THE SDSS-UKIDSS FUNDAMENTAL PLANE OF EARLY-TYPE GALAXIES

OVERALL DESCRIPTION OF THE PROJECT

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We select a magnitude limited sample of 1430 early-type galaxies from the SDSS-DR5, in the redshift range of 0.05 to 0.095, with available photometry from UKIDSS-LAS (DR2)

We derive magnitudes and structural parameters (namely the effective radius, r_e, the mean surface brightness with that radius, $<\mu>_e$, and the the Sersic index, n) in the same way for both the r- (SDSS) and K- (UKIDSS) bands

GOALS

→ Waveband dependence of the FP (from r and K band)

→ Waveband dependence of other relations (Faber Jackson, luminosity-size, Kormendy relations)

→ Optical-NIR internal color gradients of early-type galaxies

→ All of that ….. as a function of local galaxy density

TALK OUTLINE

- Introduction
- Sample selection
- SDSS/UKIDSS galaxy parameters
- The SDSS-UKIDSS FP
- Stellar populations vs. mass
- Conclusions

THE TILT

$\log R_e = a \log \sigma_0 + b \langle \mu \rangle_e + const$ → optical wavebands

a~1.2 b~0.3

↕

2T+V=0

$T/\sigma_0^2 = k_T$, $V/(L/R_e) = M/L \cdot k_V$ → expected values

a=2 b=0.4

M/L=const.

↕

non homology

$M/L \sim L^{\beta}$ → **$\beta = (2-a)/(2a) \sim 1/3$**

(homology)

WHY THE WAVEBAND DEPENDENCE

→ Understanding the origin of the TILT of the FP: a change of stellar population vs. galaxy mass is expected to be wavelength dependent, while other effects (homology breaking, dark-matter content variations, ….) are not

→ Studying the FP at high redshifts, where observations are done in different wavebands

WAVEBAND DEPENDENCE ?

OPTICAL FPs

	a	b		
Jorgensen et al .96	1.08 ± 0.08	0.34 ± 0.02	41	U
Dressler et al 87	1.32 ± 0.05	0.33 ± 0.02	40	B
De Carvalho and Djorgovski 92	1.25 ± 0.07	0.32 ± 0.01	55	B
Busarello et al. 97	1.11 ± 0.20	0.36 ± 0.04	40	B
Graham 98	1.10 ± 0.14	0.22 ± 0.04	25	B
Prugniel and Simien 94	1.42 ± 0.05	0.35 ± 0.01	102	B
Saglia et al. 93	1.05	0.35	15	B
Graham and Colless 96	1.33 ± 0.10	0.32 ± 0.04	26	V
Guzman et al. 93	1.13	0.31	37	V
Djorgovski and Davies 87	1.39 ± 0.14	0.36 ± 0.036	260	r
Hudson et al. 97	1.38 ± 0.04	0.33 ± 0.01	325	R
Jorgensen et al. 96	1.24 ± 0.07	0.328 ± 0.008	226	r
Gibbons et al. 01	1.37 ± 0.05	0.336 ± 0.001	400	R
Colless et al. 01	1.22 ± 0.09	0.33 ± 0.009	255	R

a~1.05-52

SDSS FP

	a	b		
Bernardi et al .03	1.45 ± 0.06	0.296 ± 0.004	9000	g
Bernardi et al 03	1.49 ± 0.06	0.300 ± 0.004	9000	r
Bernardi et al. 03	1.52 ± 0.05	0.312 ± 0.004	9000	i
Bernardi et al. 03	1.51 ± 0.05	0.308 ± 0.004	9000	z

a~1.45-52

NIR FPs

	a	b		
Scodeggio et al.98	1.51 ± 0.09	0.32 ± 0.01	29	H
Zibetti et al. 02	1.38 ± 0.1	0.35 ± 0.03	135	H
Pahre et al. 95	1.29 ± 0.08	0.284 ± 0.024	12	K
Pahre et al.98	1.53 ± 0.08	0.32 ± 0.01	251	K
Mobasher et al. 99	1.36 ± 0.26	0.30 ± 0.02	48	K

total 475 gals

a~1.29-53

WAVEBAND DEPENDENCE ?

→ Pahre et al. 98 find the log σ_0 coefficient, a, of the FP to increase from **~1.3** (Jorgensen et al. 96; Smith et al. 97) in the r band to **~1.5** in the K band

→ Scodeggio et al. 98 found the value of a to change from **~1.35** in the B band to **~1.7** in the K band, while Zibetti et al.'02 found **a~1.38** in the H band

→ Bernardi et al. 03 found similar values of **a~1.5** in all the four (griz) SDSS bands.

↓

So far it is still not clear if and how far the FP depends on the waveband

WAVEBAND DEPENDENCE ?

ISSUES

- Small sample size
- Different samples of galaxies
- Selection effects
- Different methods to derive FP parameters
- Different fitting procedure
- Wavelength coverage

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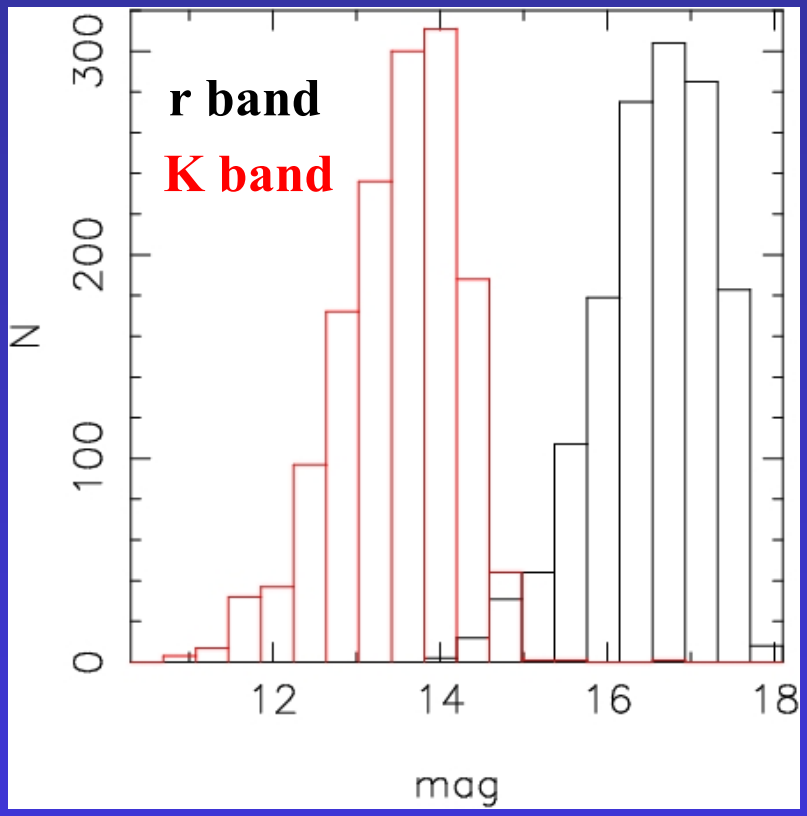
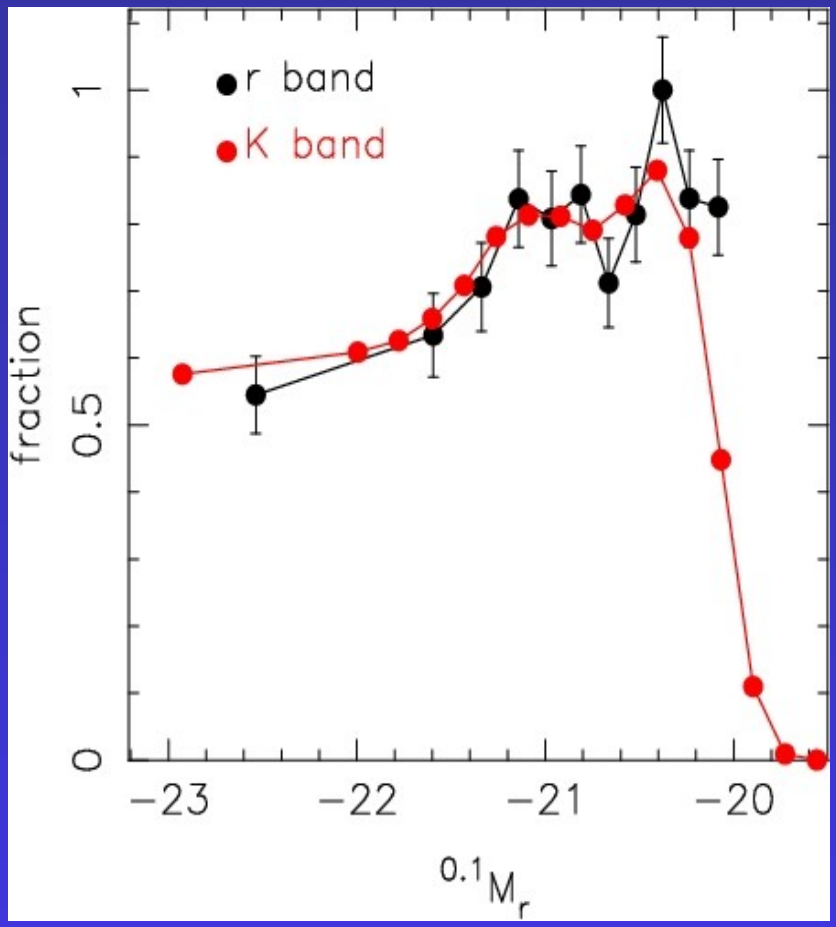
SAMPLE SELECTION

	N
Galaxies from the SDSS-DR5 with $0.05 \leq z \leq 0.095$ and $M_r < -20$	105036
Early-type galaxies (eclass$\leq$0, $DevFrac_r \geq 0.8$, zWarning=0)	47061
Available velocity dispersions, σ_0, in the range of 70 to 420 km/s	33628
Matching UKIDSS-DR2 K-band (seeing FWHM$\leq$1.0'')	1430

COMPLETENESS



r- and K-band apparent magnitude distribution of the SDSS-UKIDSS sample



Fraction of selected early-type galaxies vs. r-band magnitude. K-band mags have been corrected for the color-mag relation.

TALK OUTLINE

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DATA ANALYSIS

GOAL: measuring galaxy parameters in the same identical way for both the r- and K-band data

APPROACH: we retrieve both SDSS (N=1154) images and UKIDSS multiframes (N=1166) from the corresponding archives, and (re-)measure all the relevant quantities

⇨ **Magnitudes** { colors; K corrections (at z=0.1, see Blanton et al.03)

⇨ **Structural parameters** (r_e, $\langle\mu\rangle_e$, n)

SDSS-UKIDSS MAGNITUDES

- We measure magnitudes within an aperture radius of $2r_P$, where r_P is the SDSS-DR5 r-band Petrosian radius.
- Local background is measured in all bands with a 2.5 sigma clipping procedure, within an annulus of $3r_P$ to $4r_P$.
- Galactic extinction is corrected following Schlegel et al. 1998, ApJ. Typical corrections amount to 0.23, 0.17, 0.13, 0.09, 0.067, 0.017mag in ugrizK, respectively.

2DPHOT

(La Barbera et al. 2008, PASP accepted)

Extracting image catalogue by double-step running of S-Extractor

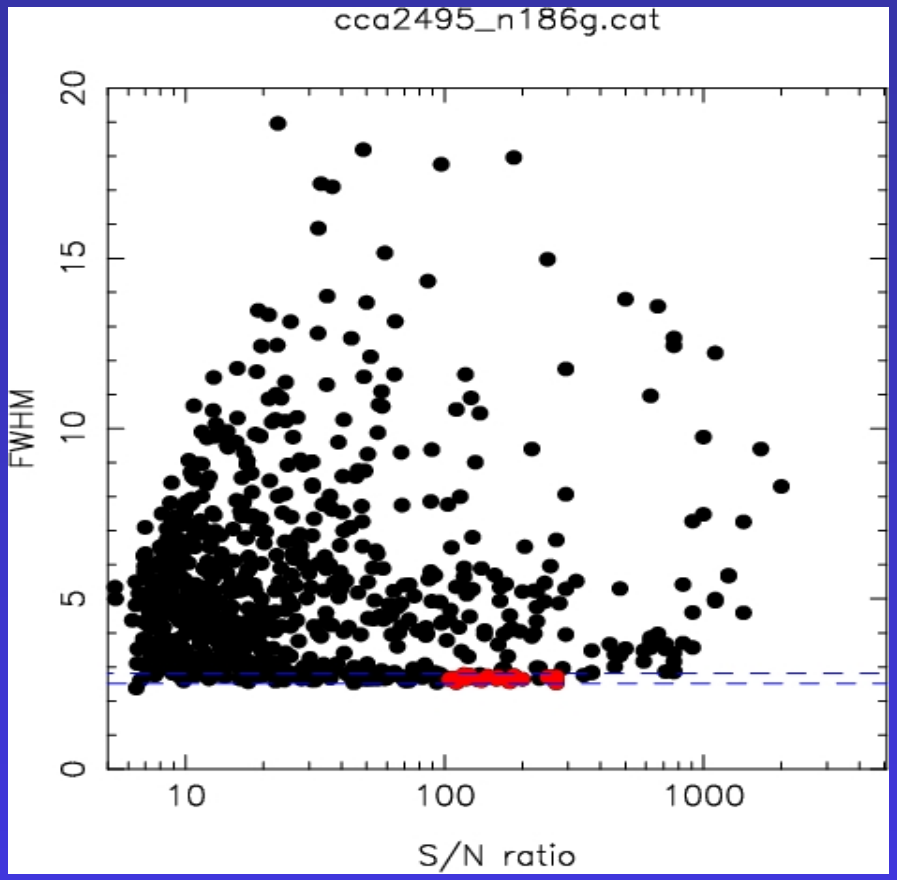
Reliable star/galaxy separation (with stellarity index and the effective radius)

