Cosmic Shear Challenges

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Finding the ellipticity of lots and lots of very small, very blurry, very noisy, objects that are hopefully galaxies with essentially zero bias

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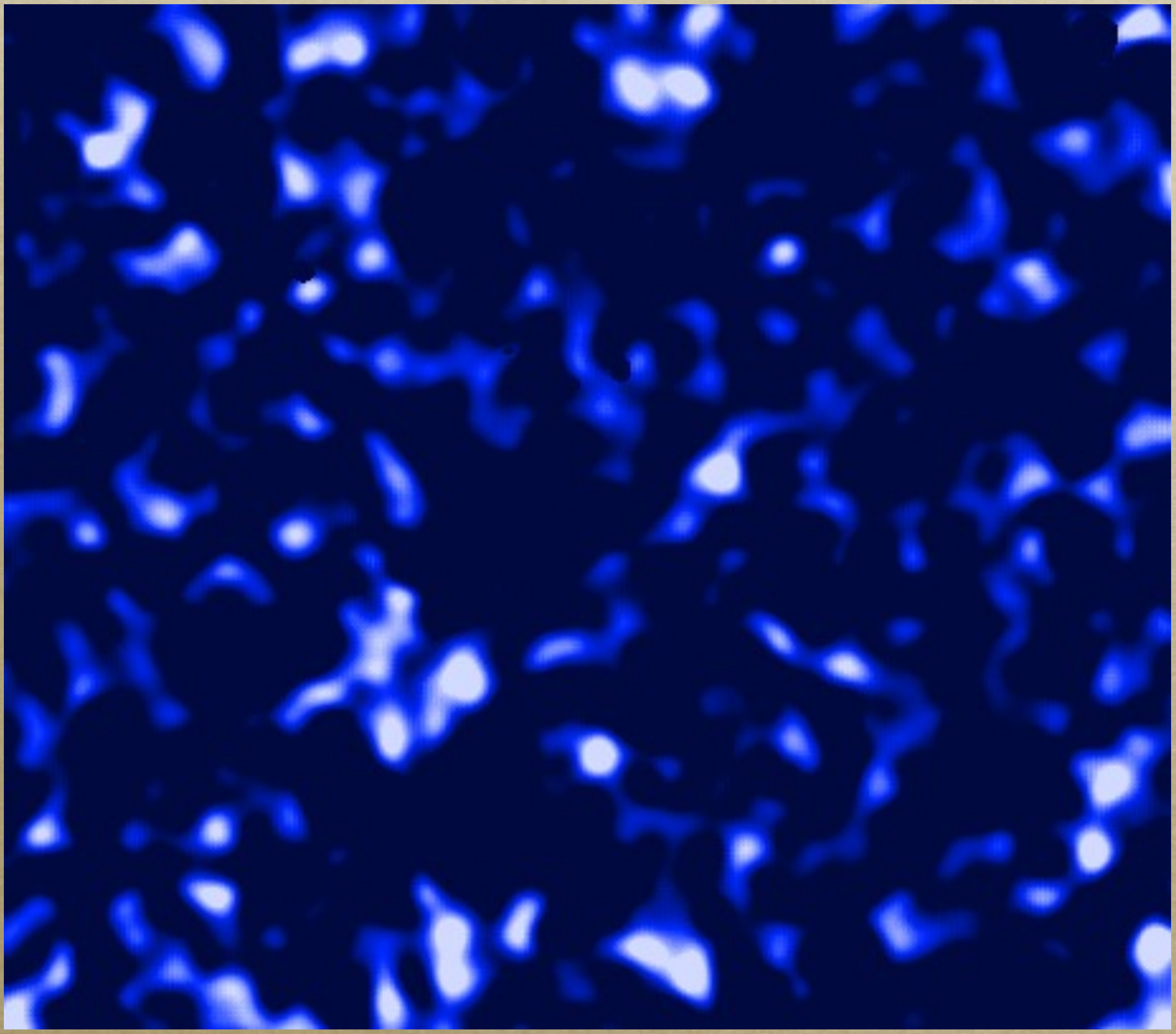
Overview

- The physics and cosmology of cosmic shear
- Why measuring shear is very hard
- Our model-fitting approach
- Challenges to model-fitters

The science goal

- *Percent-level measurements of $w(z)$ and modified-gravity measurements*
- *From structure growth and geometric distance*

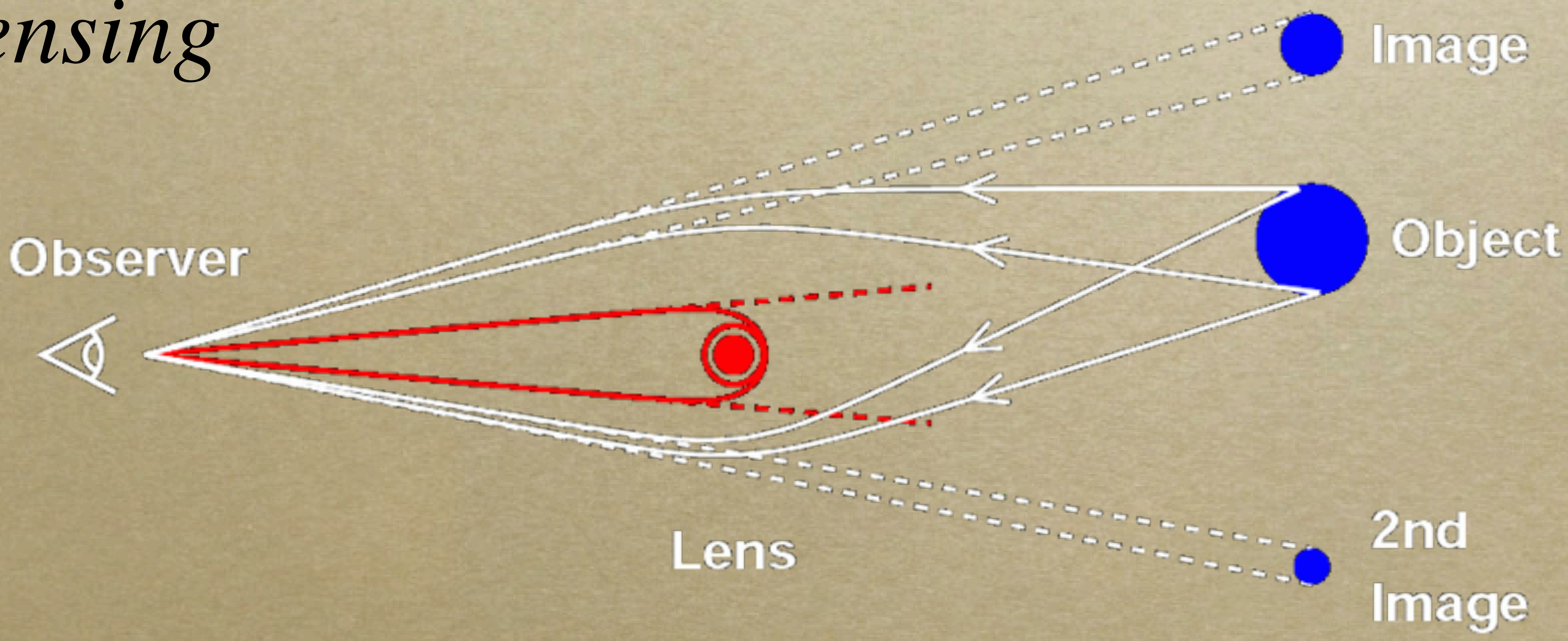
A Map of the Dark Universe



CFHTLenS: Heymans et al

The physics of lensing

- *Everyone familiar with single object lensing*



The physics of lensing

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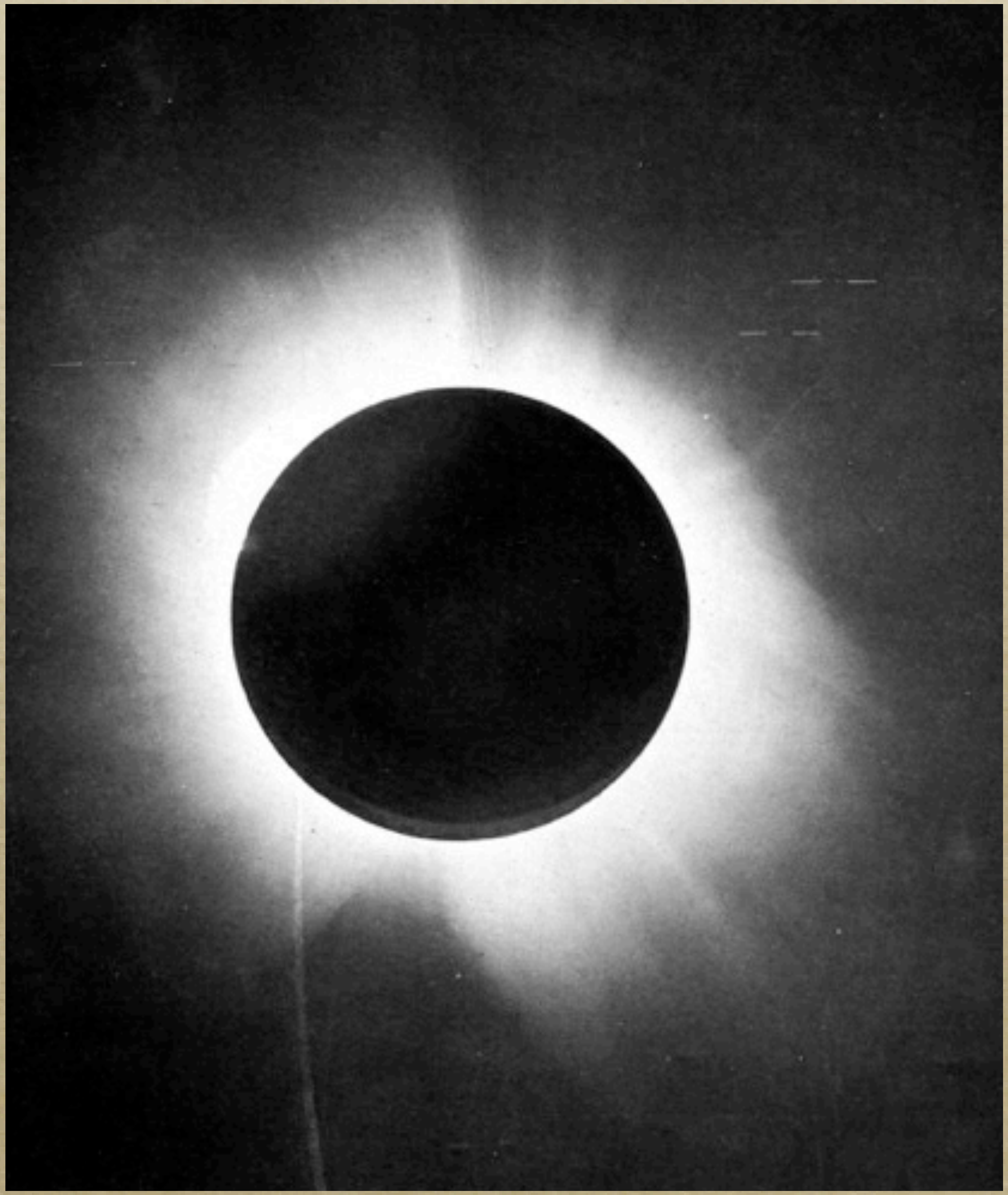

