Maximum Likelihood model fitting approach to shape measurement - statistical model and calibration perspectives

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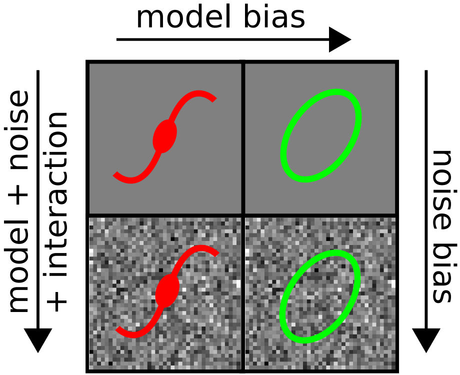
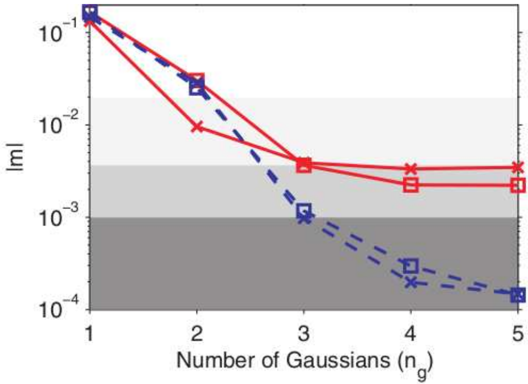
Model fitting - statistical model

- Model bias
  Voigt and Bridle 2010, Bernstein 2011, Voigt et al. 2013, in prep.
- Noise bias
  Refregier et al. 2012, Kacprzak et al. 2012
- Noise and model bias interaction
  Kacprzak et al 2013, in prep.



- Using Maximum Likelihood model fitting with Im3shape (Zuntz et al. 2013)
  `bitbucket.org/joezuntz/im3shape`
- Using galaxy model: Bulge (Sersic index 4) + Disc (Sersic index 1)
- Shear bias is usually parameterised with multiplicative and additive components: $\hat{g} = mg^{true} + c$
- Additive components usually scale with the PSF ellipticity
- Requirements for DES 1st year data: $m < 0.02$, $c < 0.001$
- g - galaxy shear, e - galaxy intrinsic ellipticity (in units of shear)

Model bias



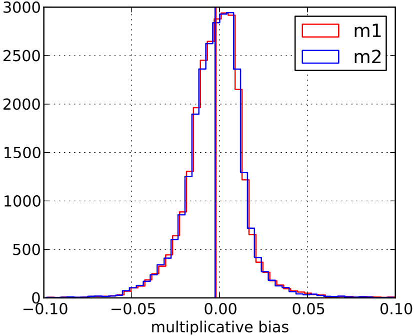
true galaxy Bulge and Disc have the same ellipticity

true galaxy Bulge and Disc have different ellipticities

fitted model had elliptical isophotes

Voigt Bridle 2010

Model bias



using 26000 galaxies from COSMOS, reconvolution using GalSim

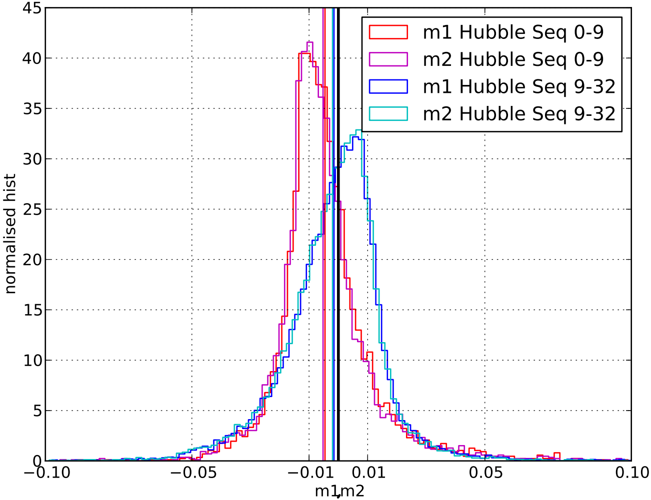
`github.com/GalSim-developers/GalSim`

m_1 : mean -0.0020 ± 0.0001 , std 0.0168

m_2 : mean -0.0025 ± 0.0001 , std 0.0166

Voigt et al. 2013, in prep.

