Alternatives to KSB and conclusions

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DUEL Weak Lensing School
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Course Summary: You should now be able to:

- Create object catalogues using SExtractor.
- Select stars and create a PSF model.
- Use KSB to measure weak lensing shear.
- Use BPZ to measure photometric redshifts
- Create a mass map!

Overview

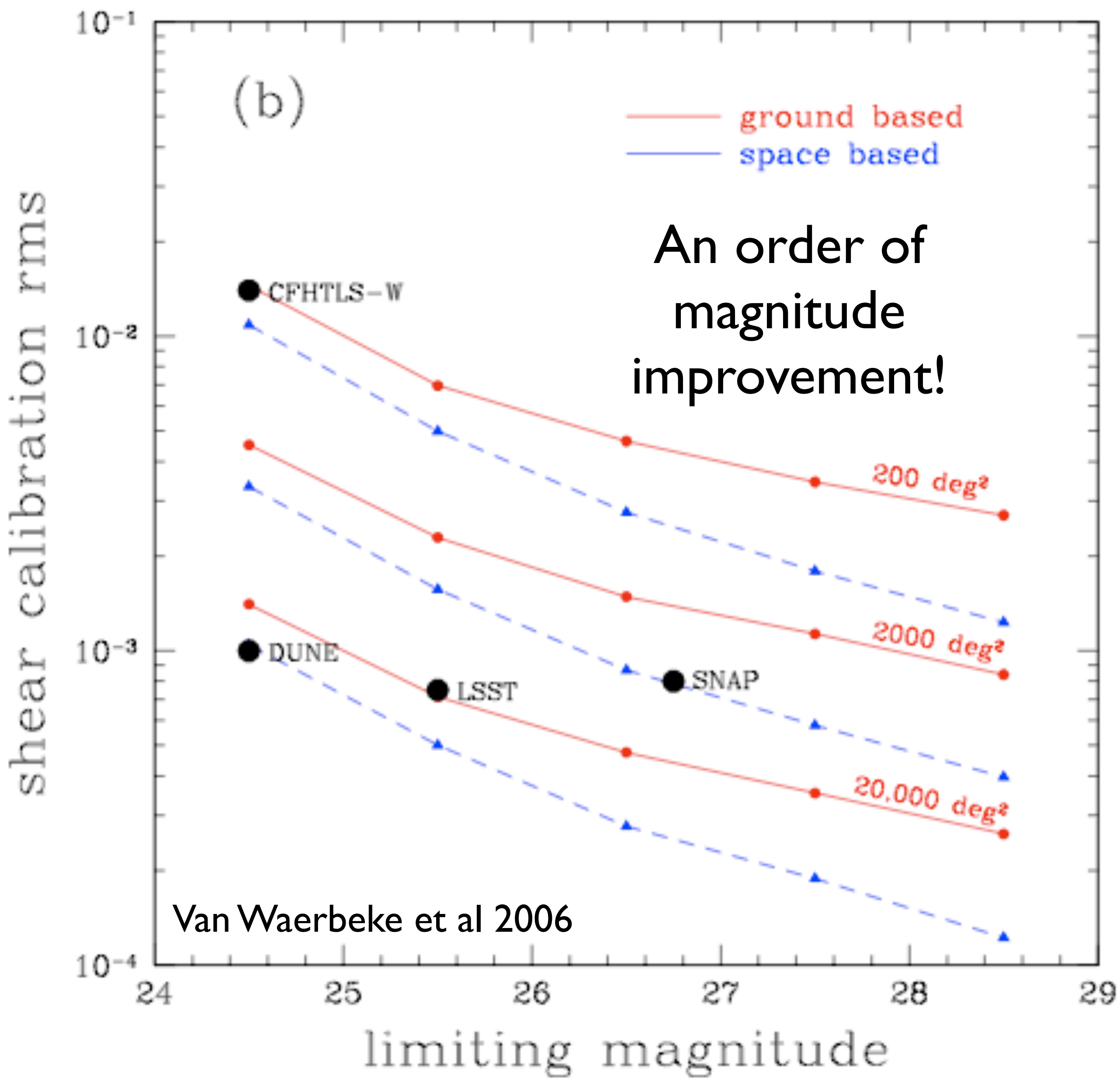
- What is wrong with KSB?
- What level of accuracy do we need for the next generation of surveys?
- Shapelet-based methods
- Model Fitting methods
- Why lensing?
- Ground based surveys of the next 5 years
- The ultimate 2015+ surveys

KSB and the next generation of surveys

- KSB works amazingly well but is based on a key assumption that the PSF is circular with a anisotropic distortion (ie constant elliptical isophotes).
- It is also very unstable to the choices in its implementation
  - A reminder again to test any changes you make in KSBf90 with STEP data!
- It has magnitude and size biases hampering 3D lensing studies
- It’s fine for cluster science but the next generation of surveys including CFHTLS need much better accuracy than KSB can provide.

Accuracy required in the future

This result comes from setting the maximum systematic error equal to the expected statistical noise from each survey



An order of magnitude improvement!

