Accurate Image Processing for Weak Lensing

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5,Challenges from accurate PSF modelling

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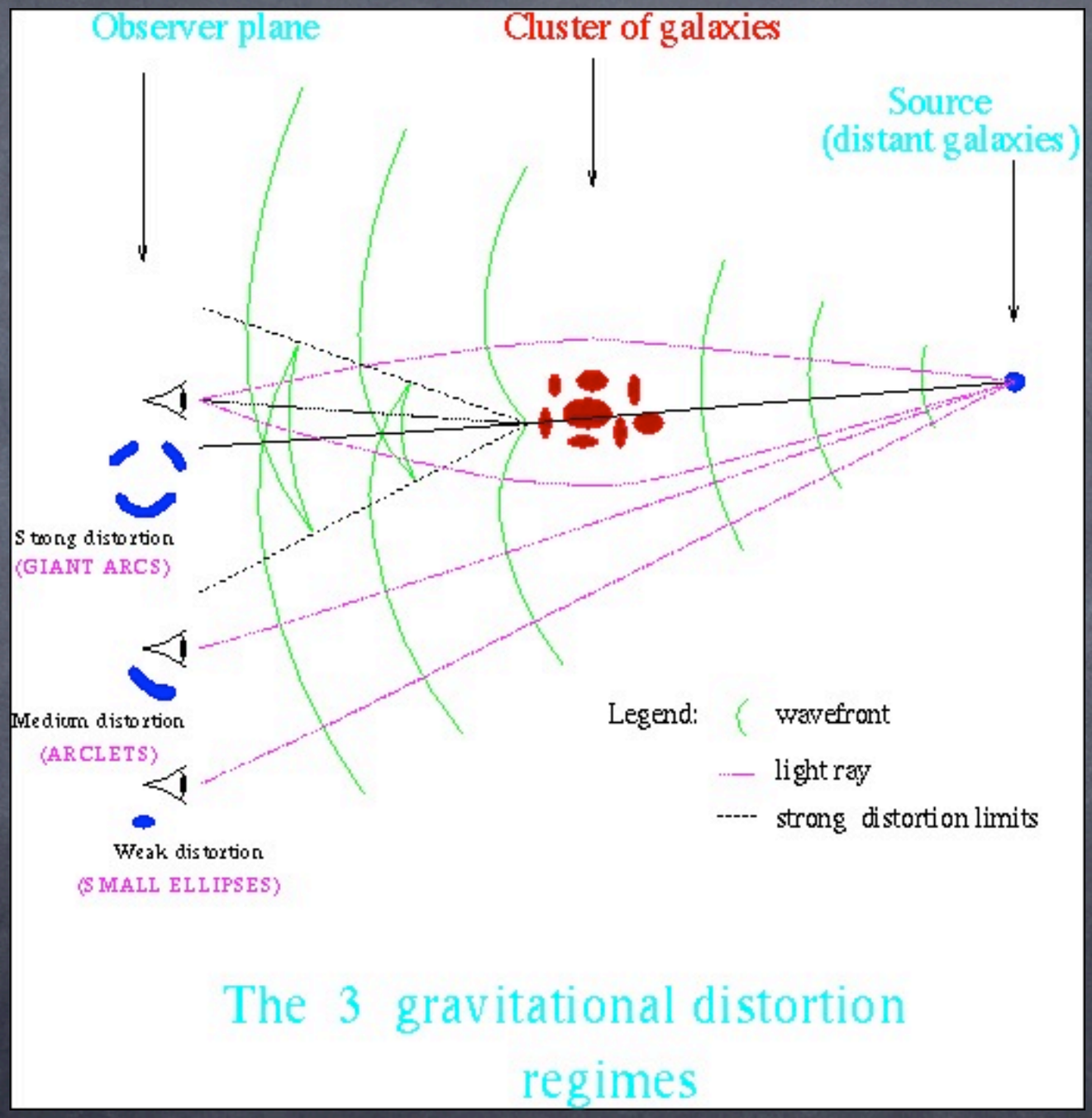
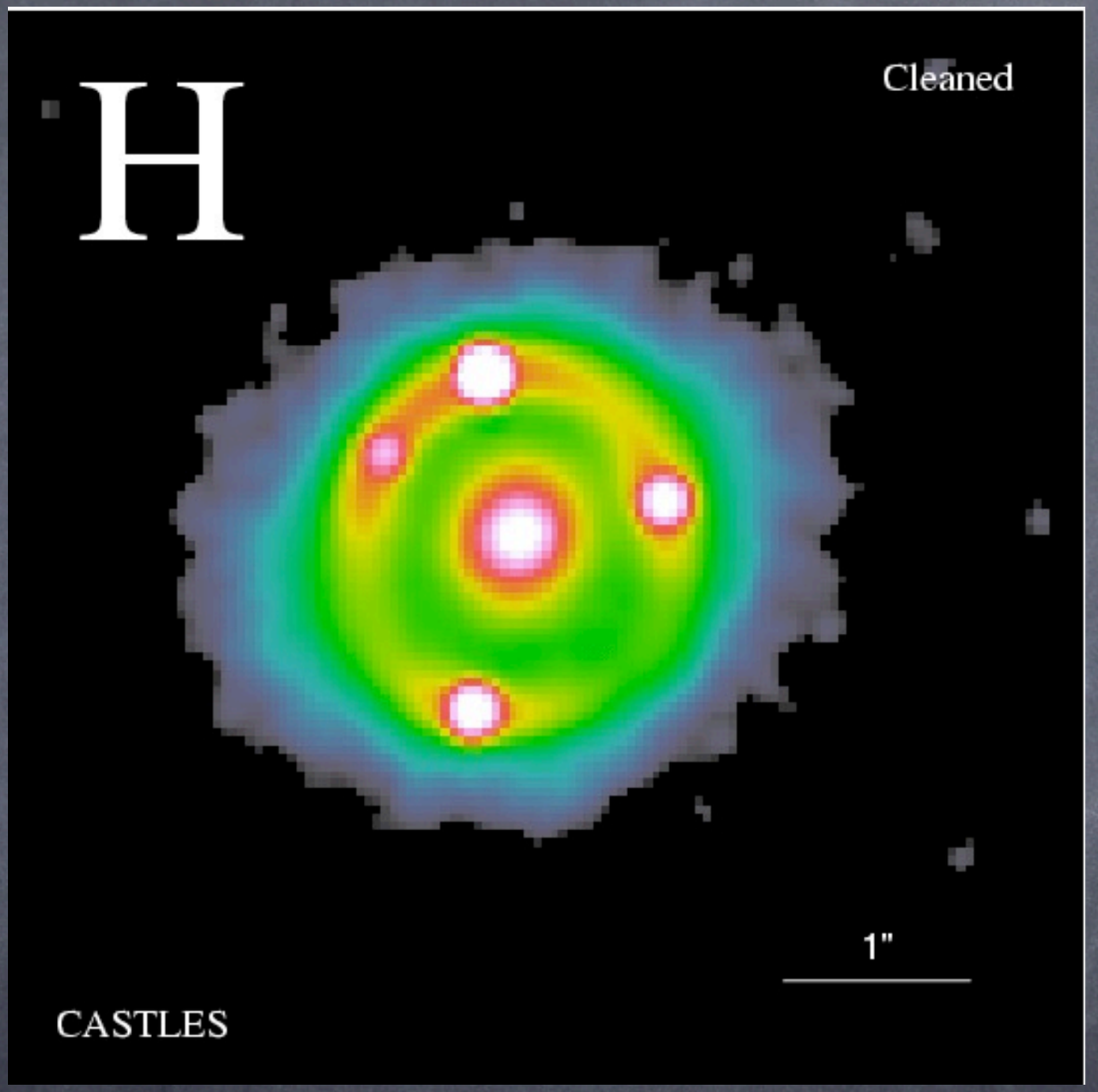
2,Our first try

Gravitational Lensing

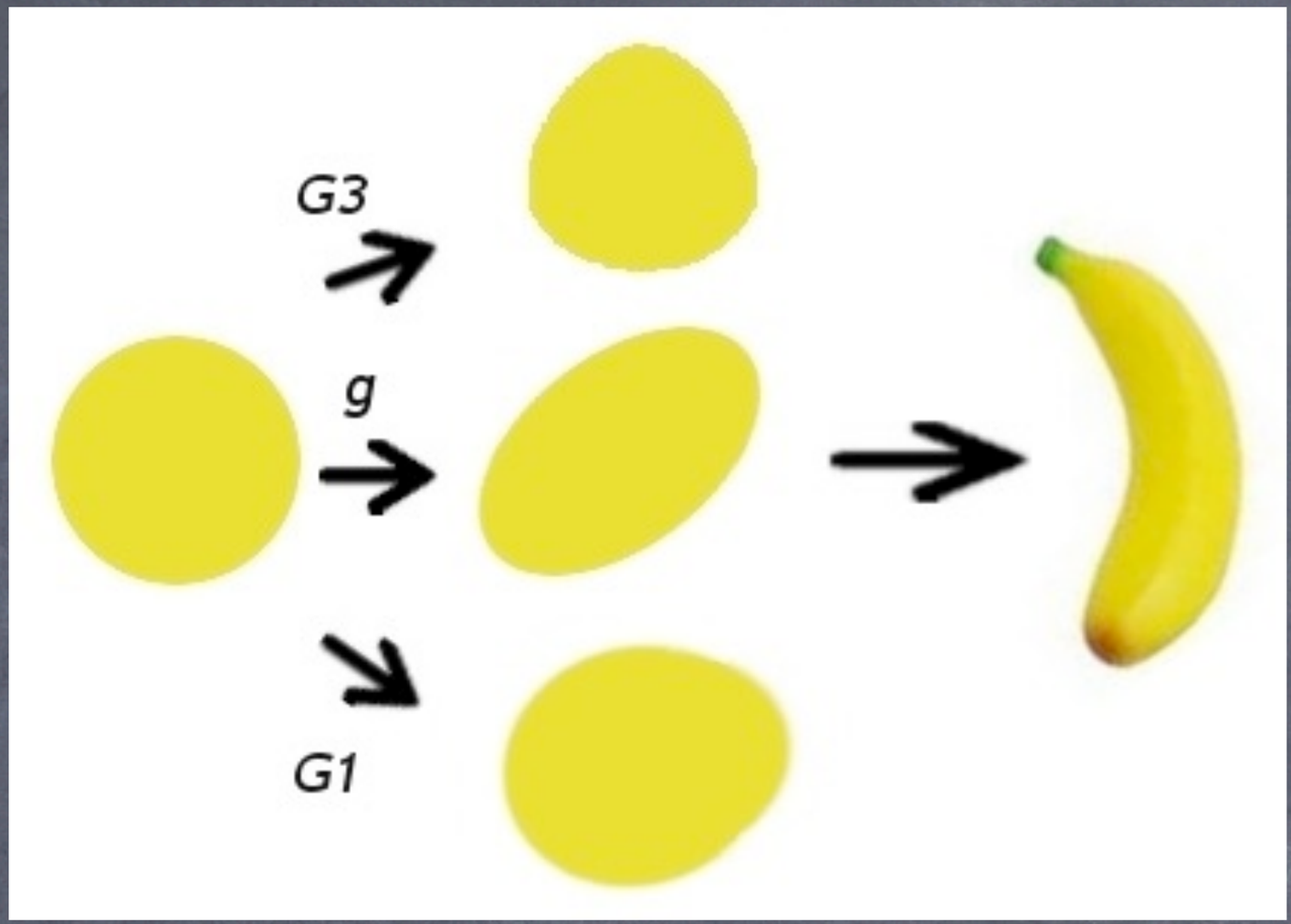


The 3 gravitational distortion regimes

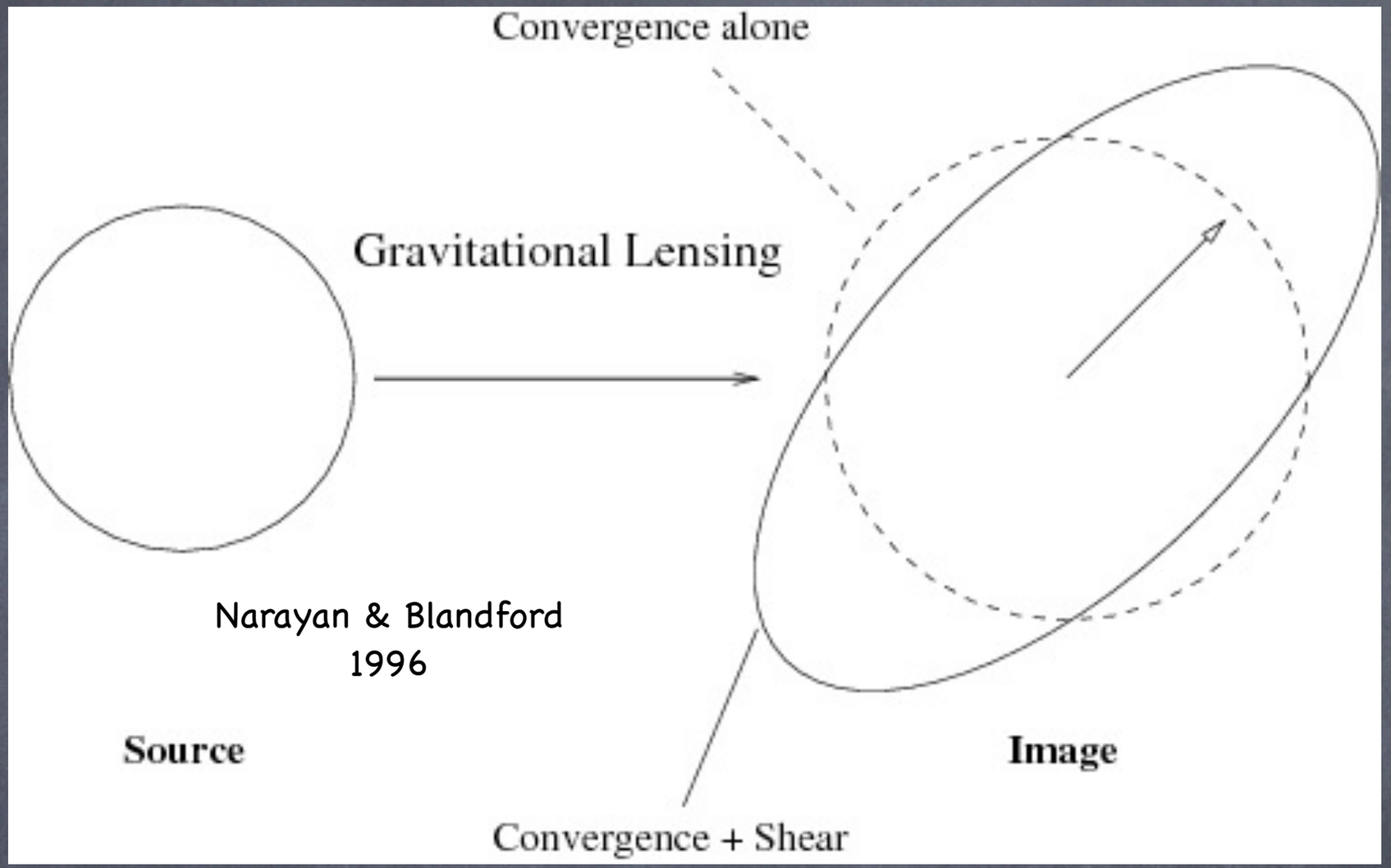
http://ned.ipac.caltech.edu/level5/Mellier/Mellier2_1.html



http://www.cfa.harvard.edu/castles,
SDSS0924+0219

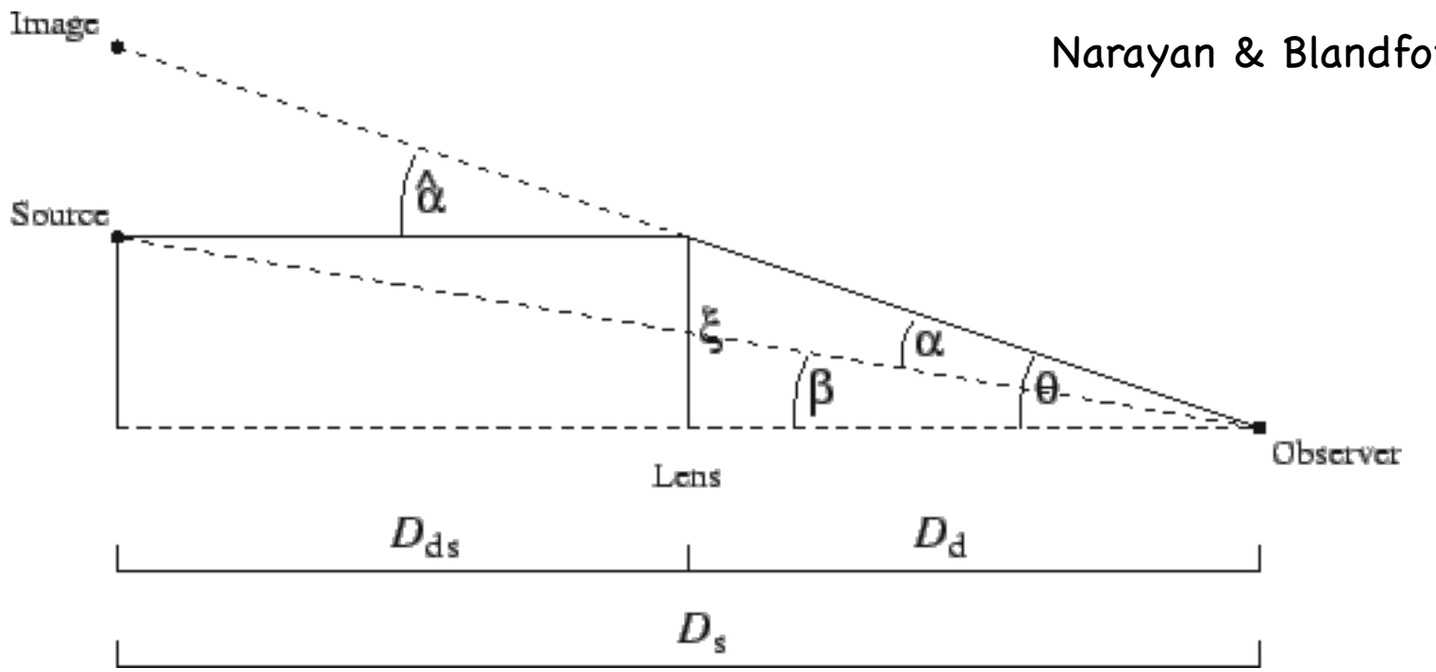


http//www.astr http o.uni-bonn.de/~xer/flexion.html


Convergence alone
Gravitational Lensing
Narayan & Blandford
1996
Source
Image
Convergence + Shear

Lensing Geometry & Lensing Equation

Narayan & Blandford 1996



$$\beta=\vartheta-\alpha$$

$$A=\partial\beta/\partial\vartheta=\begin{pmatrix} 1-\kappa-\gamma_1, & -\gamma_2 \\ -\gamma_2, & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\beta_i=A_{ij}\vartheta_j$$