The physics of lensing

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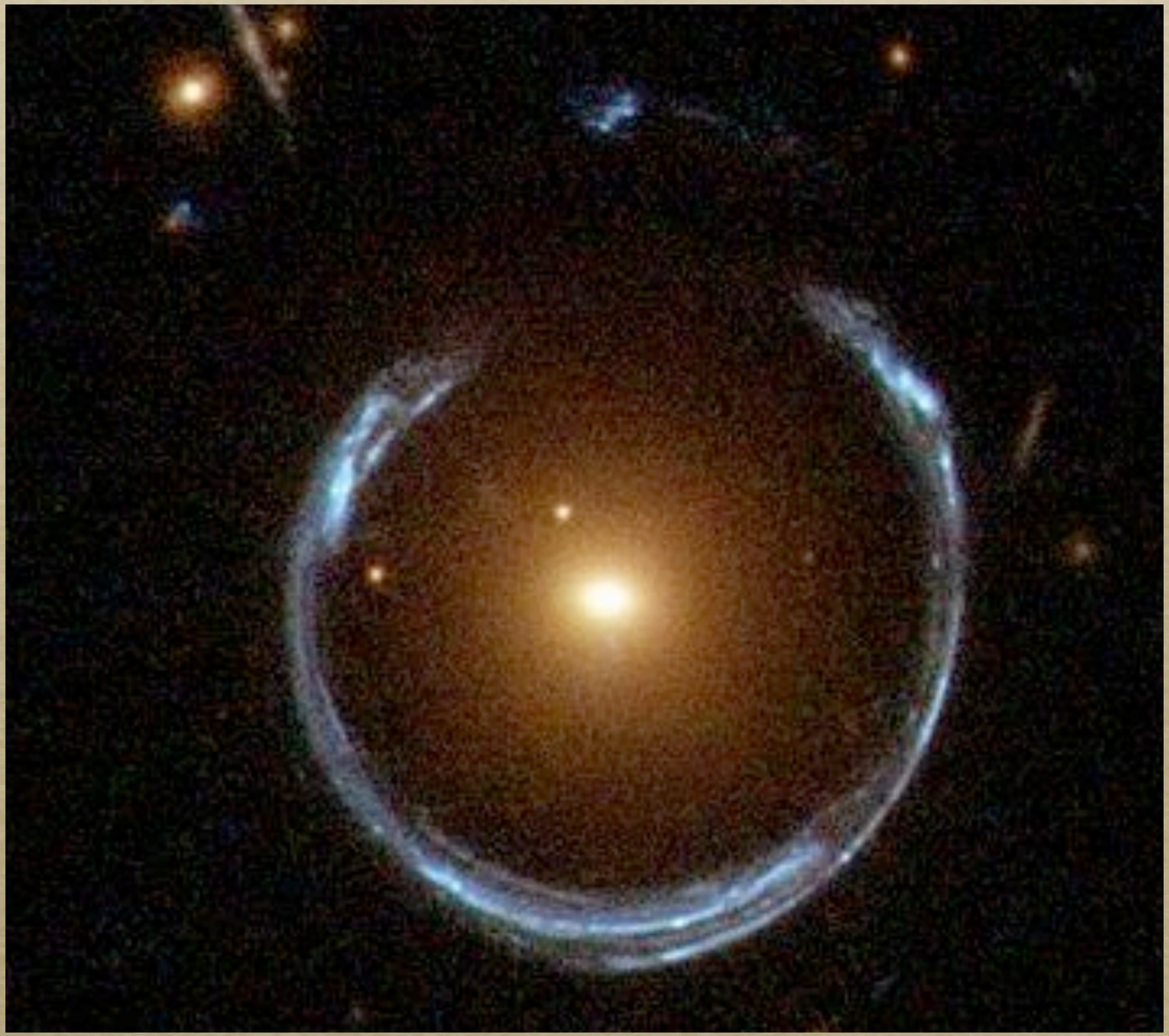
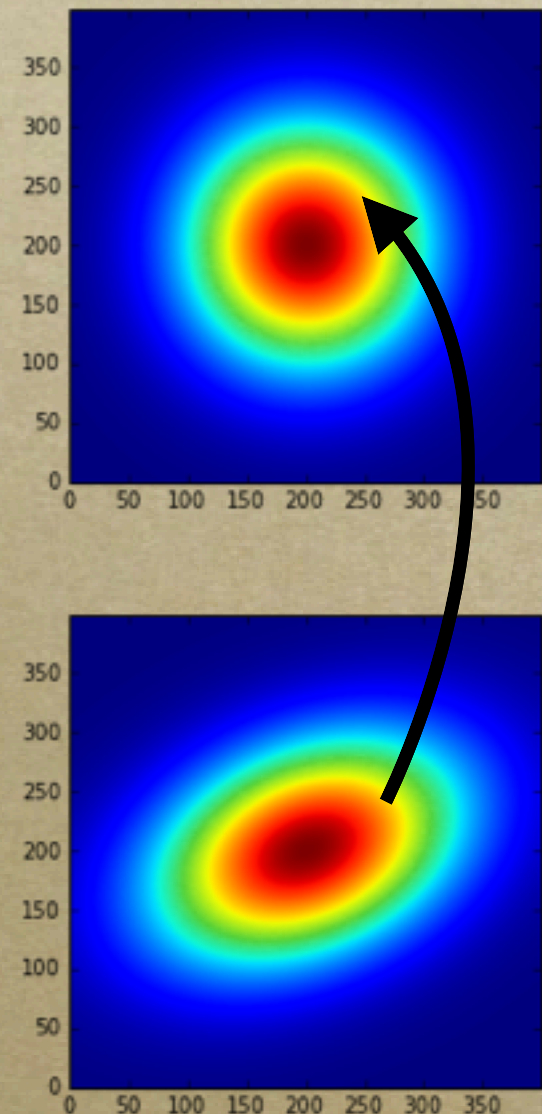


The physics of lensing

source
*s(**θ**)*

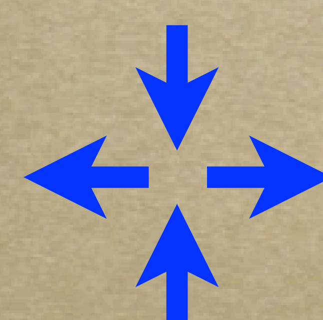
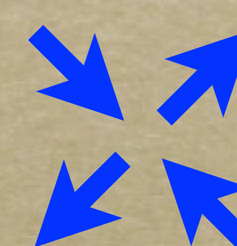
image
*f(**θ**)*