Estimate of completeness/contamination

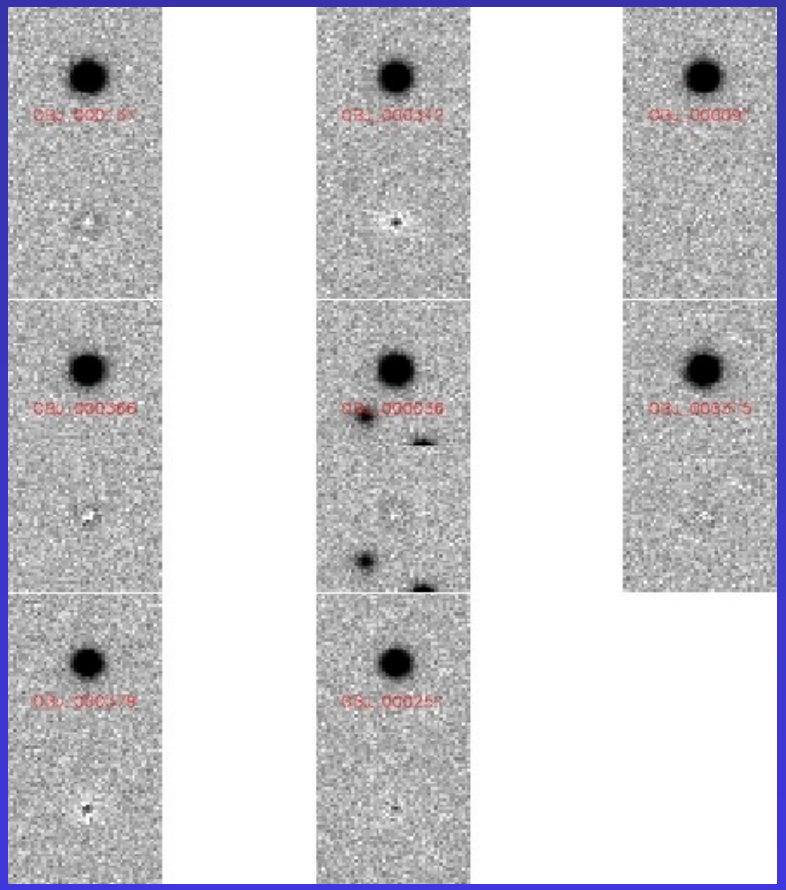
Measuring structural/morphological parameters

seeing deconvolved 2D Sersic parameters
seeing deconvolved 1D Sersic parameters
Petrosian parameters (seeing corrected)
growth curve effective parameters (seeing corrected)
+
ellipticity, PA, A_4 and B_4 profiles

2DPHOT PSF modeling



Definition of sure stars

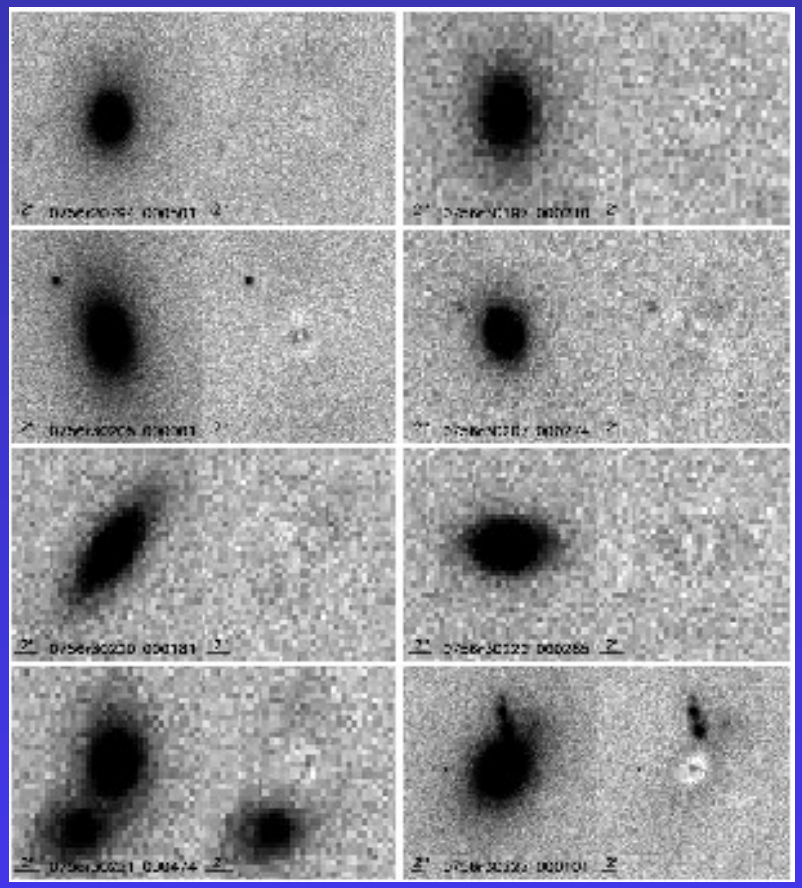


PSF fitting with 2D Moffat functions

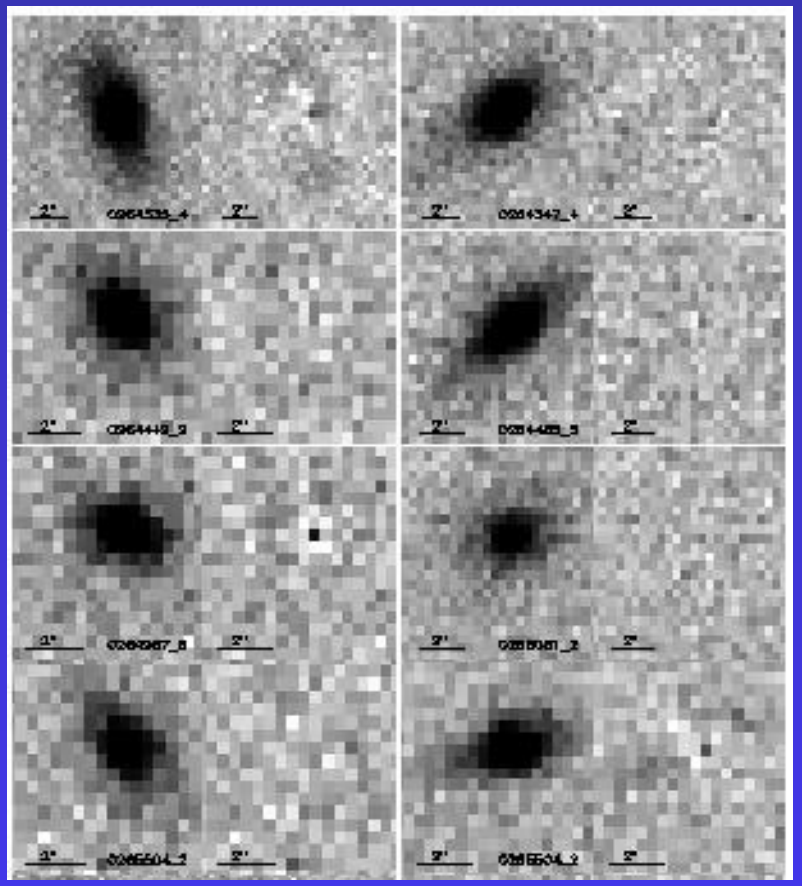
2D FITTING STRUCTURAL PARAMETERS

$$I_s(x,y)=I_0 \cdot Exp[-b_n(r/re)^{1/n}] \quad \Leftrightarrow \quad I_{obs}(x,y)=I_s \circ PSF(x,y)$$

SDSS r band

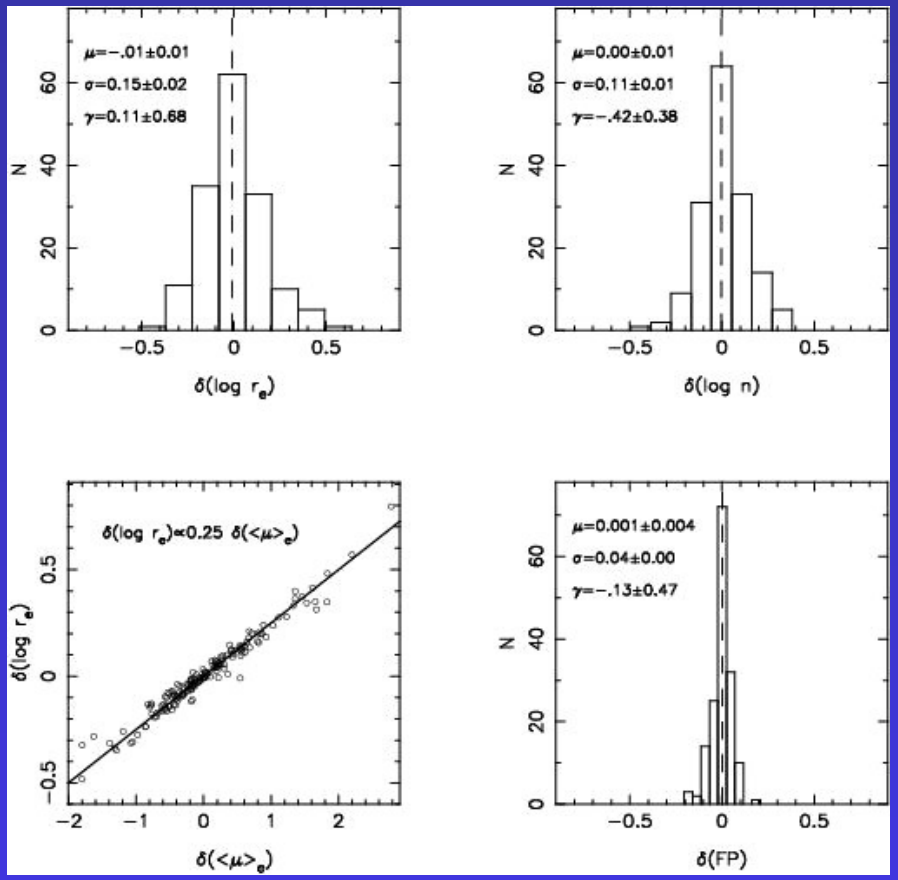


UKIDSS K band

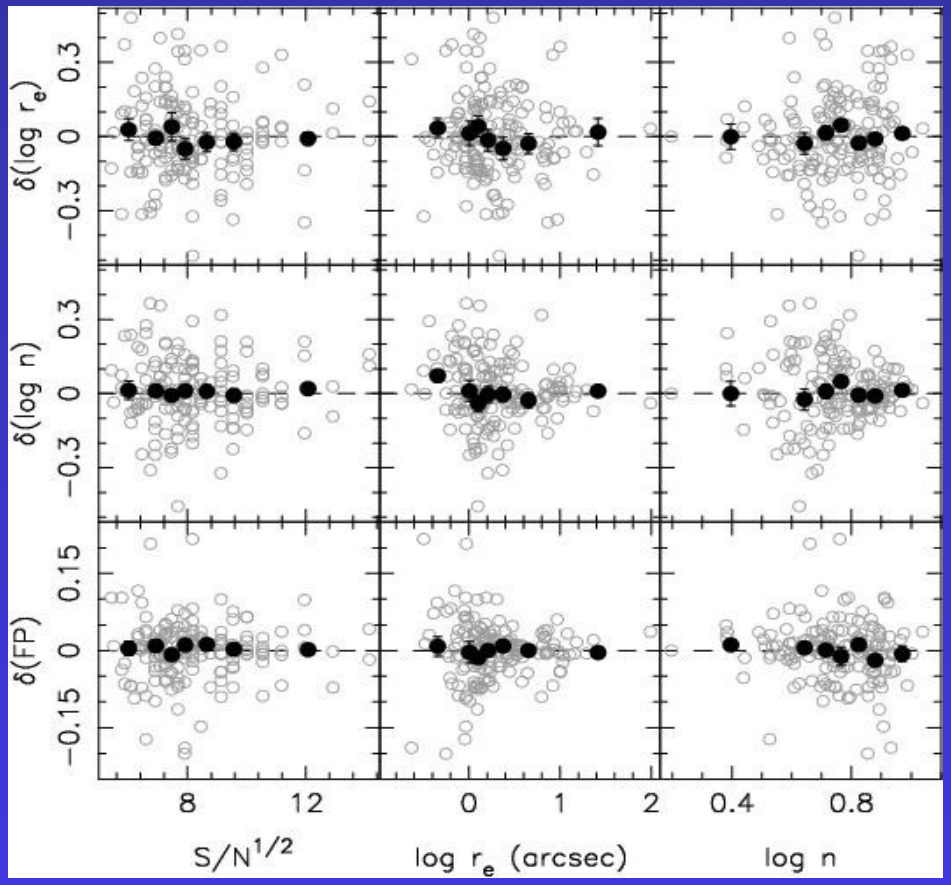


ACCURACY OF K-BAND 2DFIT PARAMETERS

N=160 galaxies have multiple K-band observations



Comparison of repeated measurements of structural parameters



Differences of repeated measurements as a function of signal-to-noise, r_e, and n, respectively.

