP Photometric Parameters

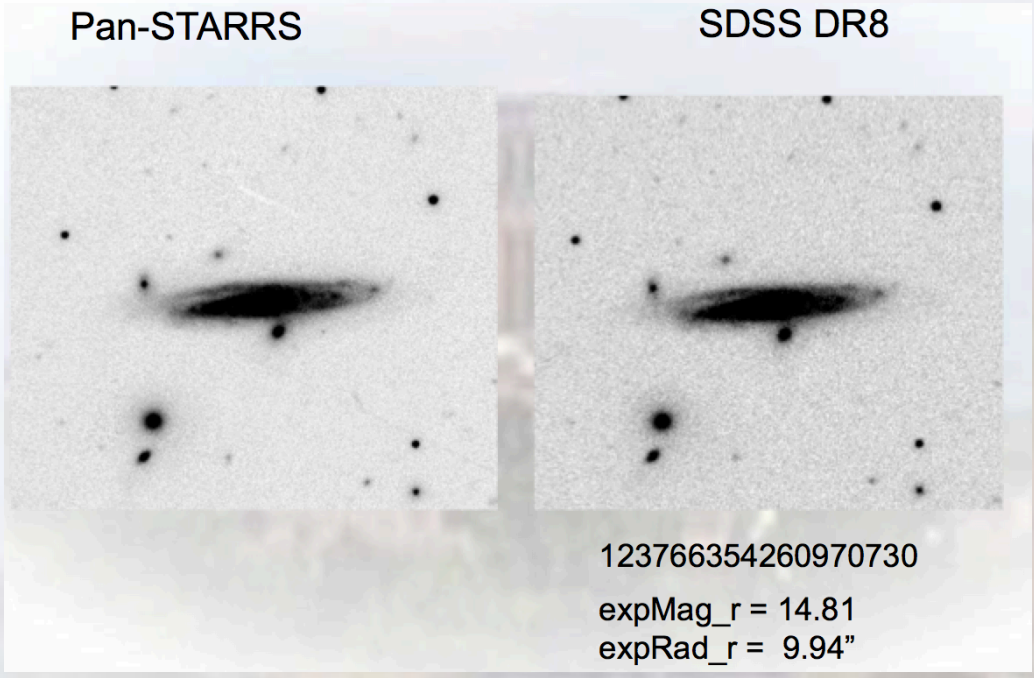
r_H Measurements now completed for the all-sky sample of 263k 2MASS XSC objects brighter than J = 14 mag with |b| > 10 deg.