$$f(\theta_i) = s(A_{ij}\theta_j)$$

$$A = \delta_{ij} - \frac{\partial^2 \Psi}{\partial\theta_i \partial\theta_j}$$

$$= \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

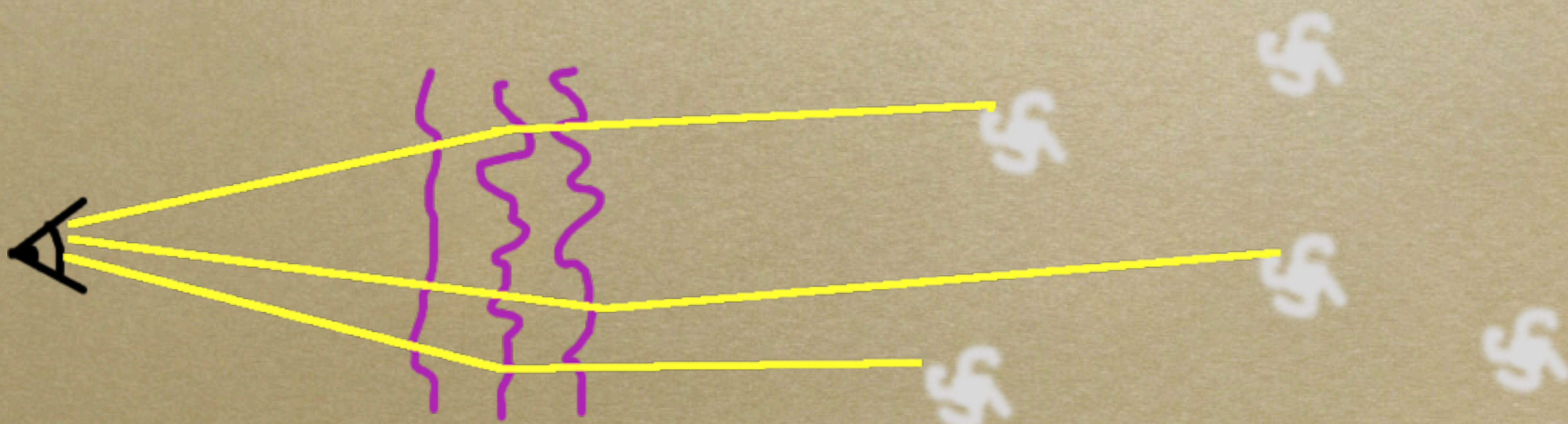
γ_1   γ_2

- *see Hoekstra & Jain for introduction*

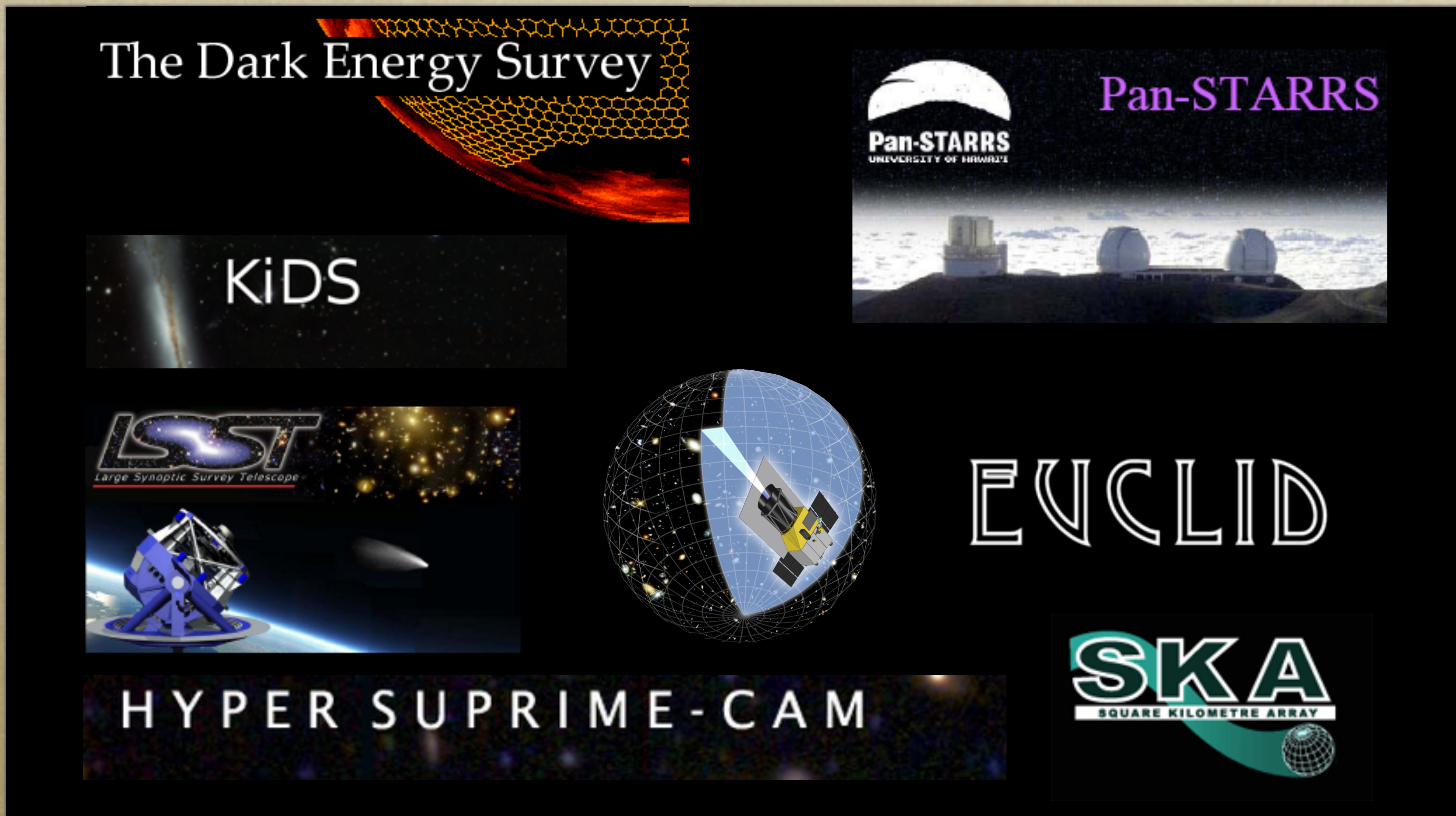
The cosmology of lensing

$$\frac{1}{2}k^2\Psi = \int_0^\infty \mathrm{d}\chi \; W(\chi) P(\chi, \chi\theta)$$

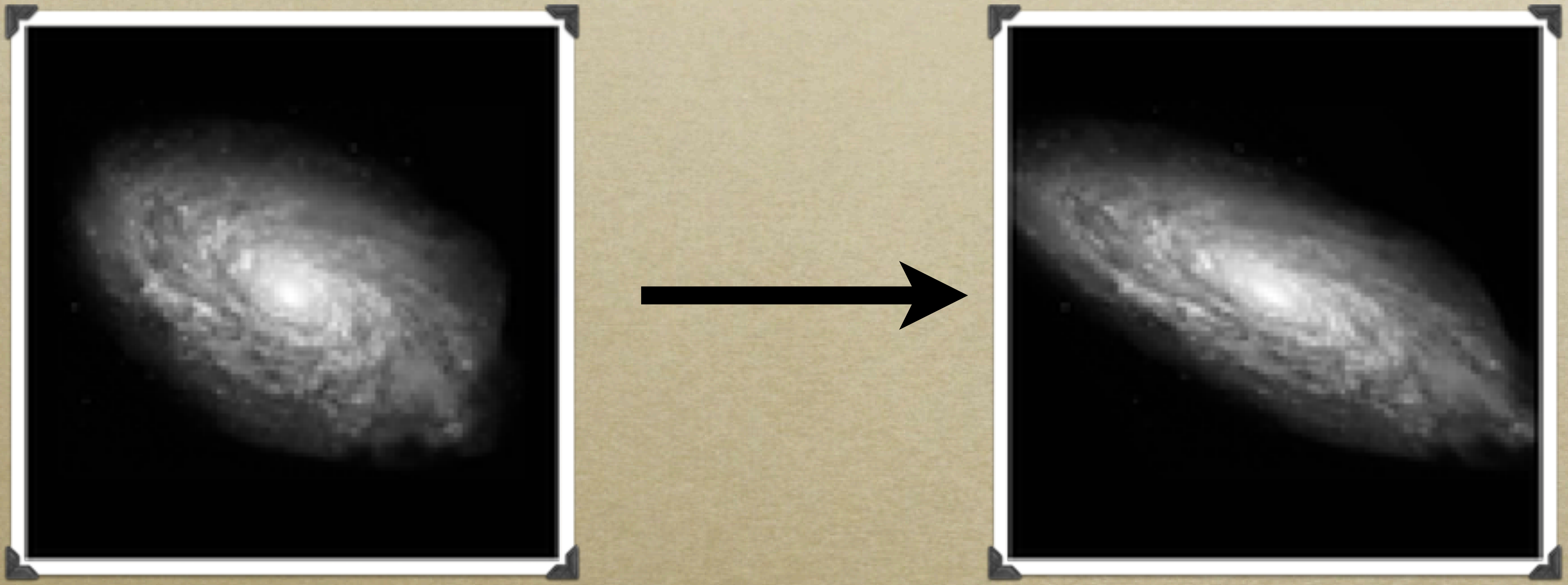
$$W(\chi) = \frac{3}{2}\Omega_m H_0^2 \chi a^{-1} \int_\chi^\infty \mathrm{d}\chi_s \; n(\chi_s) \; \frac{\chi_s - \chi}{\chi_s}$$