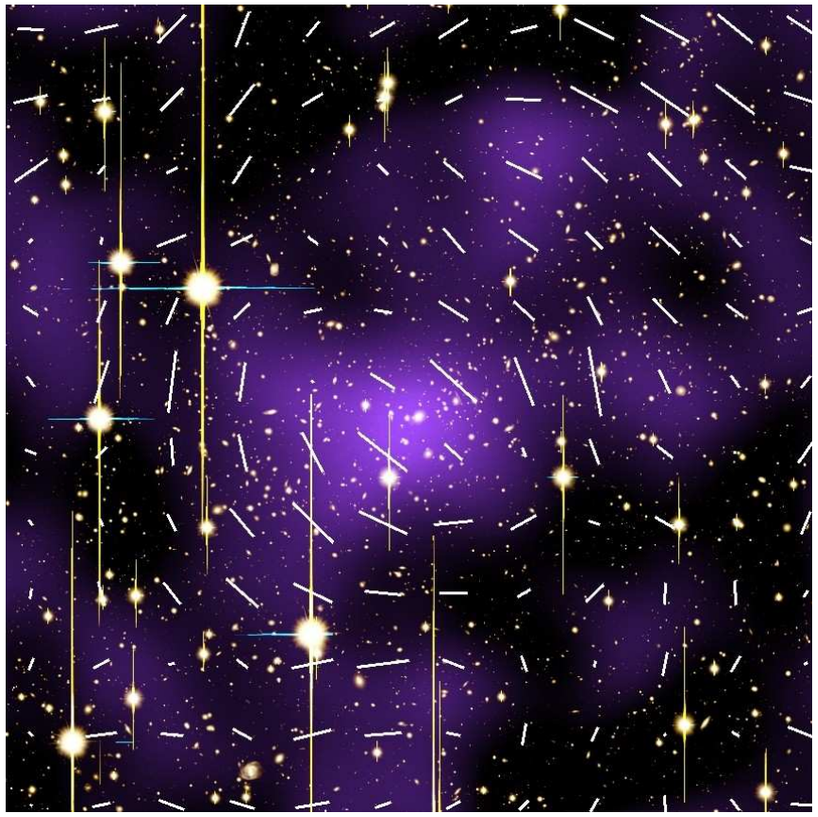
$$\beta_i=A_{ij}\vartheta_j+(1/2)D_{ijk}\vartheta_j\vartheta_k$$

Bacon et al 2006

Weak Lensing Subclass

- Cluster lensing in a deeper survey SUBARU, CFHTLens, HST...
- Galaxy-galaxy lensing

Cluster Lensing



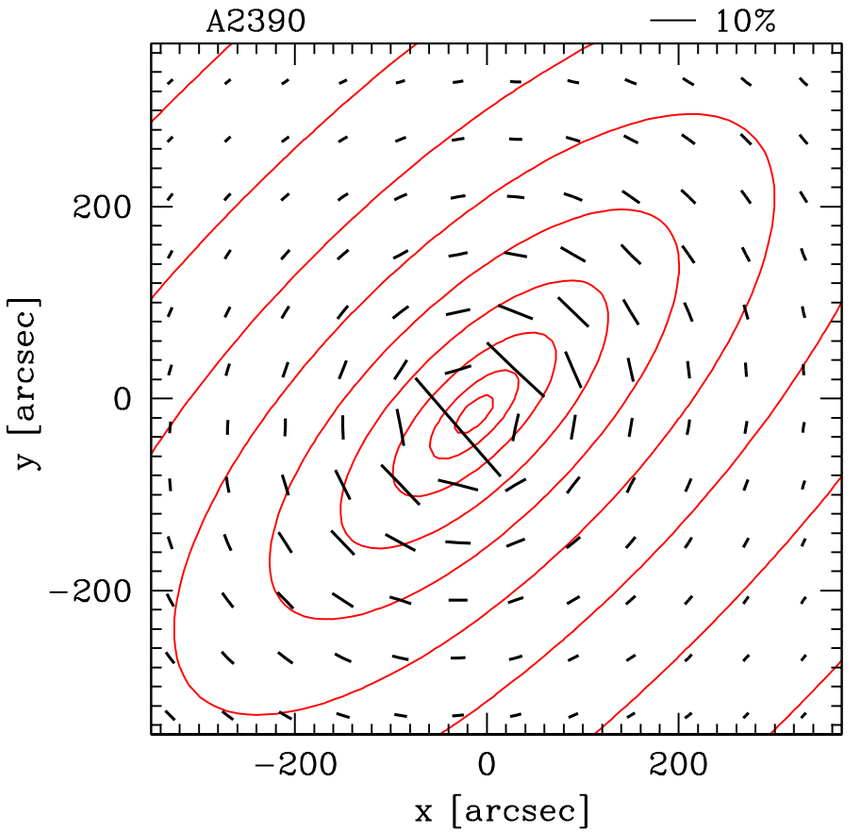
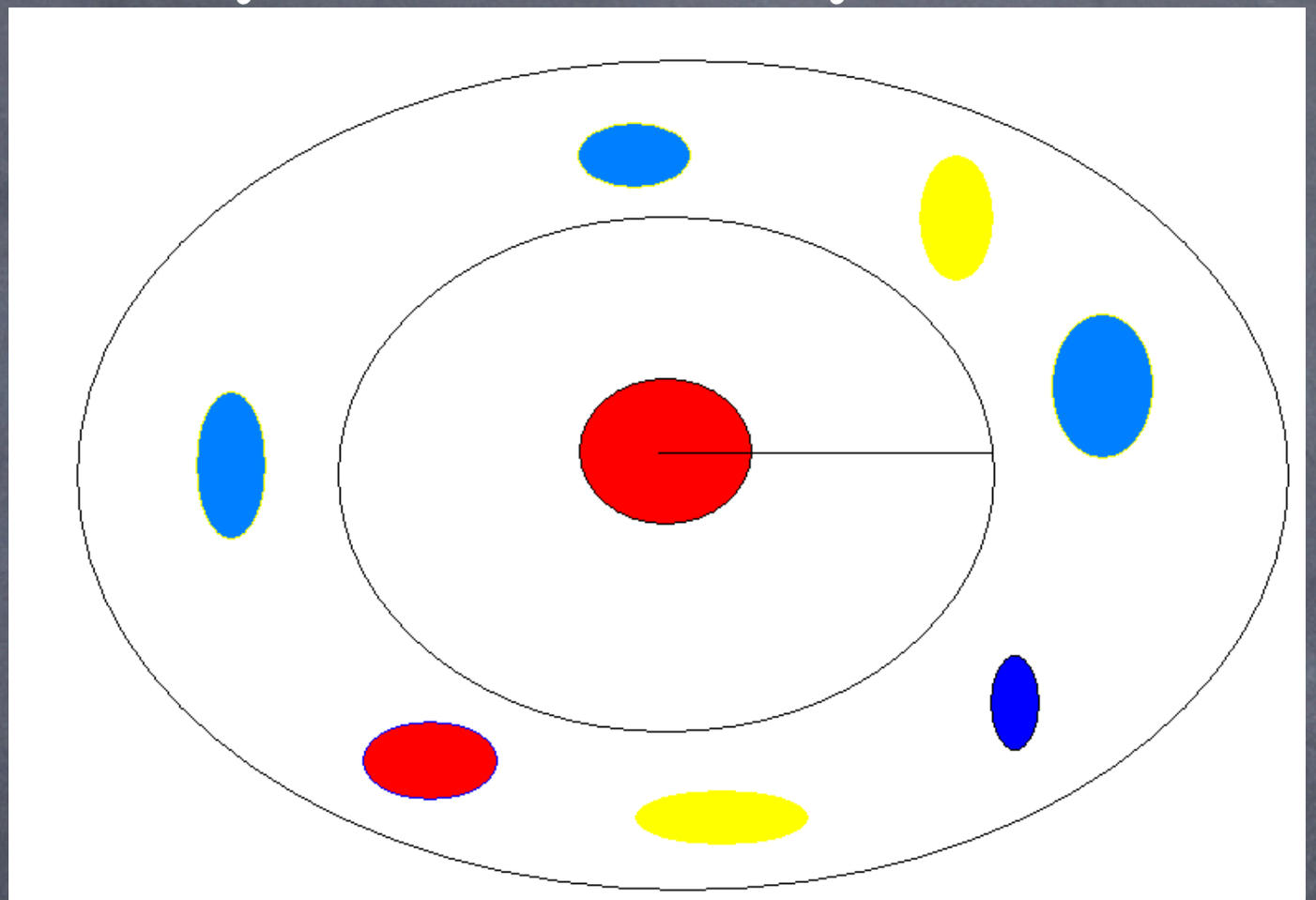


Figure 1. *Left panel:* An example of our weak lensing measurement for A2390. The size of Each panel is $12' \times 12'$. The stick in each $1' \times 1'$

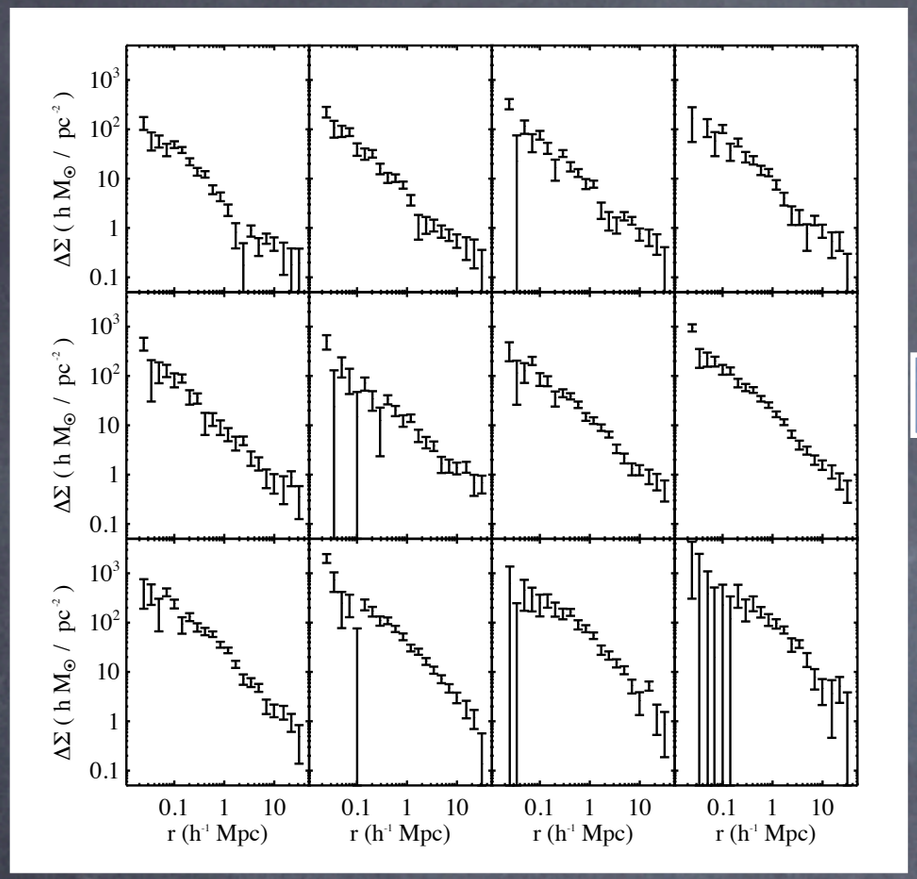
Oguri et al 2010

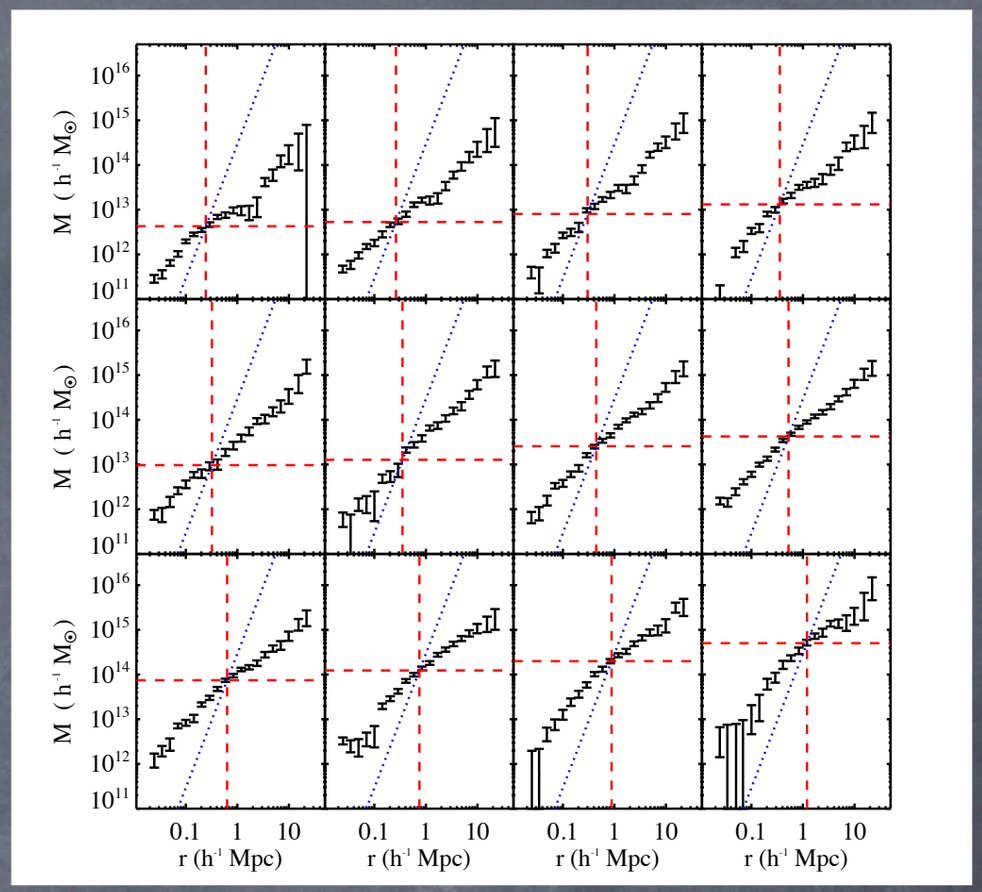
Galaxy-Galaxy Lensing



$$\gamma_{\rm t}(R)\Sigma_{\rm crit} = \Sigma(\leqslant R) - \Sigma(R) \equiv \Delta\Sigma(R).$$

$$\Delta\Sigma_{\rm s}(R|R_{\rm s}) = \Delta\Sigma_{\rm s,sub}(R) + \Delta\Sigma_{\rm s,host}(R|R_{\rm s}).$$