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FP coefficients

⇨ We adopt two fitting methods:

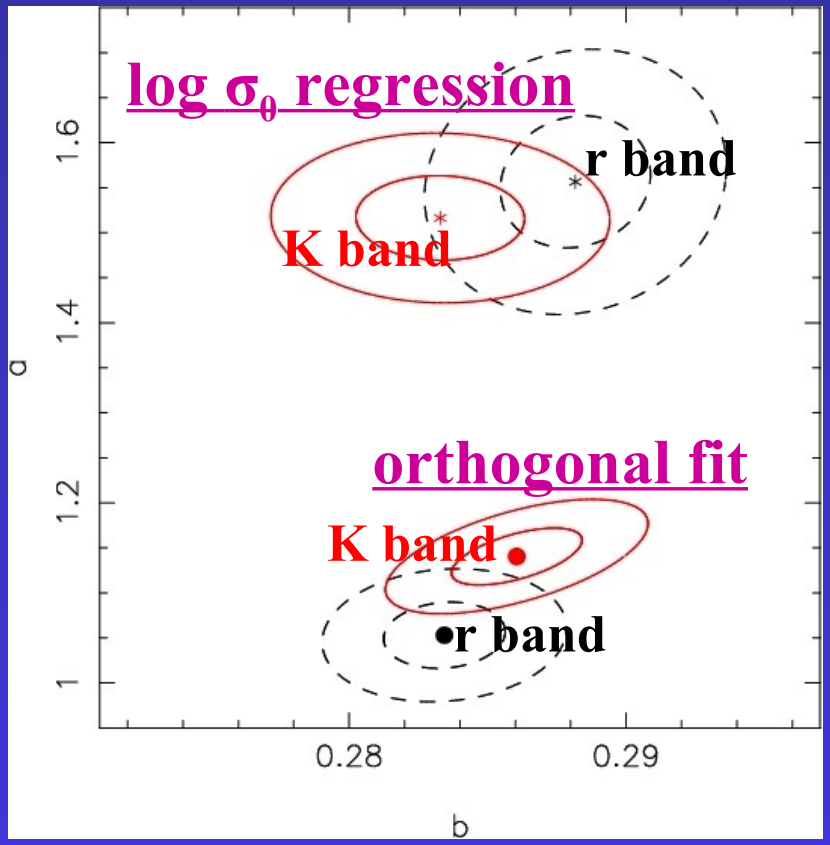
log σ_0 regression

ortogonal fit

In both cases, the fit is performed by minimizing the absolute sum of residuals about the plane

⇨ We perform several tests to analyze systematic and selection effects on fitting results

The Fundamental Plane in the r- and K-bands



FP slopes in the r- and K-bands. Ellipses plot 1σ and 2σ confidence contours, respectively.

log σ_0 regression

$\log R_e \propto (1.56\pm0.06)\log \sigma_0 + (0.288 \pm 0.003)\langle\mu\rangle_e$

$\log R_e \propto (1.52\pm0.05)\log \sigma_0 + (0.283 \pm 0.003)\langle\mu\rangle_e$

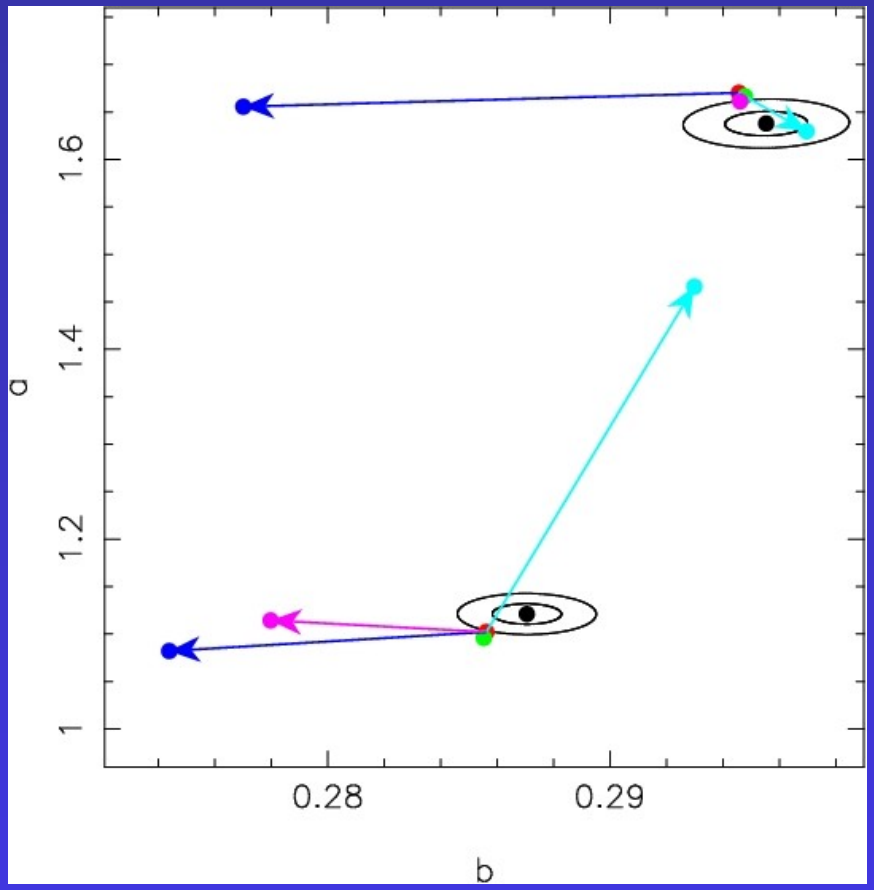
orthogonal fit

$\log R_e \propto (1.06\pm0.05)\log \sigma_0 + (0.284 \pm 0.003)\langle\mu\rangle_e$

$\log R_e \propto (1.14\pm0.04)\log \sigma_0 + (0.286 \pm 0.003)\langle\mu\rangle_e$

(ALMOST) NO WAVEBAND DEPENDENCE

Simulations: selection effects and the FP



r-band FP coefficients with 1σ and 2σ confidence contours

r-band simulated FP coefficients

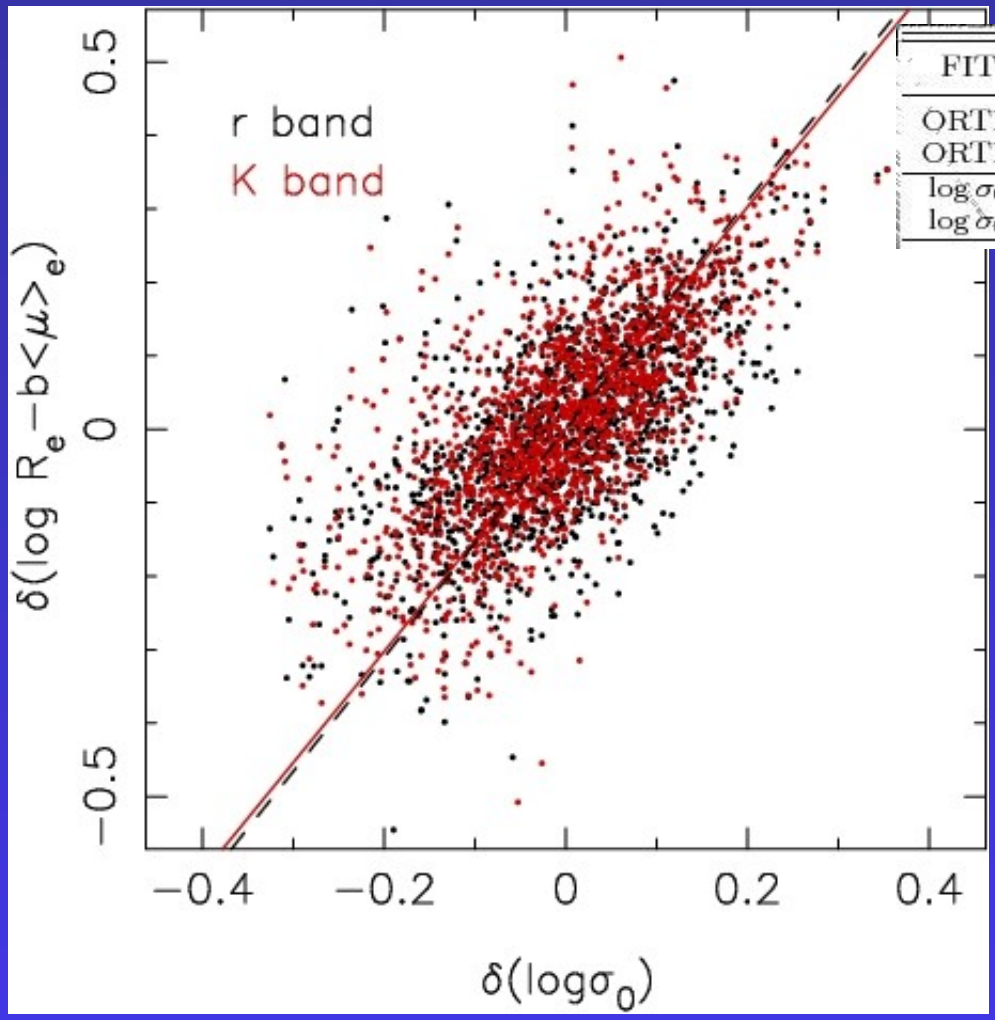
Removing magnitude cut

Adding correlated shifts on effective parameters

K-band selection function

Removing $70<\sigma_0<420$ selection

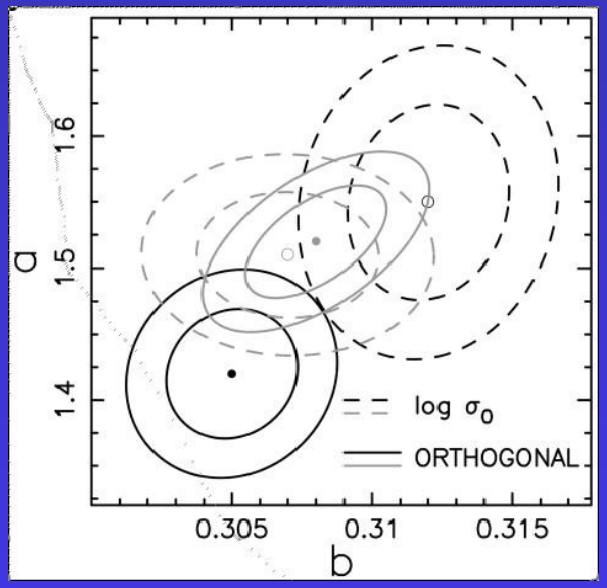
The Fundamental Plane in the r- and K-bands



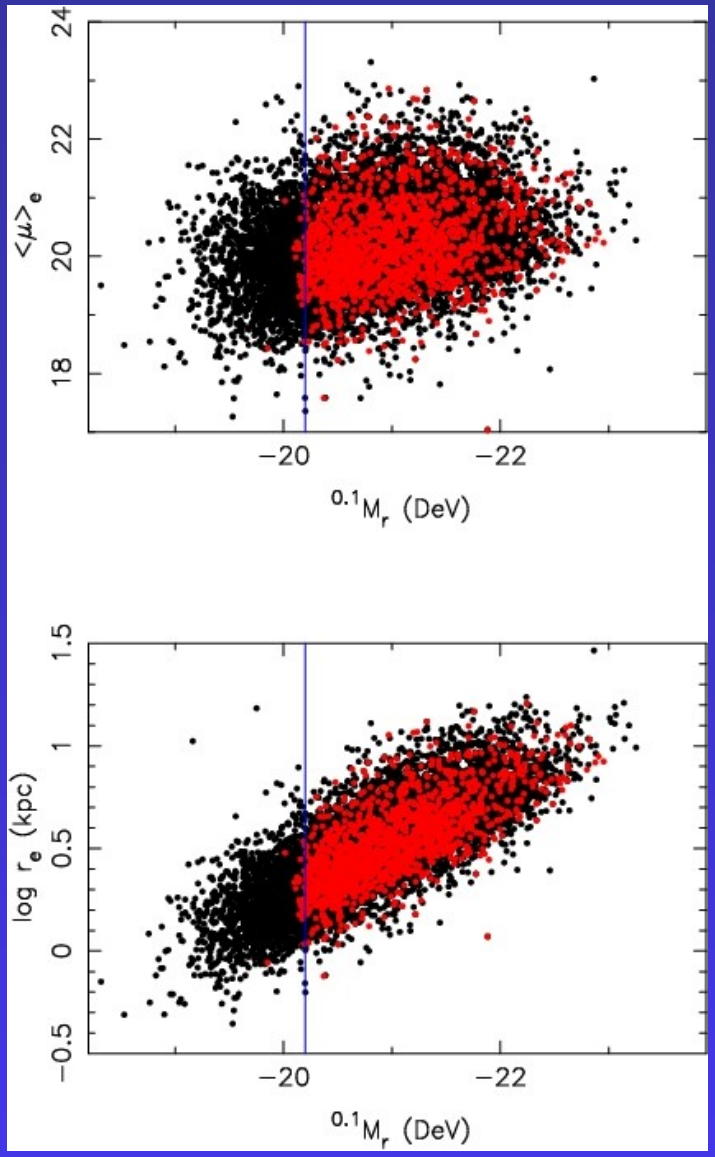
Short edge-on projection of the FP

FIT	BAND	a	b	c	rms
ORTH	r	1.42 ± 0.05	0.305 ± 0.003	-8.8 ± 0.1	0.064
ORTH	K	1.53 ± 0.04	0.308 ± 0.003	-8.6 ± 0.1	0.062
$\log \sigma_0$	r	1.55 ± 0.07	0.312 ± 0.003	-9.1 ± 0.1	0.081
$\log \sigma_0$	K	1.51 ± 0.04	0.307 ± 0.003	-8.6 ± 0.1	0.073