Model bias



m1 Hubble Seq 0-9
m2 Hubble Seq 0-9
m1 Hubble Seq 9-32
m2 Hubble Seq 9-32
normalised hist
m1,m2
45
40
35
30
25
20
15
10
5
0
−0.10
−0.05
−0.01
0.01
0.05
0.10

Noise biases

Bias of the maximum likelihood estimator in presence of Gaussian noise

$$\langle a_i^{(2)} \rangle = \frac{1}{2}\sigma^2_{noise} F^{-1}_{ik} F^{-1}_{lj} D^{(1)}_{kp} D^{(2)}_{ljp}$$

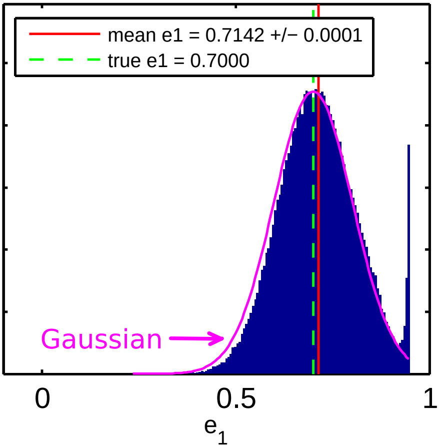
Where

$$D^{(1)}_{ip} := \frac{\partial f_p(\mathbf{a}^t)}{\partial a_i} \qquad D^{(2)}_{ijp} := \frac{\partial^2 f_p(\mathbf{a}^t)}{\partial a_i \partial a_j} \qquad F_{ij} := \frac{\partial f_p(\mathbf{a}^t)}{\partial a_i}\frac{\partial f_p(\mathbf{a}^t)}{\partial a_j} = D^{(1)}_{ip} D^{(1)}_{jp}$$