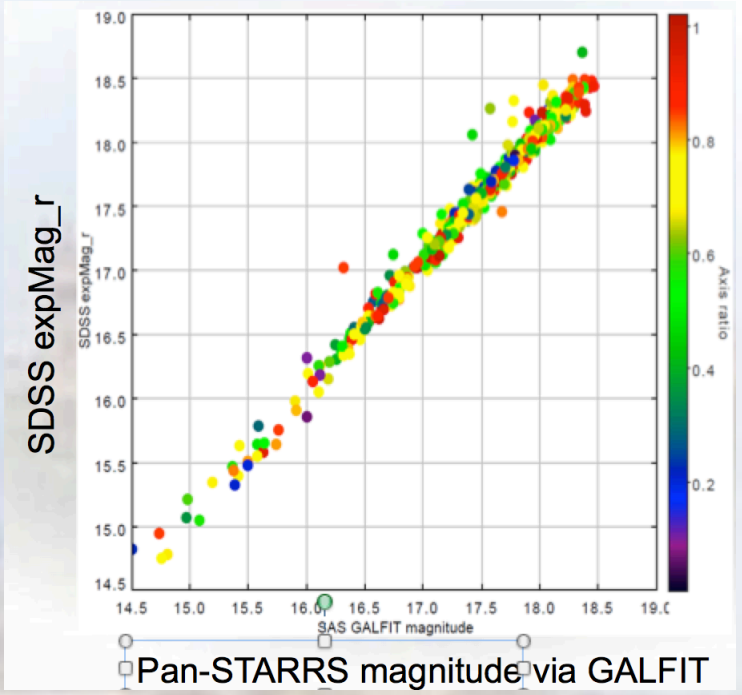


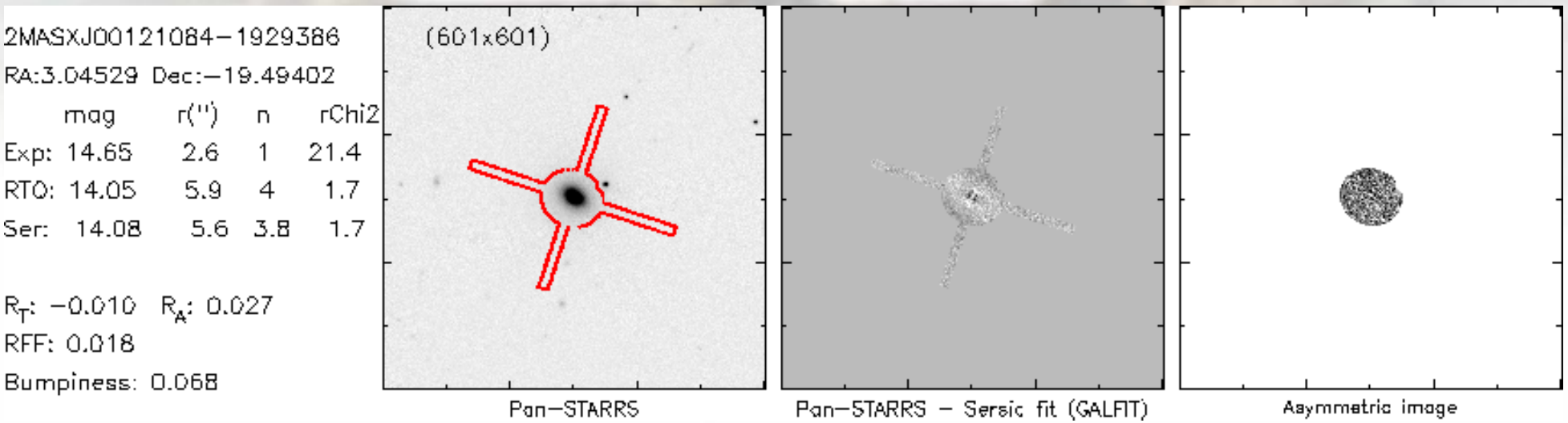
Redshift distribution of the 65k J <14 XSC objects in the -30 < Dec < 0.



Links to 3-Pi Pan-STARRS grizy imagery for Dec > -30







PanSTARRS1 3PI Image Access

2MASXJ00121084-1929386 | Submit | Reset | Clear | *Help*

Filters: ☑ color ☑ g ☑ r ☑ i ☐ z ☐ y

File types: ☑ stack ☐ warp

Auxiliary data: ☑ data ☐ mask ☐ wt ☐ exp ☐ expwt ☐ num

Cutout image size: 240 pixels (60.00 arcsec) *(sets spatial size of the FITS image)*

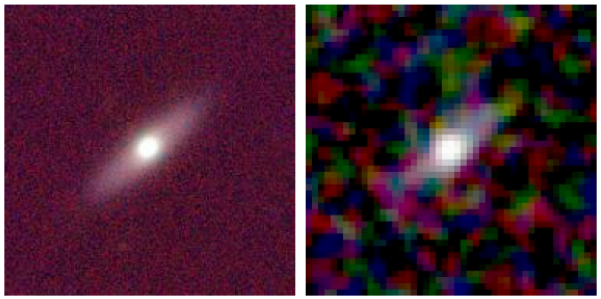
JPEG display size: pixels *(sets resolution of the JPEG previews)*