Van Waerbeke et al 2006

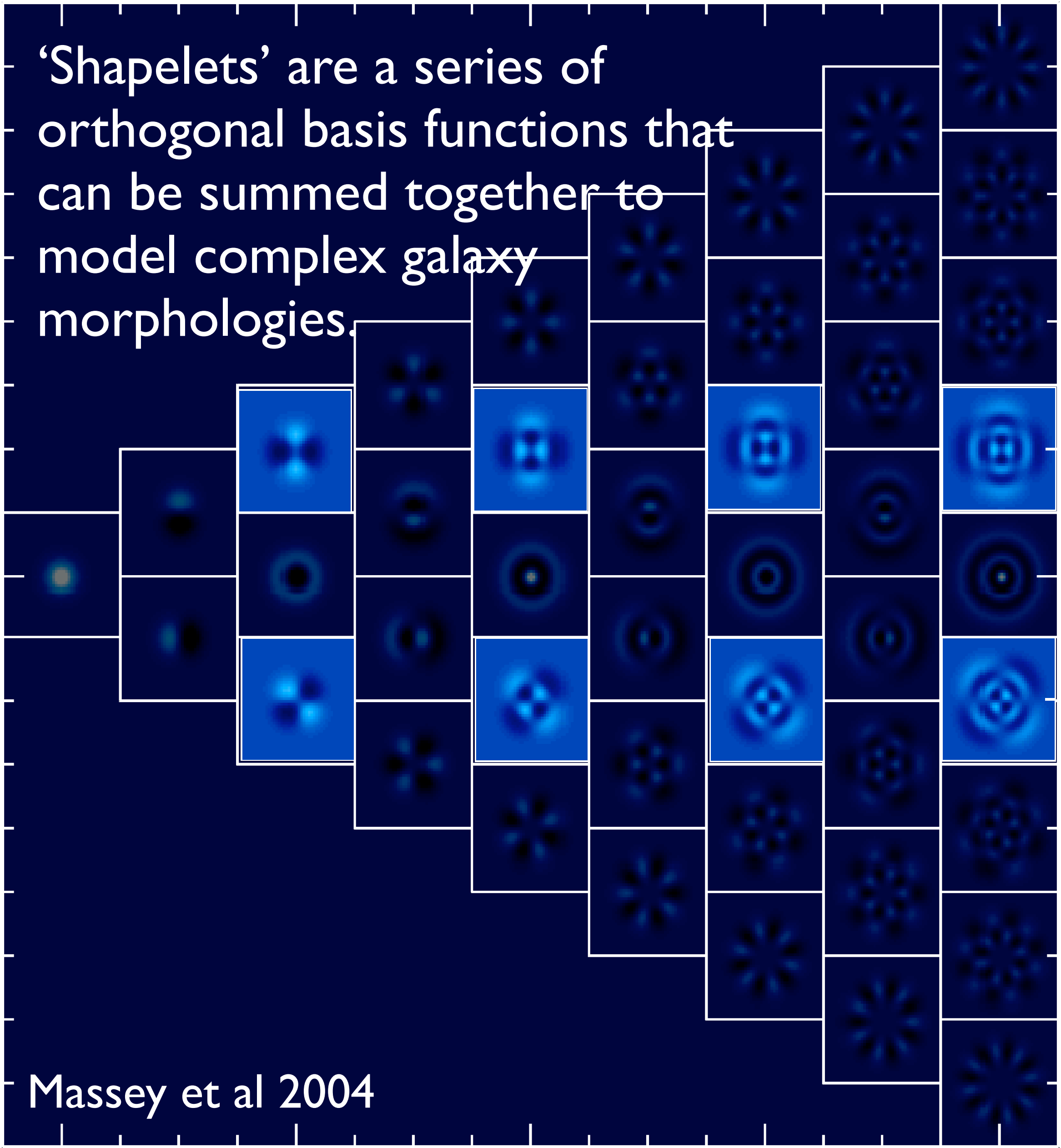
STEP Classification of different methods