p - pixel index $\qquad i, j, k, l$ - model parameter indices

Refregier et al. 2012

Histograms of measured e_1

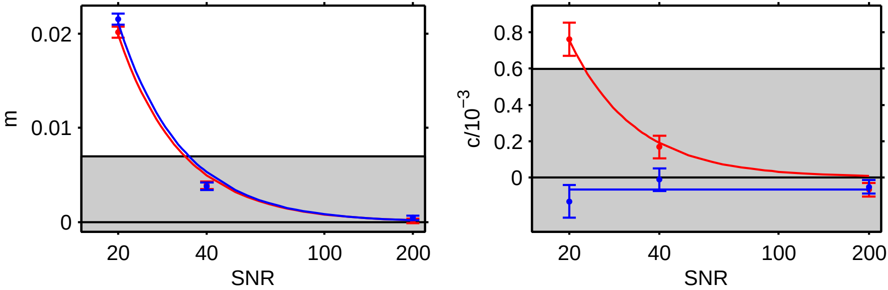


true model is a member of the fitted model

SNR=20

Kacprzak et al. 2012

Bias on the shear vs SNR



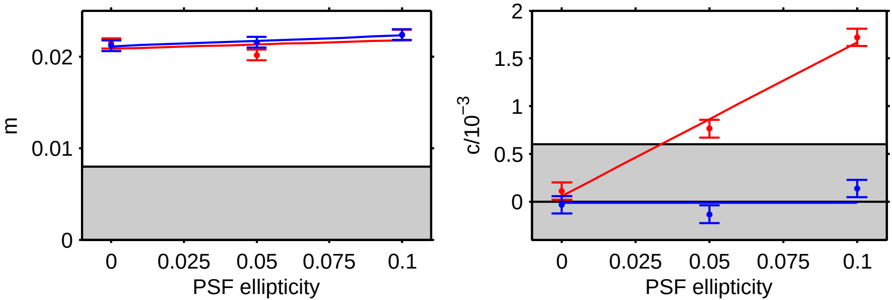
red : m_1 / c_1 , blue : m_2 / c_2

PSF ellipticity $e_1 = 0.05$, $e_2 = 0$

true model is a member of the fitted model

Kacprzak et al. 2012

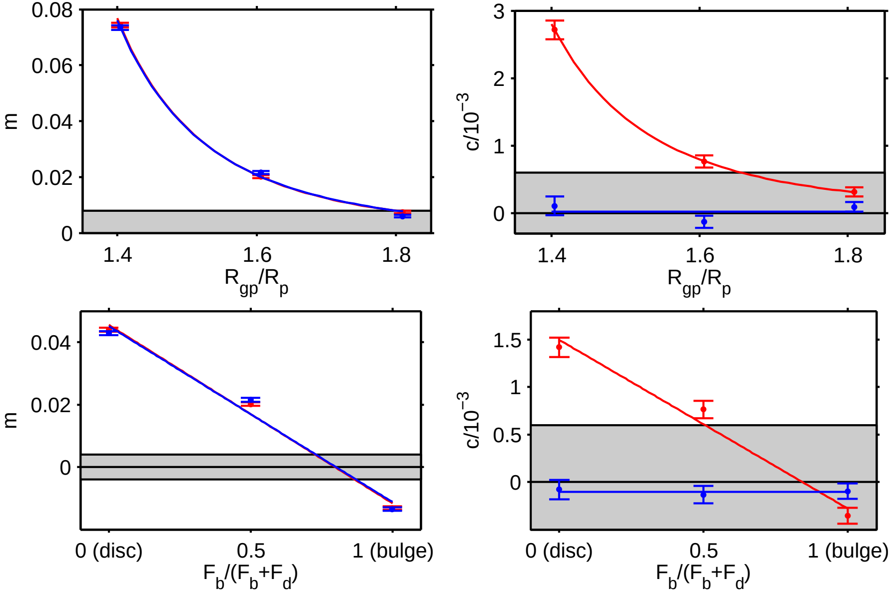
Bias on the shear vs PSF ellipticity



red : m_1 / c_1 , blue : m_2 / c_2

PSF ellipticity $e_2 = 0$

Bias on the shear vs galaxy size



Noise bias calibration schemes

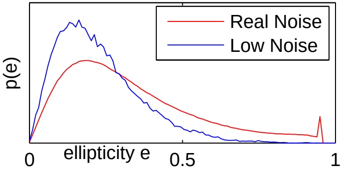
Created ellipticity bias model **ellip_bias_func**$(e^{true}, \theta^{true})$, a function of *true* ellipticity e^{true}, and other parameters θ^{true} : size, SNR, bulge-disc-flux-ratio

Galaxy-by-galaxy calibration scheme:

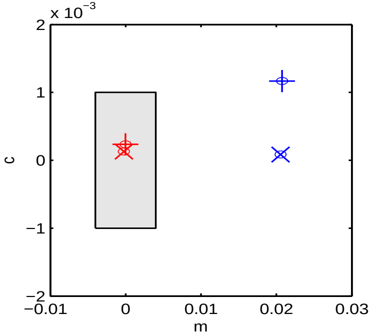
$$g^{calib} = \langle \hat{e} \rangle - \int \textbf{ellip\_bias\_fun}(\hat{e}, \hat{\theta}) \; p(\hat{e}, \hat{\theta} | e^{true}, \theta^{true}) p(e^{true}, \theta^{true}) \; d\hat{e} \; d\hat{\theta}$$