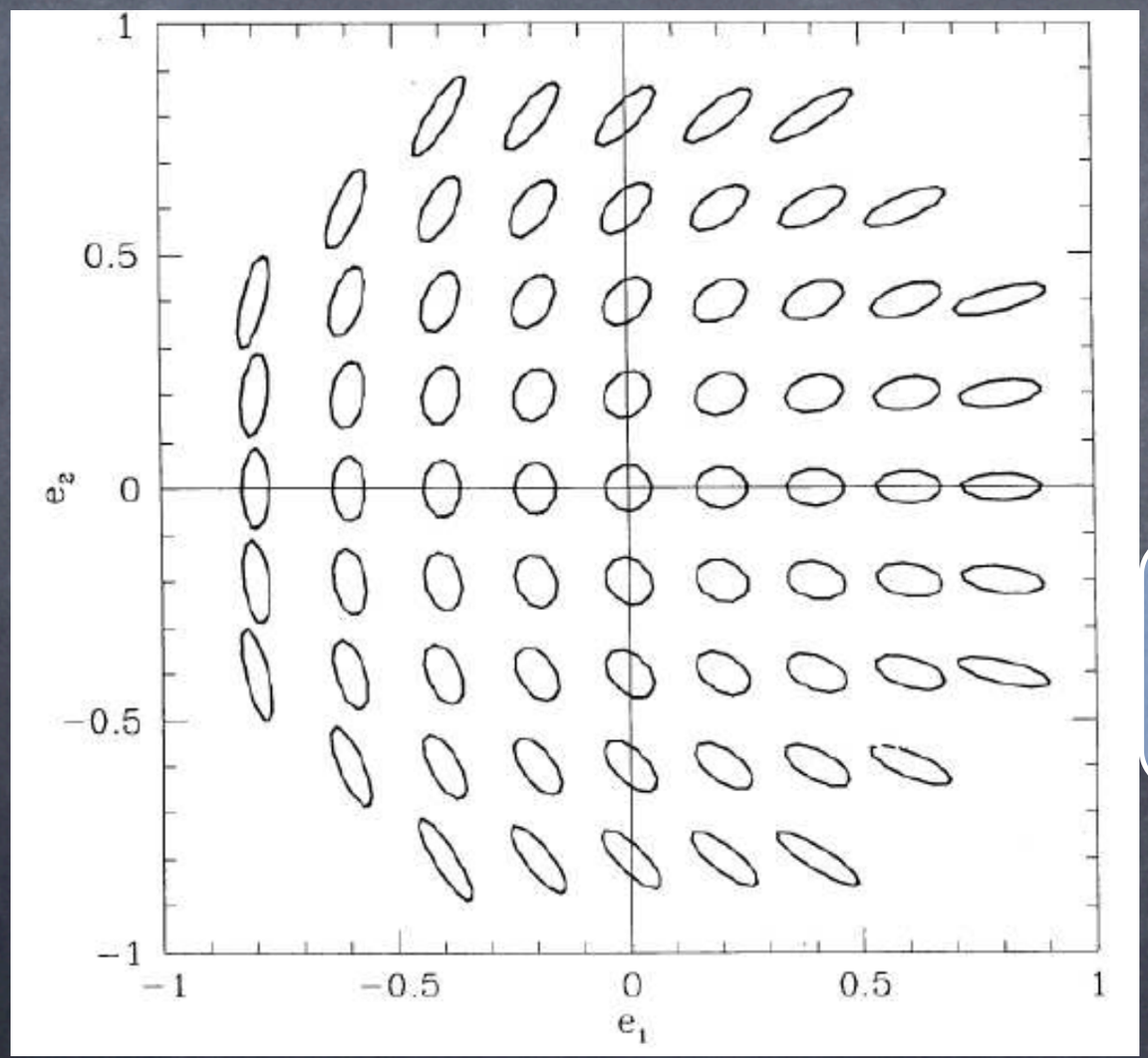


Johnston et al 2007

Ellipticity parameters

$e_+=(Mxx-Myy)/(Mxx+Myy)$

$e_x=(2Mxy)/(Mxx+Myy)$



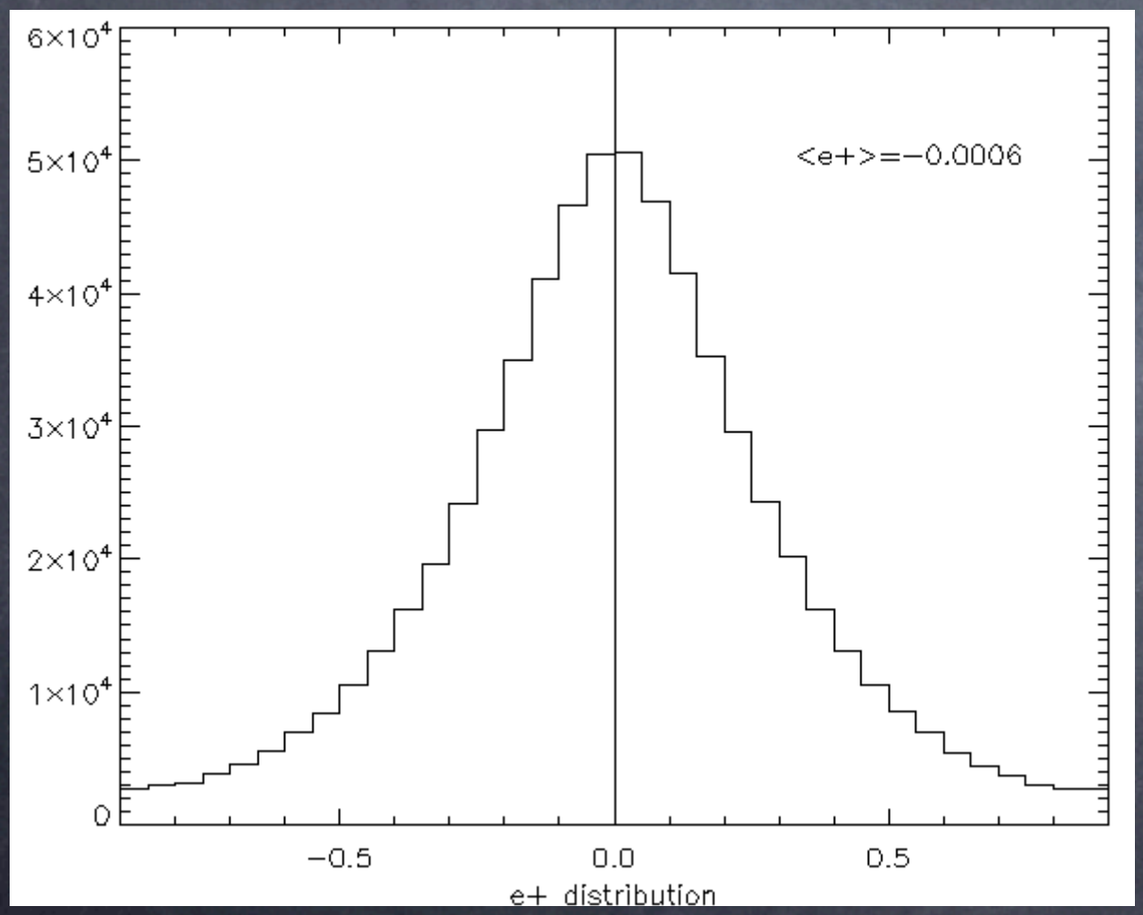
Kaiser 1995

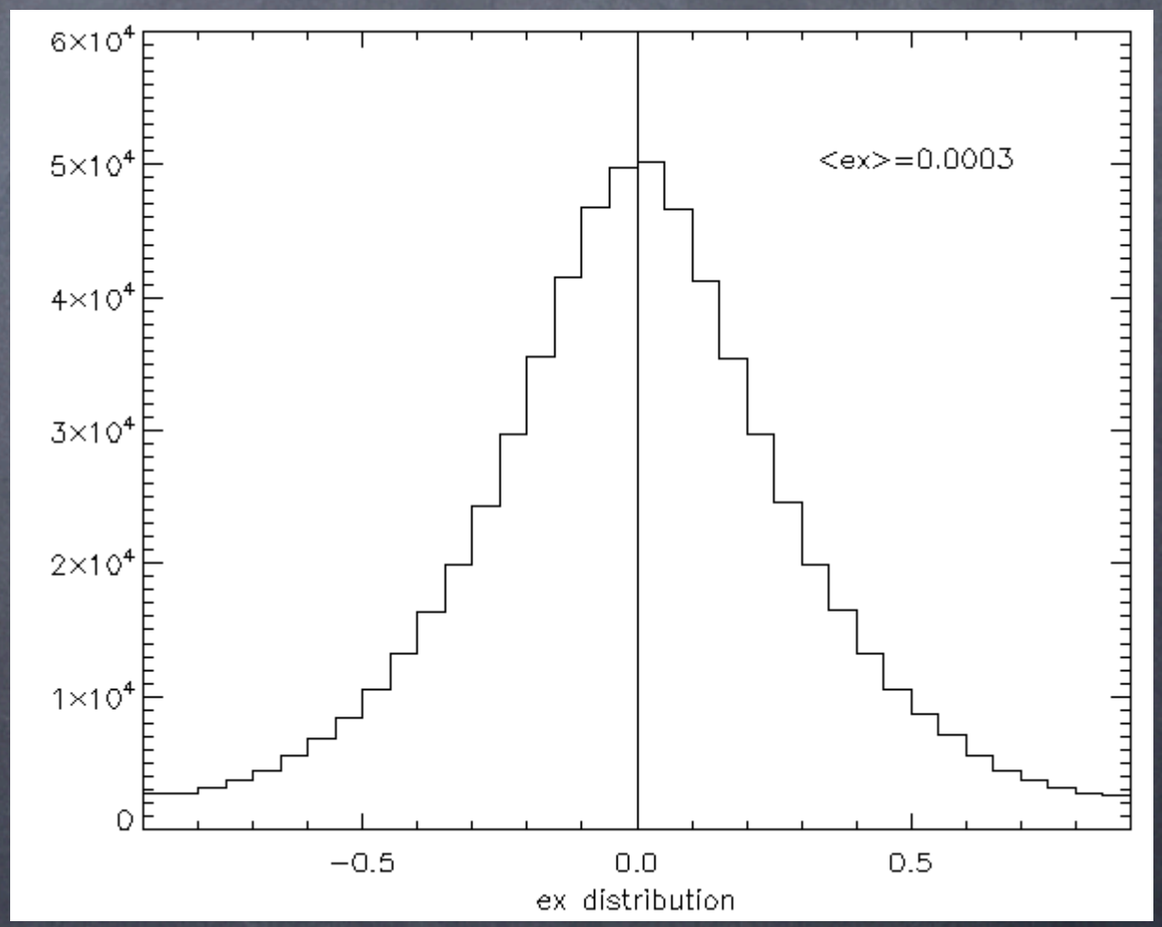
How to measure & How weak

$e^{obs}=e^{int}+2\gamma_T R$, $R\sim 1-\langle e^2\rangle$

Assuming an isotropic distribution of galaxy shape

$\langle e^{obs}\rangle=2R\langle\gamma_T\rangle$





Poisson Noise

$PN \sim \langle e^{obs} \rangle = 0 \pm 0.14/\sqrt{N}$

Num~6×10^5, PN~0.00018

Num~8600, PN~0.0015

Num~1000,PN~0.0044 SN~1σ for a typical shear value

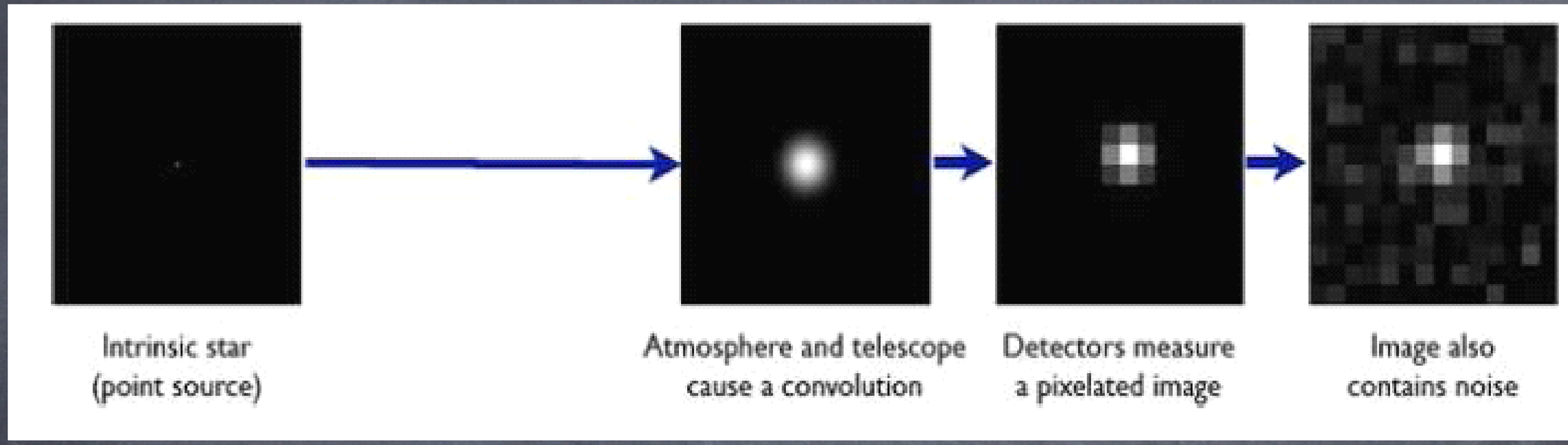
In the absence of other systematics !!,However… …

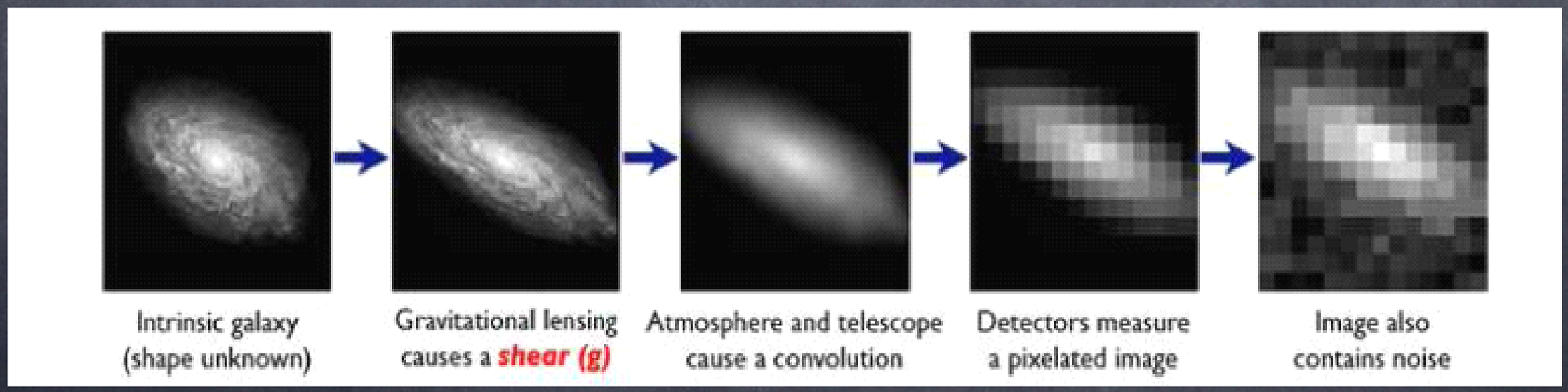
Systematics

Calibration bias (per cent)			
PSF dilution	$[-2.2, +2.9]$	$[-2.2, +4.0]$	$[-2.8, +3.9]$
PSF reconstruction	± 2.1	± 2.4	± 2.5
Selection bias	$[0, 5.7]$	$[0, 10.3]$	$[0, 11.1]$
Shear responsivity error	$[0.0, 1.7]$	$[0.0, 1.7]$	$[0.0, 1.7]$
Noise rectification	$[-1.0, 0]$	$[-3.8, 0]$	$[-1.2, 0]$
Total 2σ $\delta\gamma/\gamma$ (per cent)	$[-5, +12]$	$[-8, +18]$	$[-6, +19]$

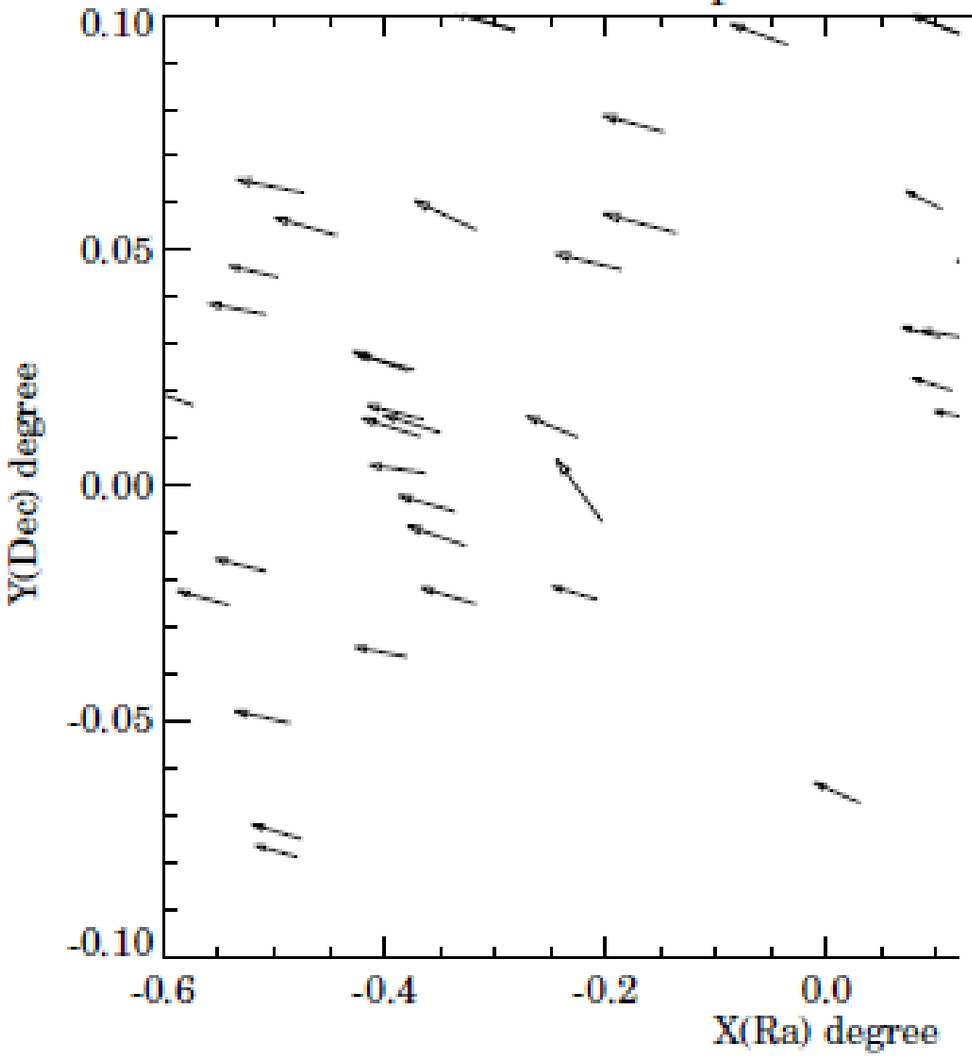
Mandelbaum et al 2005

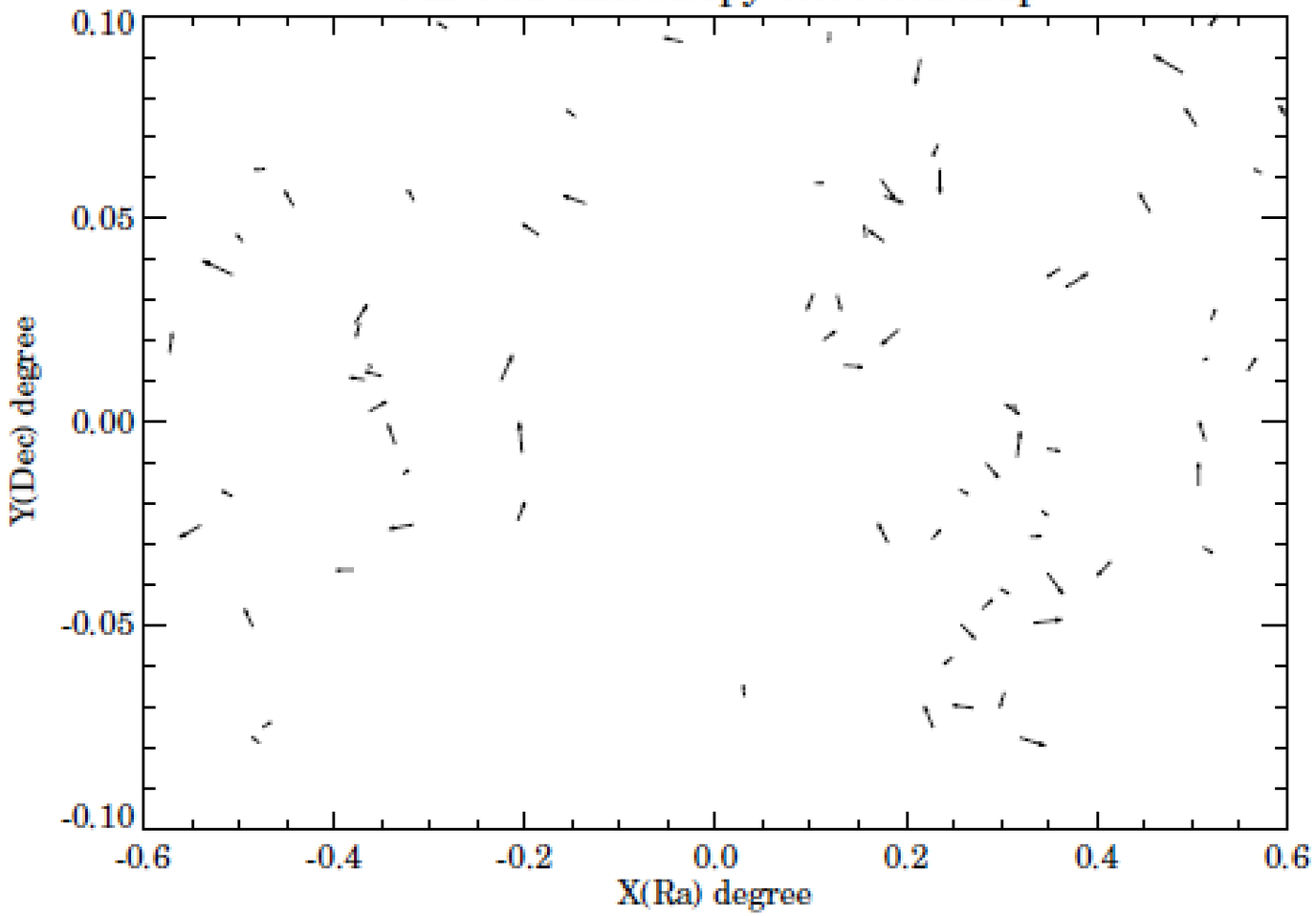
Point Spread Function



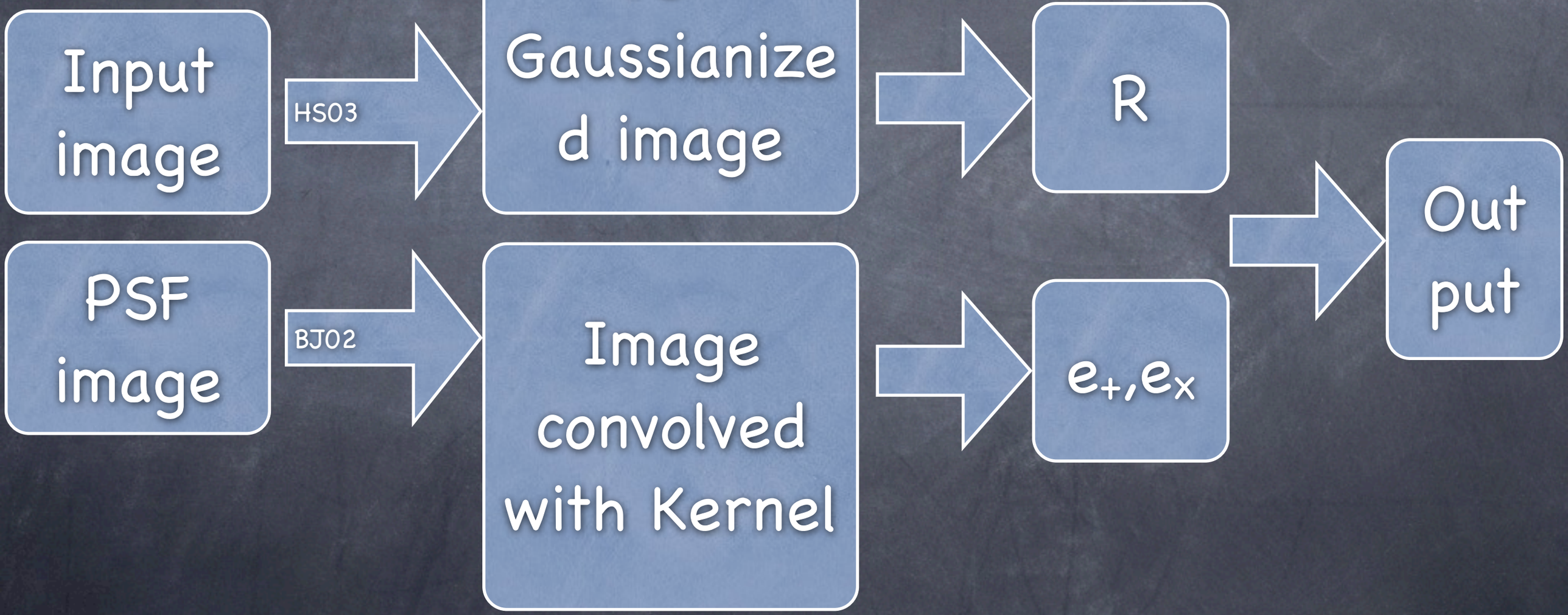


GREAT08 Handbook, Bridle et al 2008


SDSS polarization map
0.10
0.05
0.00
-0.05
-0.10
-0.6
-0.4
-0.2
0.0
X(Ra) degree
Y(Dec) degree