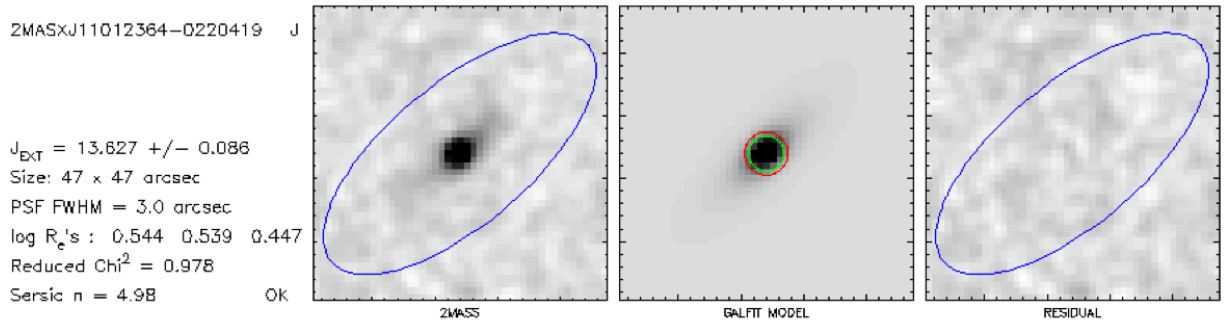
2MASXJ00121084-1929386 (ra = 3.045250, dec = -19.494030)

stack 881.017 i/r/g	stack 881.017 g	stack 881.017 r	stack 881.017 i
Display	Display FITS FITS-cutout	Display FITS FITS-cutout	Display FITS FITS-cutout

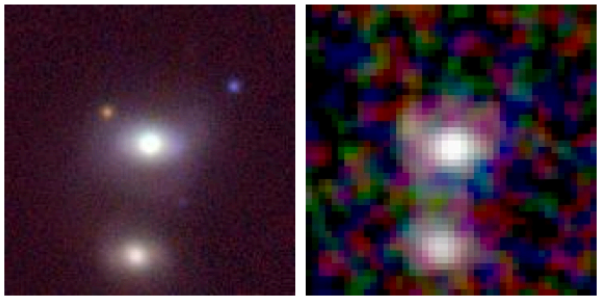
Pan-STARRS vs 2MASS

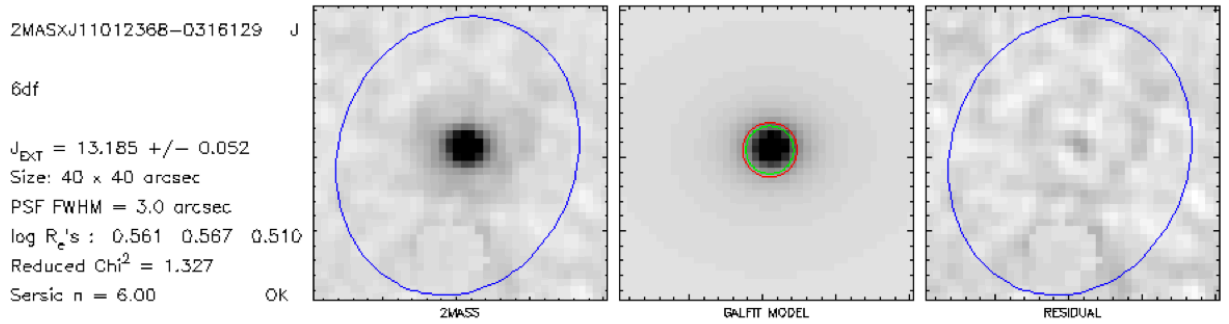
2MASXJ11012364-0220419 NED **z = 0.046062** $(g-i)^0_{7.43} = 1.138$ $(J-K)^0_{7.43} = 1.063$