The cosmology of lensing



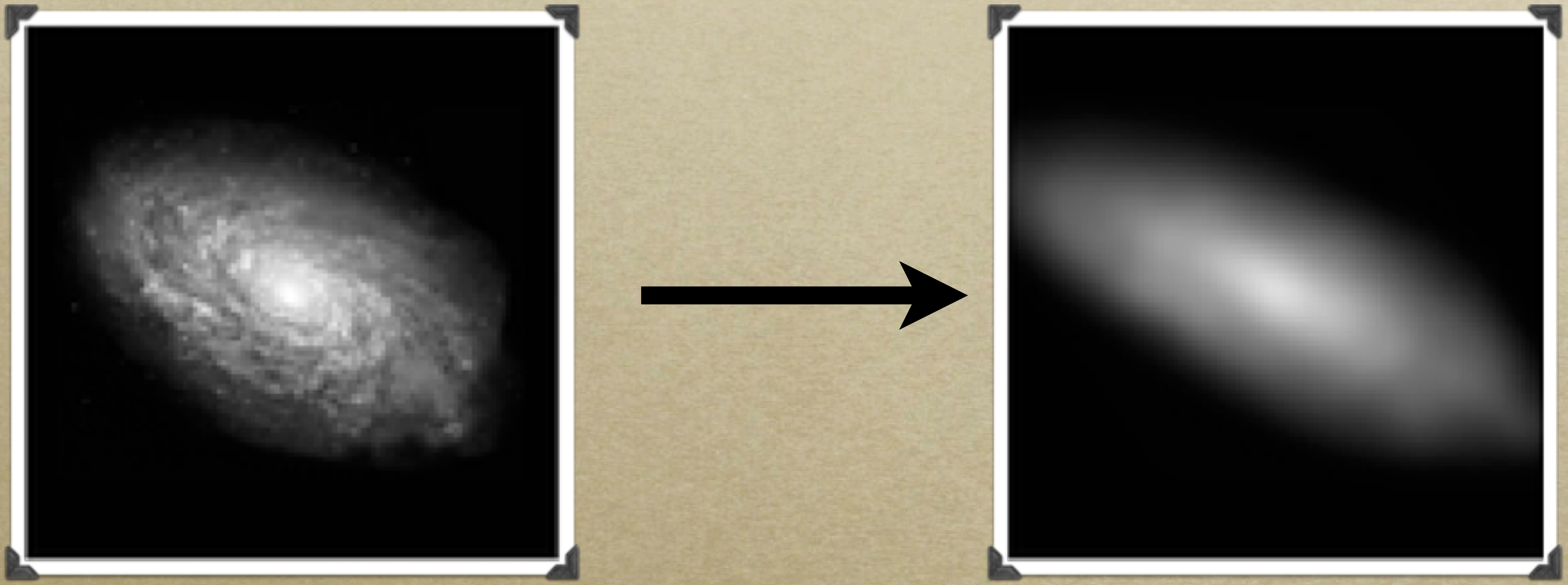
Measuring Shear



Shear

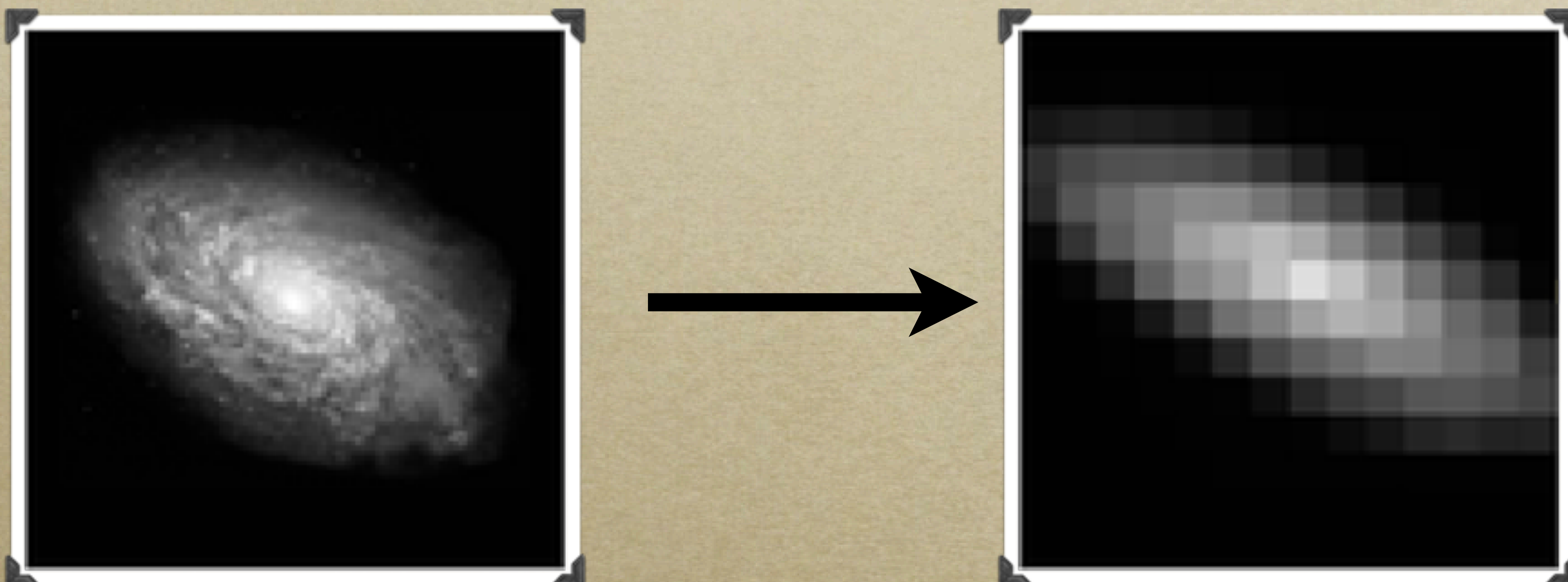
Images: Bridle et al 2008

Measuring Shear



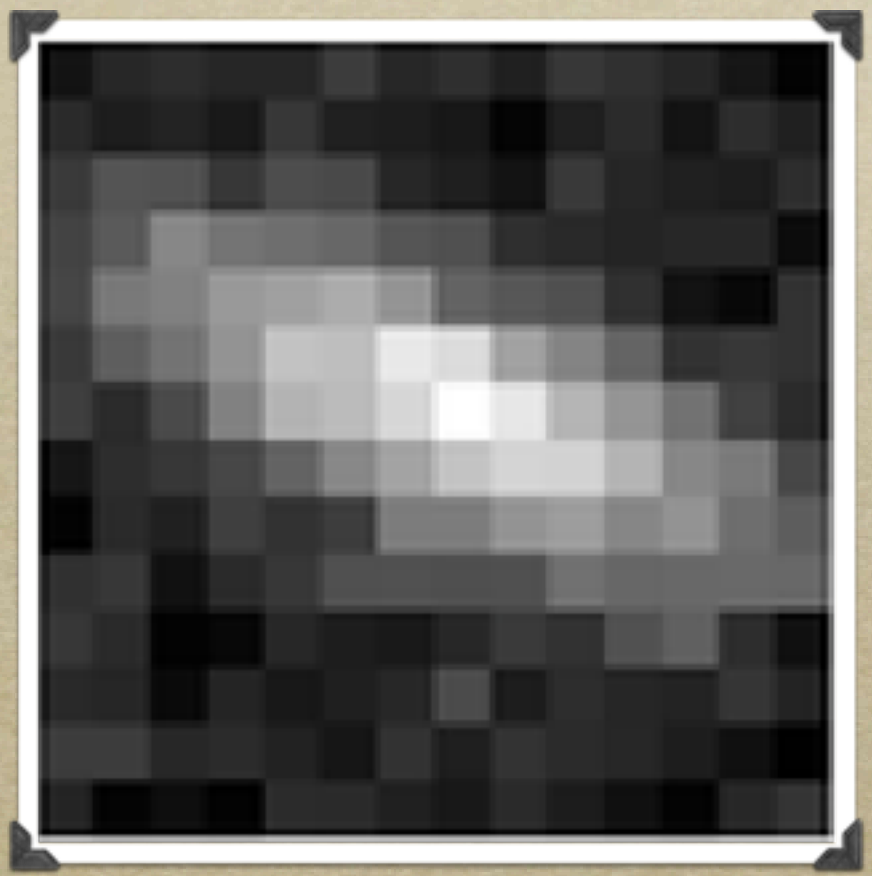
Shear + ***Point-spread***

Measuring Shear



*Shear + point-spread + **pixelization***

Measuring Shear



Shear + point-spread + pixelization + ***noise***

Requirements

- *How well do we have to do this? Taylor expand our estimates:*

$$\hat{\gamma}_i \approx (1 + m_i)\gamma_i + c_i$$

- *Then we require for upcoming experiments:*

$$m_i < 4 \cdot 10^{-3}$$

$$c_i < 6 \cdot 10^{-4}$$

Some approaches

- *Estimators - quadrupole moments, KSB*
- *Shapelets and other simple fits*
- *Other methods*
- *Modelling methods*

Modelling Galaxies

- *Forward modelling methods: fit parameters (including ellipticity)*
- *A maxim:*
  "Don't model your data. Model the process that led to your data"

Basic Galaxy Model

Basic Galaxy Model

Exponential Disc

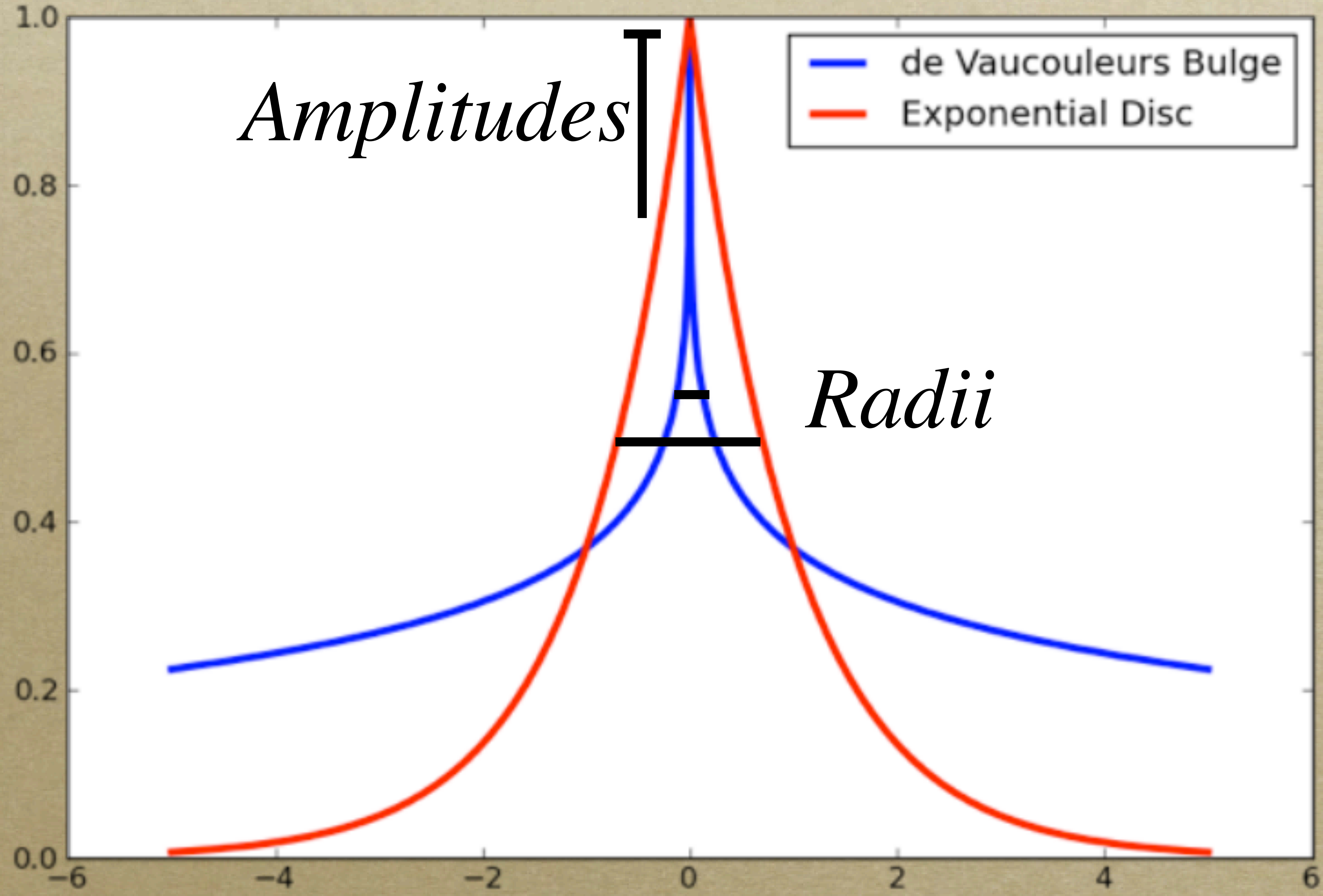
$$\exp - \left(x^T M x\right)^{\frac{1}{2}}$$

Basic Galaxy Model

De Vaucouleurs Bulge

$$\exp - \left(x^T M x\right)^{\frac{1}{8}}$$

Basic Galaxy Model



Basic Galaxy Model

Parameter	Meaning	Fixed
x_0	Horizontal centroid	
y_0	Vertical centroid	
e_1	x-y shear	
e_2	45° shear	
r_d	Disc half-light radius	
A_b	Bulge peak flux	
A_d	Disc peak flux	
R_r	Bulge-disc size ratio	✓
n_d	Disc Sérsic index	✓
n_b	Bulge Sérsic index	✓
Δe	Bulge-disc ellipticity	✓
$\Delta\theta$	Bulge-disc angle	✓

Im3Shape

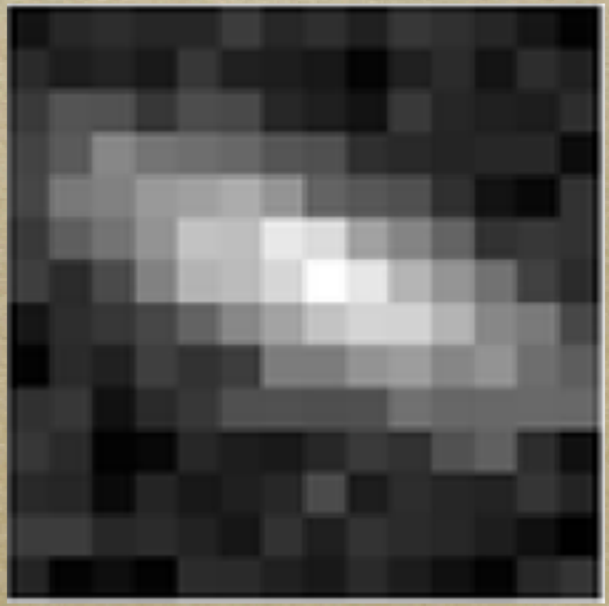
- *Reimagining of Bridle im2shape code*
- *Forward-model ML method*
- *Optimized but pleasant C code*
- *Flexible: Very easy to add components*