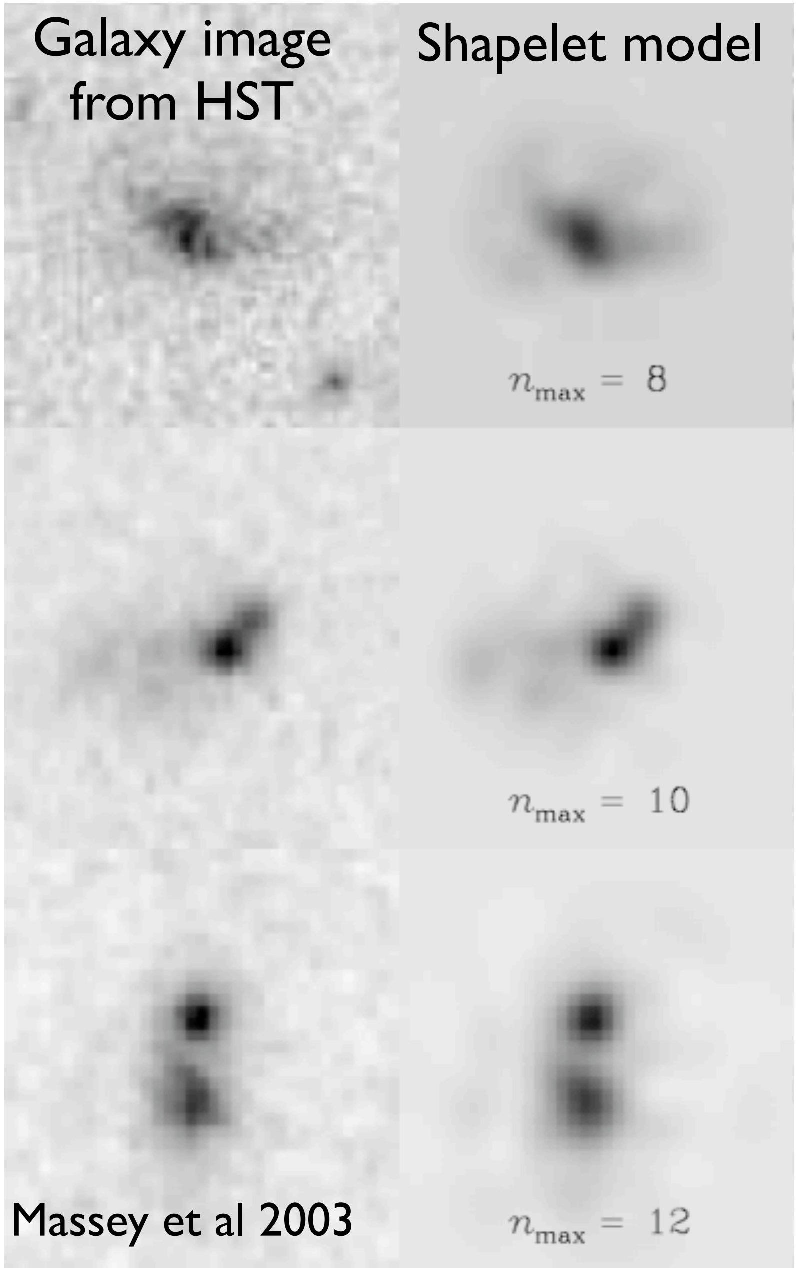
Shear measurement method

PSF correction scheme	**Passive** Measure a number from the data	**Active** Fit a model to the data
Subtraction Subtract a number from the data	KSB+ (various) Reglens (RM) RRG* K2K* Ellipto*	BJ02 (MJ, MJ2)
Deconvolution Invert the PSF convolution	Shapelets (JB)	Lensfit Shapelets (KK) BJ02 (RN) im2shape*

‘Shapelet’ methods

‘Shapelets’ are a series of orthogonal basis functions that can be summed together to model complex galaxy morphologies.





Orthogonal basis functions

- Model the galaxy and PSF as a sum of basis functions (Gaussians, Hermite or Laguerre polynomials)
- Deconvolution of the PSF is then a 'simple' matrix inversion process

centroid

Model $$f(\mathbf{x}) = \sum_{n=0}^{\infty} \sum_{m=-n}^{n} a_{nm} \chi_{nm}(\mathbf{x} - \mathbf{x}_c; \beta)$$

Scale

n,m are both even or both odd

Massey et al Gaussian example

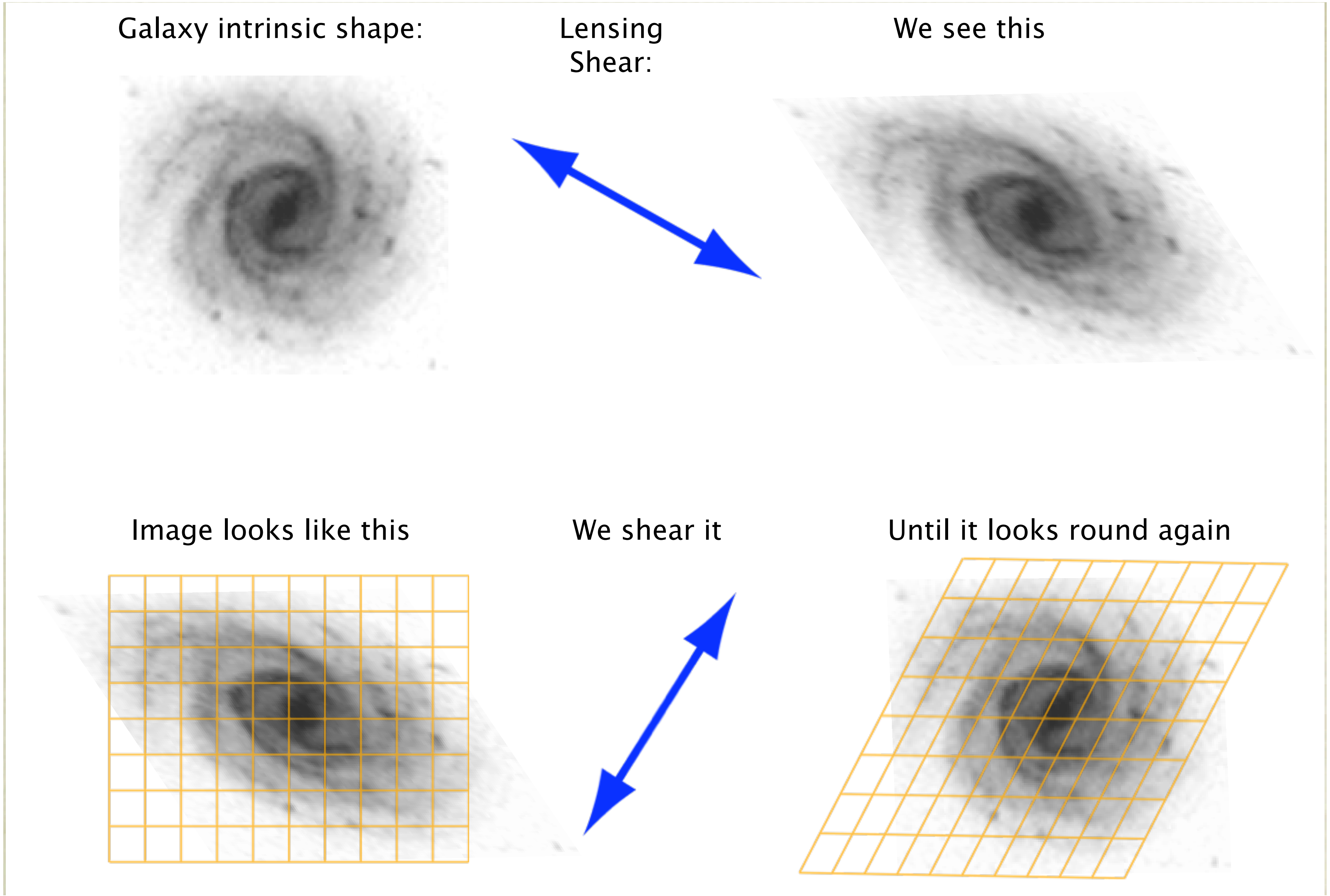
$$\chi_{n,m}(r,\theta;\beta) = \frac{(-1)^{\frac{n-|m|}{2}}}{\beta^{|m|+1}\sqrt{\pi}} \left[\frac{\left(\frac{n-|m|}{2}\right)!}{\left(\frac{n+|m|}{2}\right)!} \right]^{\frac{1}{2}} r^{|m|} L^{|m|}_{\frac{n-|m|}{2}} \left(\frac{r^2}{\beta^2}\right) e^{\frac{-r^2}{2\beta^2}} e^{im\theta}$$