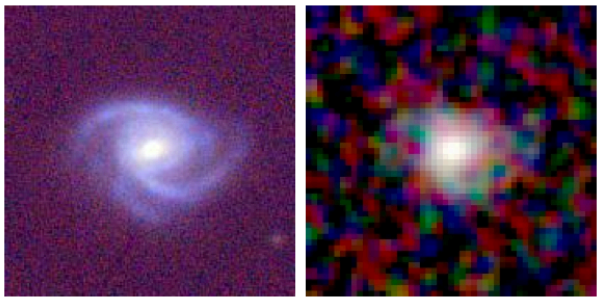


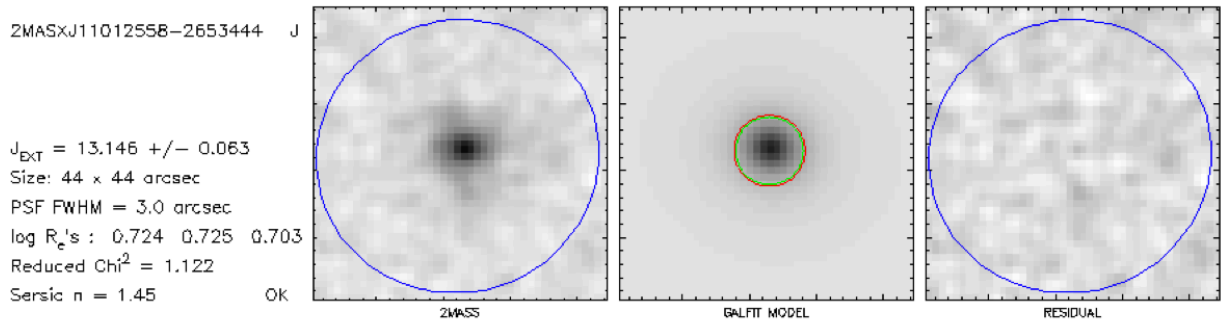
2MASXJ11012368-0316129 NED **z = 0.03272** $(g-i)^0_{7.43} = 1.004$ $(J-K)^0_{7.43} = 0.971$