Known Biases

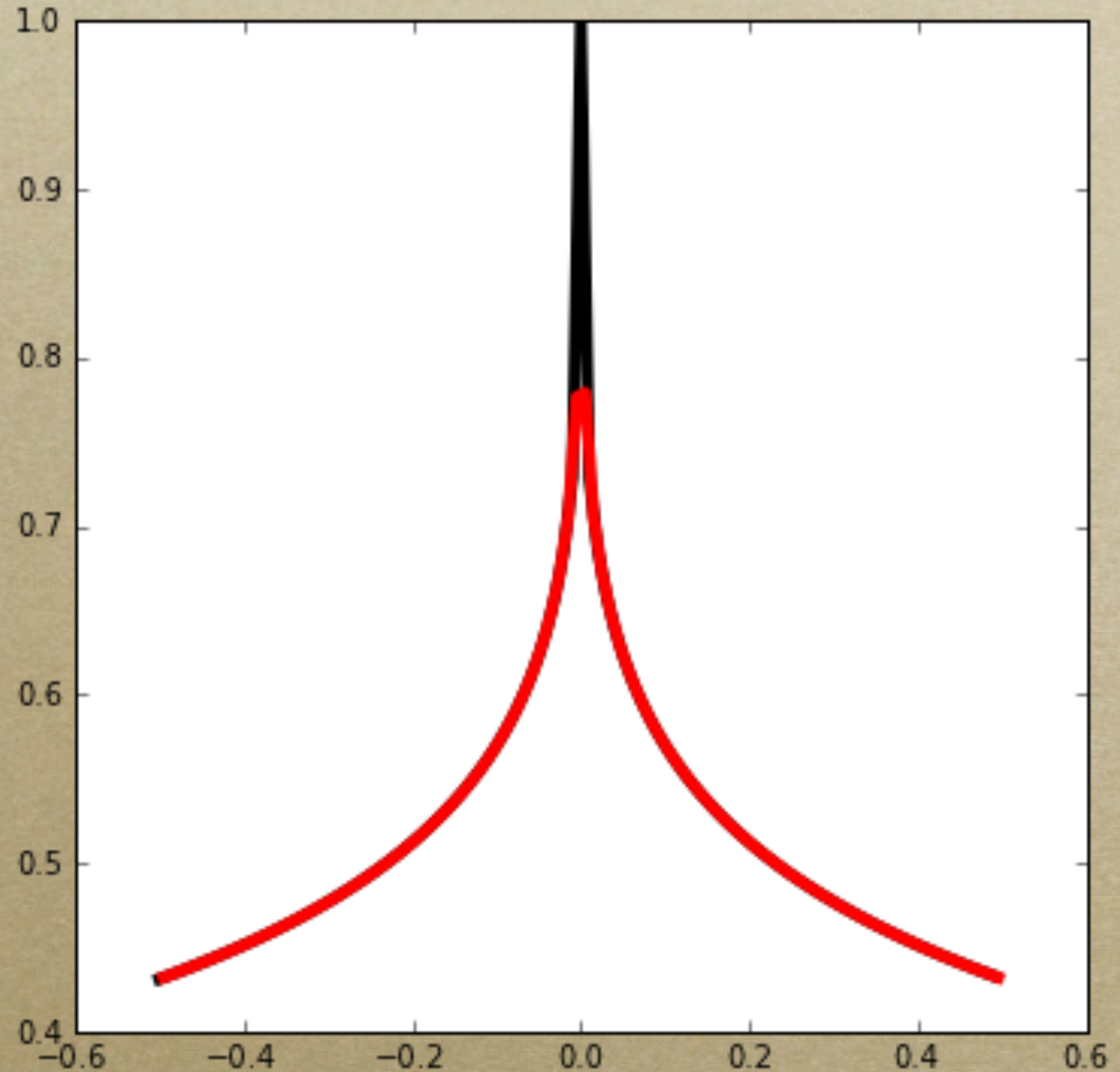
- *Resolution bias*
- *Model bias*
- *Noise bias*

Resolution Bias

- *True model has infinite resolution*
- *Matter most for sharp bulges*
- *Central pixel double upsampling*