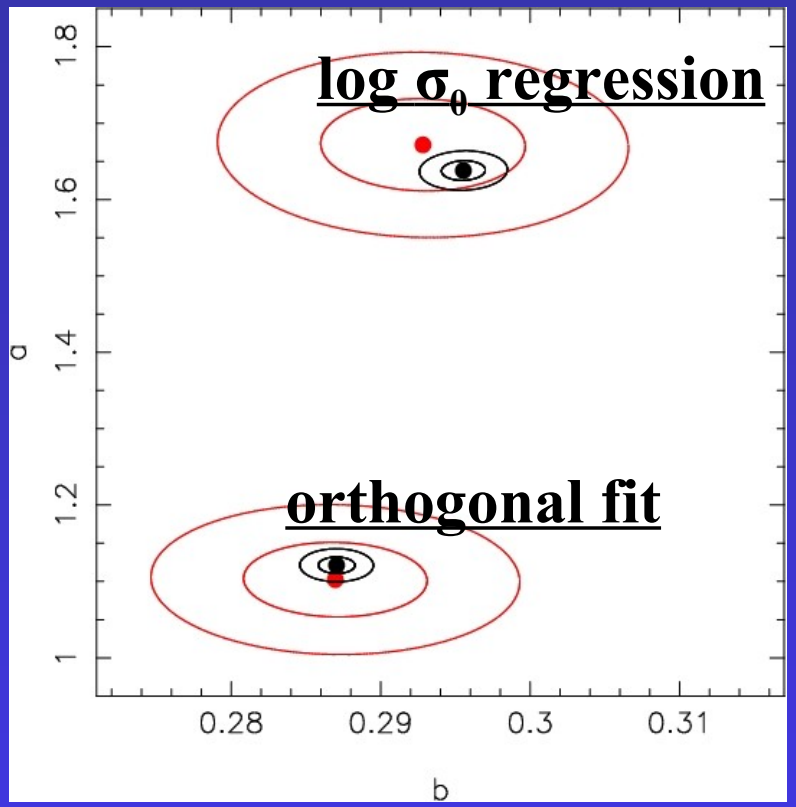
FP coefficients after correcting for selection effects



Selection effects

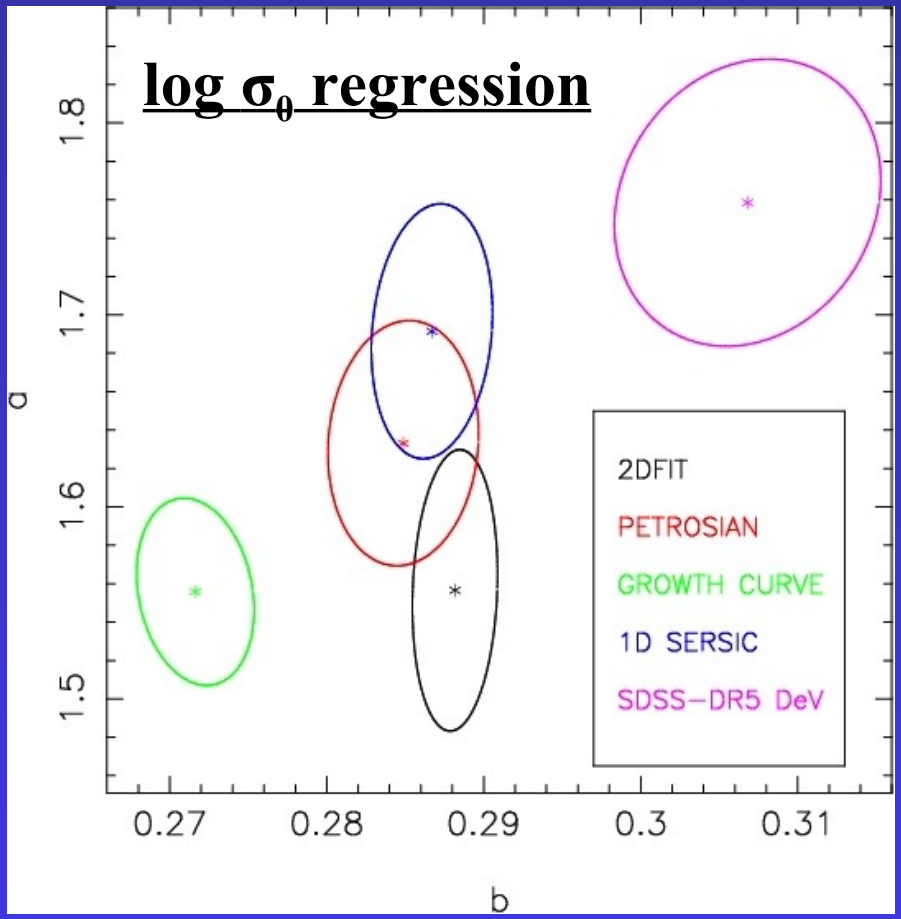


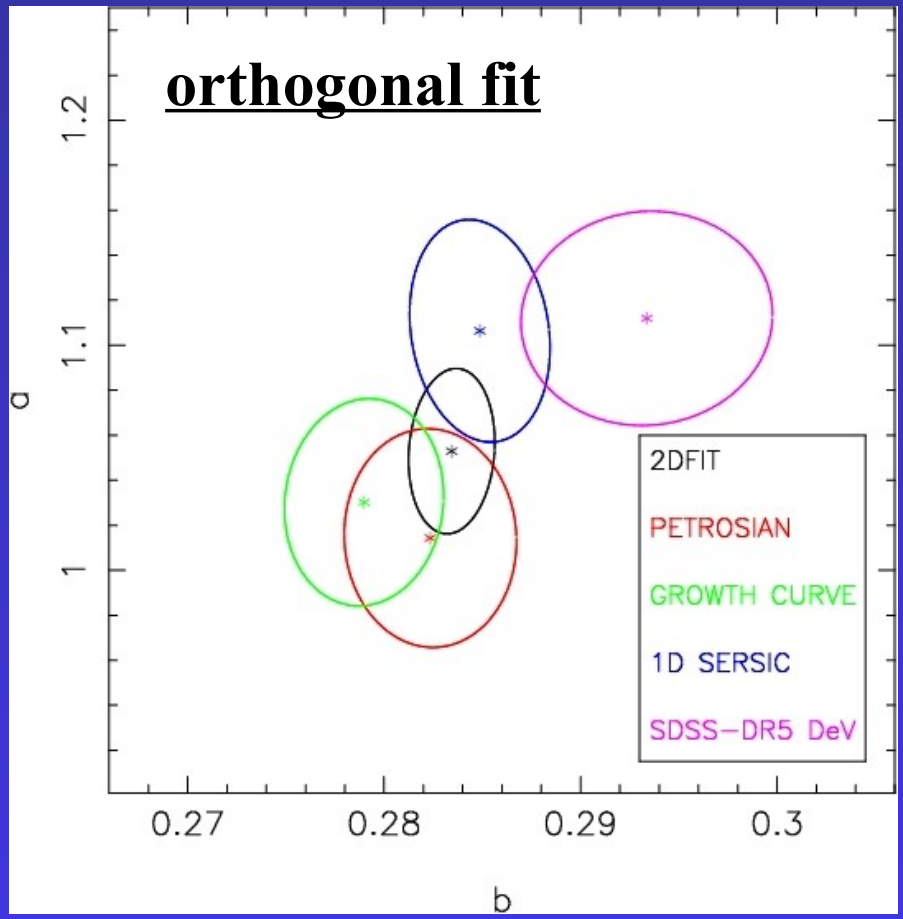
Comparison of SDD/UKIDSS sample with the entire DR5 early-type galaxy sample in the redshift range of 0.05 to 0.095.



FP slopes of the SDSS/UKIDSS sample and the DR5 early-type galaxy sample. Ellipses plot 1σ and 2σ confidence contours, respectively.

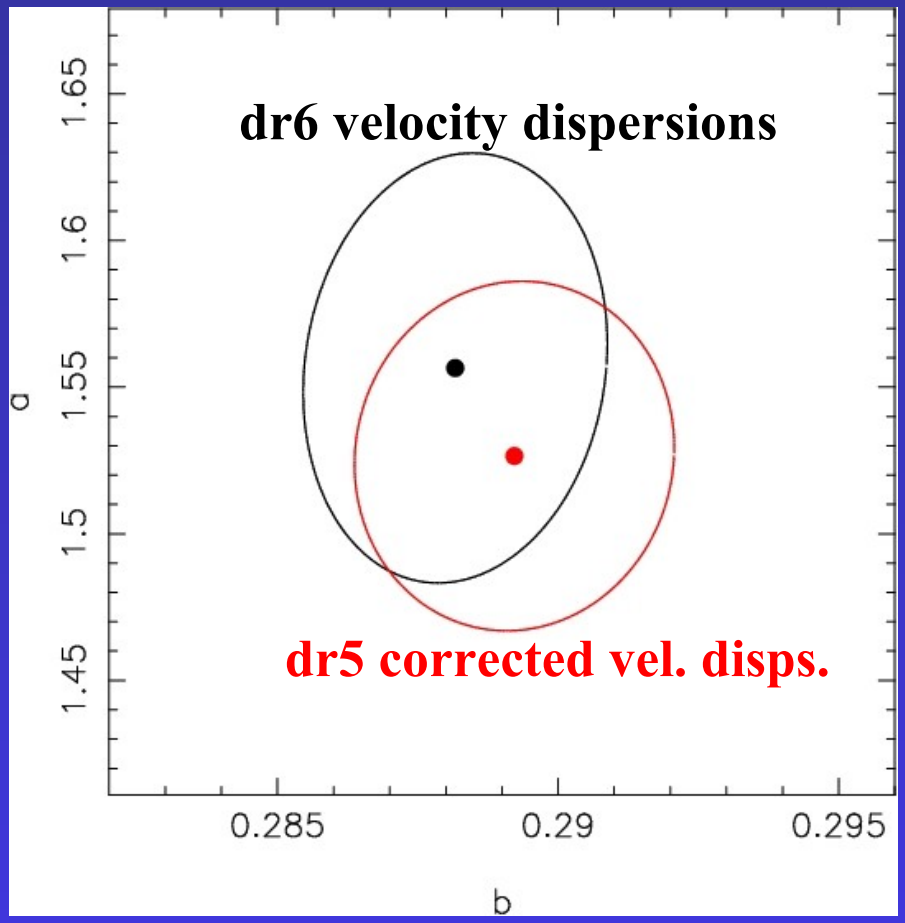
Systematics related to FP parameters





FP slopes derived by measuring structural parameters with different methods. Ellipses correspond to 1σ confidence contours.

Systematics related to FP parameters



FP slopes from DR5 and DR6 velocity dispersions, derived by the log σ_0 fitting method. Ellipses plot 1σ confidence contours.

Comparison of r-band FPs as derived with DR5 and DR6 velocity dispersions.

DR5 velocity dispersions have been corrected for the σ_0<150km/s systematic effect discussed by Bernardi 07, AJ.

TALK OUTLINE

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- **Stellar populations vs. mass**
- Conclusions

Stellar populations vs. Mass

$$M/L \propto M^{\beta+\beta^*} \rightarrow \beta+\beta^* = \frac{(2-a)}{(2+a)}$$

$$\beta = \frac{\partial \log M/M_*}{\partial \log M} \rightarrow \text{independent of waveband}$$

$$\beta^* = \frac{\partial \log M_*/L}{\partial \log M} \rightarrow \text{change of stellar population parameters with mass}$$

$$\beta \quad \beta_r^* \quad \beta_r^*$$

Stellar populations vs. Mass

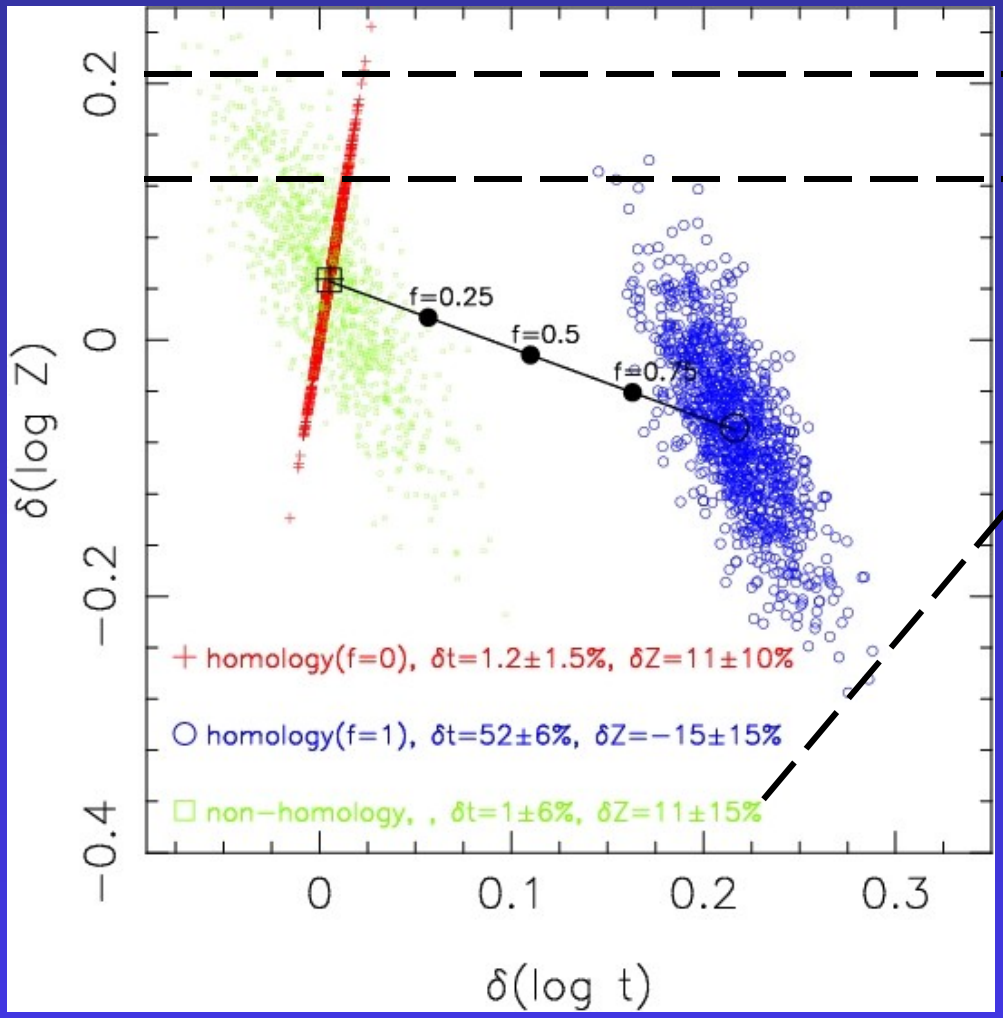
We set $f=\beta_k^*/(\beta+\beta_k^*)$ → fraction of the K band M/L to M relation due to stellar population effects