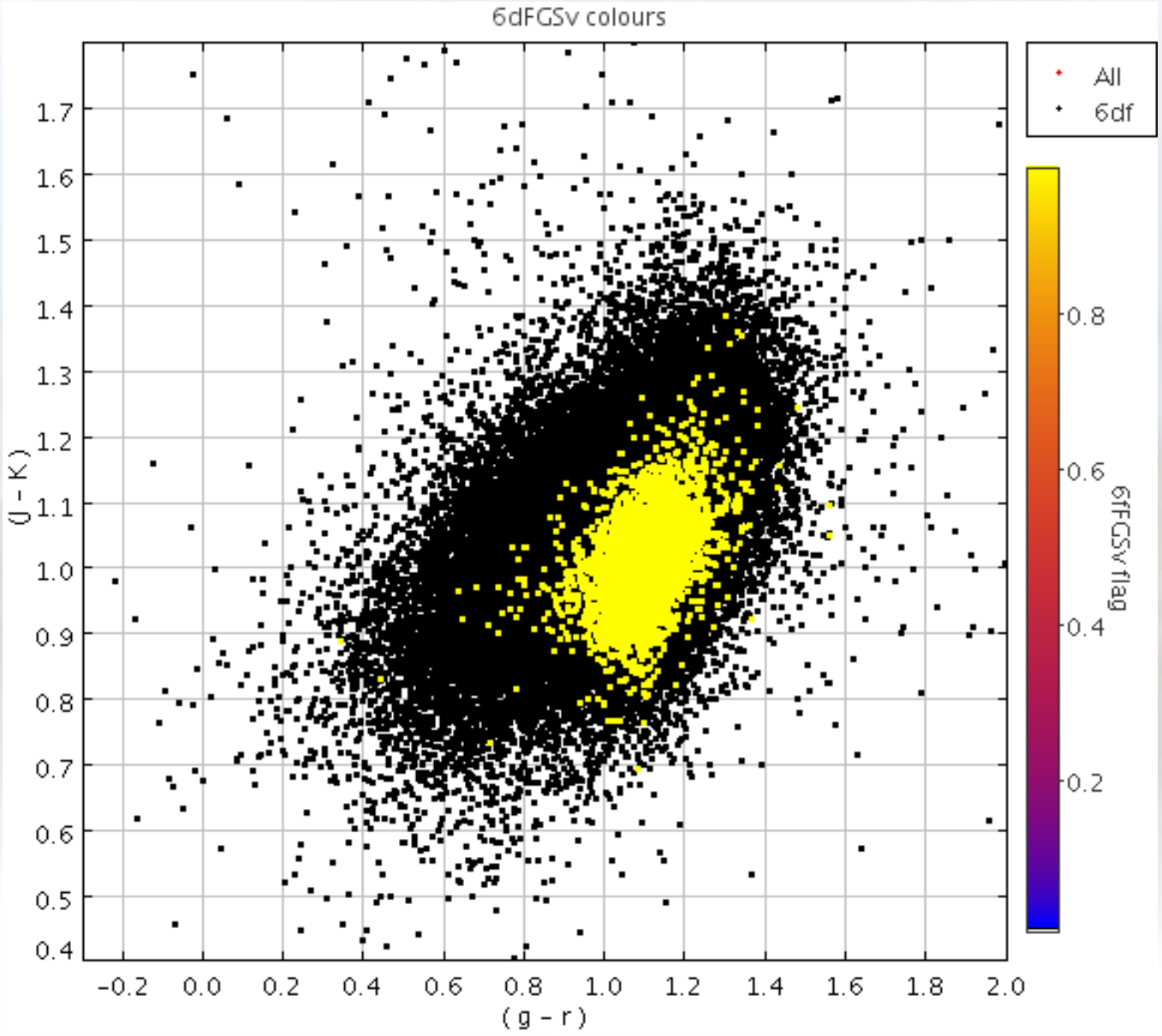


2MASXJ11012558-2653444 NED **z = 0.05755** $(g-i)^0_{7.43} = 0.780$ $(J-K)^0_{7.43} = 1.087$

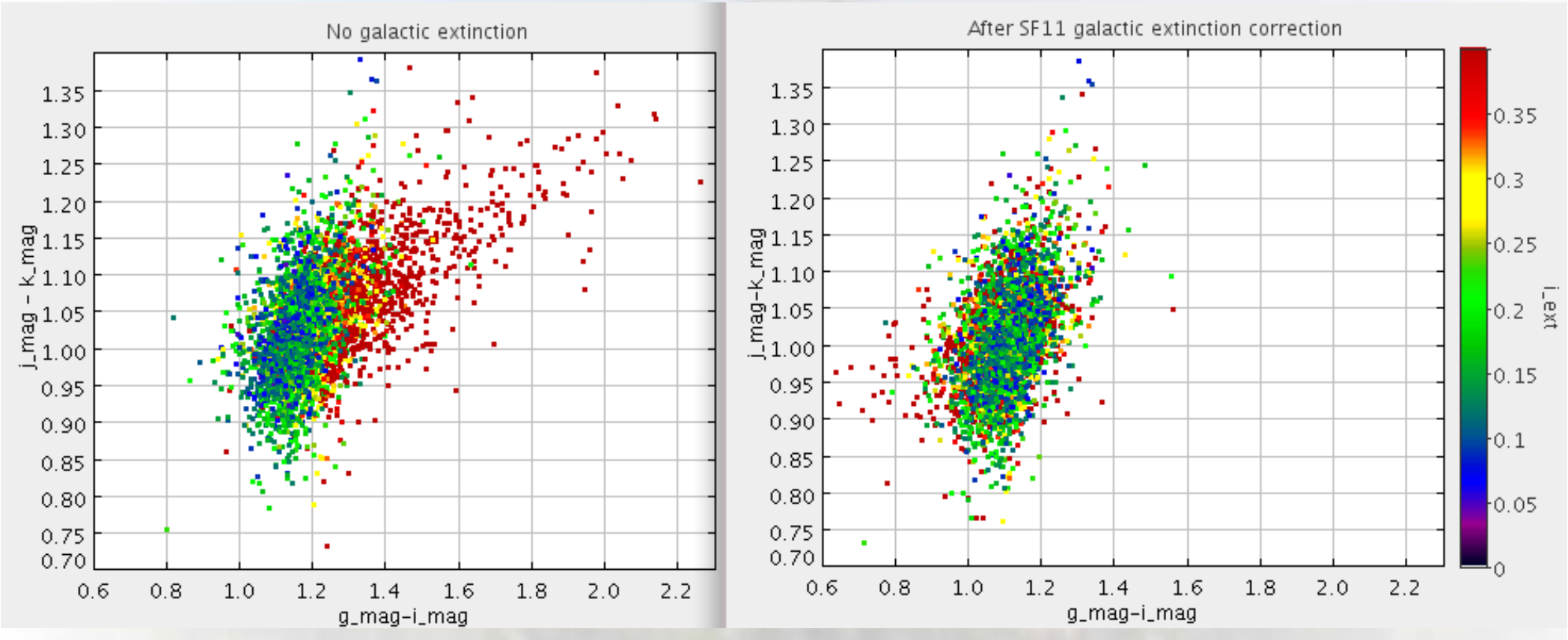




Pan-STARRS (g-r) and 2MASS (J-K) Colours for 6dFGSv Galaxies in the -30 > Dec > 0 zone