Our PSF anisotropy corrected map
0.10
0.05
0.00
-0.05
-0.10
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
X(Ra) degree
Y(Dec) degree

The Structure of Our Pipeline



Bernstein & Jarvis 2002; Hirata & Seljak 2003

Various Testing Data

- STEP 2 Massey et al 2007
- NASA Kaggle competition
- SHERA Mandelbaum et al 2011

Shear TEsting Program 2

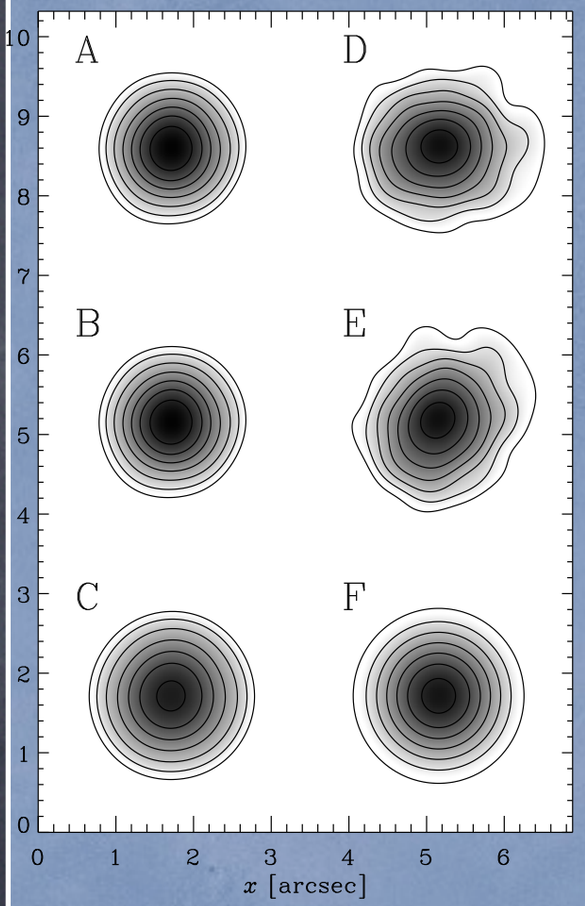


Image set	PSF description	Galaxy type
A	Typical Subaru PSF ($\sim 0.6''$)	shapelets
B	Typical Subaru PSF ($\sim 0.6''$)	pure exponential
C	Enlarged Subaru PSF ($\sim 0.8''$)	shapelets
D	Elliptical PSF aligned along x-axis	shapelets
E	Elliptical PSF aligned at $45°$	shapelets
F	Circularly symmetric Subaru PSF	shapelets

$$\tilde{\gamma} = (e^{\rm obs,unrot} + e^{\rm obs,rot})/2\,. \qquad (4)$$

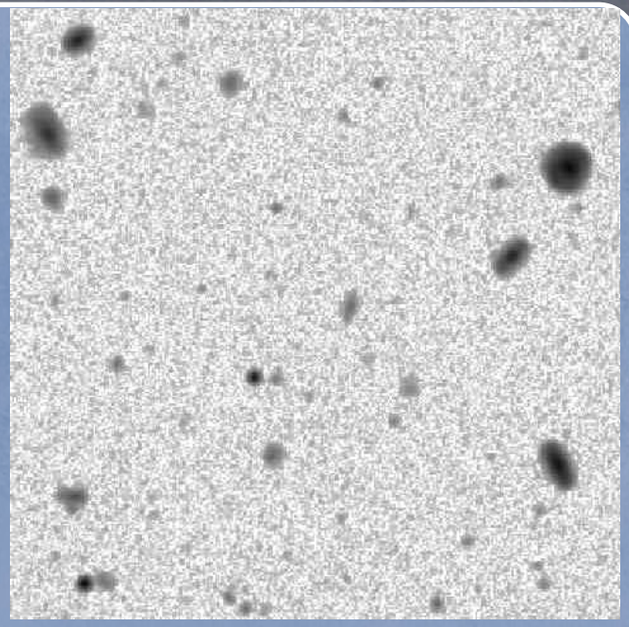
Since $e^{\rm int,unrot} = e^{\rm int} = -e^{\rm int,rot}$, we can use equation (2) to find

$$\begin{aligned}\tilde{\gamma} &= \left(\frac{e^{\rm int}+\gamma}{1+\gamma^* e^{\rm int}} + \frac{-e^{\rm int}+\gamma}{1-\gamma^* e^{\rm int}}\right)/2 \\ &= \frac{\gamma - \gamma^* (e^{\rm int})^2}{1-(\gamma^* e^{\rm int})^2}\,. \qquad (5)\end{aligned}$$

Averaging this shear estimator over $N/2$ galaxy pairs now gives a shot noise error in $\langle\tilde{\gamma}\rangle$ of

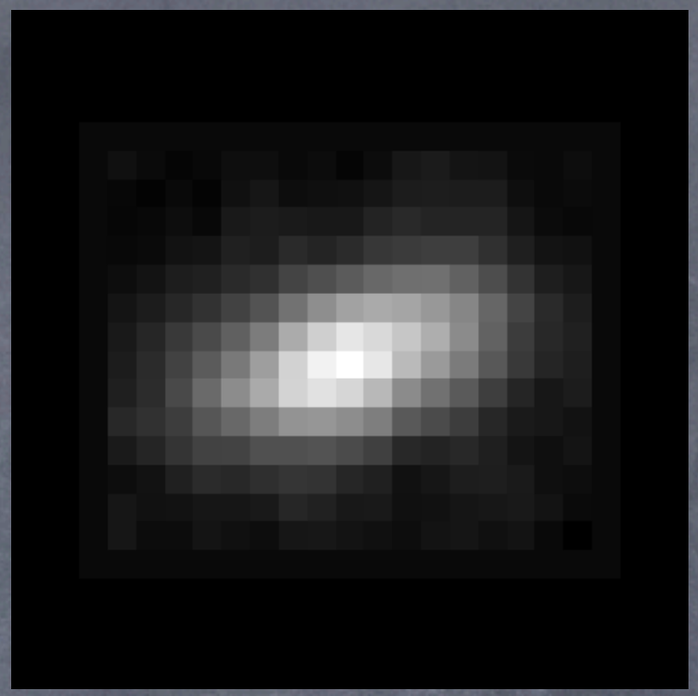
$$\text{SN error} \approx \gamma\langle(e_i^{\rm int})^2\rangle = 0 \pm \gamma\sqrt{\frac{\langle(e^{\rm int})^4\rangle}{2N}} \qquad (6)$$

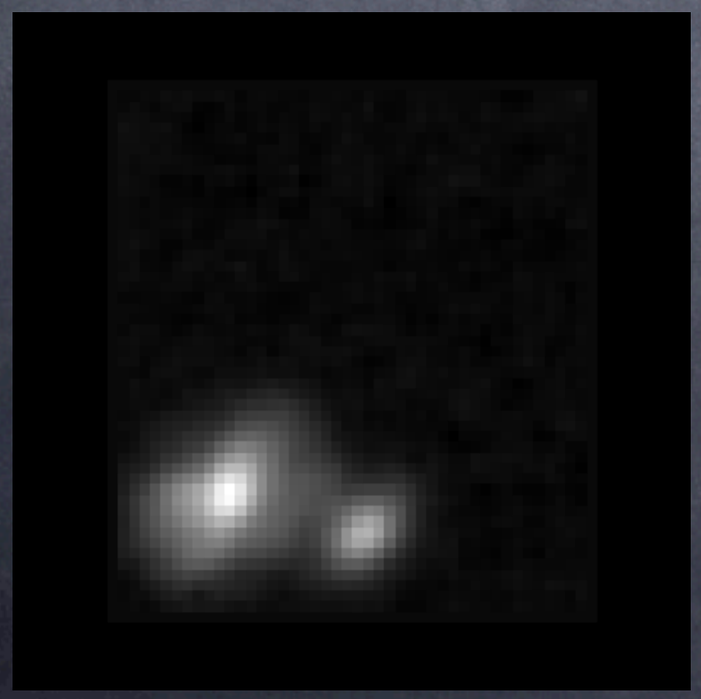
SN~0.0001 for N~1000

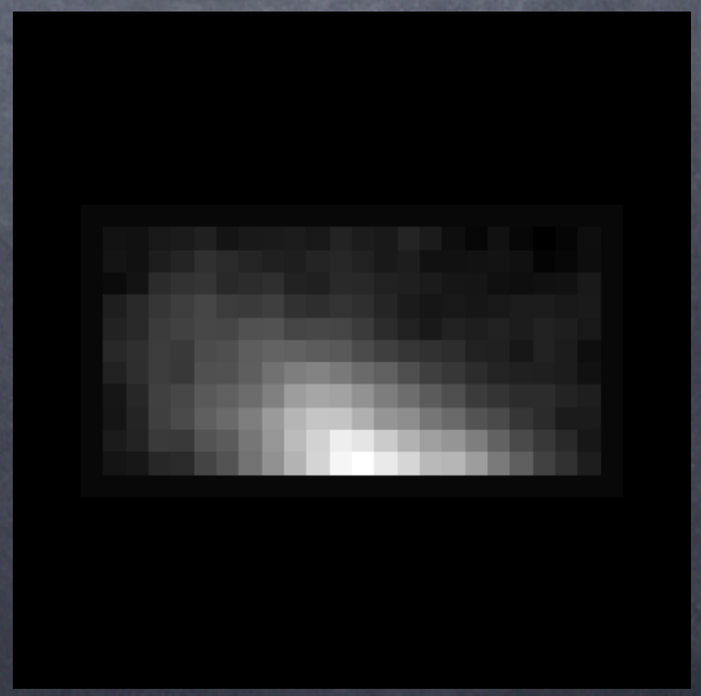


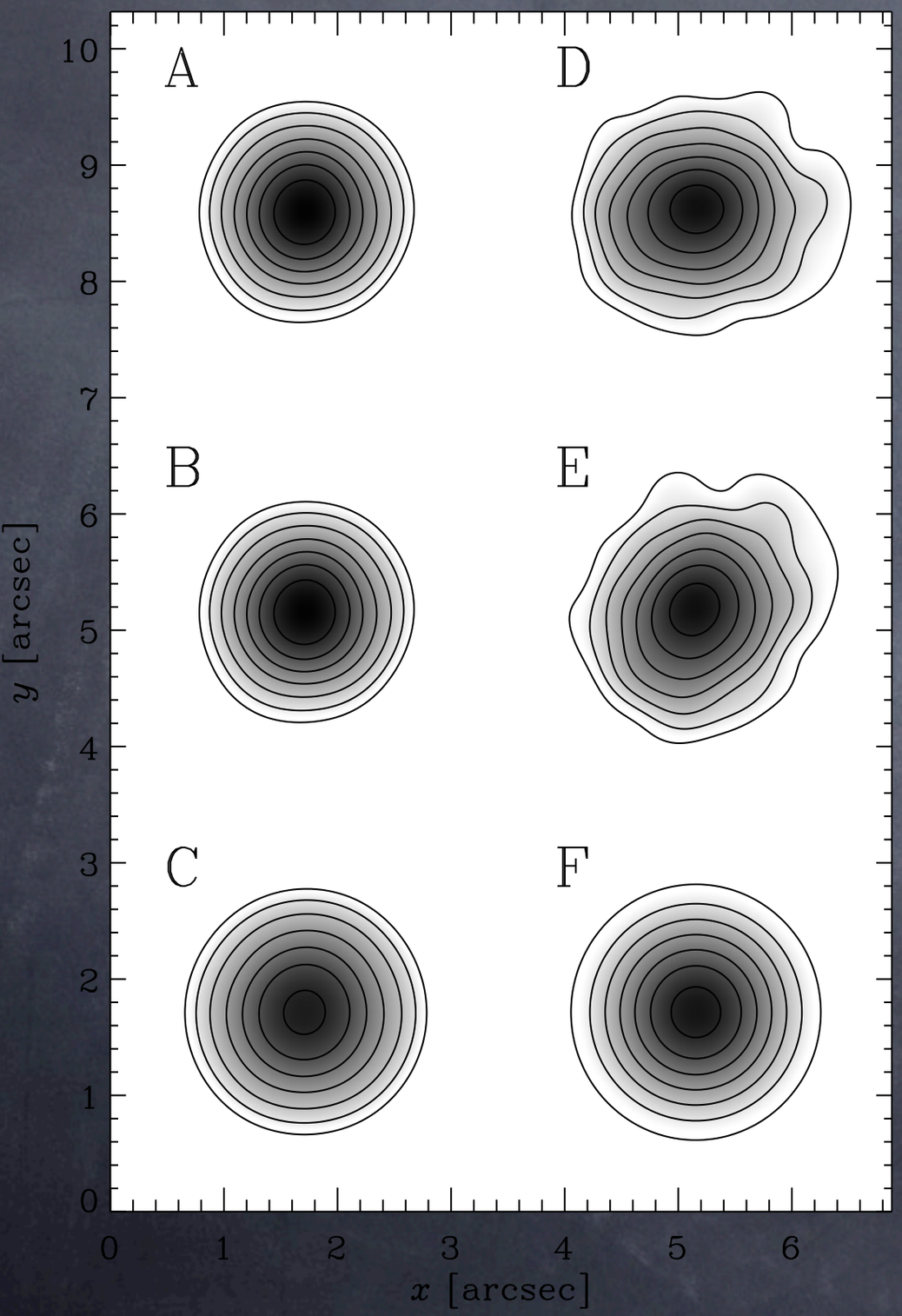
Massey et al 2007

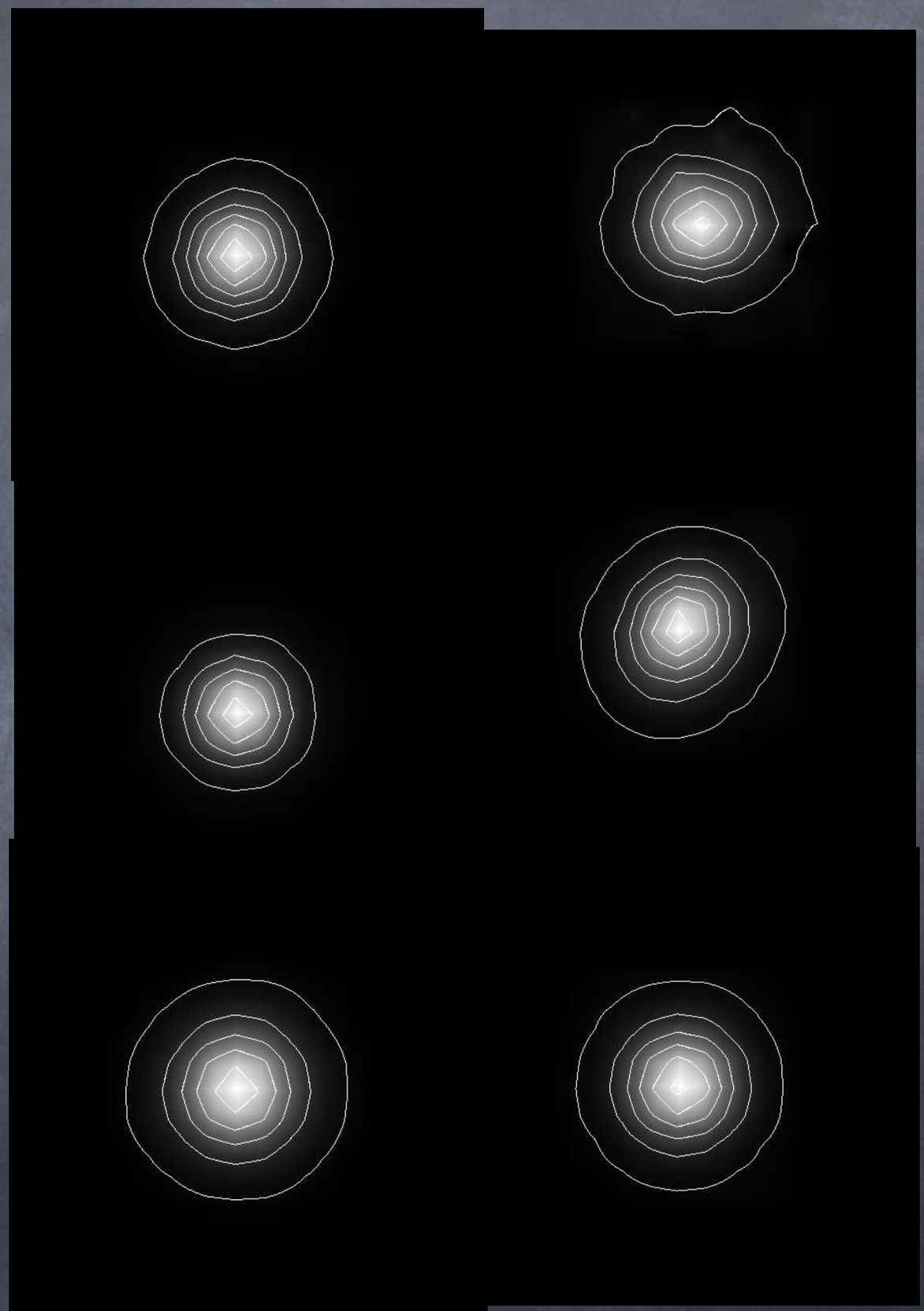
- ⭐ Object detection (Source EXTRACTOR Bertin et al)
- ⭐PSF Modeling (PCA)