Shapelet coefficients

$$a_{n,m} = \int_0^{2\pi} d\theta \int_0^{\infty} r\, dr\, f(r,\theta)\, \chi_{n,m}(r,\theta;\beta)$$

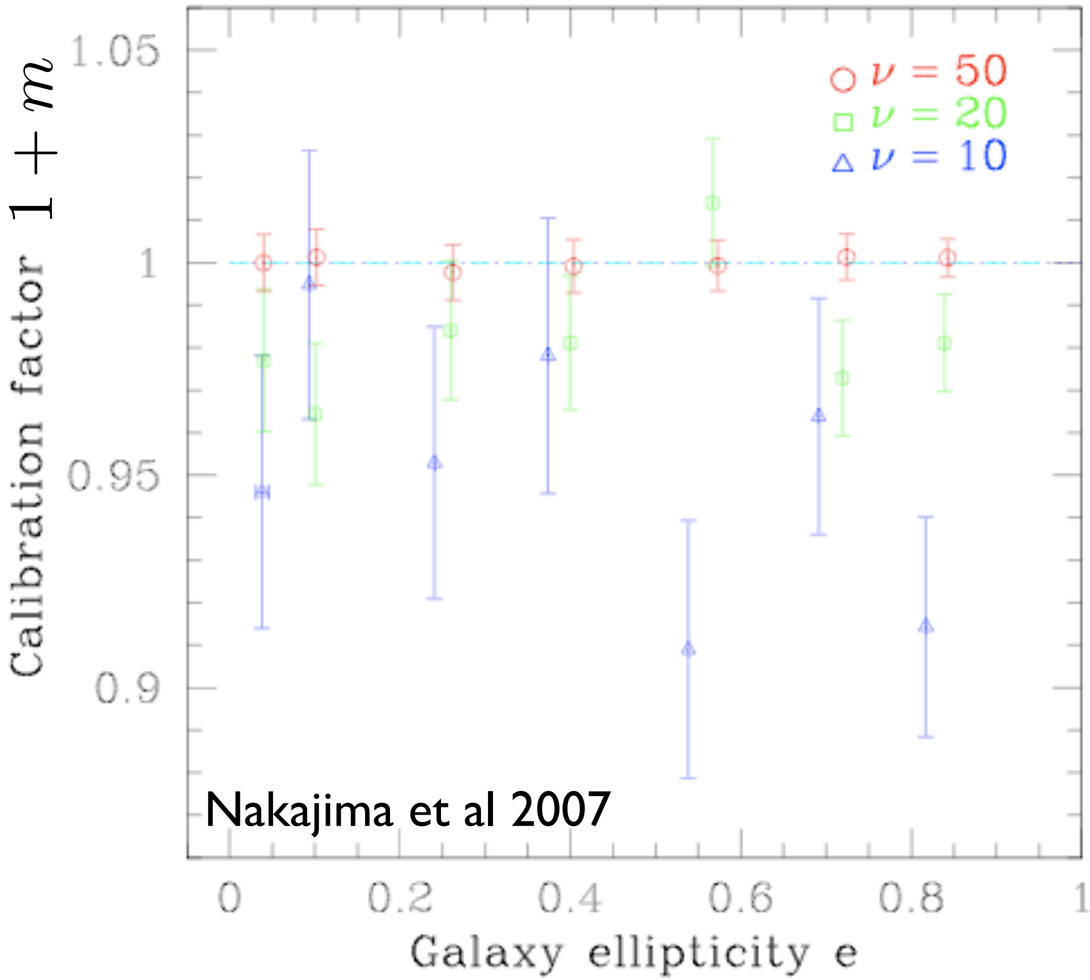
Calculate from the data

Bernstein, Jarvis and Nakajima method

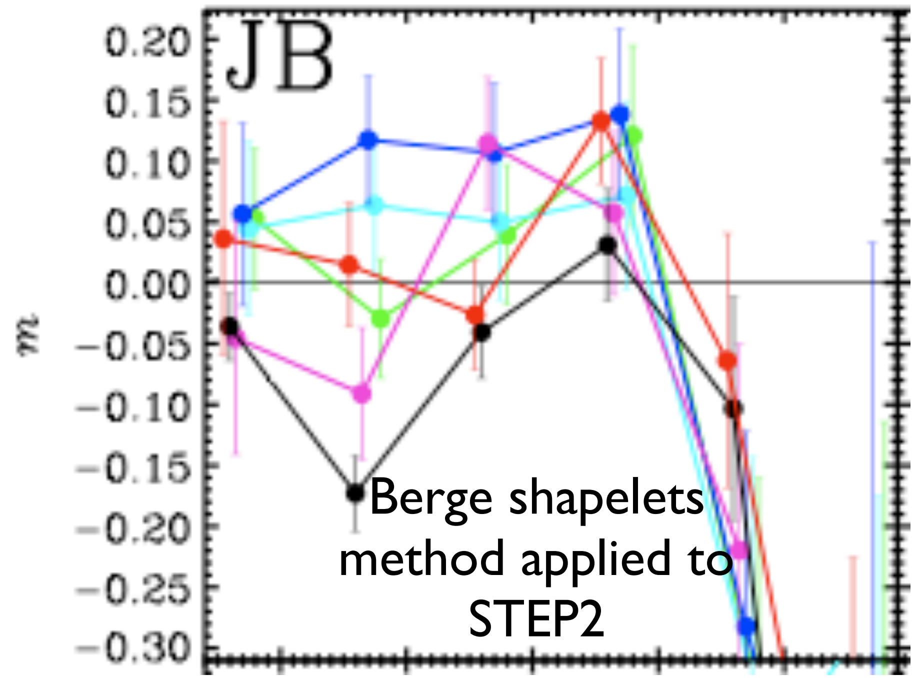


How accurate are shapelet-based methods?