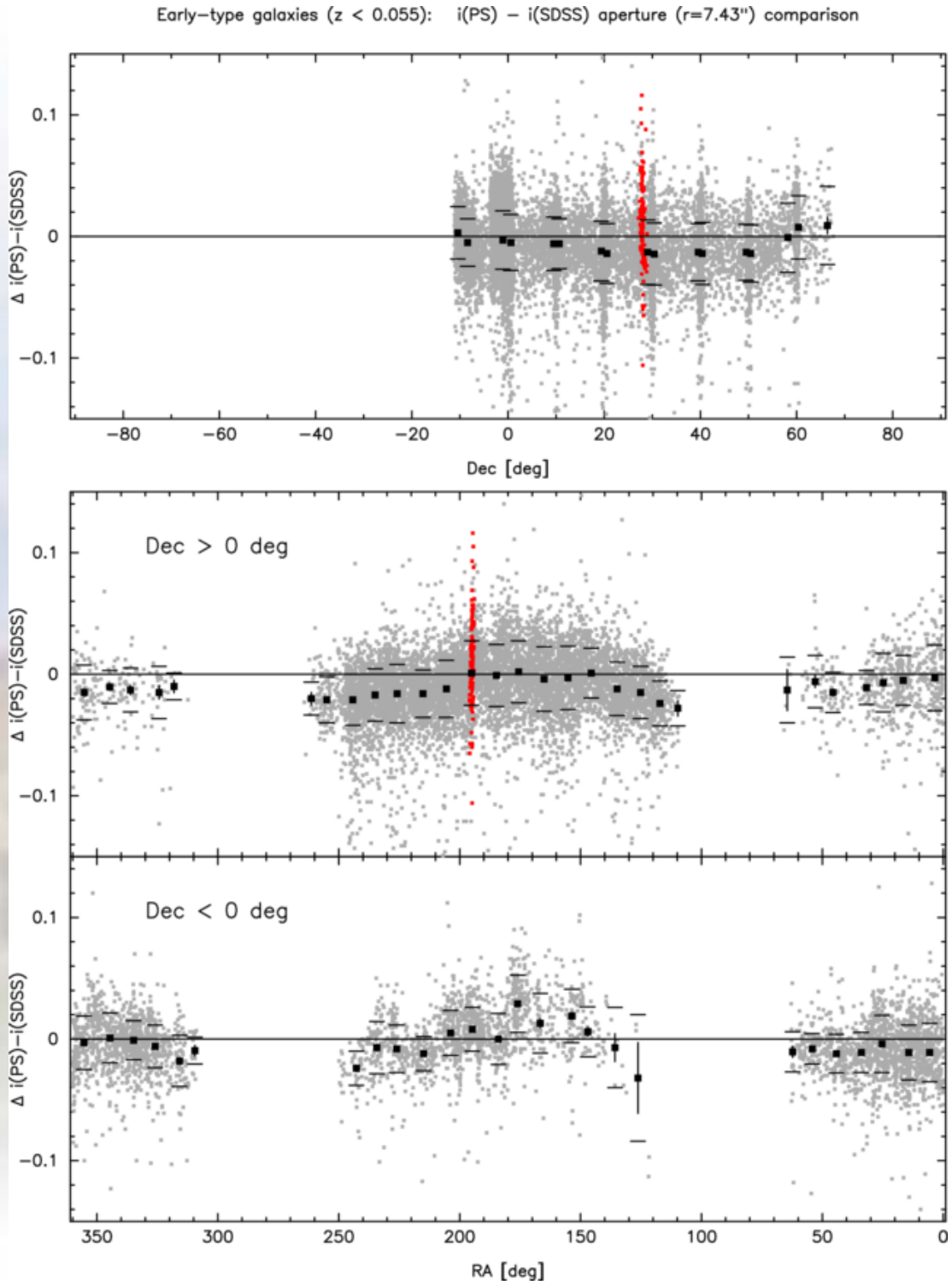
Tests of the SF11 Galactic Extinction



SF11 work!