Calibration scheme using Low Noise (LN) data:

$$g^{calib} = \langle \hat{e} \rangle - \int \textbf{ellip\_bias\_fun}(e^{LN}, \theta^{LN}) \; p(e^{LN}, \theta^{LN}) \; de^{LN} \; d\theta^{LN}$$



Noise bias calibration - result



blue: before calibration , red: after calibration

$+$ (plus) : g_1 , x (cross) : g_2

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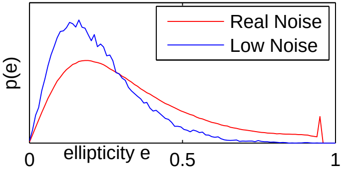
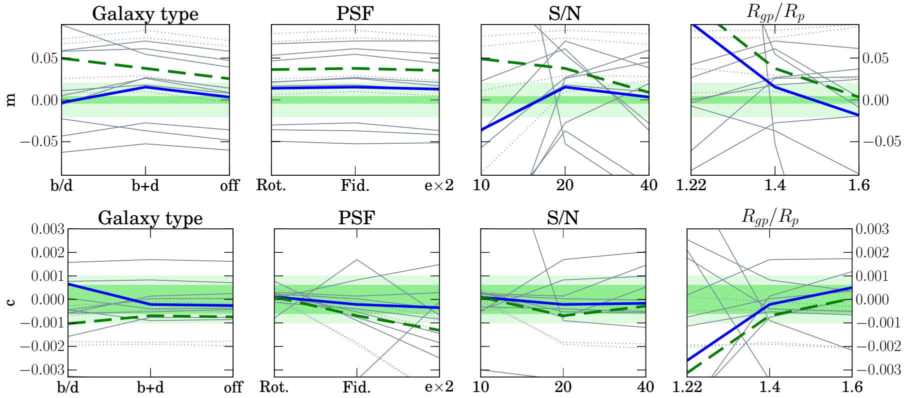
Calibration scheme using Low Noise (LN) data:

$$g^{calib} = \langle \hat{e} \rangle - \int \textbf{ellip\_bias\_fun}(e^{LN}, \theta^{LN}) \; p(e^{LN}, \theta^{LN}) \, de^{LN} \, d\theta^{LN}$$



GREAT08 results



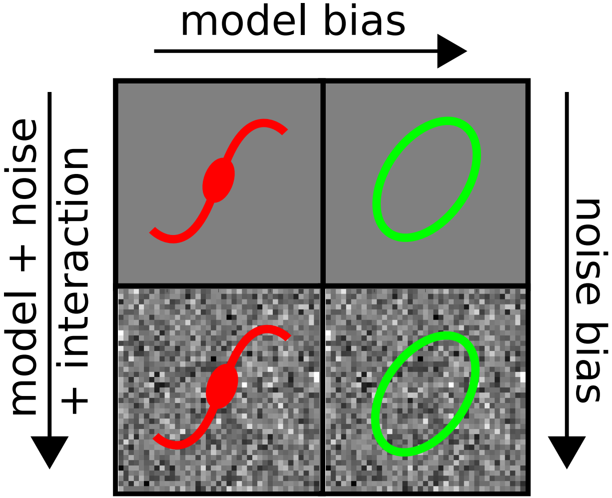
error on points above $\mathbf{std}(m) = 0.004$ $\mathbf{std}(c) = 0.0001$

green dashed - before calibration

blue solid - after calibration

Zuntz et al. 2013

Noise and model bias interaction



Kacprzak et al. 2013, in prep

Noise and model bias interaction

- Is Sersic a good enough representation of real galaxies to make accurate calibration simulations?
- Can we separate model and noise bias calibration?
- Can we use distributions of Sersic parameters to validate that our calibration pipeline is robust?