$$\gamma_{\rm obs} = (1+m)\gamma_{\rm true}$$



Nakajima et al 2007

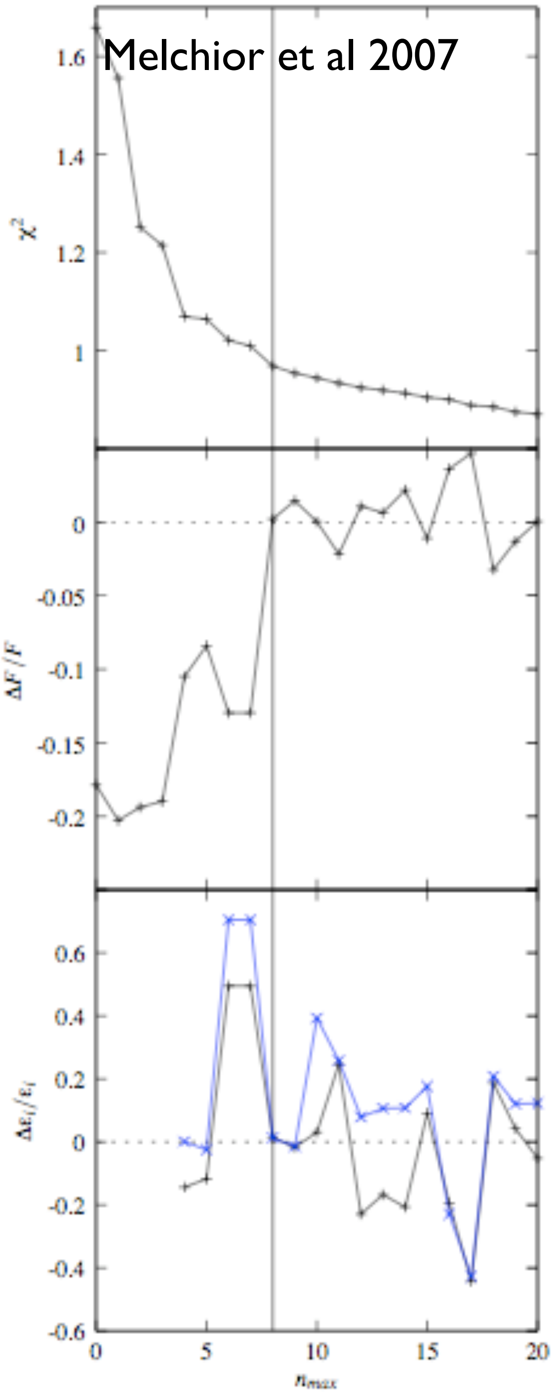


Berge shapelets method applied to STEP2

Magnitude

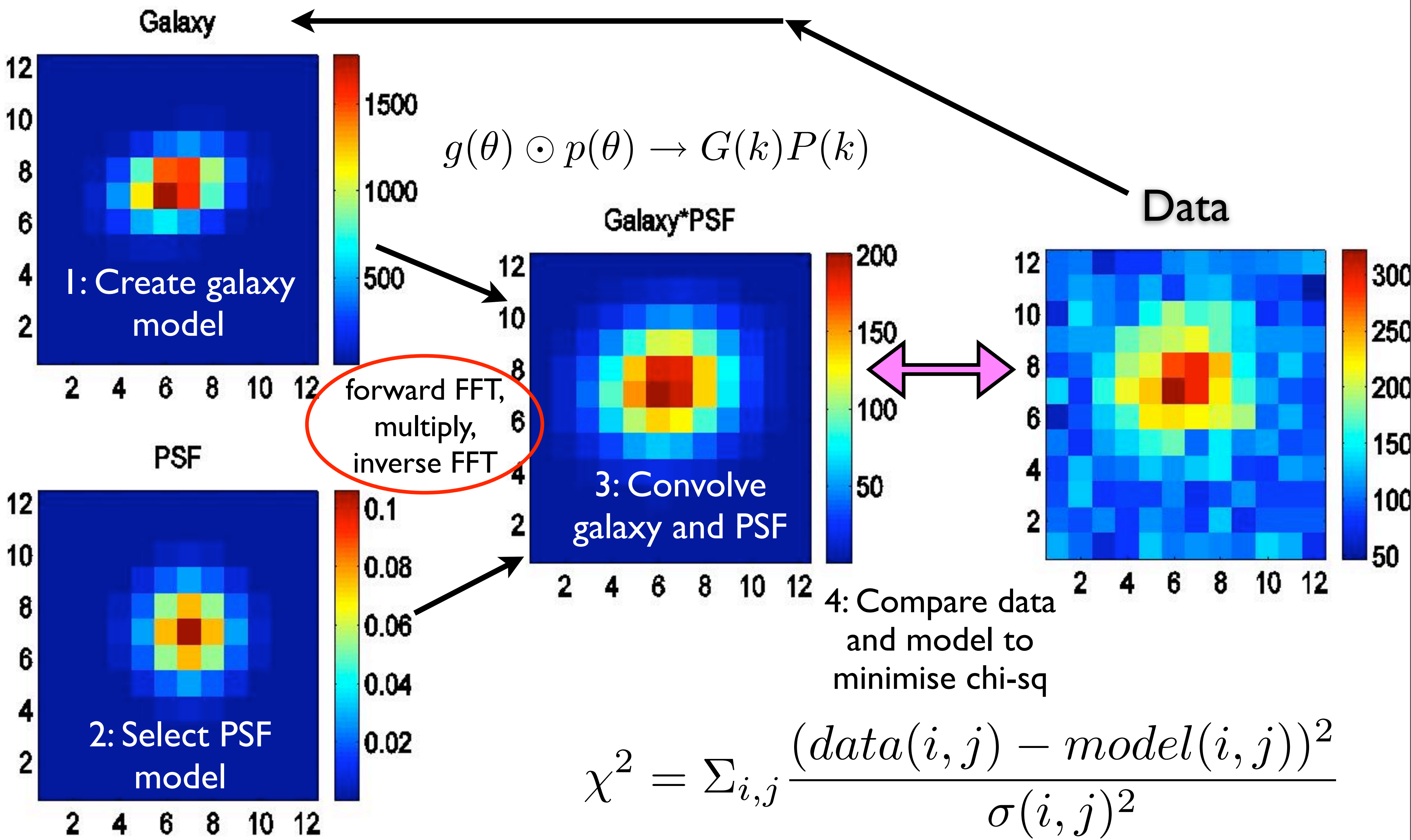
Shapelet methods work well for well resolved or high S/N galaxies

Choosing your shapelets: where to stop



- The flexibility of shapelets to model any galaxy morphology feature is also the main drawback.
- Increasing the number of shapelets (nmax), improves the fit - but you end up just fitting noise!