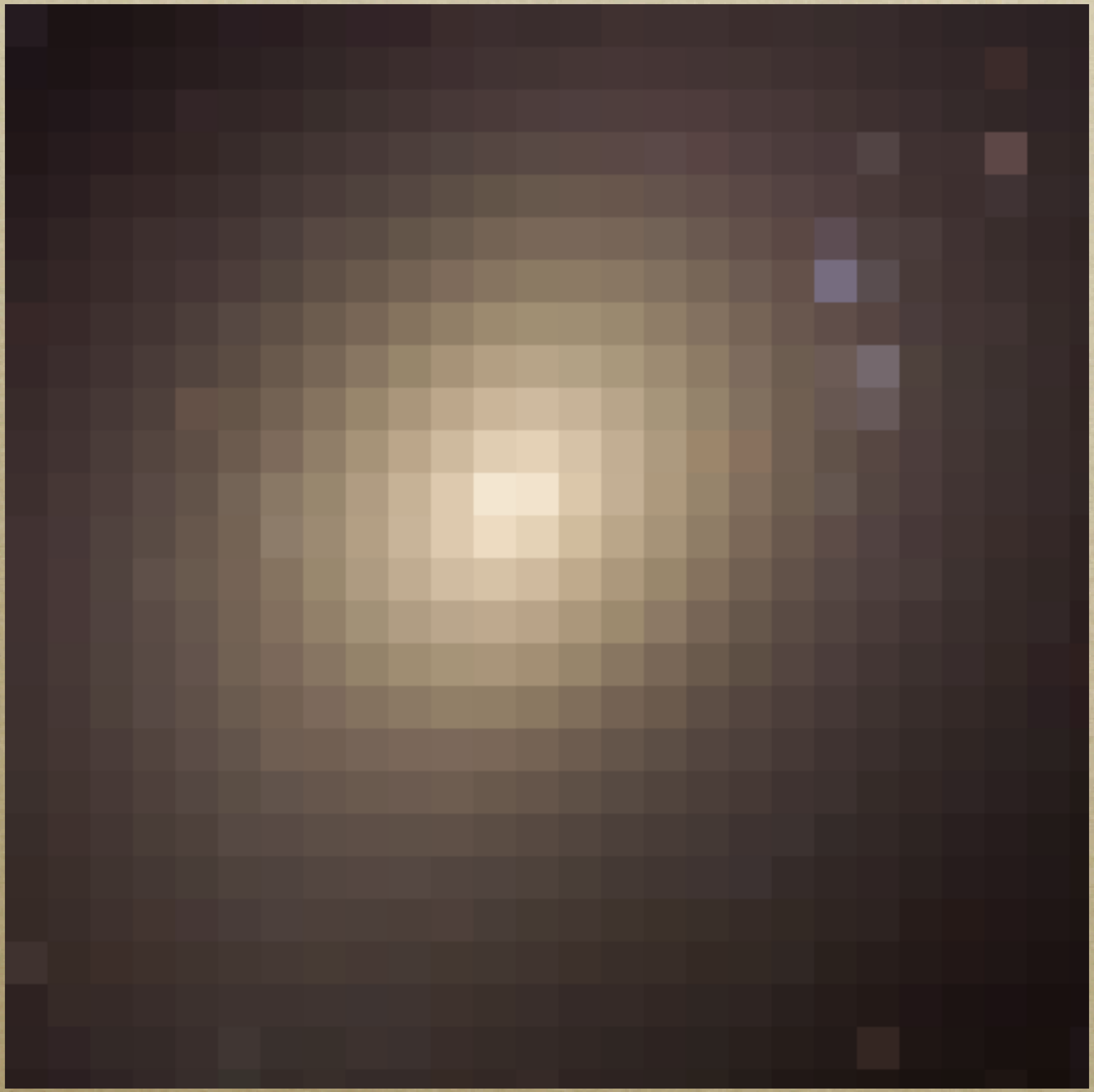


Resolution Bias: Sharp Centers

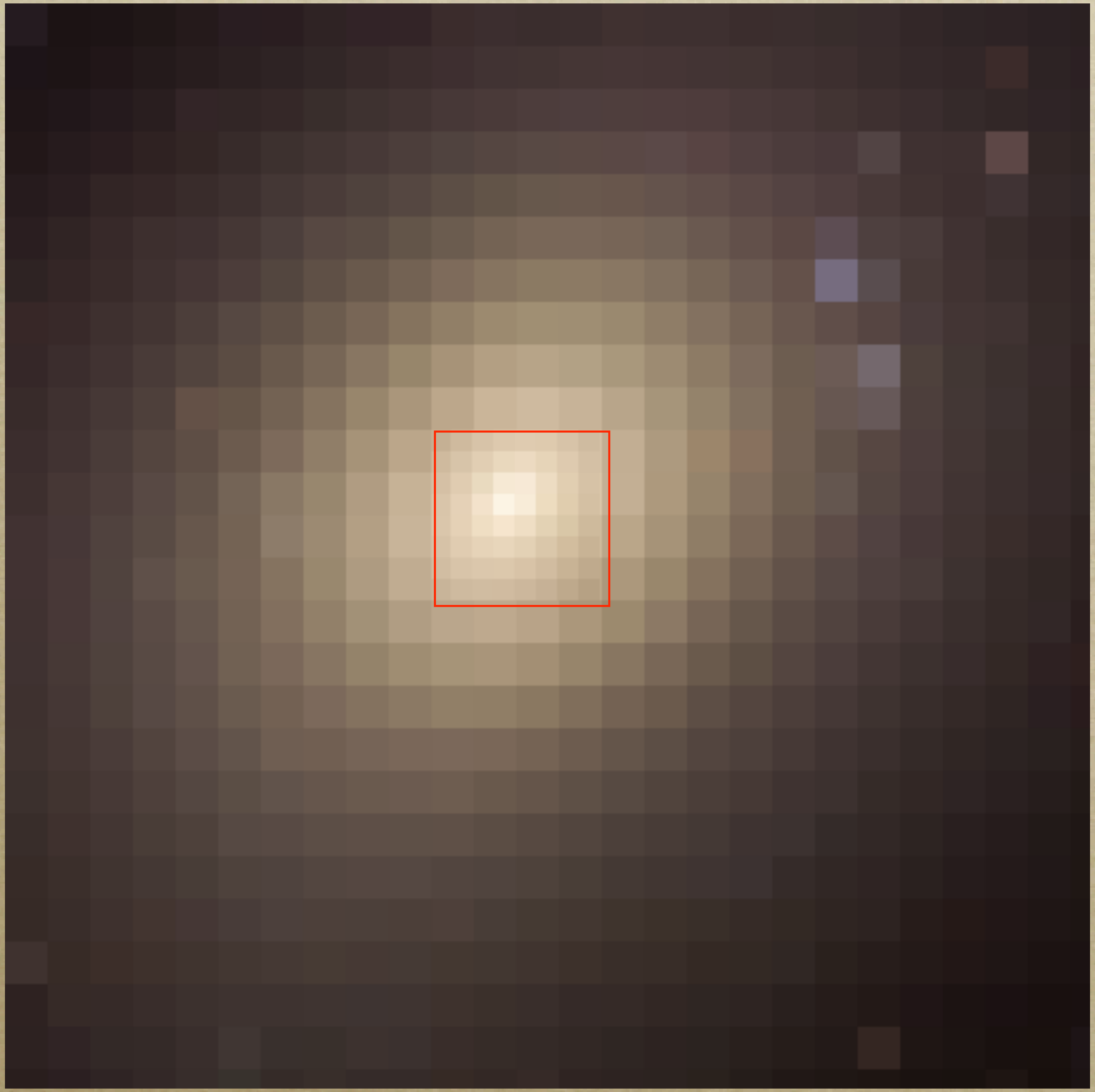


Central Pixel Upsampling

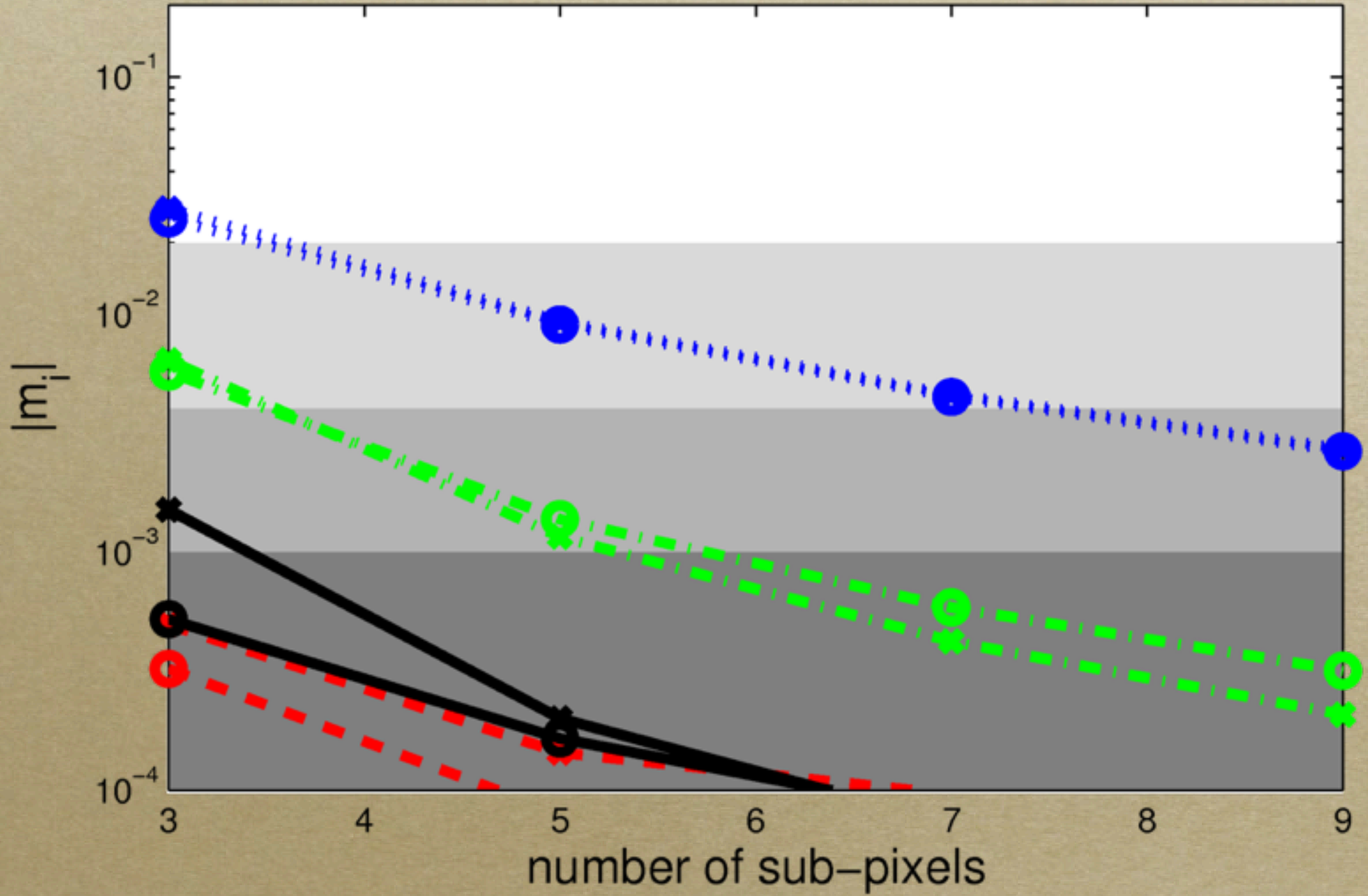
Central Pixel Upsampling



Central Pixel Upsampling



How much area is higher res?