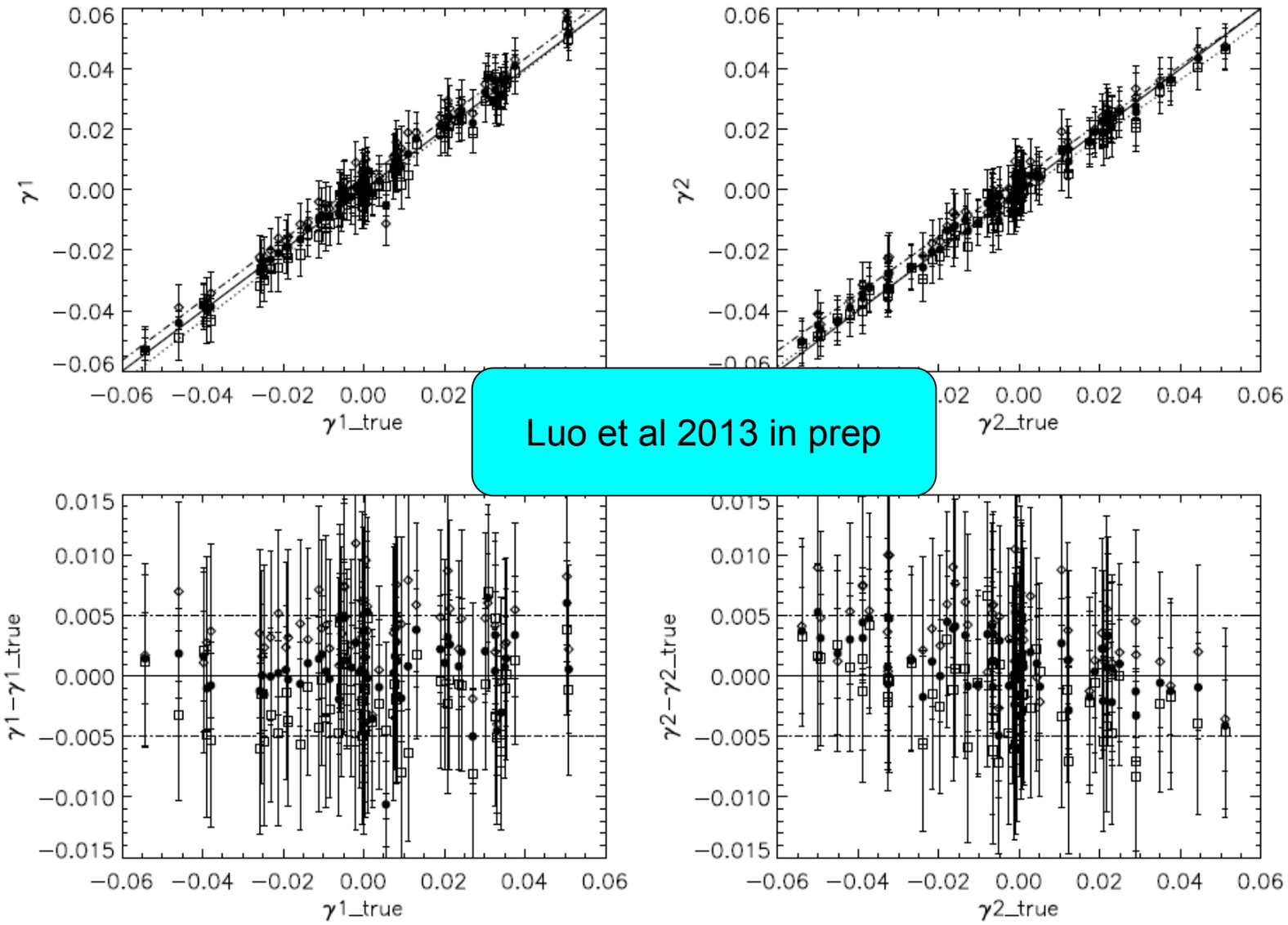



A
B
C
D
E
F
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
y [arcsec]
x [arcsec]



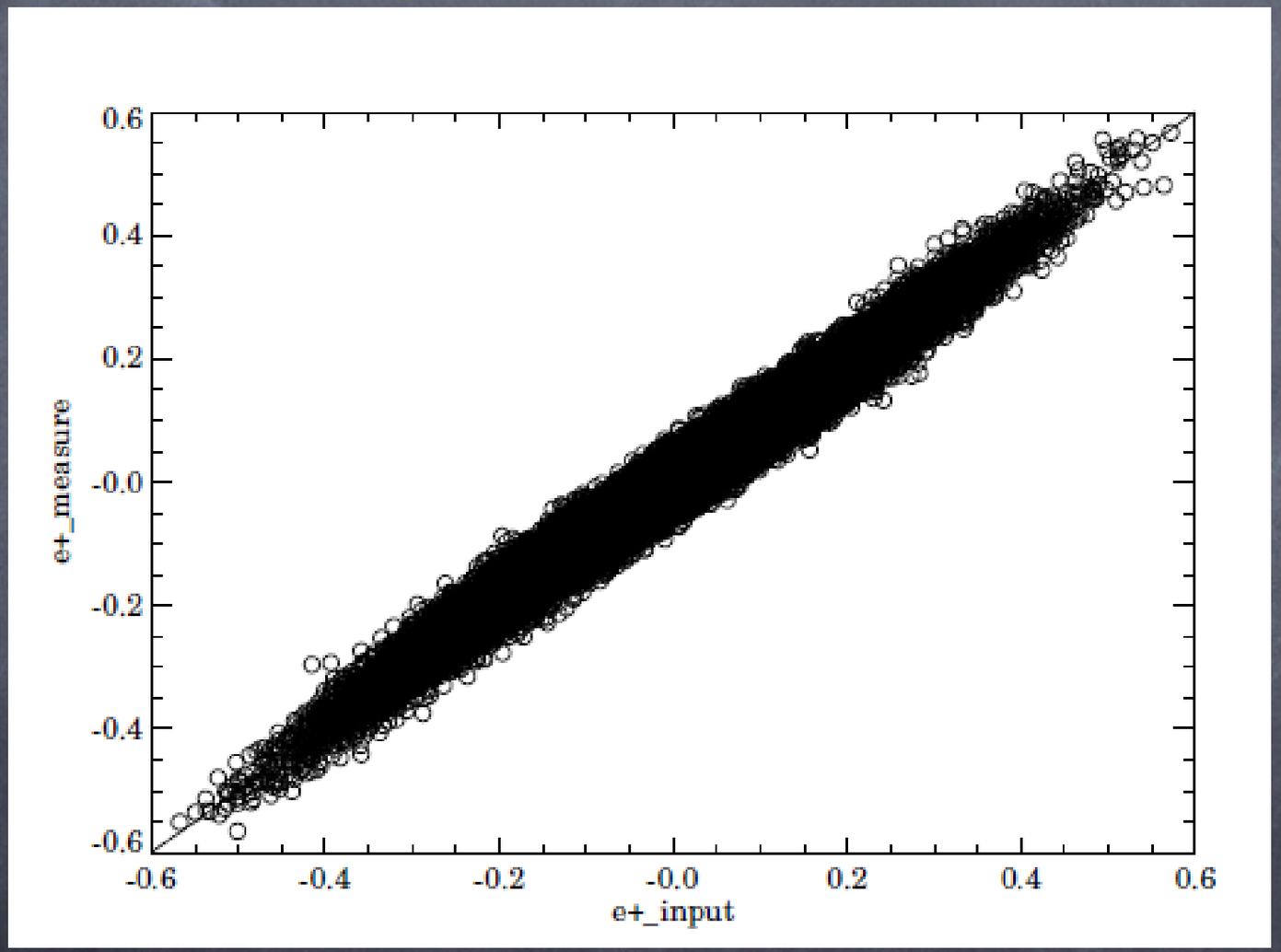
psf type	e1_psf	e2_psf	e1_psf KSB+	e2_psf KSB+	b00	b22	b21
A	-0.0084	0.0114	-0.0068 ± 0.0010	0.0121 ± 0.0007	0.35435	0.01390	0.00386
B	-0.0127	0.0123	-0.0066 ± 0.0007	0.0128 ± 0.0005	0.34930	0.01737	0.00139
C	-0.0046	0.0091	-0.0047 ± 0.0007	0.0097 ± 0.0006	0.28248	0.01533	0.00099
D	0.1142	0.0220	0.1149 ± 0.0110	0.0220 ± 0.0014	0.29742	0.02187	-0.00372
E	-0.0395	0.1815	-0.0221 ± 0.0014	0.1129 ± 0.0016	0.31819	0.02561	0.00291
F	-0.0006	0.0002	-0.0001 ± 0.0012	0.0001 ± 0.0001	0.30144	0.01788	-0.00040

STEP2 PSF F



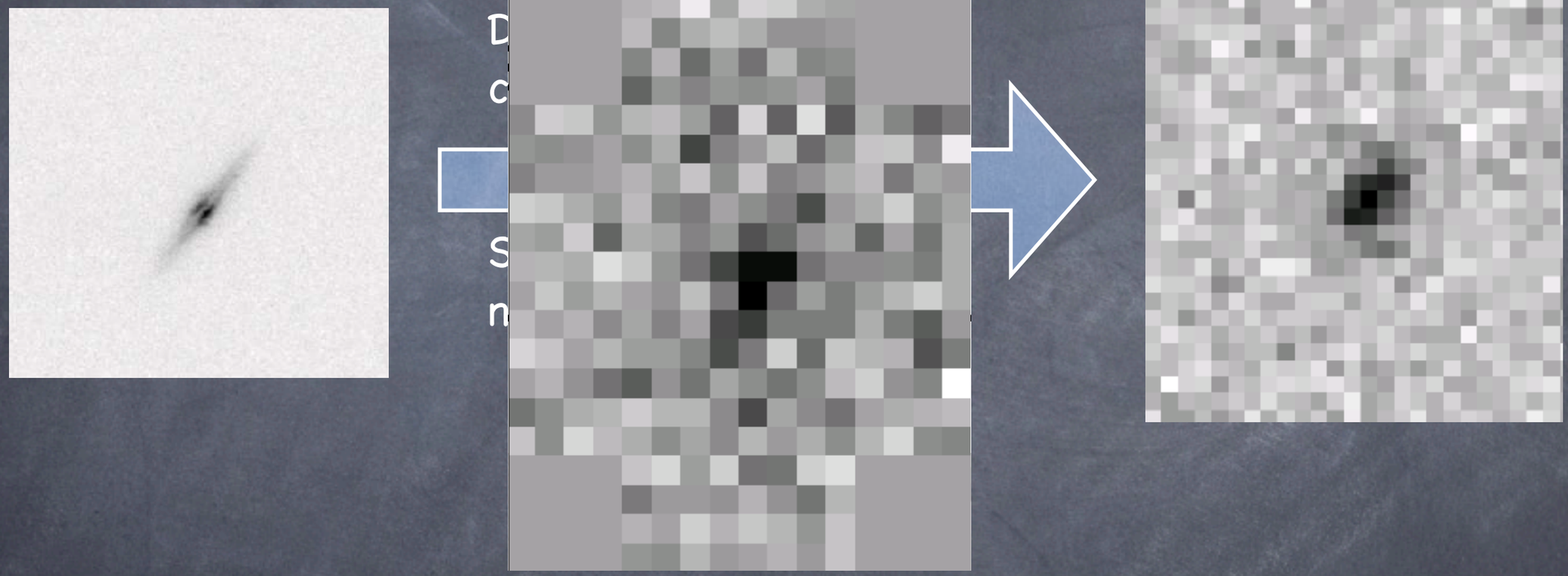
Luo et al 2013 in prep

NASA kaggle competition
$3000.00 bonus

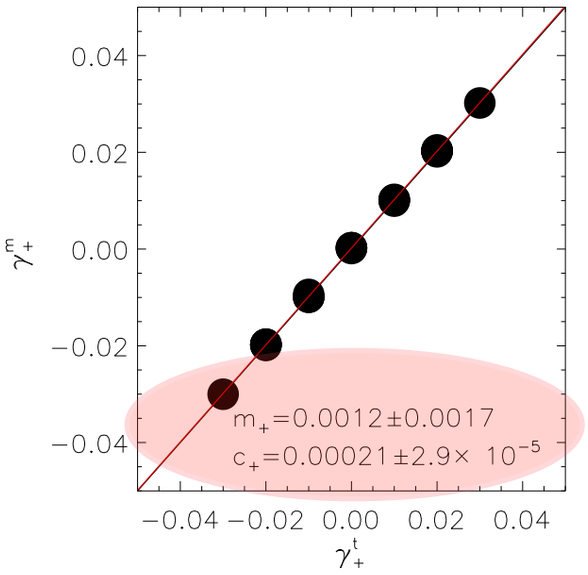


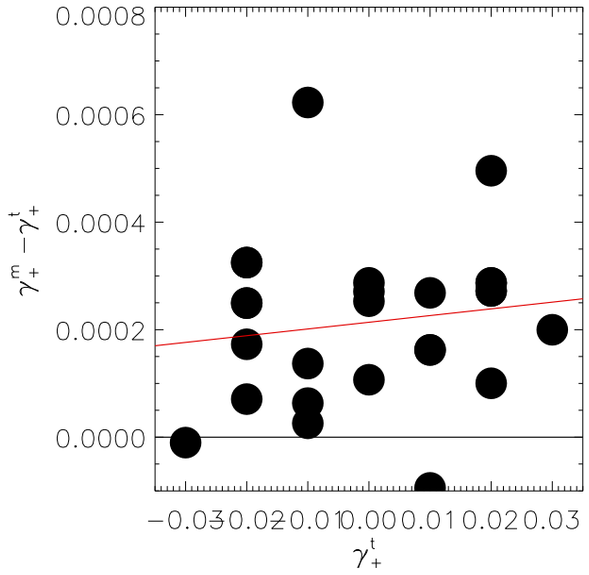
#	Δ1w	Team Name	RMSE	Entries	Last Submission UTC (Best Submission - Last)	
1	-	DeepZot *	0.0150907	16	Sat, 13 Aug 2011 23:38:22 (-26.9h)	
2	-	Zooma	0.0151276	70	Wed, 17 Aug 2011 17:05:33 (-25.5h)	
-		**Wentao Luo**	0.0170657	-	Fri, 28 Sep 2012 02:59:05	Post-Deadline
32	-	**mwilhelm**	0.0171998	1	Sun, 17 Jul 2011 06:04:14	
33	-	**NSchneider**	0.0172156	11	Wed, 17 Aug 2011 16:24:53 (-36.1d)	
34	-	**Mladen**	0.0174832	4	Sun, 07 Aug 2011 03:06:53	
35	-	**Wentao Luo**	0.0175070	4	Sun, 14 Aug 2011 22:33:13	

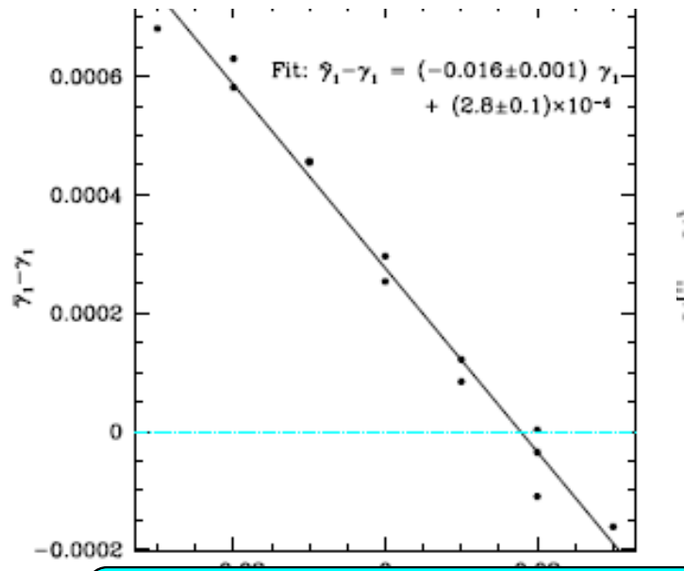
SHERA Mandelbaum et al 2011



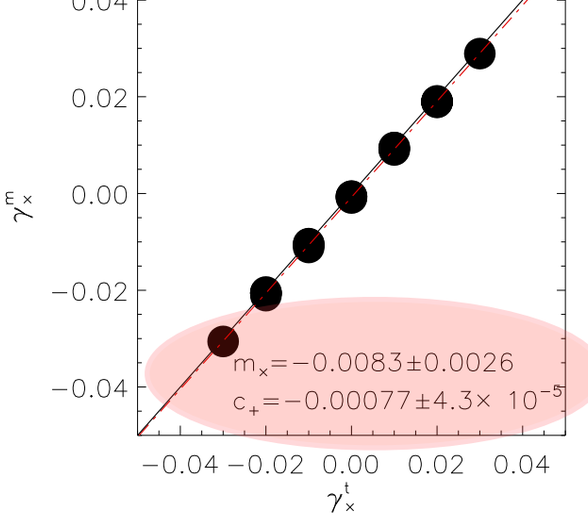
Reality is cruel!!