- You have to set a criteria of when to stop fitting, otherwise you bias your result.
- Shapelets is therefore well suited to model high S/N objects, but the faint fuzzy objects that make up the majority of the lensing survey don't gain much from this type of analysis.
- It makes no poor assumptions about the PSF like KSB, but gives the galaxy model too much freedom.

Model fitting: Ideal shape measurement method



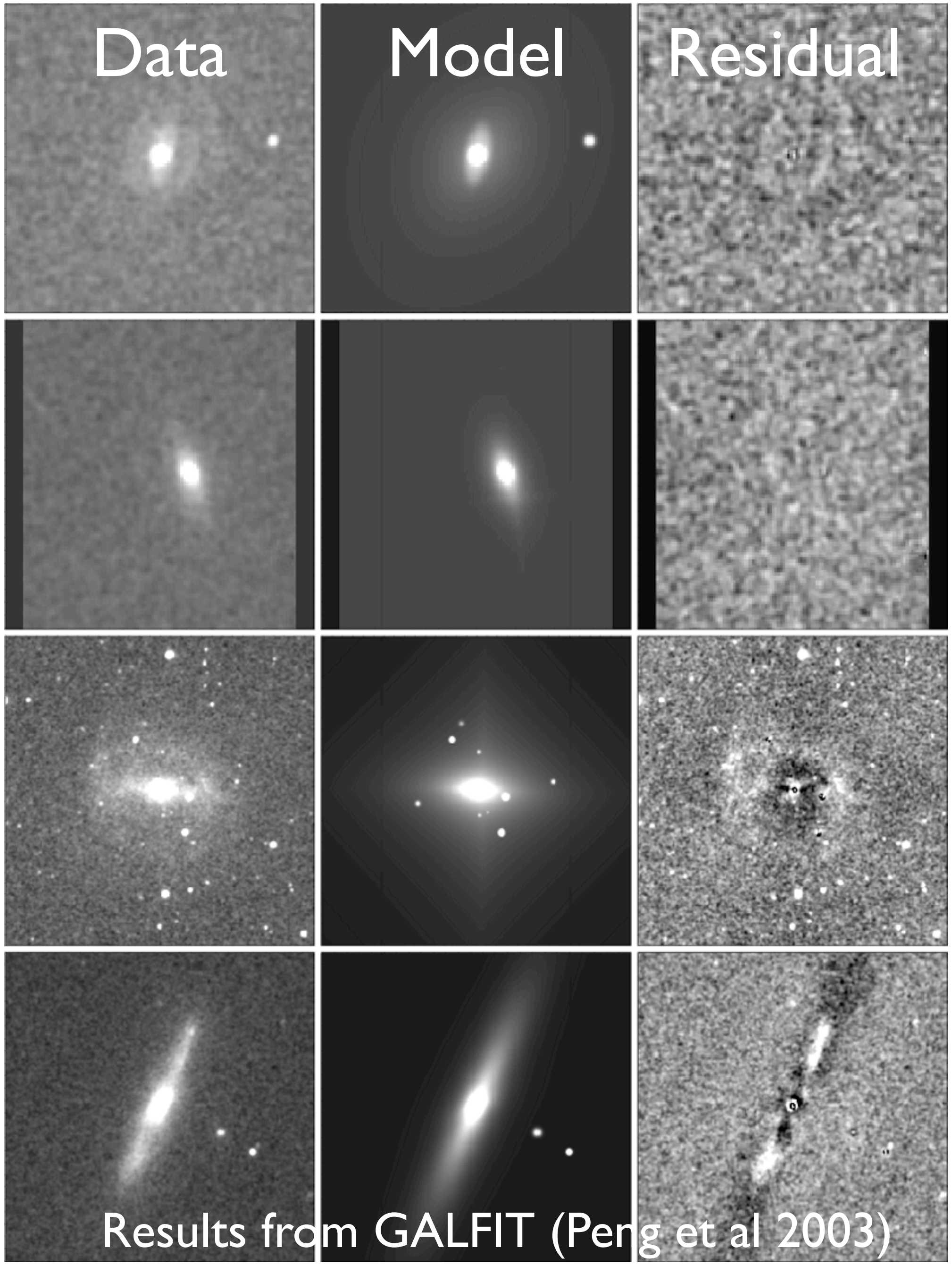
$$\chi^2 = \Sigma_{i,j} \frac{(data(i,j) - model(i,j))^2}{\sigma(i,j)^2}$$