↕

$$\beta^* = \delta(\log M_*/L) = \frac{\partial \log M_*/L}{\partial \log t}\,\delta(\log t) + \frac{\partial \log M_*/L}{\partial \log Z}\,\delta(\log Z)$$

.....as estimated for SSPs from Bruzual & Charlot (2003)

Stellar populations vs. Mass



CM relation (Kodama et al. '98)

absorption-line indices (Thomas et al. 2005)

spherical, isotropic, non rotating, one component Sersic models

$\sigma_0, r_e, \langle\mu\rangle_e \longrightarrow \sigma_t, r_g, \langle\mu\rangle_g$

$\log r_g \propto (2.3\pm0.2) \log \sigma_t + (0.4\pm0.03) \langle\mu\rangle_g$

matching the VT expectation (see Trujillo et al.'04)

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CONCLUSIONS

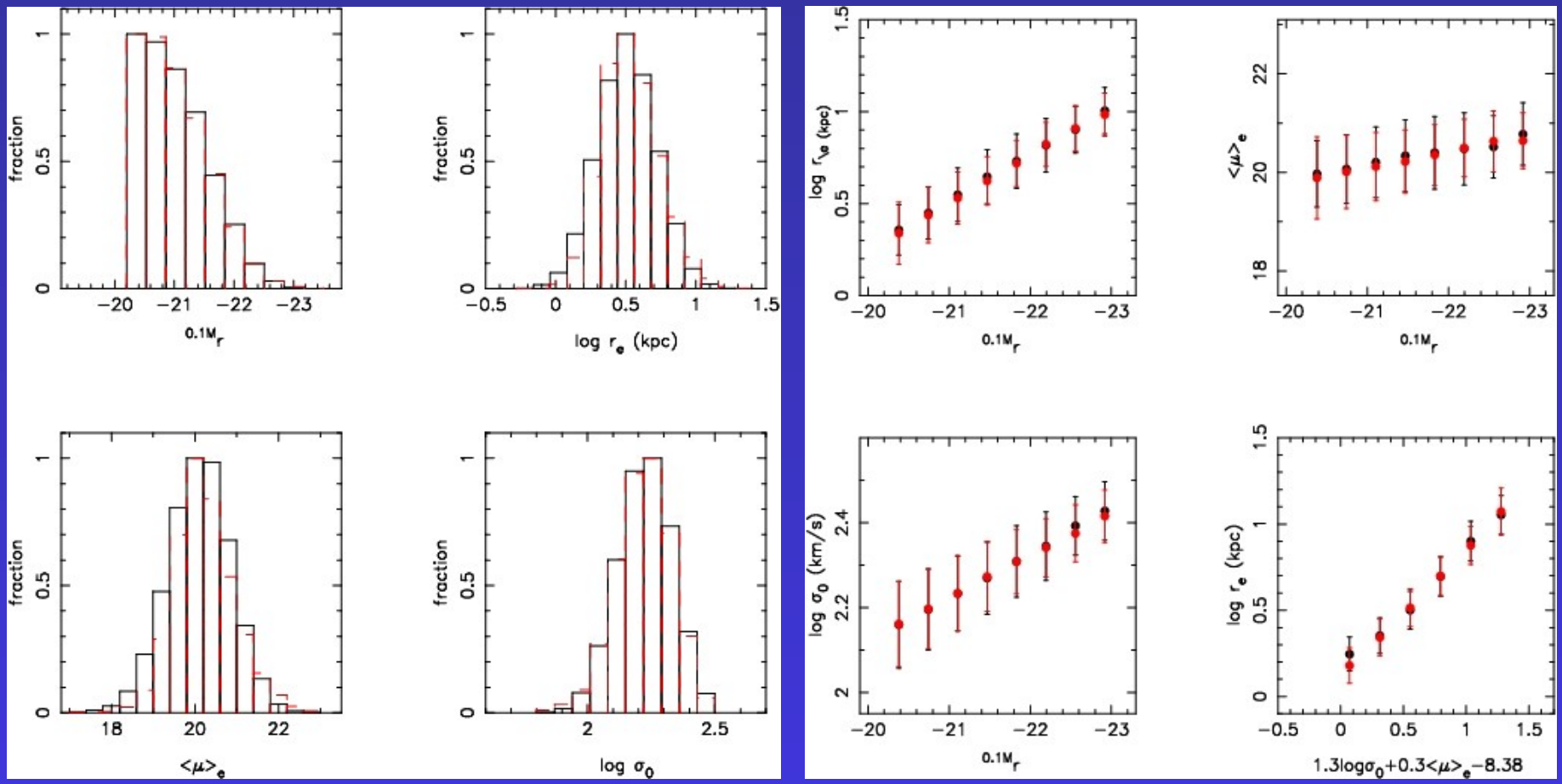
The FP turns out to be almost independent of waveband (with the log σ0 coefficient changing at most by +8% from the K to the r band).

Massive galaxies have to be mildly more metal rich (by ~11%) than less massive ones, and have surprisingly sincronised ages (with an age variation smaller than few percents)

Selection effects: simulations

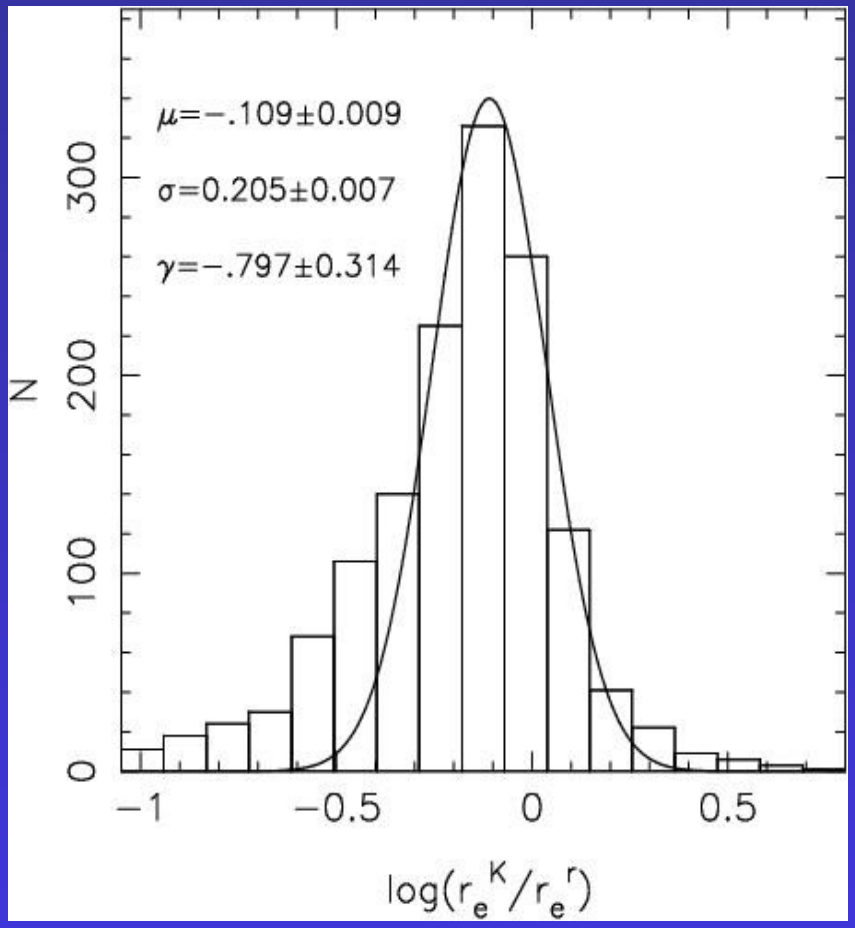
- We create random samples of magnitudes, radii, and velocity dispersions resembling the distribution of early-type galaxies in the r-band FP space
- Galaxy magnitudes are assigned according to a Schechter function (whose parameters are derived by fitting DR5 data)
- Effective radii are computed according to the luminosity-size relation (see Shen et al.2003, MNRAS)
- Velocity dispersions are assigned according to a given FP relation, whose coefficients (slopes and scatter) are chosen to match those of the r-band FP (as derived by different fitting procedures), after selection effects are applied

Simulated vs. observed FP

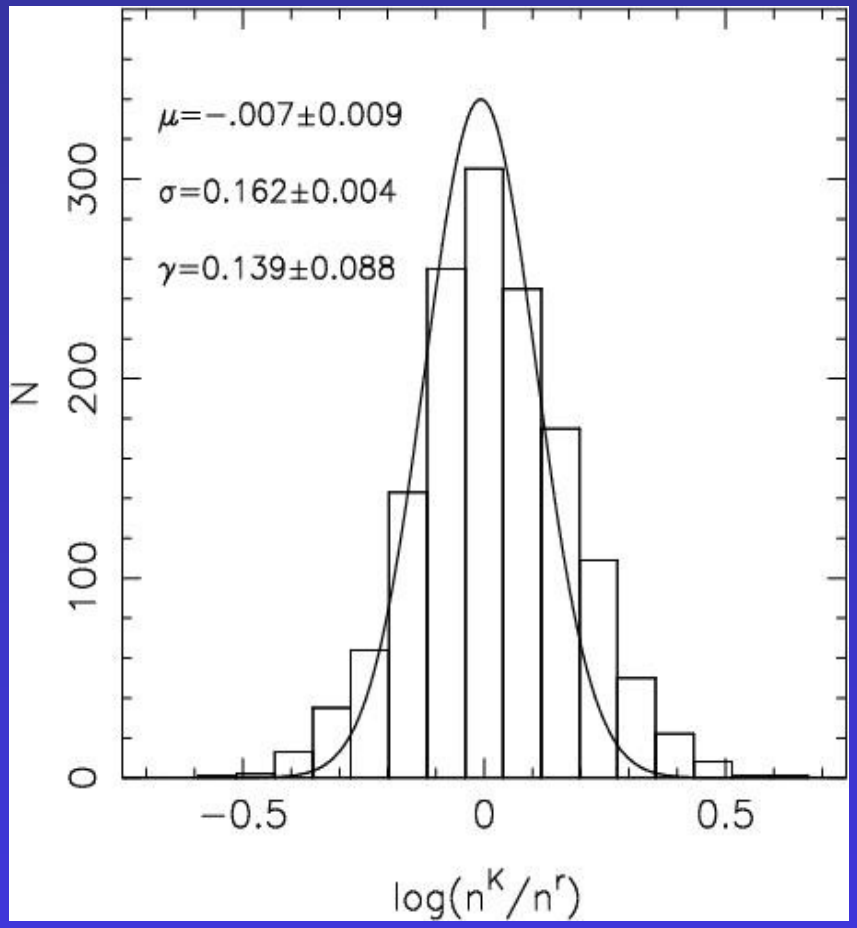


Comparison of distributions and correlations of FP parameters between simulated and observed samples. Simulated samples match all the properties of galaxies in the space of FP variables.