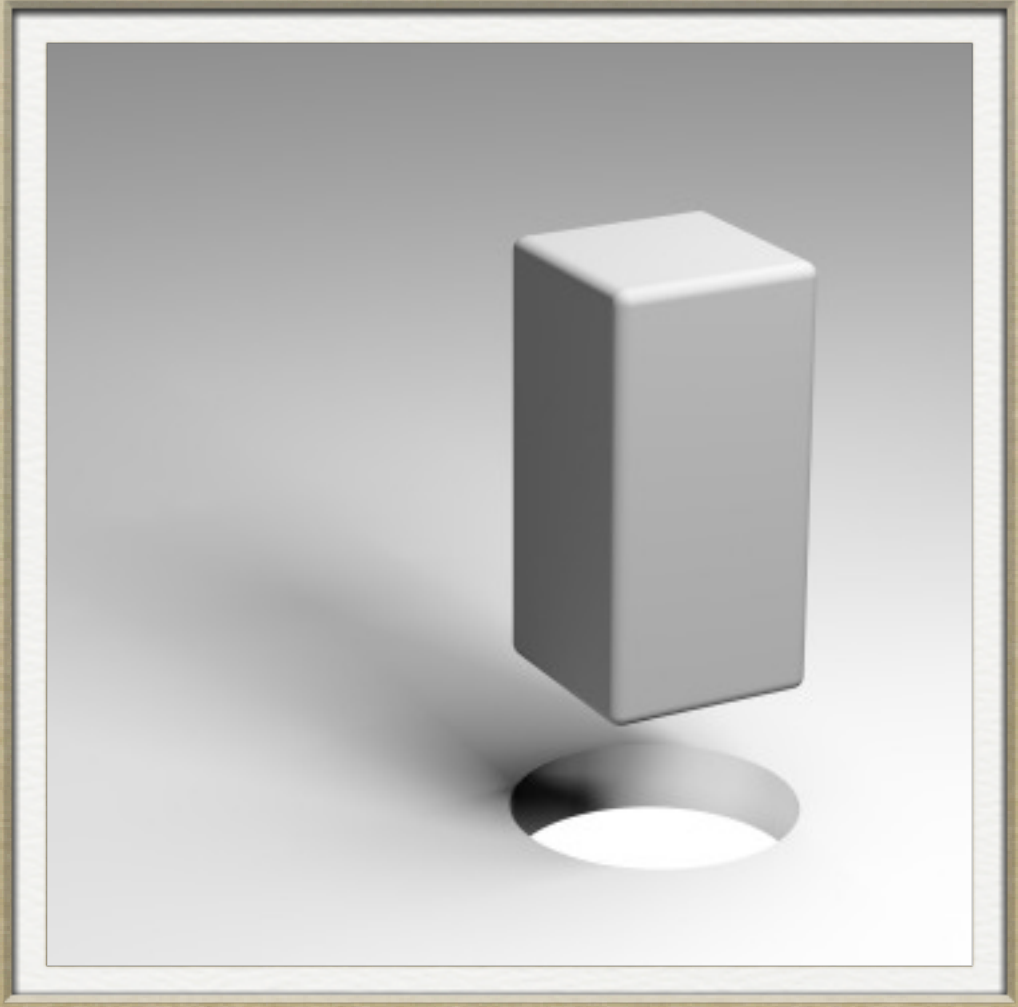
High-res area

1x1

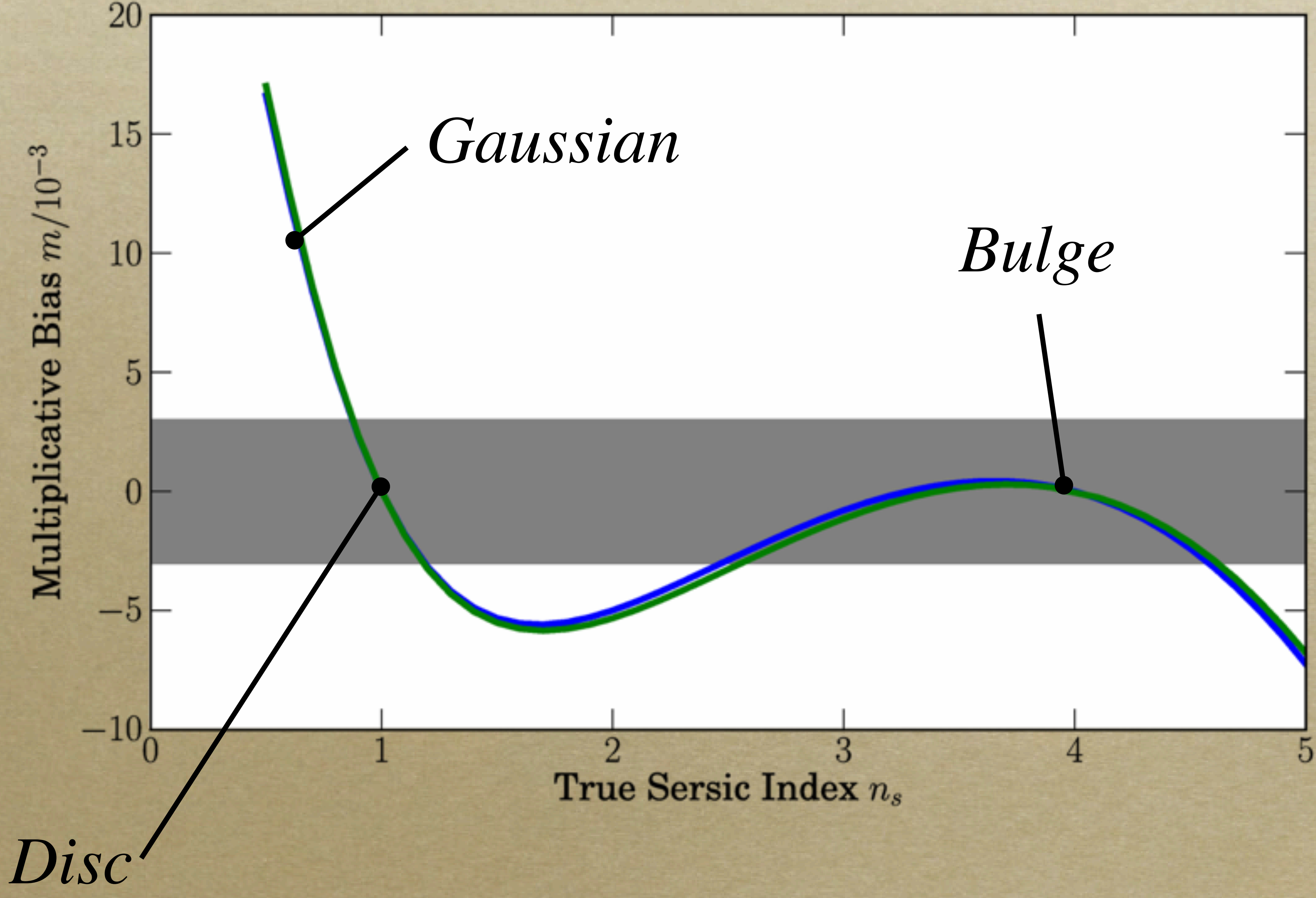
3x3

Model bias

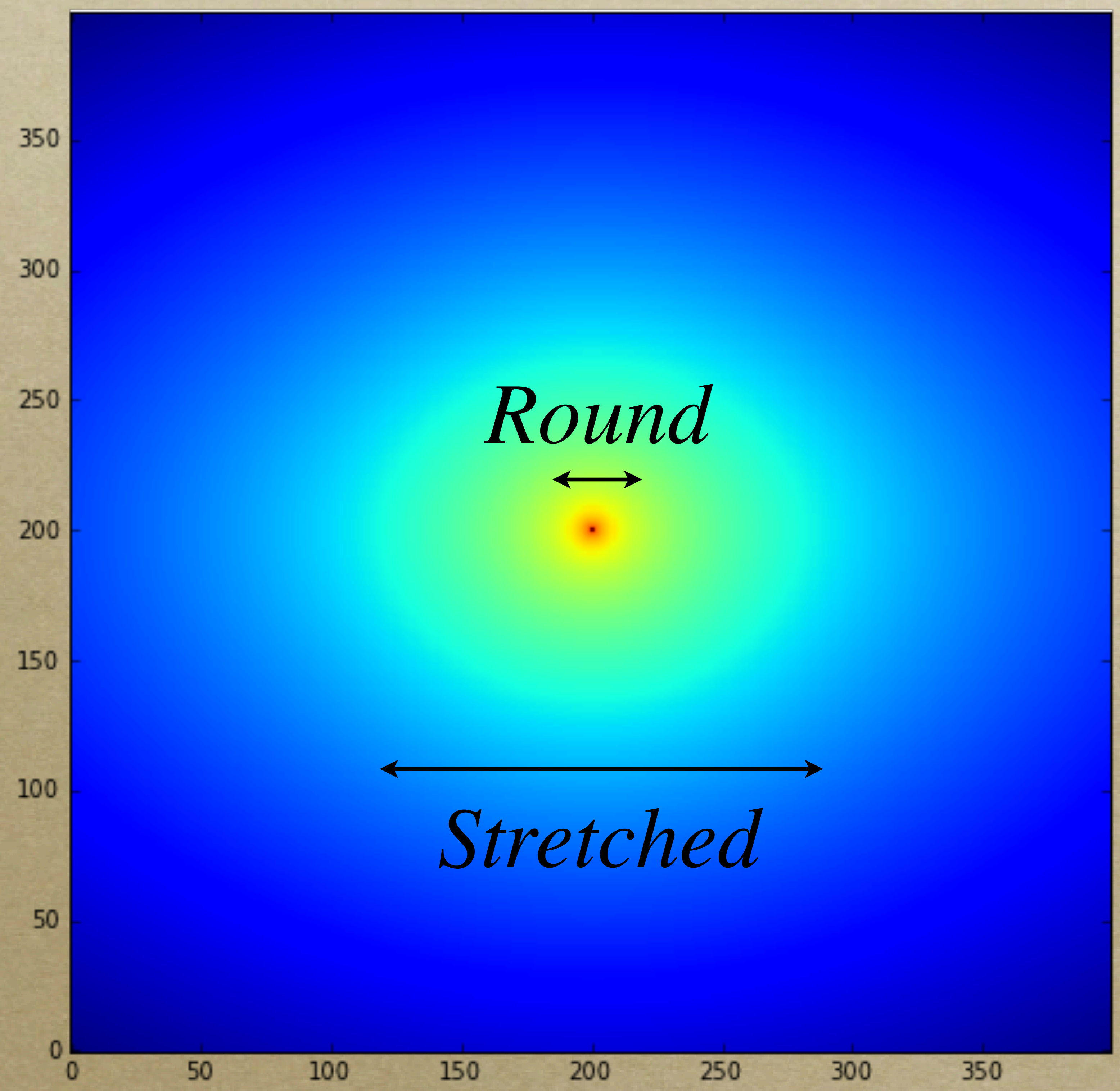
- *When you fit an "incorrect" model to the data*
- *e.g.*
  - *Different profiles*
  - *Off-centering*
  - *Radius ratio*



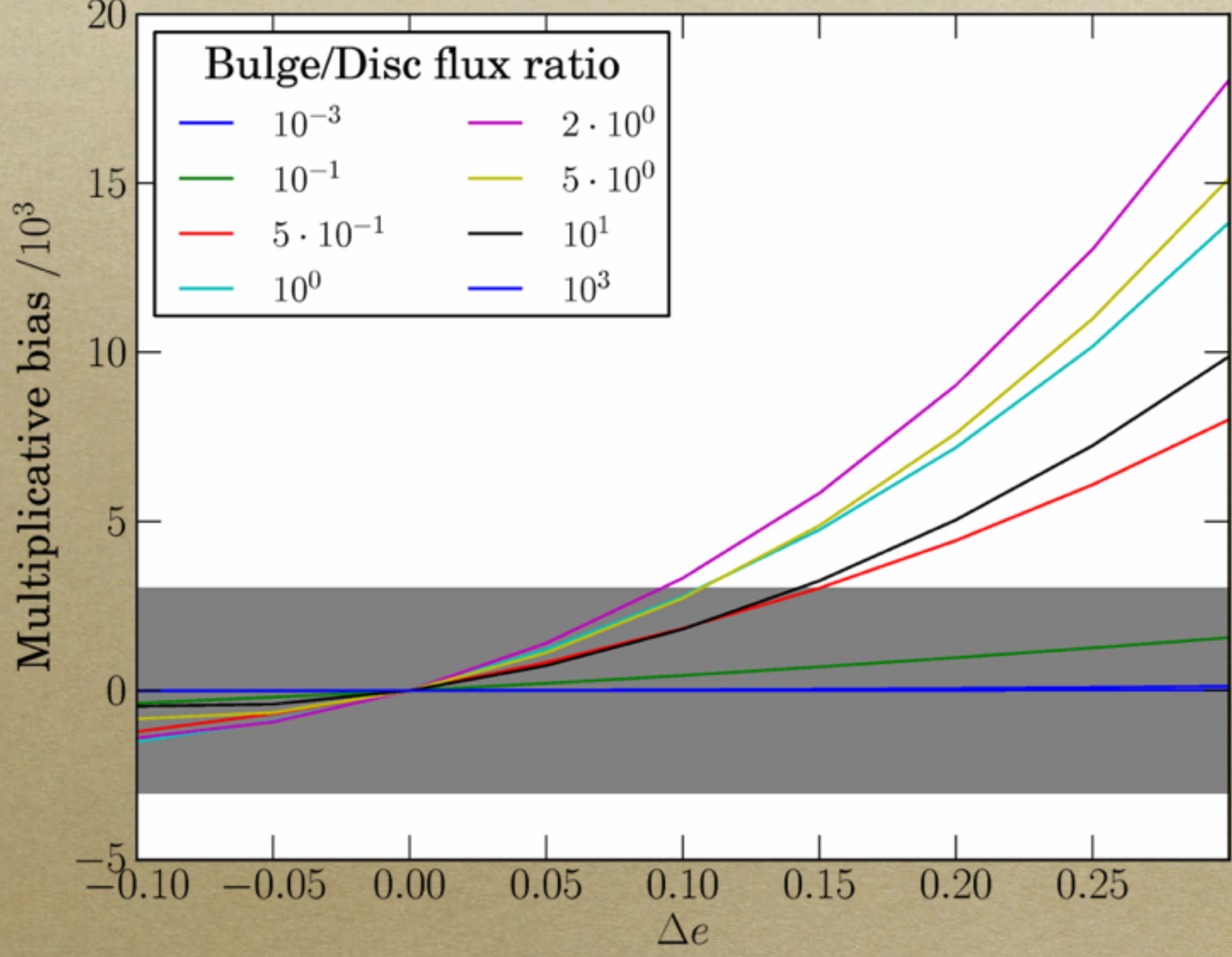
Model Bias:


Gaussian
Bulge
Disc
Multiplicative Bias $m/10^{-3}$
True Sersic Index n_s
20
15
10
5
0
−5
−10
0
1
2
3
4
5