Model fitting using galaxy profiles

Most galaxies are well fit by an elliptical Sersic profile

$$I(r) = I_o \exp -(r/r_c)^{1/n}$$

- This profile has 7 parameters
  - rc - a scaling parameter
  - n - the sersic index
  - x,y - a centroid
  - Io - a peak amplitude
  - a/b - axial ratio
  - theta - orientation



Results from GALFIT (Peng et al 2003)

Lensfit - a Bayesian model fitting method

Bayesian Estimation

Likelihood (of data given ellipticity)

(Intrinsic ellipicity) Prior

$$p_i(\mathbf{e}|\boldsymbol{y}_i) = \frac{\mathcal{P}(\mathbf{e})\,\mathcal{L}(\boldsymbol{y}_i|\mathbf{e})}{\int \mathcal{P}(\mathbf{e})\,\mathcal{L}(\boldsymbol{y}_i|\mathbf{e})\,d\mathbf{e}}$$

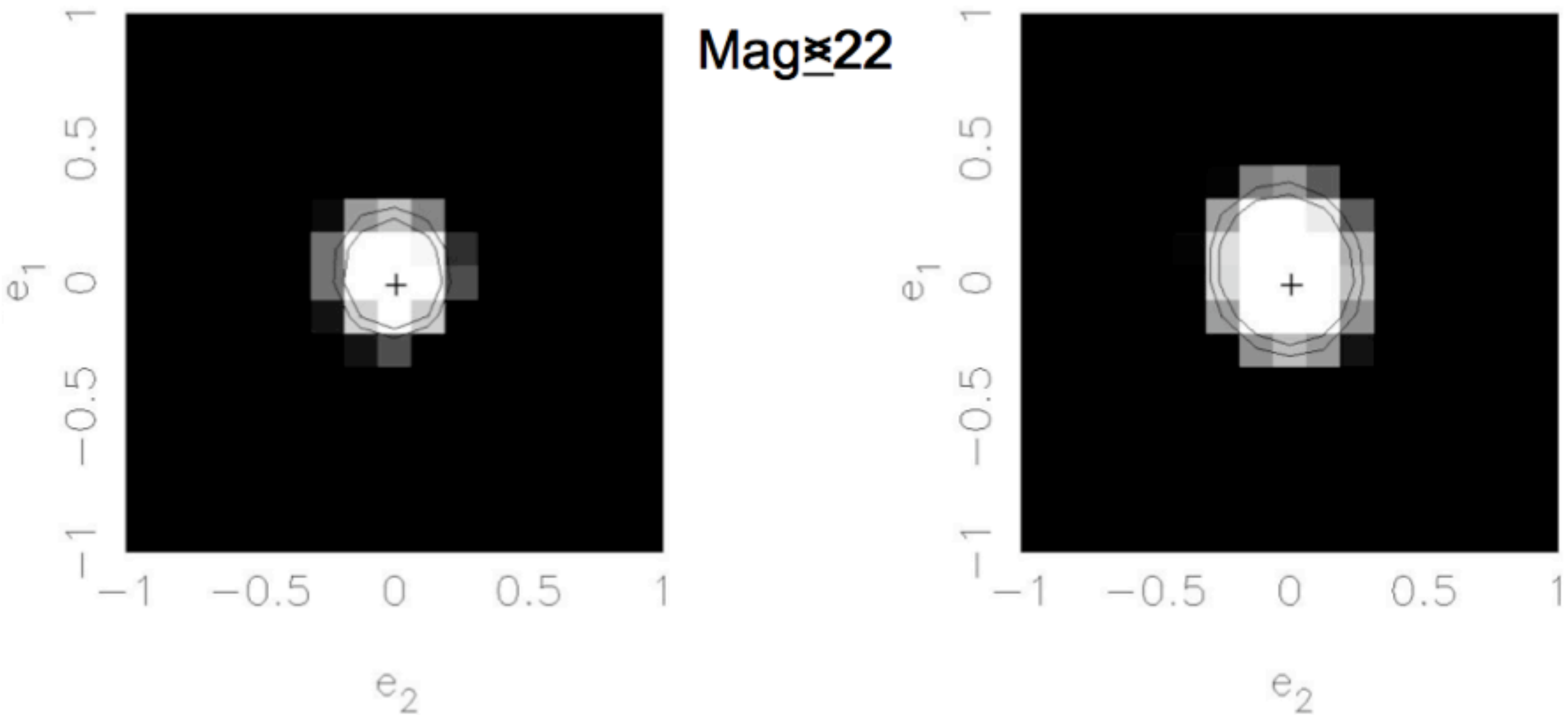
Miller et al 2008

Posterior (likelihood of ellipticity given data)