Noise and model bias interaction

Expansion around best fit parameters $\mathbf{a}^t$

use residual image $r_p := g_p - f_p(\mathbf{a}^t)$ (real galaxy image - best fit model image)

$$\langle a_i^{(2)} \rangle = \sigma_n^2 \tilde{F}_{ik}^{-1} [\tilde{F}_{lj}^{-1} D_{jp}^{(1)} D_{lkp}^{(2)} - \tilde{F}_{lj}^{-1} F_{lj} \tilde{F}_{lj}^{-1} D_{jp}^{(1)} D_{lkp}^{(2)} + \frac{1}{2} \tilde{F}_{lj}^{-1} F_{lj} \tilde{F}_{lj}^{-1} D_{ljkp}^{(3)} r_p - \frac{1}{2} \tilde{F}_{lj}^{-1} F_{lj} \tilde{F}_{lj}^{-1} D_{kp}^{(1)} D_{ljp}^{(2)}]$$

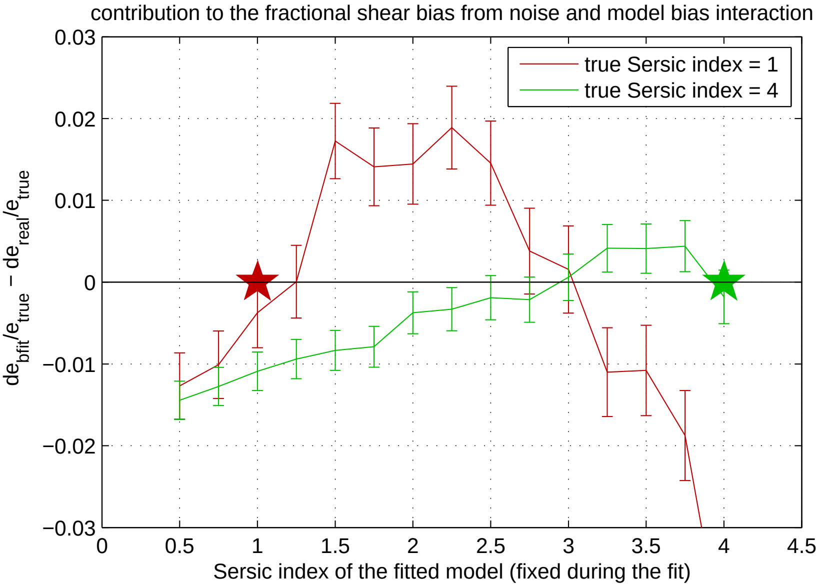
where

$$D_{ip}^{(1)} := \frac{\partial f_p(\mathbf{a}^t)}{\partial a_i} \qquad D_{ijp}^{(2)} := \frac{\partial^2 f_p(\mathbf{a}^t)}{\partial a_i \partial a_j} \qquad D_{ijkp}^{(3)} := \frac{\partial^3 f_p(\mathbf{a}^t)}{\partial a_i \partial a_j \partial a_k}$$

$$F_{ij} := \frac{\partial f_p(\mathbf{a}^t)}{\partial a_i} \frac{\partial f_p(\mathbf{a}^t)}{\partial a_j} = D_{ip}^{(1)} D_{jp}^{(1)} \qquad \tilde{F}_{ik} := F_{ik} - r_p D_{ikp}^{(2)}$$

p - pixel index $\qquad i, j, k, l$ - model parameter indices

Toy model



contribution to the fractional shear bias from noise and model bias interaction
true Sersic index = 1
true Sersic index = 4
0.03
0.02
0.01
0
−0.01
−0.02
−0.03
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
$de_{bfit}/e_{true} - de_{real}/e_{true}$
Sersic index of the fitted model (fixed during the fit)

Summary

- Model fitting is a promising and well understood approach to measuring shear
- It requires careful calibration using low noise data
- Calibration sample has to represent the survey sample well
- Effort to create low bias, robust methods is crucial, so the calibrations can be as small as possible
- Is noise and model bias interaction significant for real data? Work in progress.