r-K STRUCTURAL PARAMETERS

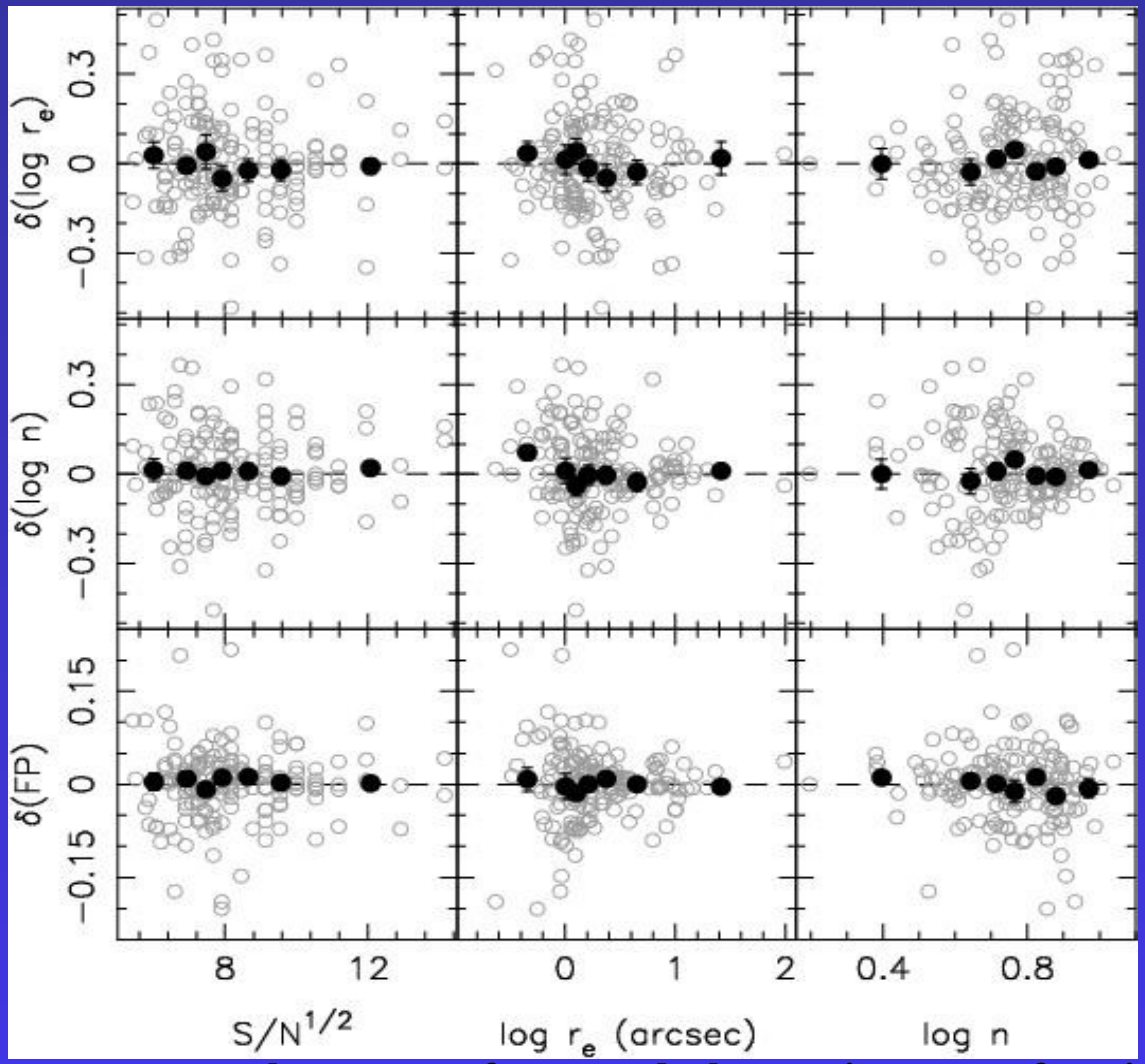


Ratio of r- and K-band effective radii. The NIR radii are smaller than the optical ones by 25±2%, with a significant tail towards small r_e^K/r_e^R values.



Comparison of r- and K-band Sersic indices. The mean value of the distribution (-1.6±2%) is fully consistent with zero.

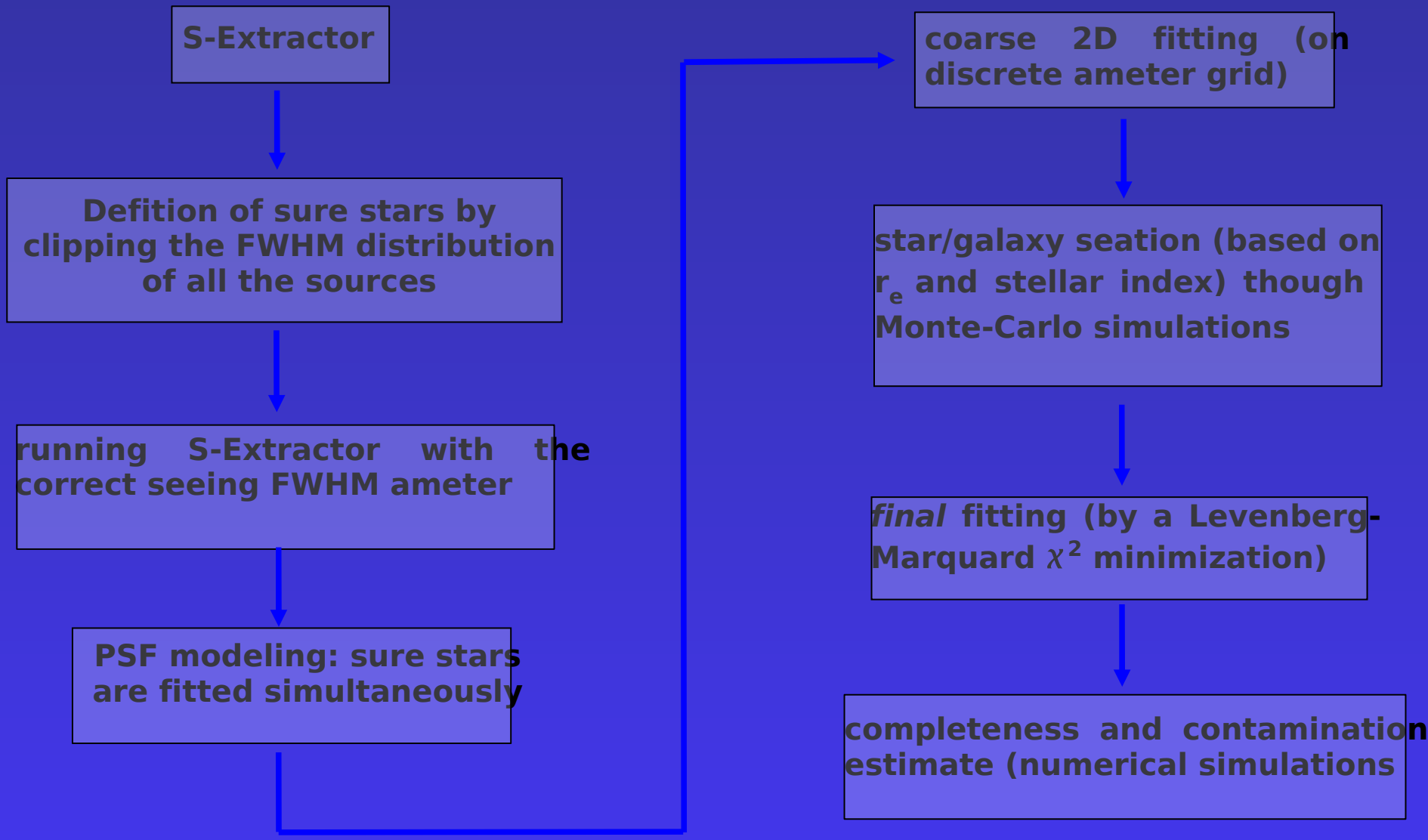
ACCURACY OF K-BAND STRUCTURAL AMETERS



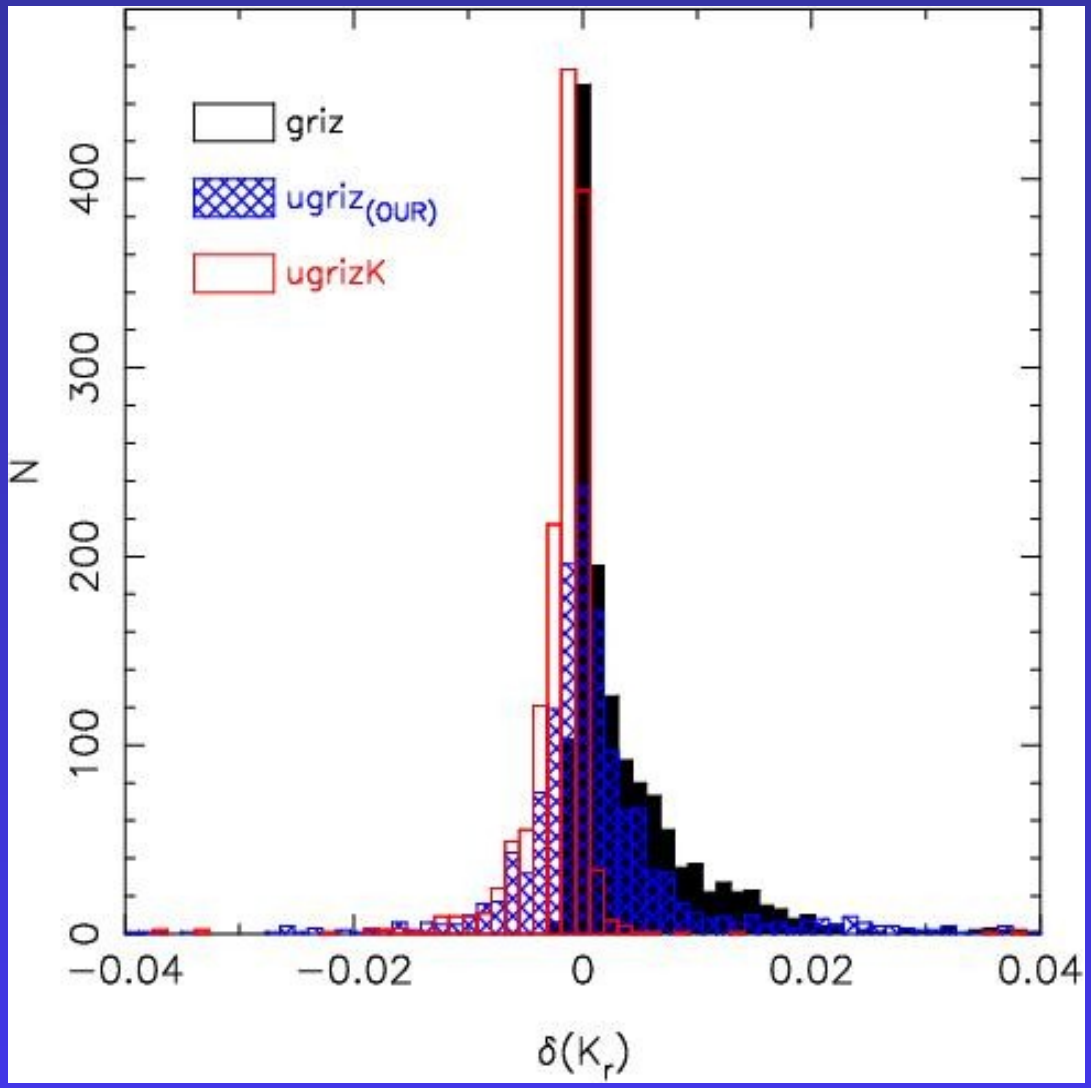
Differences among structural ameters of repeated observations as a function of S/N ratio (left), log r_e (middle), and log n (right).

The 2DPHOT package

How it works……



MEASURING SDSS/UKIDS MAGNITUDES

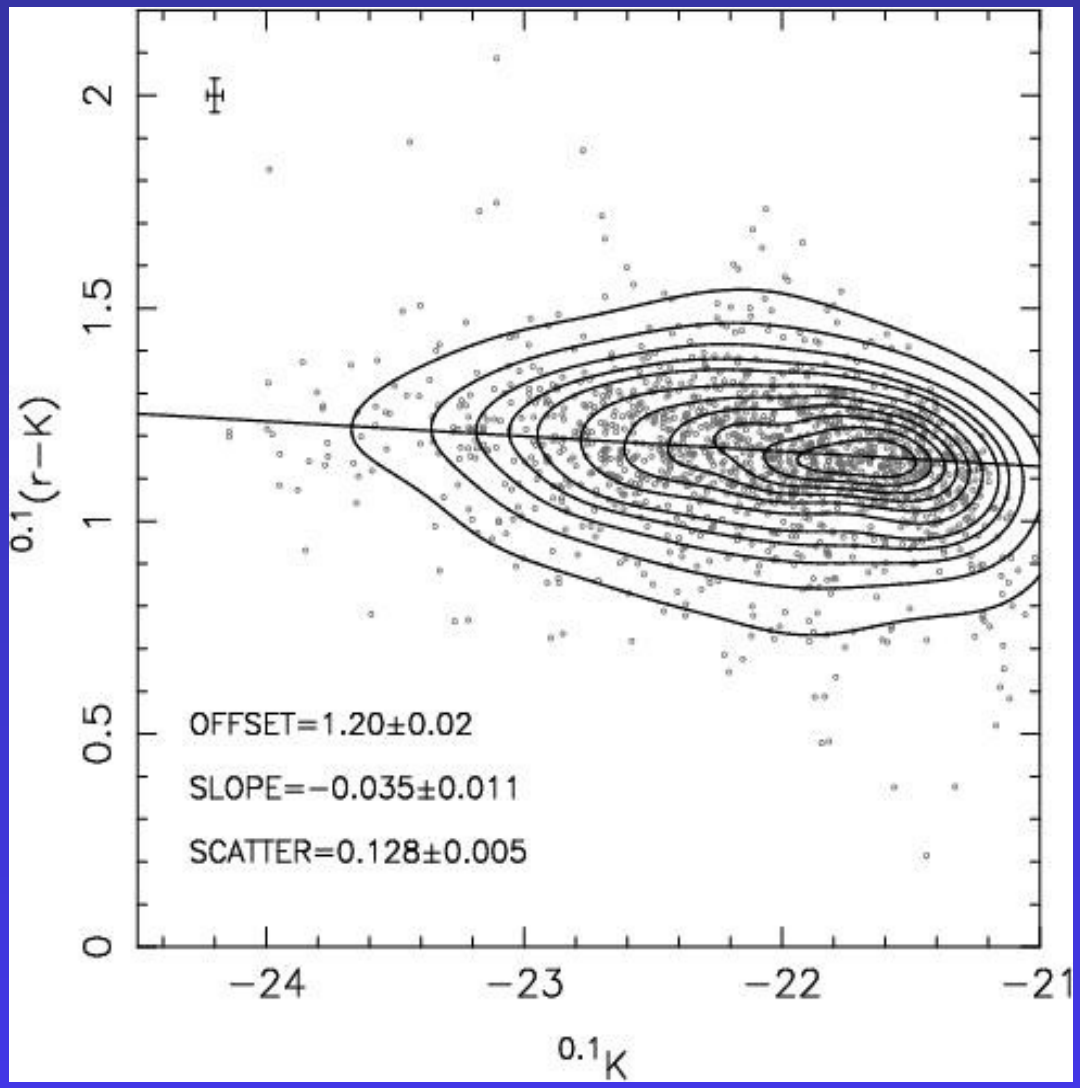


K-corrections are derived by using the software KCORRECT (version 4.1.4, see Blanton et al.20XX). In order to minimize the uncertainty on k-cors the restframe filters are blue shifted by (1+z), with z=0.1.