Model bias: Component e_i

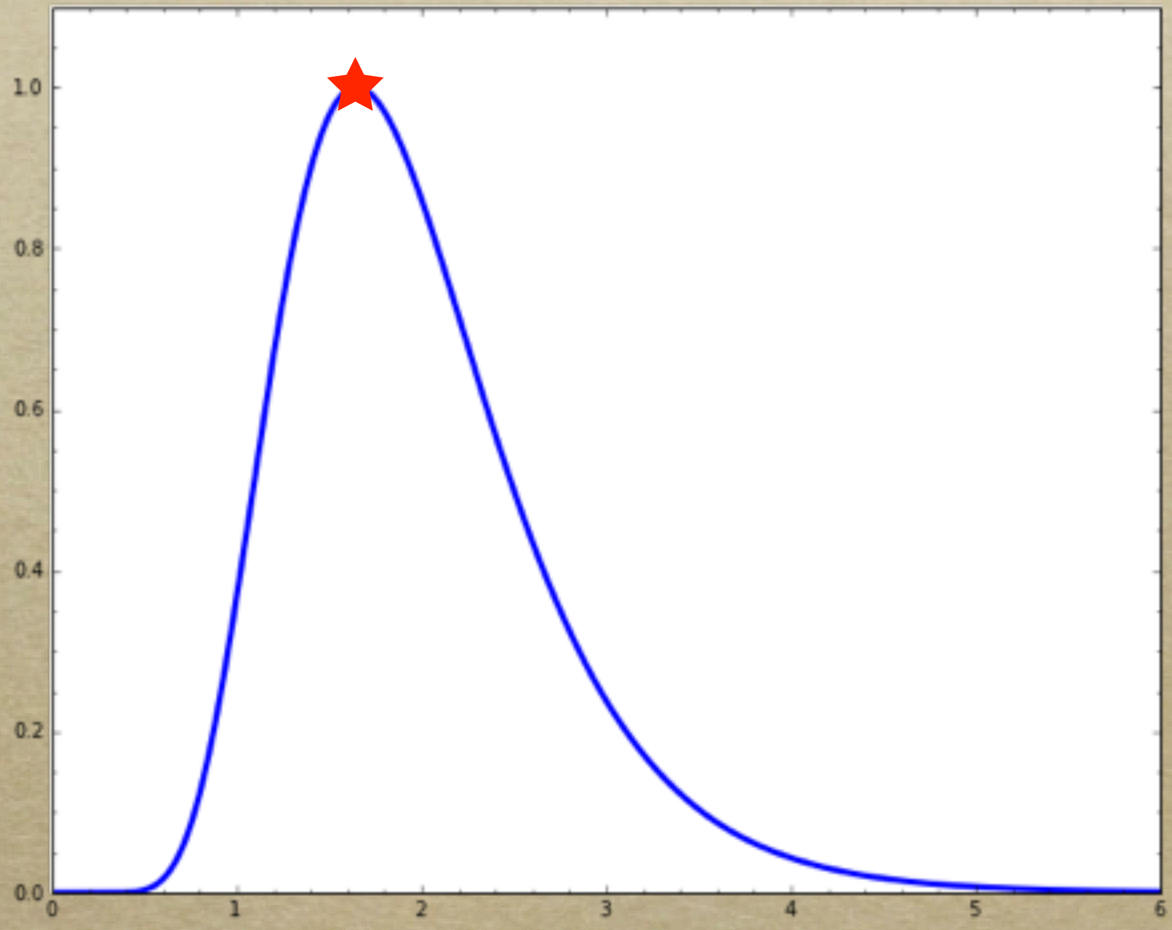


Model bias: Component e_i

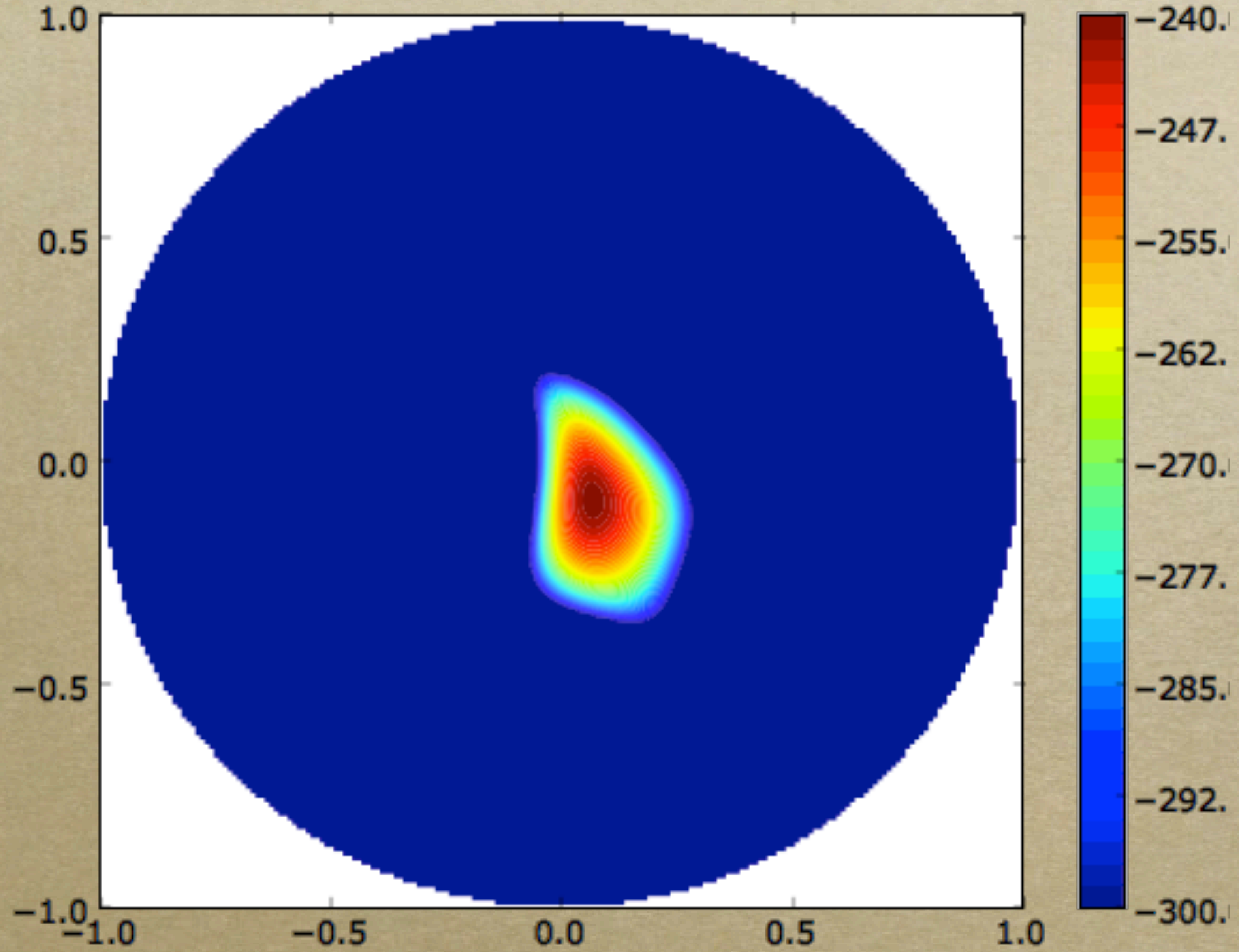


Noise bias

- *Mean of ML ≠ ML of Mean*
- *Combining galaxies we should multiply PDFs*
- *Nonlinear dependence of pixels on ellipticity*



Noise Bias: Origin



Noise Bias: Origin

- *Refrigier et al 2012*
- *Kacprzak et al 2012*

$$b[\hat{a}_i] = -\frac{1}{2}(F^{-1})_{ij}(F^{-1})_{kl}B_{jkl} + O(\rho^{-4})$$

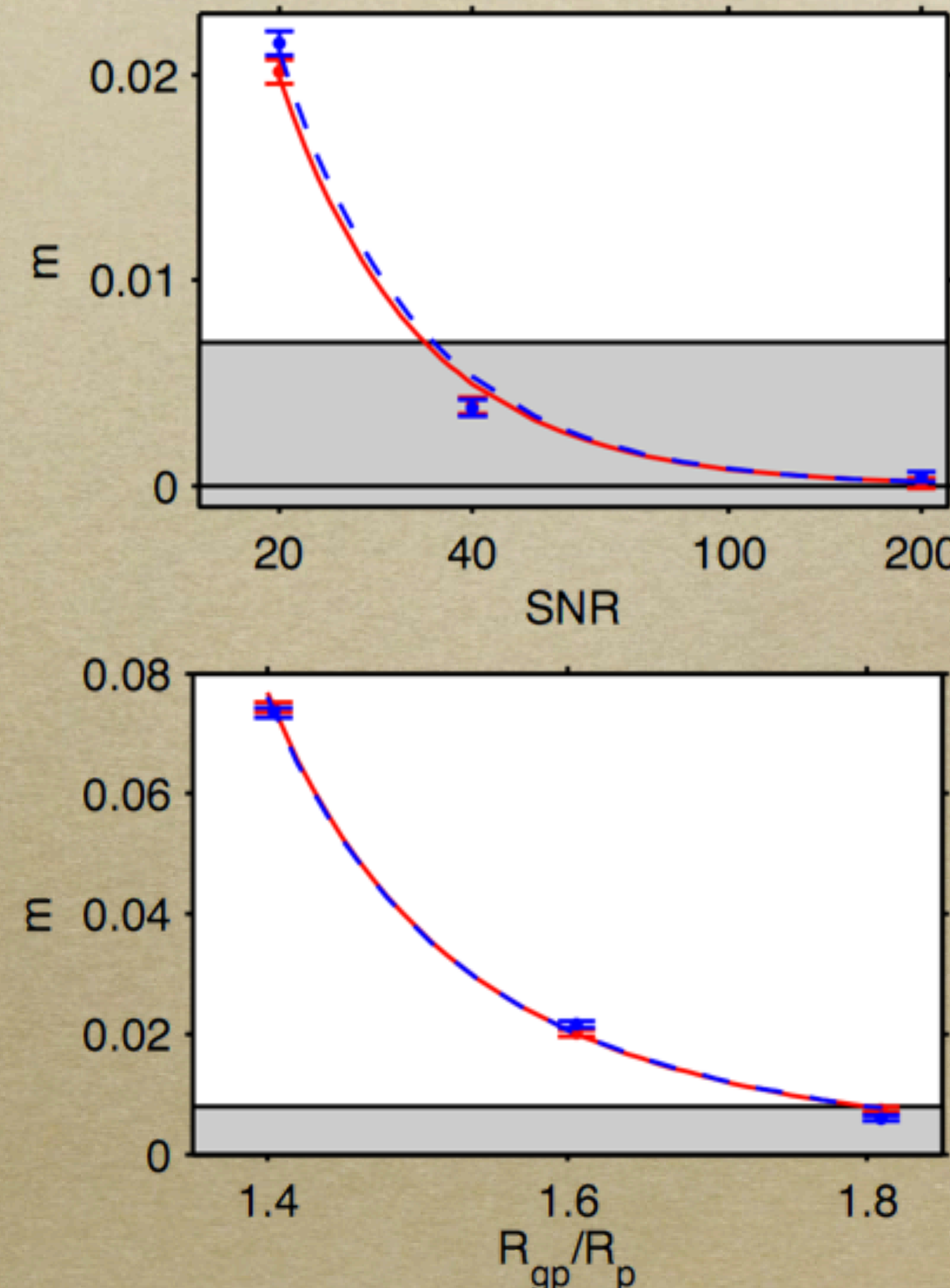
$$B_{ijk} = \left\langle -\frac{1}{2}\frac{\partial^3 \ln L}{\partial a_i \partial a_j \partial a_k} + \frac{\partial \ln L}{\partial a_j}\frac{\partial^2 \ln L}{\partial a_i \partial a_k} \right\rangle$$

Some fun facts

To minimize:	$error^2$	Π(w*error)	abs(error)
Take from your posterior the…	Mean	Mode (ML)	Median

Calibrating noise bias

- *Calibrate with simulations over relevant parameters*
- *Apply with polynomial fit*
- *"Bias-on-bias" problem*



Dodging noise bias?

- *Can we avoid noise bias altogether?*
- *Samples from $P(e|I)$*
- *Requires prior information and power spectrum estimation that can cope*

Summary

- We are about to release a shear-measurement code called *Im3shape* which fits bulge+disc galaxy models to images
- Resolution bias pushes us to high model resolution requirements, especially at image centers
- Model biases are not quite enough to worry us yet
- Noise bias is very significant to ML methods but can be calibrated

Unanswered Question

- *How do the different biases interact?*