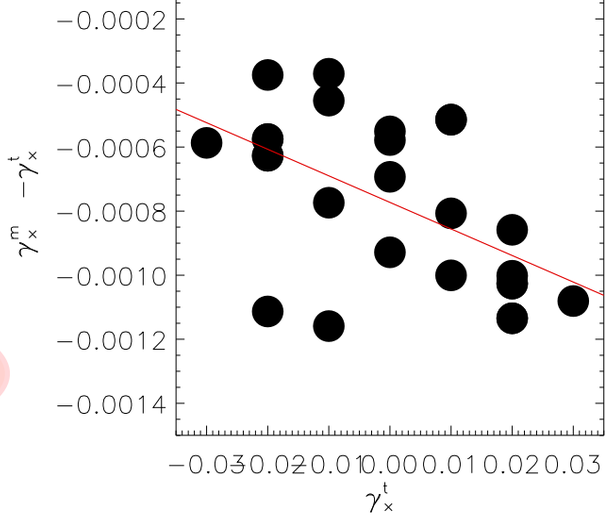


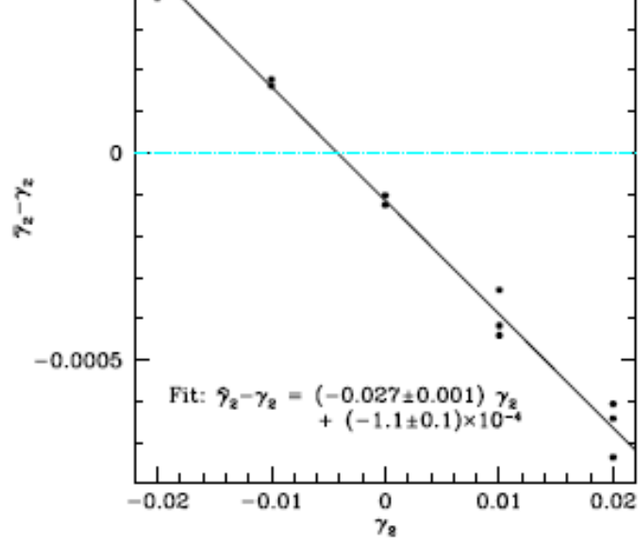




Mandelbaum et al 2011



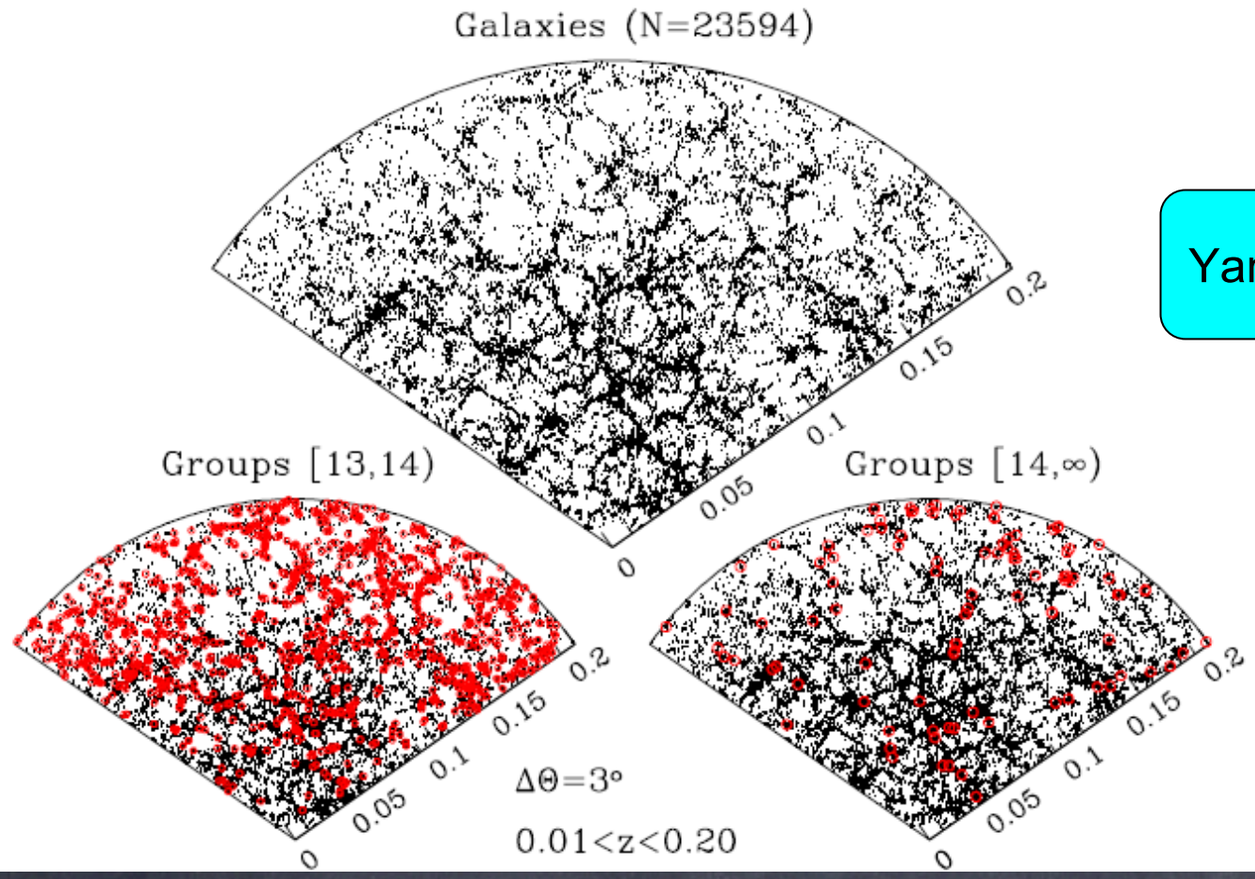




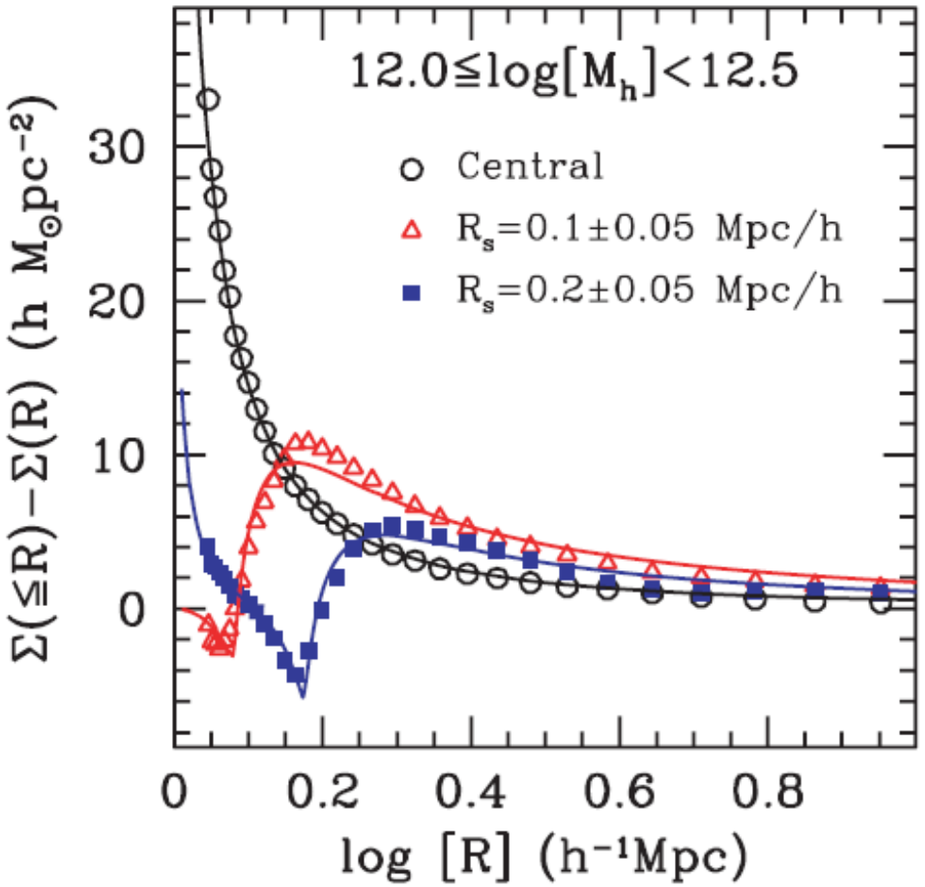
e+_psf~-0.036 ex_psf~-0.048

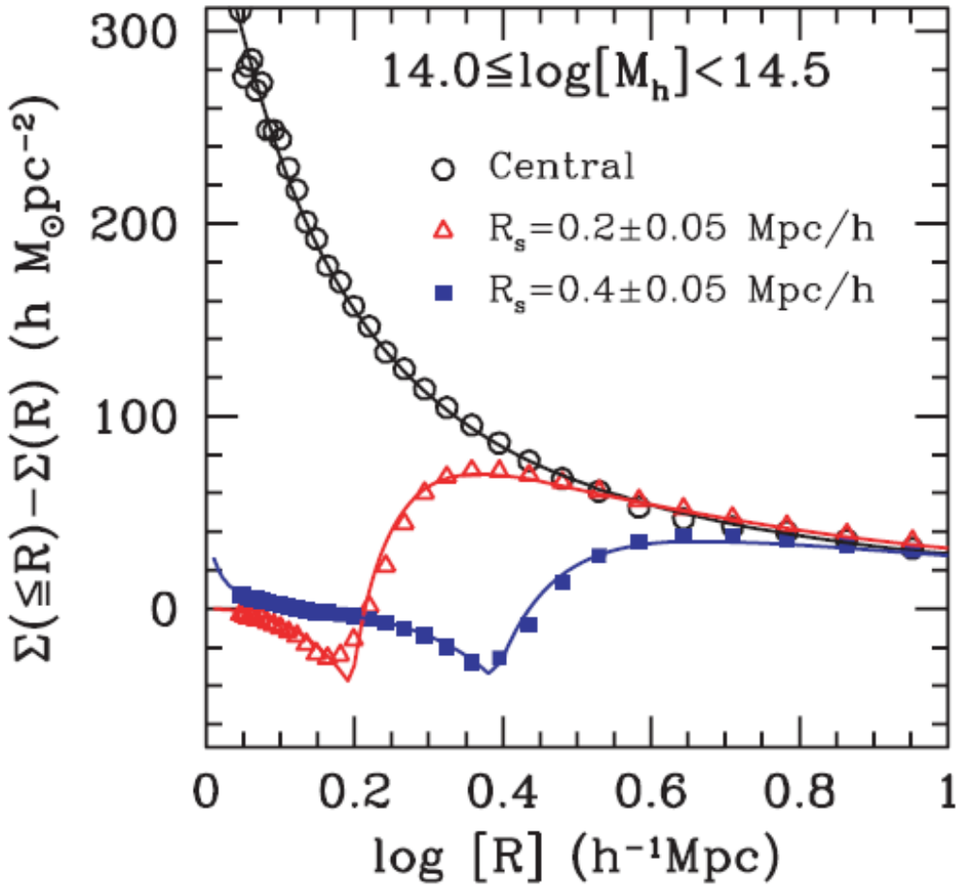
Group-galaxy lensing from x ray-optical cross identified groups