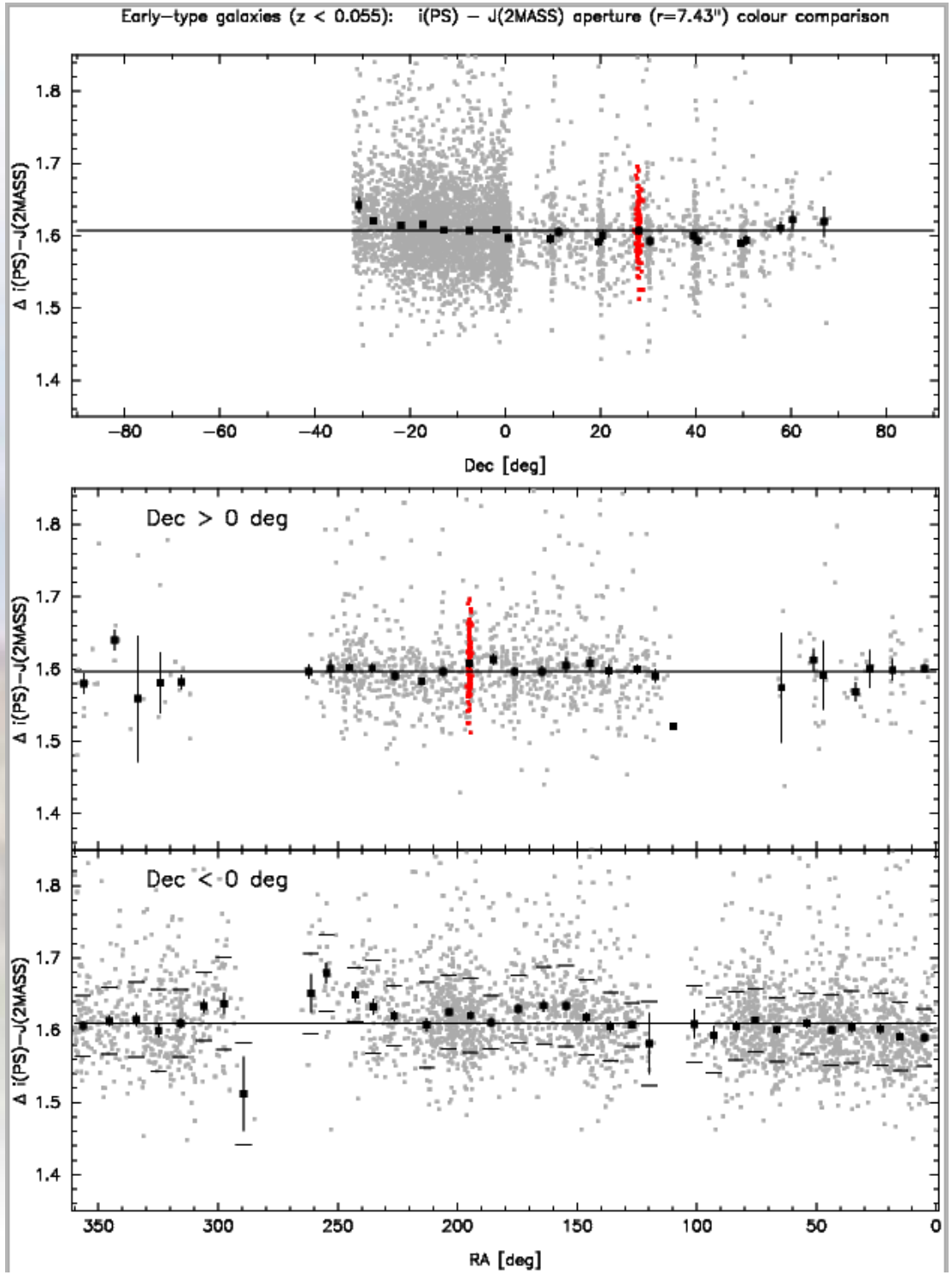
Test of Photometric ZPs

Comparison of Pan-STARRS i-band with SDSS i-band.



Test of Photometric ZPs

Comparison of Pan-STARRS i-band with 2MASS J-band.



Final Remarks

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

TAIPAN and LORCA supplemented by existing work like 6dFGSv, SDSS etc will provide new higher quality velocity dispersions.

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

Second Golden Age of
Peculiar Velocity Studies
~2012 to ~2027?