The plot comes k-corrections in the r band as estimated with different magnitudes/filters to those estimated from the SDSS ugriz petrosian magnitudes.

The typical uncertainty of the K-corrections amounts to ~0.005mag

r-K CM RELATION

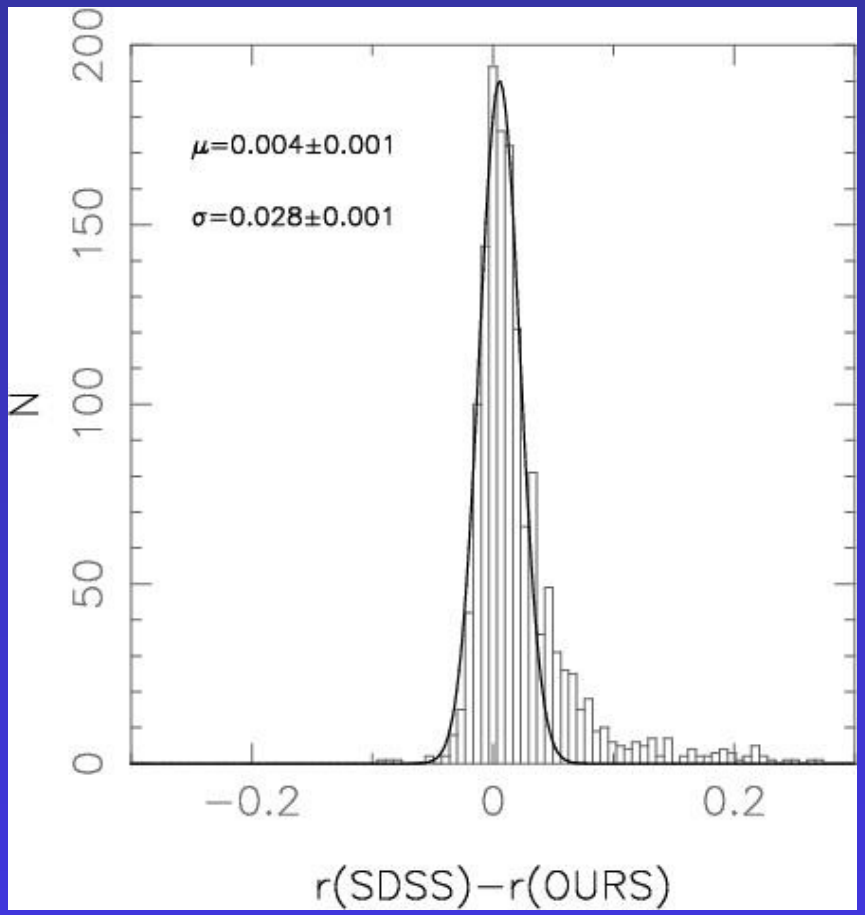


The petrosian magnitudes are used to estimated k-corrected galaxy colors.

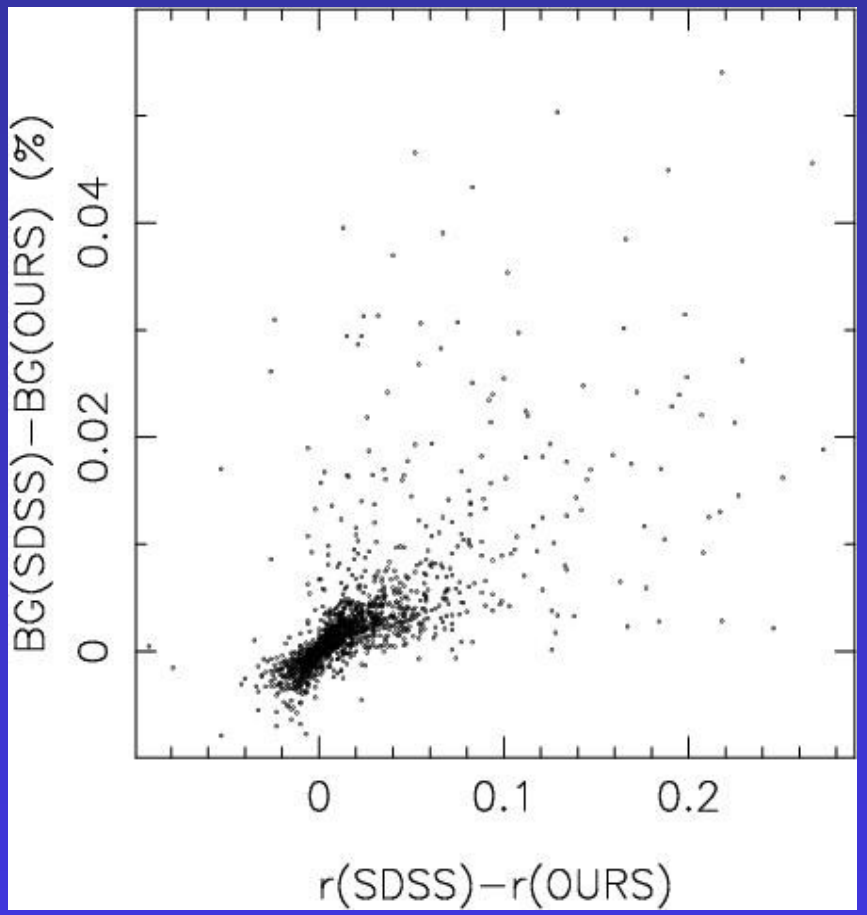
Grey curves in the figure show isodensity number contours.

The r-K CM relation is fitted as follows. The slope value is changed on a grid ranging from 0. to -0.2, with a step of 0.0001. For each grid point, the bi-weight scatter around the relation is computed, and the final slope/offset are chosen as those corresponding to the lowest scatter estimate.

MEASURING SDSS/UKIDS MAGNITUDES

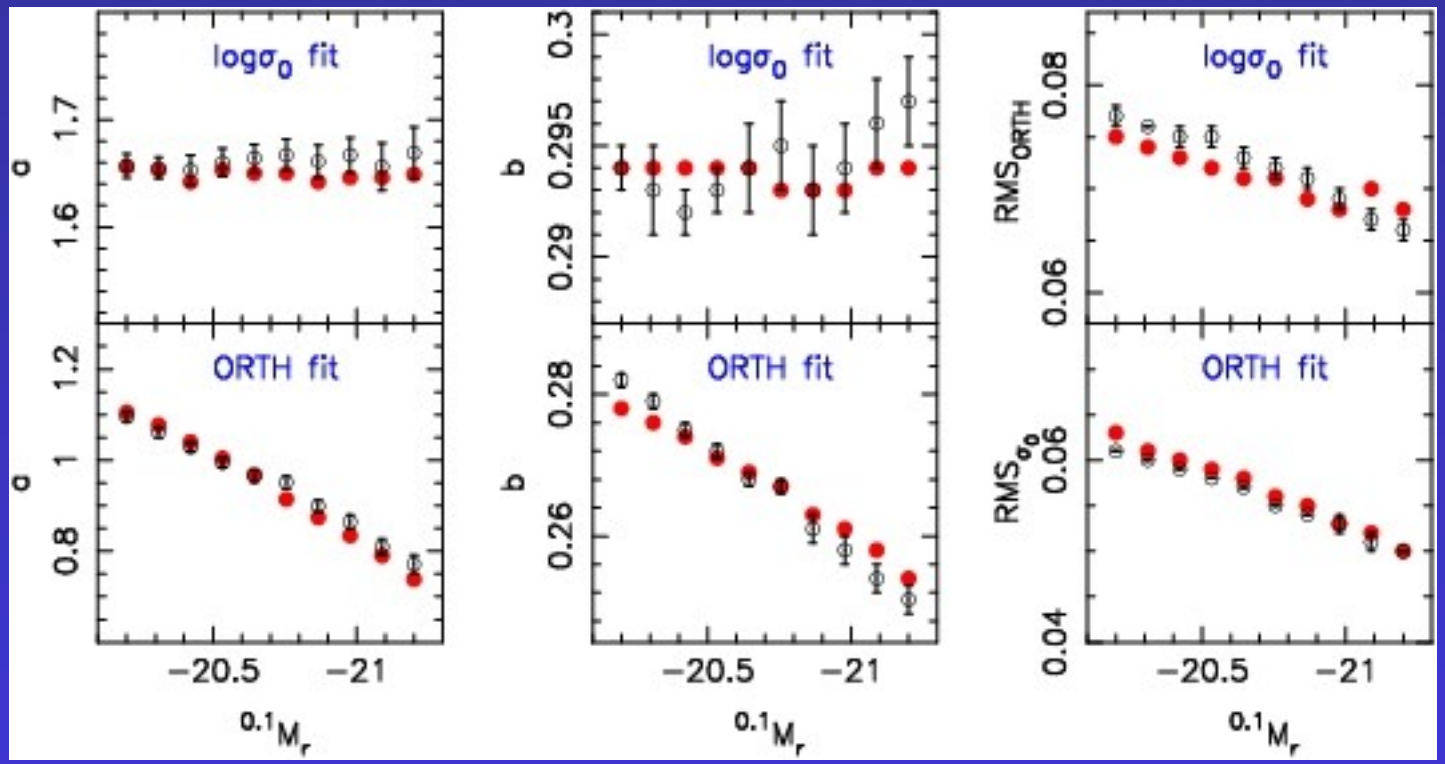


Histogram of differences among the SDSS and the new measured r-band magnitudes



Differences of background values are plotted as a function of the differences of r-band magnitudes. Each difference is computed between SDSS and OUR values

Simulated vs. observed FP



Effect of varying the magnitude limit of both the simulated and observed samples on the FP slopes and scatter. Both samples show the same trends, proving that simulated data are a reliable tool to correct FP coefficients for selection effects.

LAYOUT OF THIS TALK

- Introduction
- Sample selection
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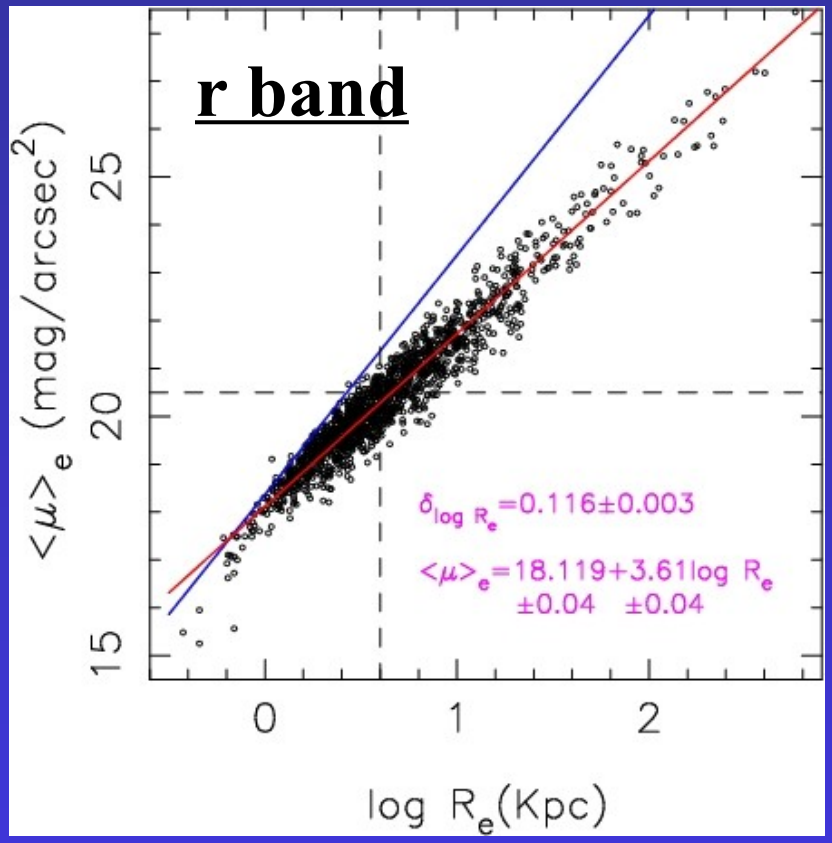
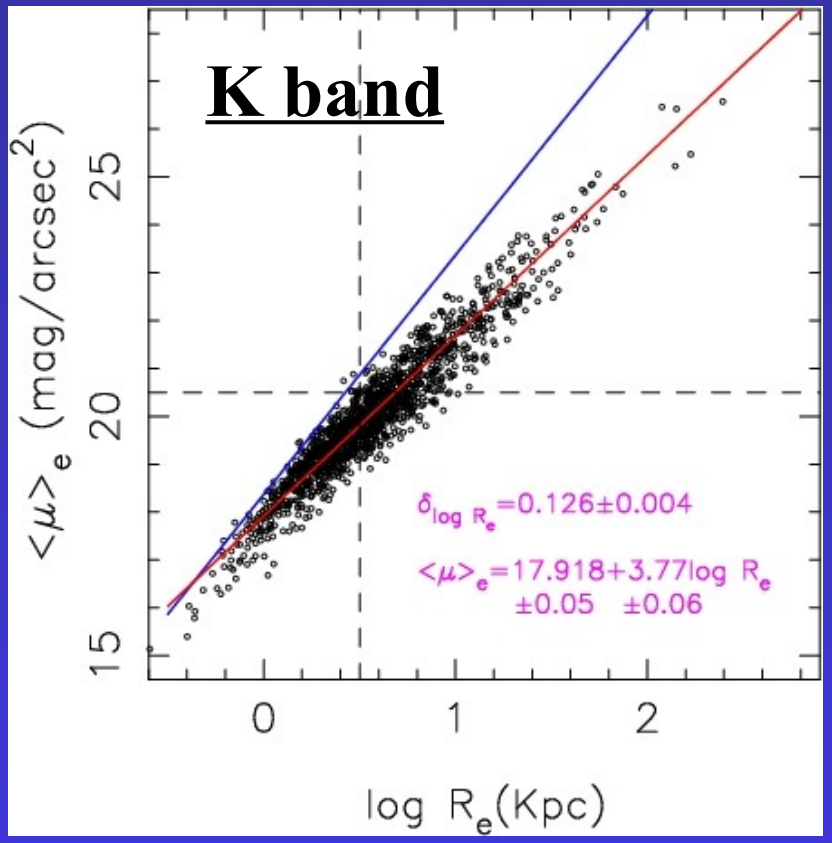
- **Structural parameters, Re-<μ>e, L-σ relations**
- The SDSS-UKIDSS FP
- Conclusions