Galaxy Groups from SDSS Survey



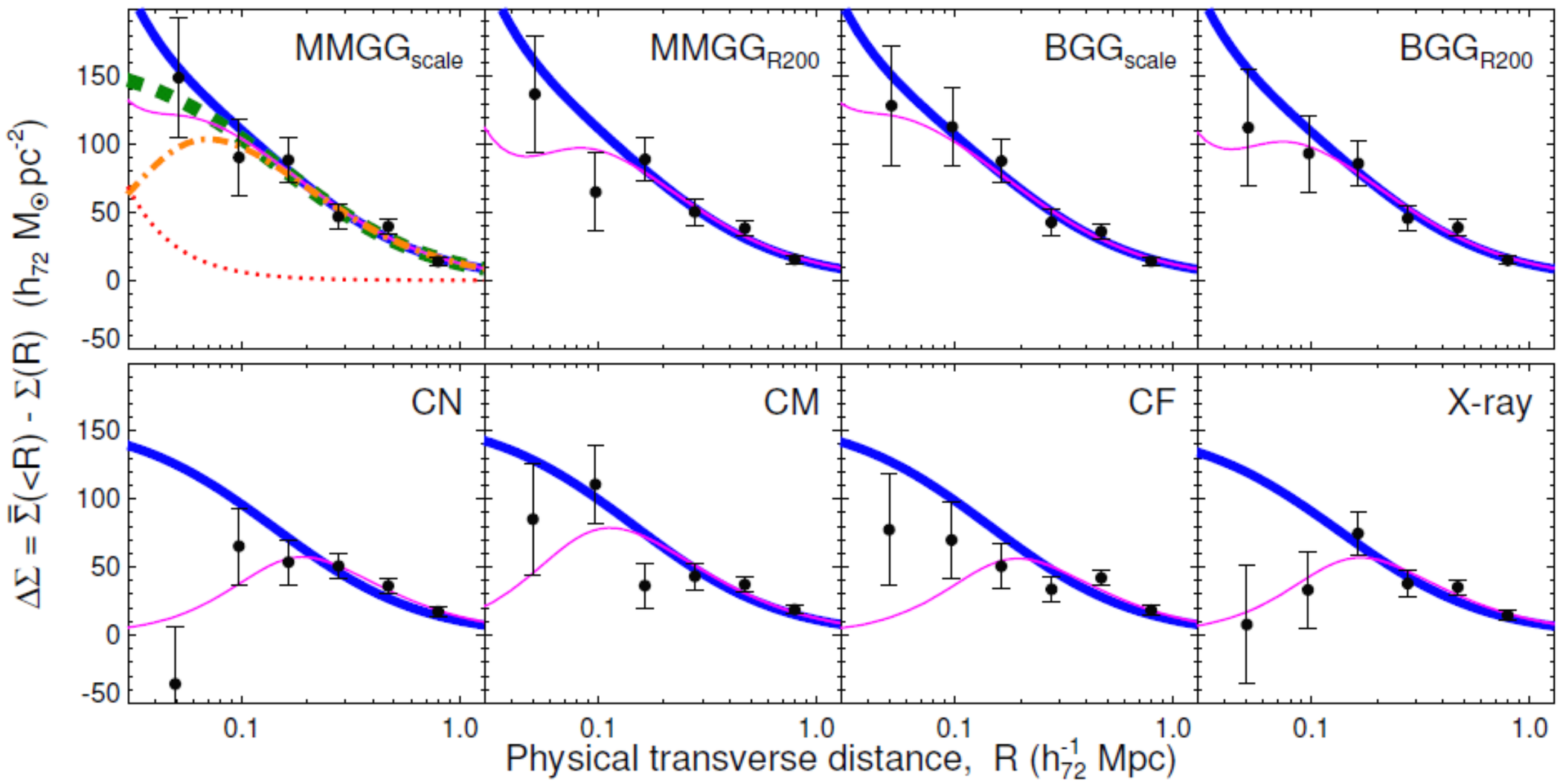
Yang et al 2007

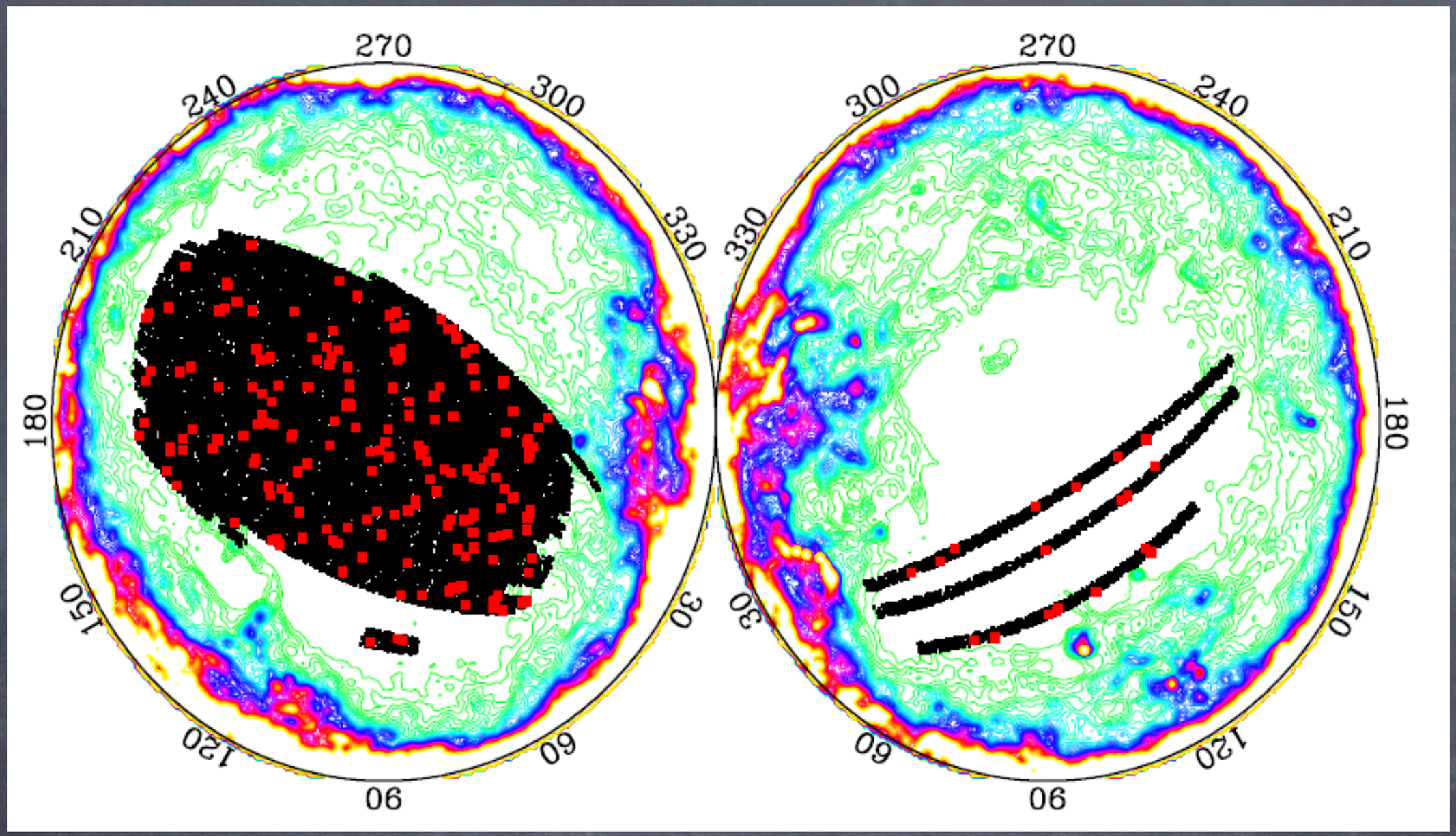




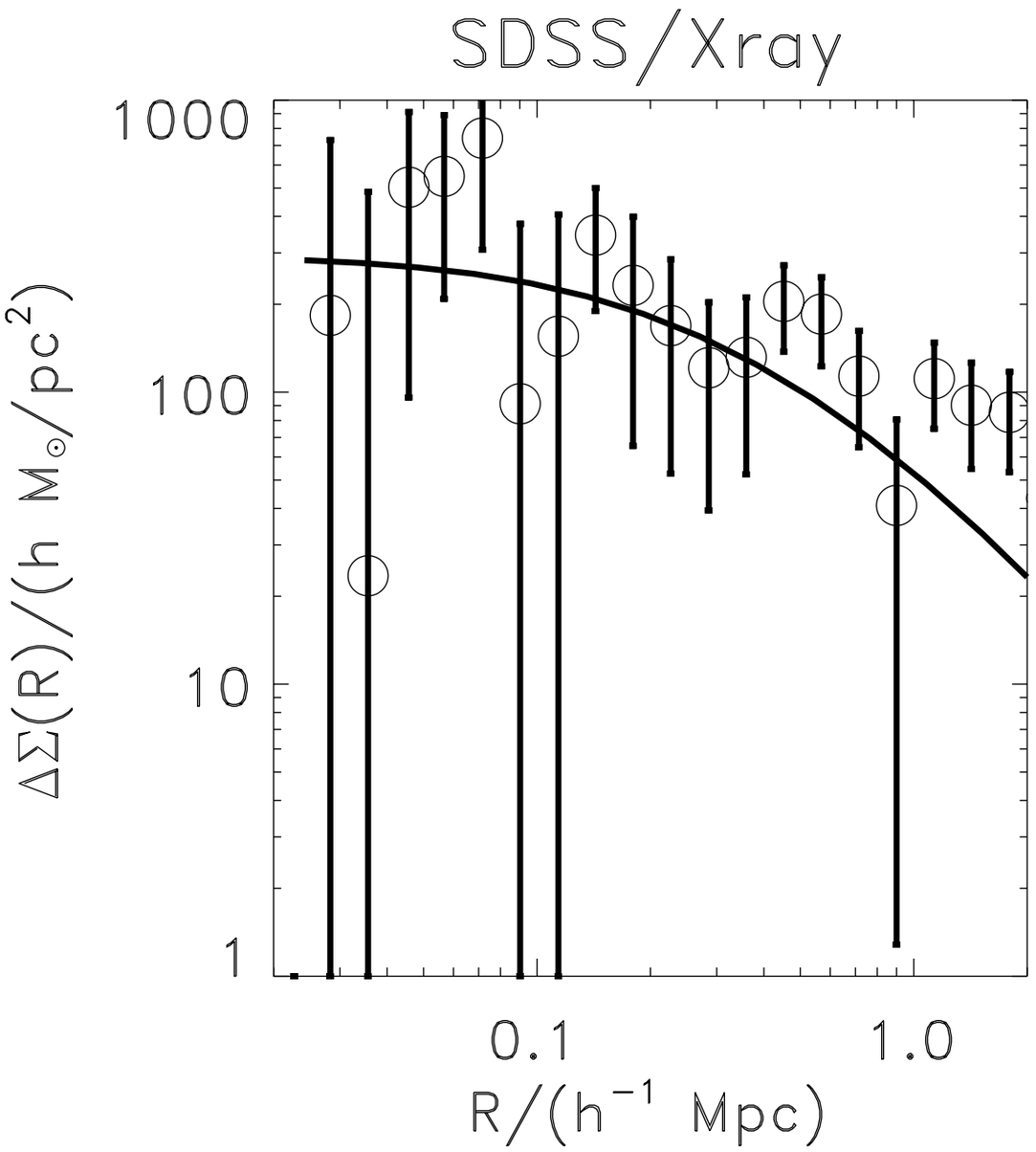
Yang et al 2006

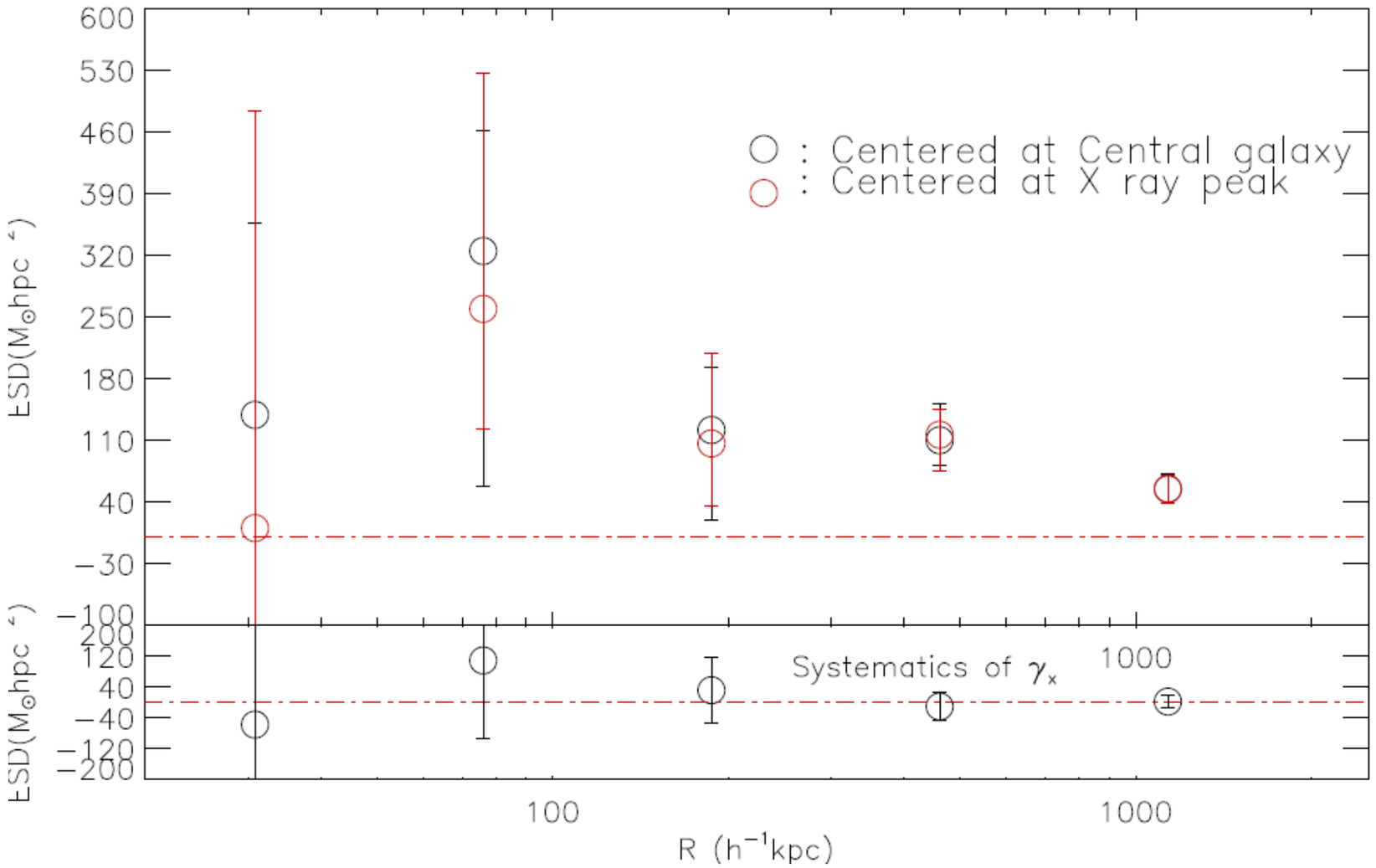
Goerge et al 2012





Wang et al 2012


SDSS/Xray
1000
100
10
1
0.1
1.0
ΔΣ(R)/(h M⊙/pc²)
R/(h⁻¹ Mpc)



Luo et al in prep

Accurate PSF Challenge

- PSF modeling Moffatlets G. Li & W. Luo in prep
- Re-test our pipeline using step2 and GREAT10 in future to make 100% sure

$$P_l(r) = \frac{1}{\sqrt{\pi\sigma^2}} e^{-\frac{r^2}{2\sigma^2}} L_l(\frac{r^2}{\sigma^2})$$

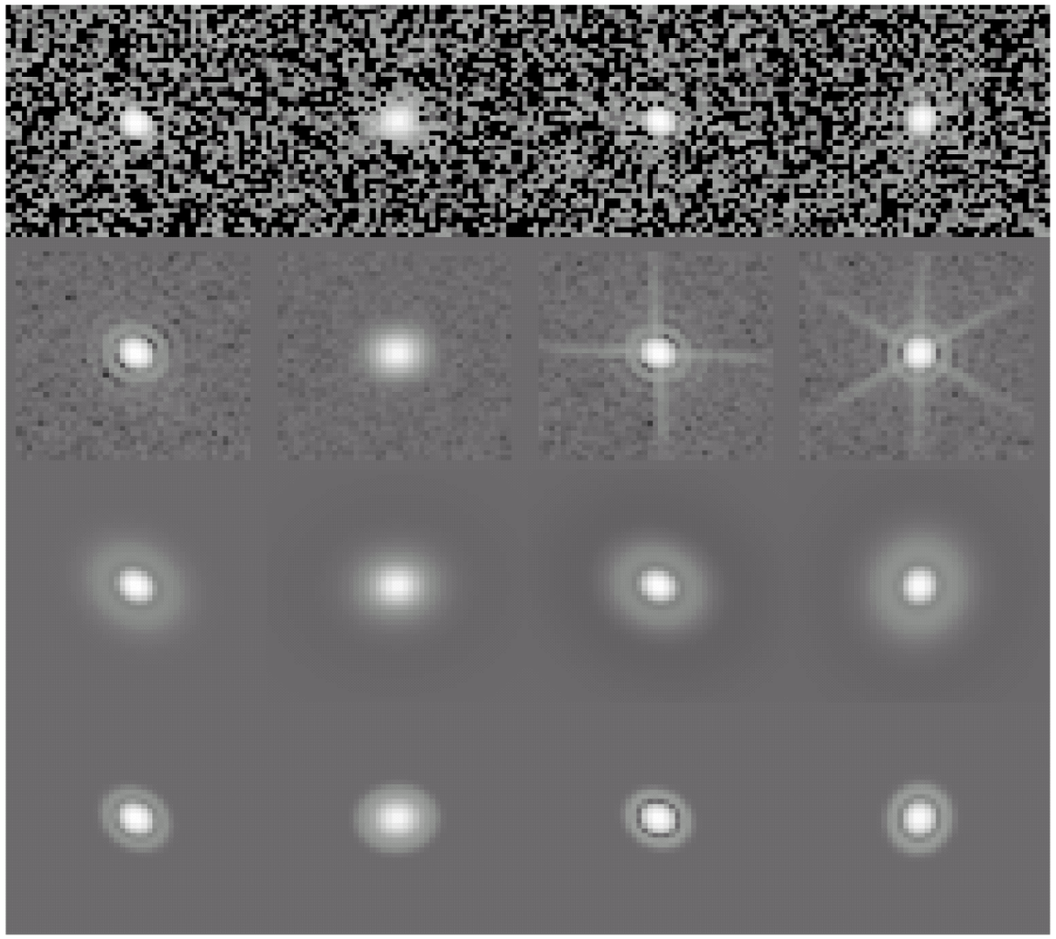
$$P_l(r) = \sqrt{\frac{2\beta-1}{\pi r_d^2}} L_l[v(r)][1+\left(\frac{r}{r_d}\right)^2]^{-\beta}$$

One star in different data set

Principal Component Analysis (PCA)

Moffatlets

Gaussianlets



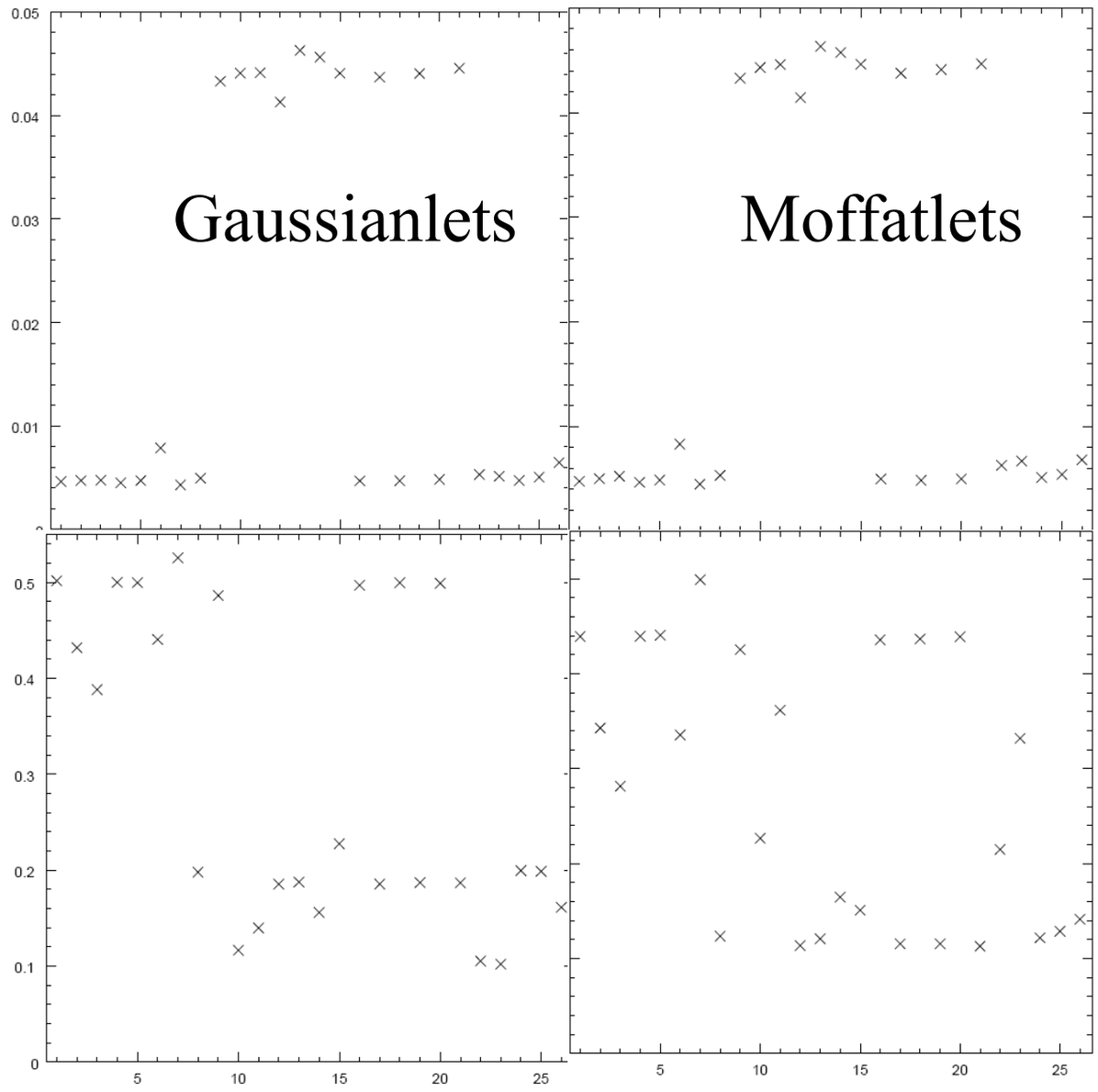
G. Li & W. Luo in prep

G. Li & W. Luo in prep

PSF attribute	Metrics
PSF Ellipticity	$E(e) = \sqrt{\left\langle (e_{calc} - e_{true})^2 \right\rangle} / 2$ $\sigma(e) = stdev\,(e_{calc} - e_{true}) / \sqrt{2} / \sqrt{N}$
PSF Size	$E(R^2) = \sqrt{\left\langle (R^2_{calc} - R^2_{true})^2 \right\rangle} / \langle R^2_{true} \rangle$ $\sigma(R^2) = stdev\,(R^2_{calc} - R^2_{true}) / \langle R^2_{true} \rangle / \sqrt{N}$

E(e)

E(R)



$$q_{ij} = \frac{\sum_p w_p I_p (\theta_i - \bar{\theta}_i)(\theta_j - \bar{\theta}_j)}{\sum_p w_p I_p}, \quad i,j \in \{1,2\},$$

$$e = \frac{q_{11} - q_{22} + 2iq_{12}}{q_{11} + q_{22} + 2(q_{11}q_{22} - q_{12}^2)^{1/2}}$$

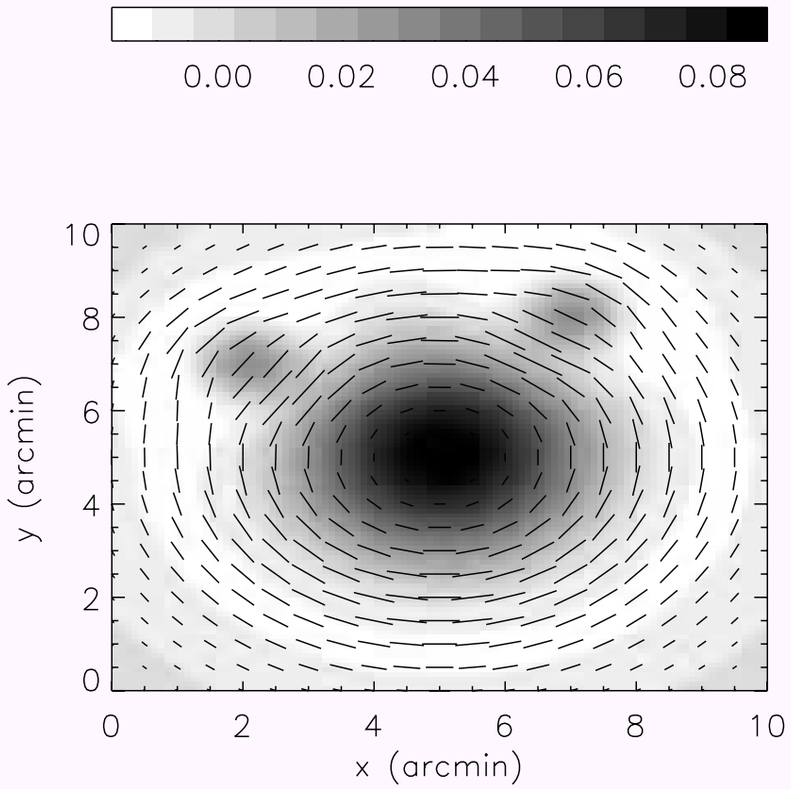
$$R^2 = q_{11} + q_{22}.$$

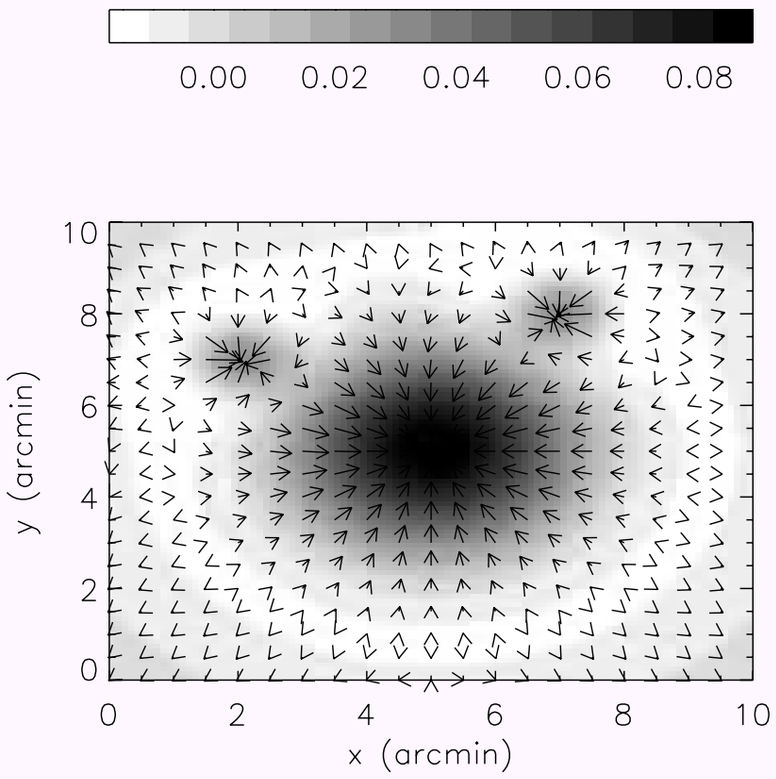
Method Name	$1/\sigma(e)$	$\sigma(e)/10^{-4}$	$1/[\sigma(R^2)/R^2]$	$[\sigma(R^2)/R^2]/10^{-3}$
B-Splines	3953	2.53	1348	0.742
IDW	3448	2.90	1212	0.825
RBF	3155	3.17	1259	0.794
RBF-thin	2985	3.35	1258	0.795
Kriging	1049	9.53	490	2.042
Gaussianlets	1473	6.79	392	2.548
IDW Stk	1058	9.45	277	3.604
PSFEx	1279	7.82	378	2.647
Shapelets	1256	7.96	379	2.642
PCA+Kriging	1339	7.47	314	3.180
MoffatGP	2545	3.93	429	2.331
Stacking	1441	6.94	309	3.237

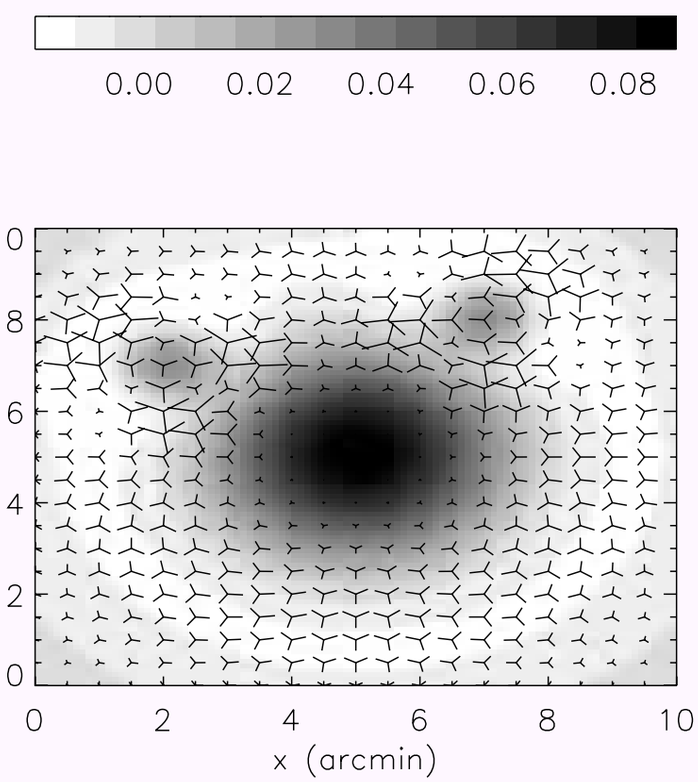
G. Li et al 2010

Why flexion in future?

- Complementary to shear analysis at smaller scales
- Sensitive to substructure

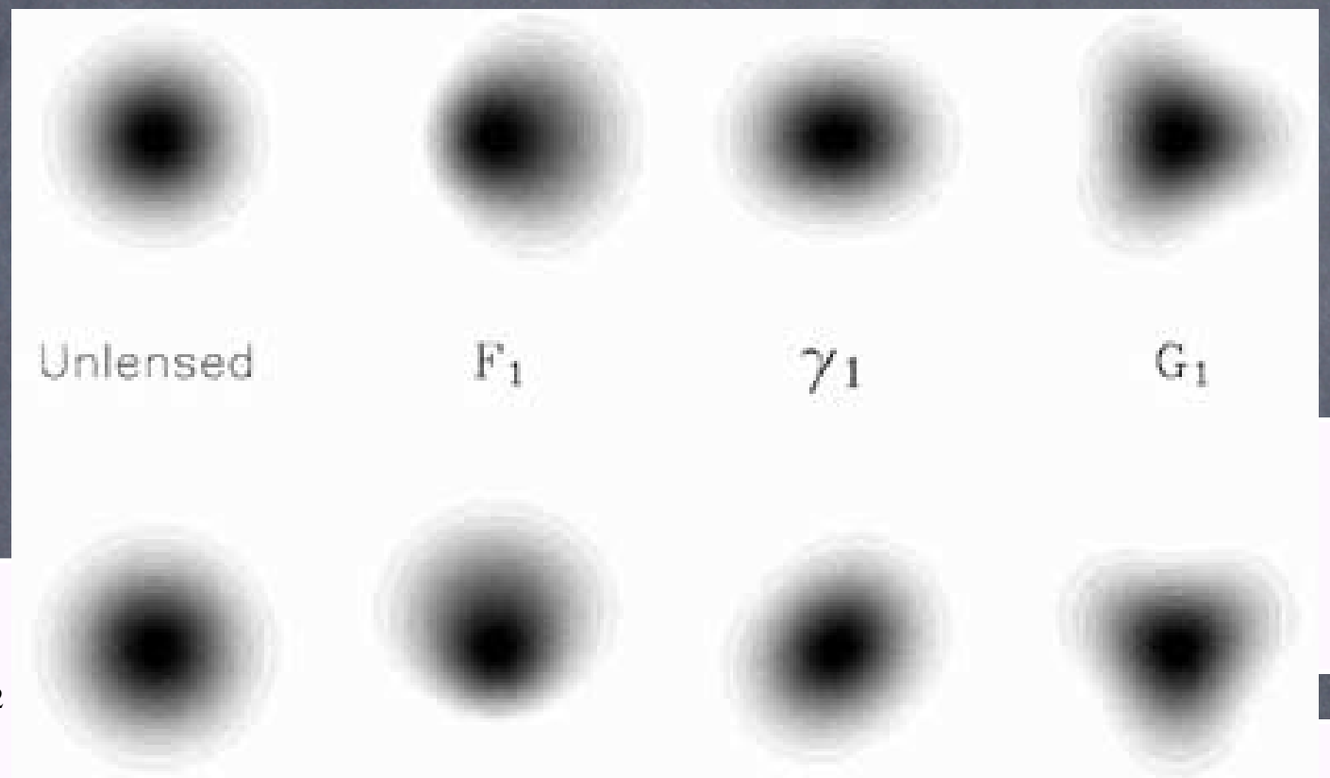






Shear Spin-1 Flexion F Spin-3 Flexion G

Quantification of Flexion components



$$D_{ij1} = \begin{pmatrix} -2\gamma_{1,1} - \gamma_{2,2} & \\ -\gamma_{2,1} & \end{pmatrix}$$

$$D_{ij2} = \begin{pmatrix} -\gamma_{2,1} & -\gamma \\ -\gamma_{2,2} & 2\gamma_{1,2} \end{pmatrix}$$

$$\mathcal{G} = (\partial_1\gamma_1 - \partial_2\gamma_2) + \mathrm{i}(\partial_1\gamma_2 + \partial_2\gamma_1).$$

G1 G2

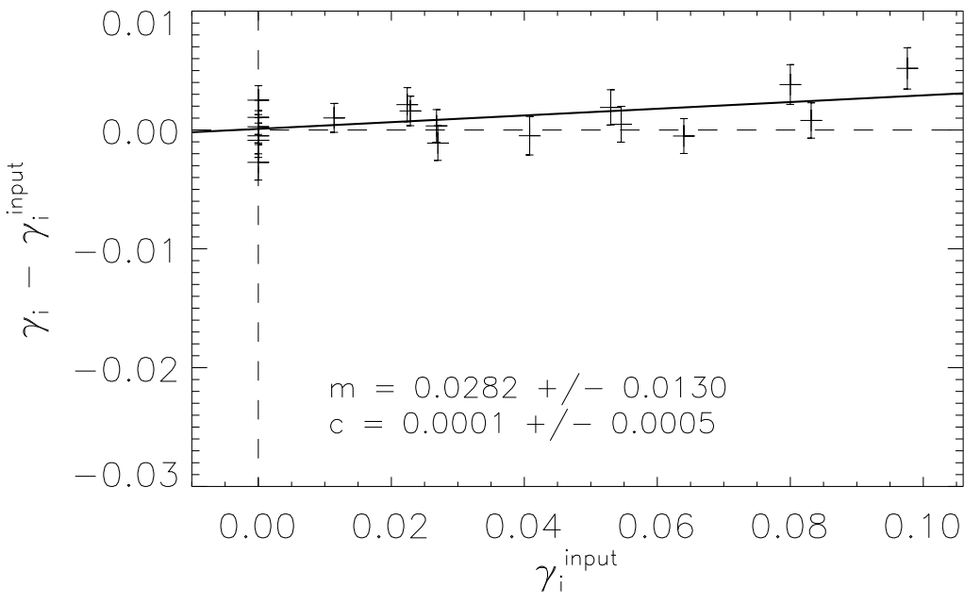
Bacon et al 2006; Kaiser 1995

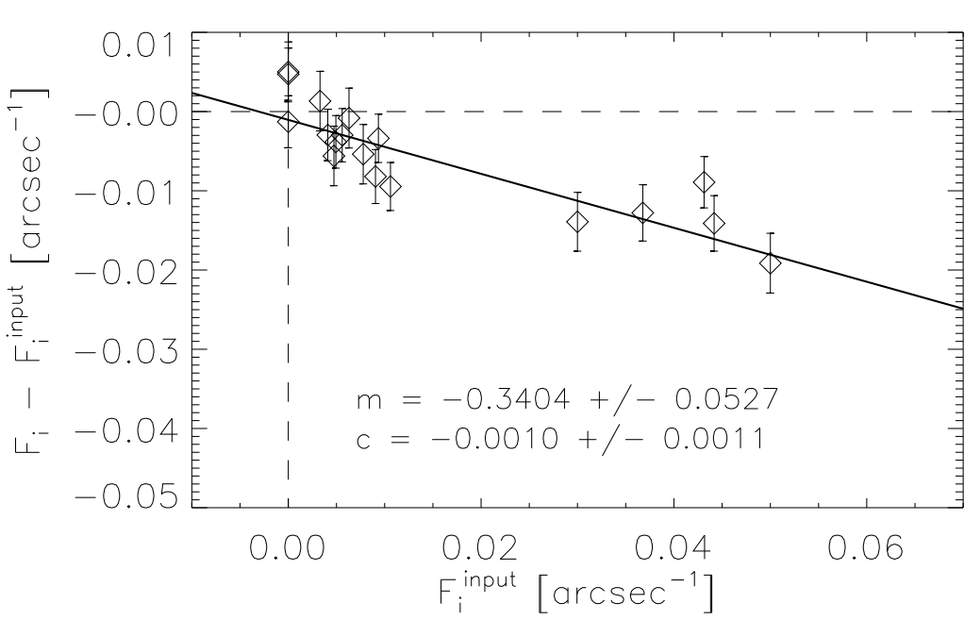
$$f = f_1 + \mathrm{i} f_2 = \frac{q_{111} + q_{122} + \mathrm{i}(q_{112} + q_{222})}{q_{1111} + 2q_{1122} + q_{2222}},$$

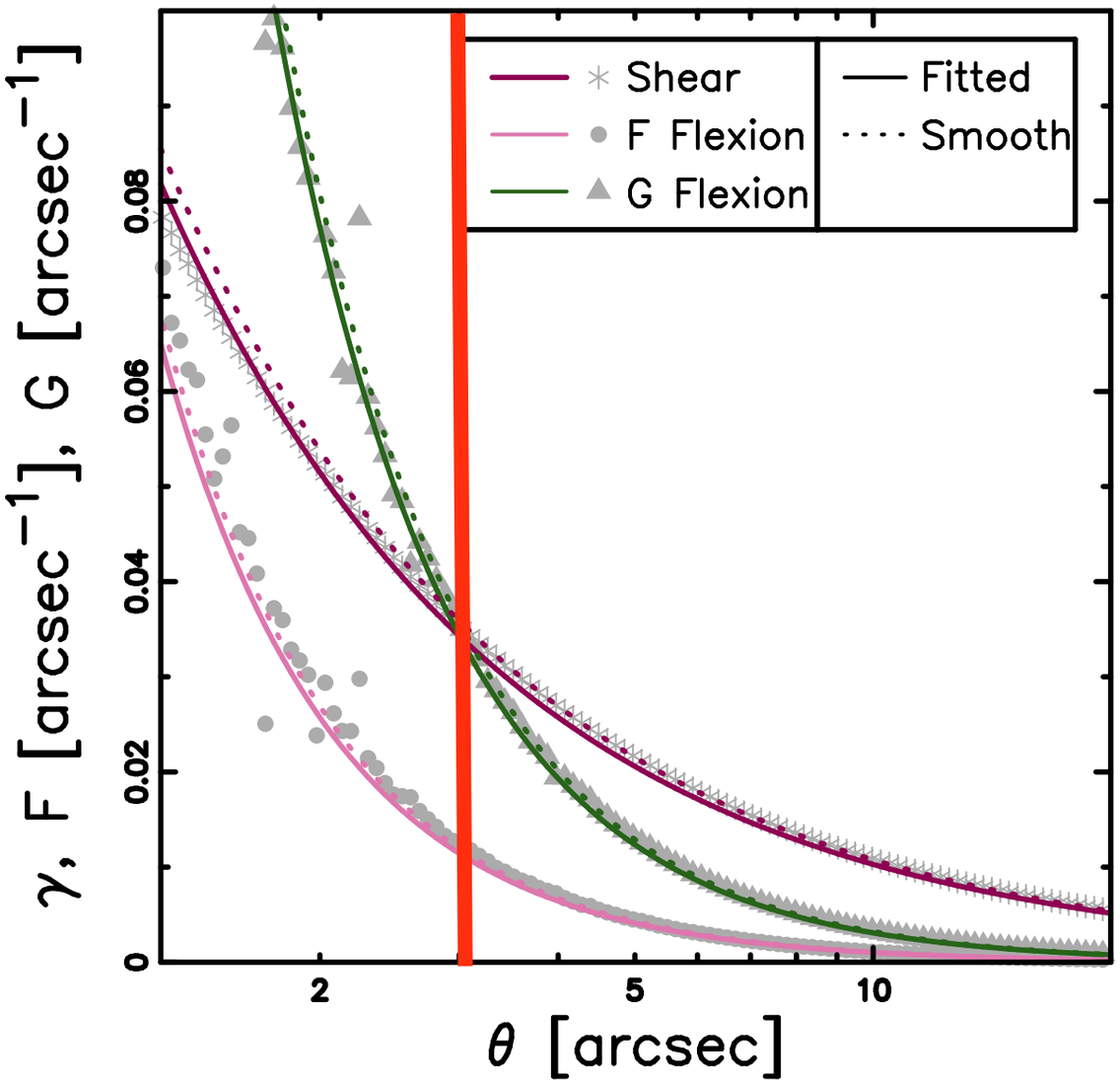
$$g = g_1 + \mathrm{i} g_2 = \frac{q_{111} - 3q_{122} + \mathrm{i}(3q_{112} - q_{222})}{q_{1111} + 2q_{1122} + q_{2222}}$$

Okura et al 2007; Rowe et al 2012

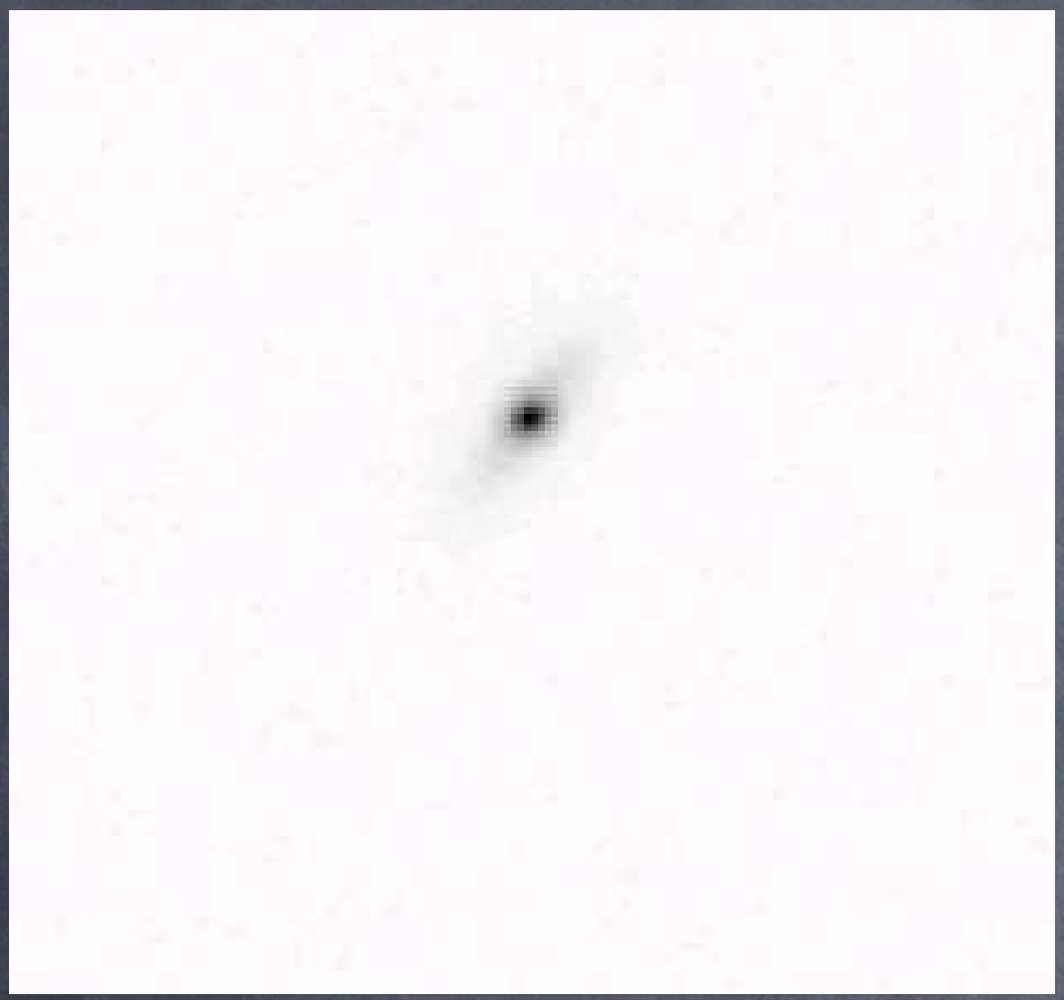
Rowe et al 2012

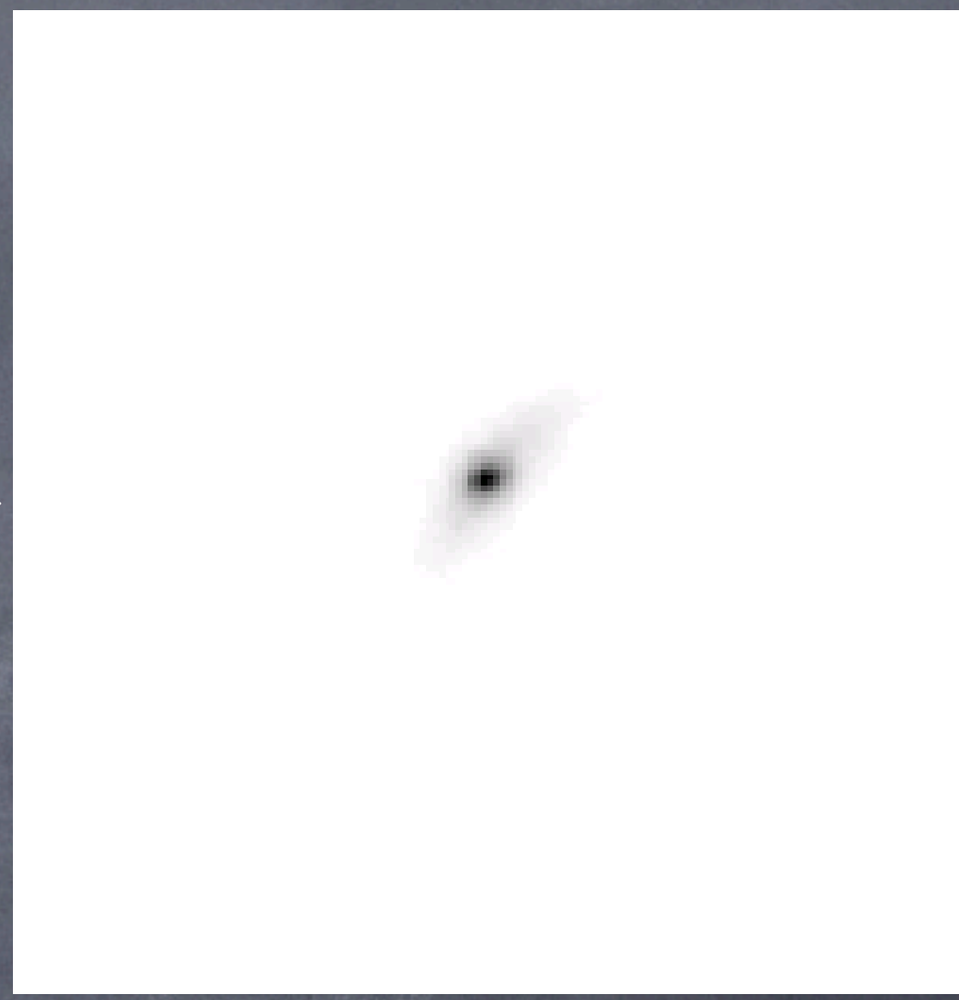






Velander et al 2011





F=0.009-i0.002;G=0.001+i0.014

Next Step

- We have to figure our a new high moment measurement method, because a gaussian adaptive moment can weight out flexion information
- Various systematics: PSF, Poisson noise, light from central galaxy... ...

Conclusion

- Accurate image processing are needed to constraints the systematics under 1% which is comparable to the statistical error for LSST
- Group-galaxy lensing study preliminary results shows that the most massive galaxies are closer to the real potential center
- Moderate flexion can be a powerful tool to study substructures and complementary to g-g lensing shear

Thank you!