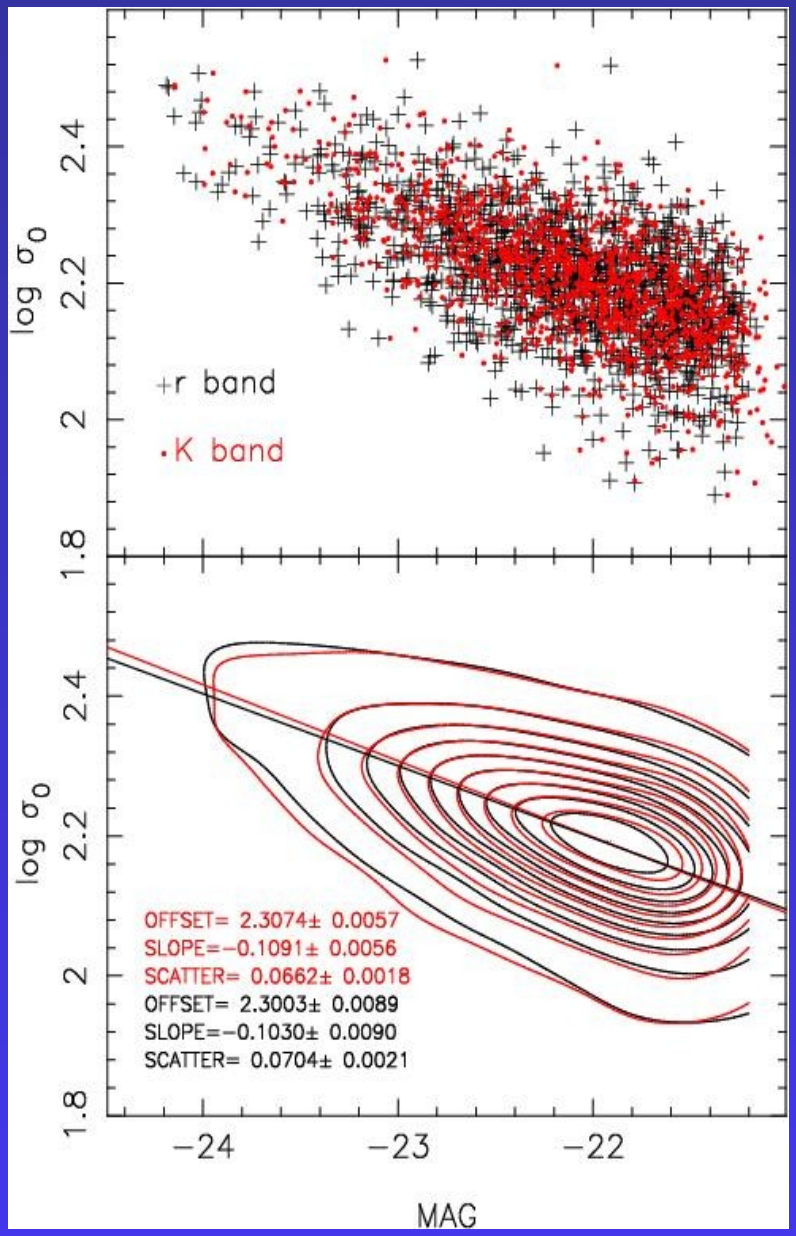
R_e-$\langle\mu\rangle_e$ RELATIONs





Comparison of the R_e-$\langle\mu\rangle_e$ relations in the r- and K-bands. Both relations have similar offset and scatter (~30% in R_e), while the slope may be slightly larger in K rather than in r band. The mean r-K color has been subtracted to the K-band $\langle\mu\rangle_e$ values.

FABER-JACKSON RELATIONs



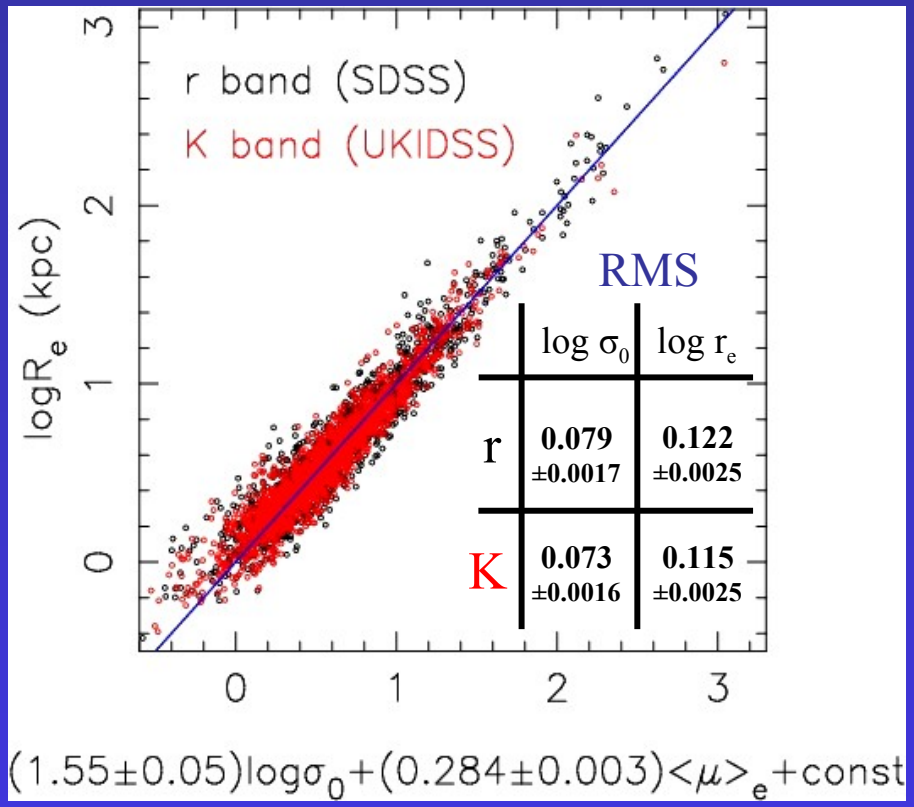
Velocity dispersion as a function of r- and K-band Petrosian magnitudes. The r-band magnitudes have been *corrected* for the mean r-K color.

Curves in the lower panel show isodensity number contours.

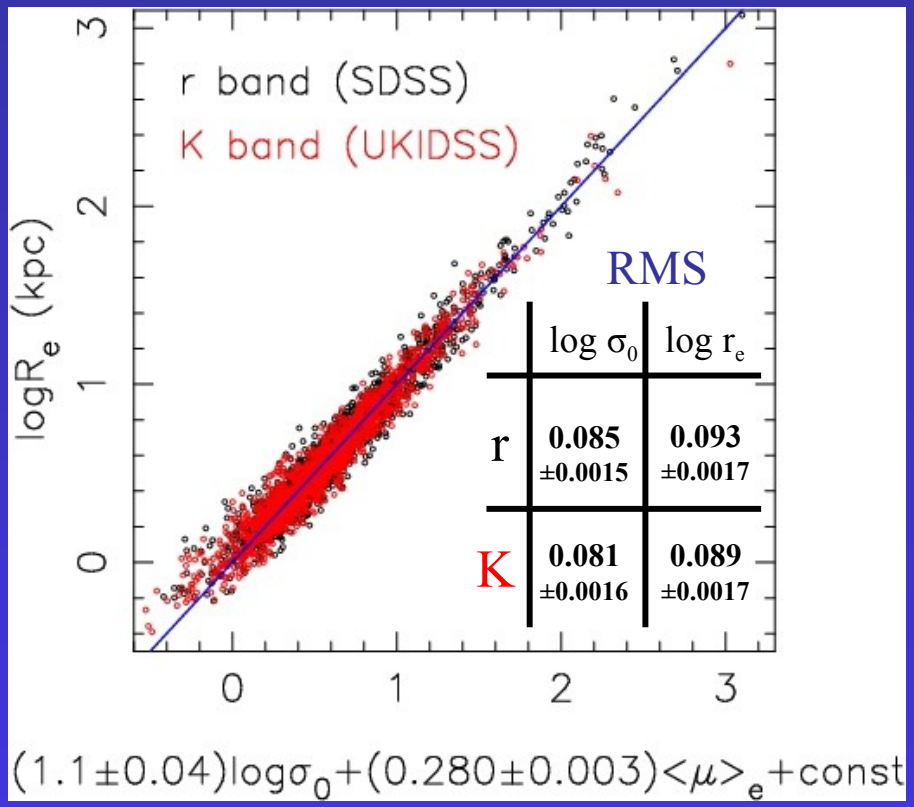
The red and black lines show the best fitted relations, and turn out to be fully consistent between both bands.

The Fundamental Plane in the r- and K-bands

log σ_0 regression



orthogonal fit

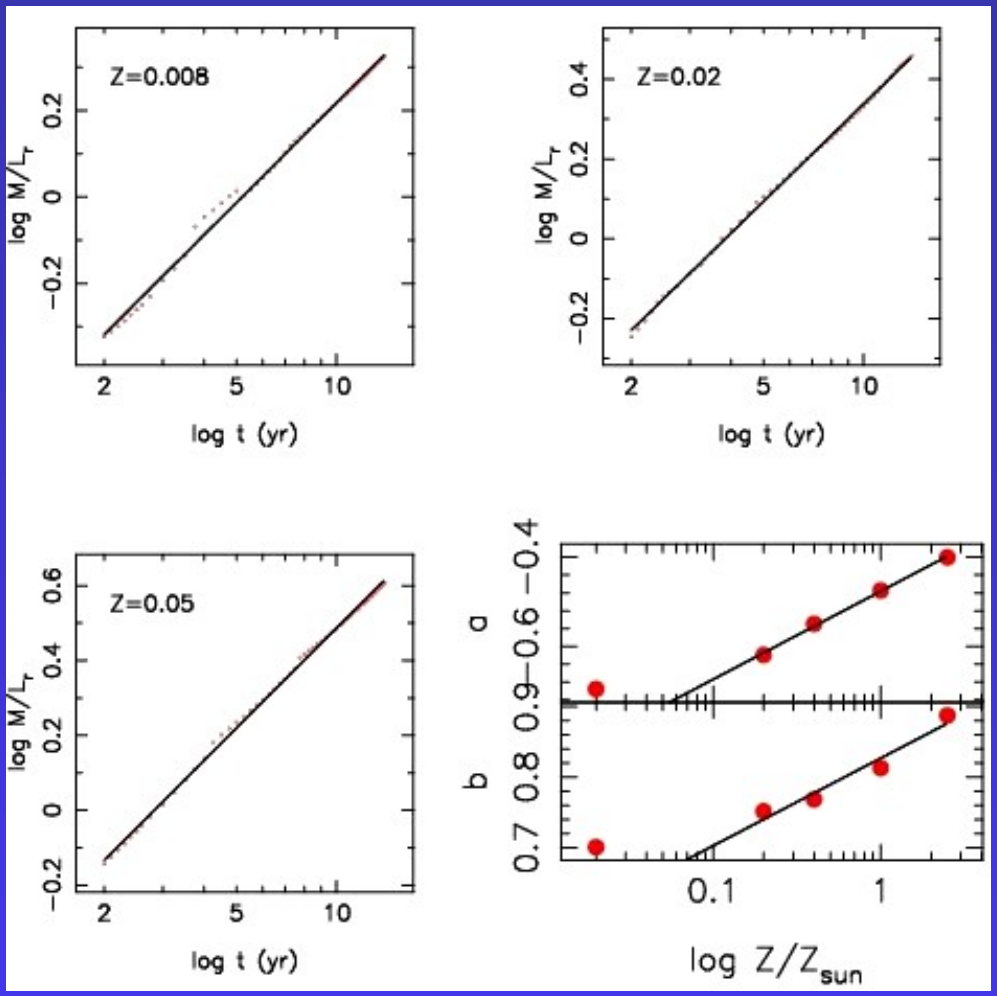


Edge-on views of the r- (black) and K- (red) band FPs for the log σ_0 (left) and orthogonal (right) fits. The scatter about the plane shows a tiny difference of ~1% between the r- and K-bands.

Stellar populations and M/L ratios

$$\delta \log M_*/L_K = \partial \log M_*/L_K/\partial \log t \cdot \delta \log t + \partial \log M_*/L_K/\partial \log Z \cdot \delta \log Z$$

$$\delta \log M_*/L_r = \partial \log M_*/L_r/\partial \log t \cdot \delta \log t + \partial \log M_*/L_r/\partial \log Z \cdot \delta \log Z$$



The M/L ratio of a simple stellar population can be well described as

$$\log M^*/L = a(Z) + b(Z) \cdot \log t$$

In the range of $Z/Z_\odot = 0.4$ to $Z/Z_\odot = 2.5$, a and b are proportional to log Z