Slide from Tom Kitching see http://www.physics.ox.ac.uk/lensfit

Example Posteriors $P(e_1,e_2)$

As galaxies become fainter P(e1,e2) becomes flatter



Slide from Tom Kitching see http://www.physics.ox.ac.uk/lensfit

Lensfit - a Bayesian model fitting method

A Bayesian Shear Estimator

Miller et al 2008

Expectation Value of the ellipticity (Integral over the whole ellipicity probability surface)

gals

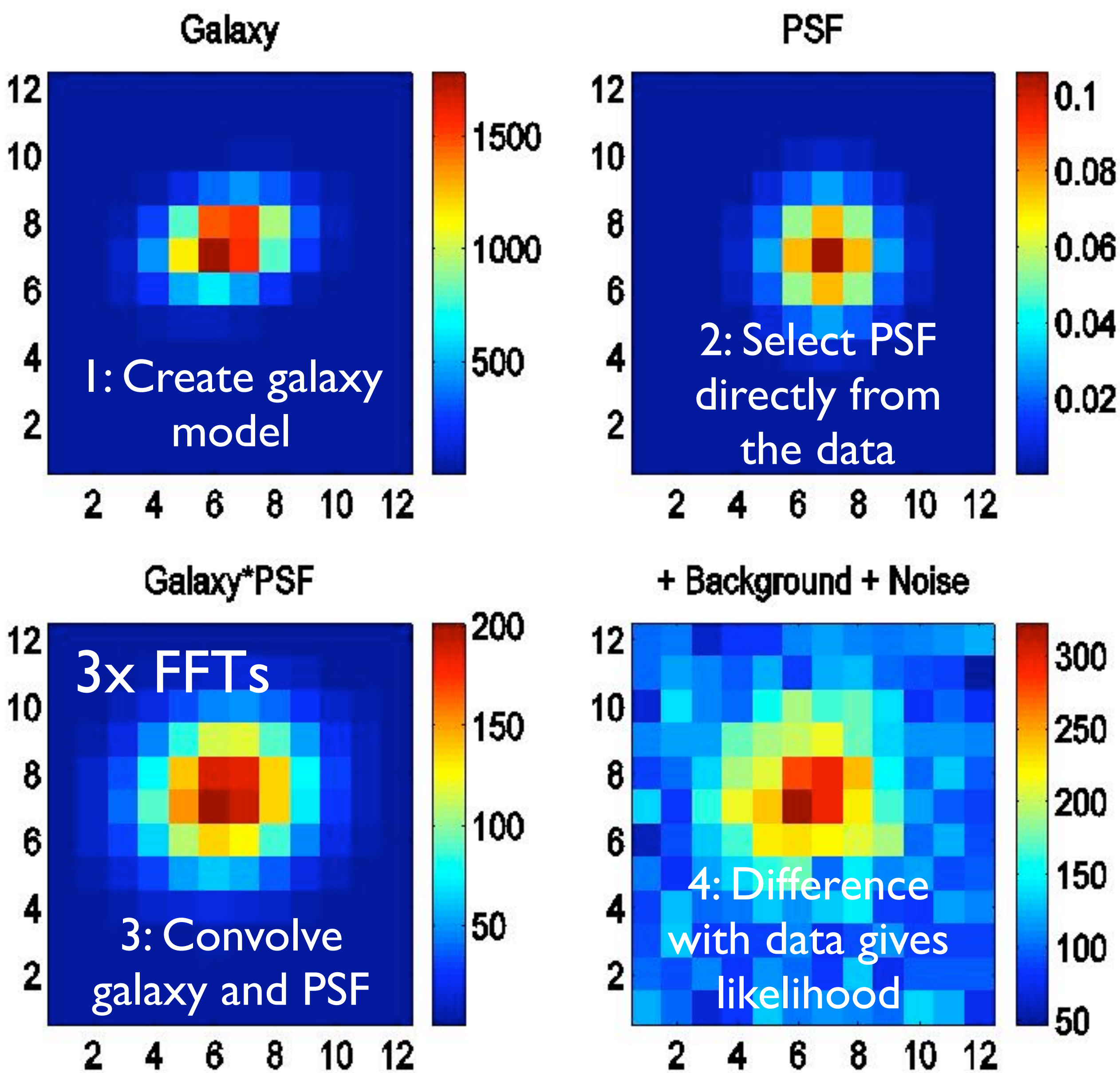
$$\hat{g} = \frac{\sum_i^N \langle e \rangle_i}{\sum_i^N |\partial \langle e \rangle_i / \partial g|}$$

Shear Sensitivity: can calculate directly from the prior on a galaxy-by-galaxy basis (polarisability, responsivity)

Downweighs noisy measurements in your sample

Slide from Tom Kitching see http://www.physics.ox.ac.uk/lensfit

Problem 1: Processing time



- How do we get a likelihood estimate for each galaxy in under a second?
- A Sersic model has 7 parameters to vary
- Each model has to be fourier transformed
- Then multiplied with the PSF fourier transform
- Inverse fourier transform
- and difference to get a likelihood

Lensfit solution: Marginisation

- In lensing we want to know e1 and e2 only (2 parameters)
- Lensfit sets the Sersic index to 4 (common for Elliptical galaxies)
- It uses a neat technique to marginalise over the centroid position (see Miller et al 2008 for details)
- It normalises the peak flux to 1 in both the model and data, so Io=1
- The final stage is to marginalise over the scale parameter

$$\mathcal{L}(e_1, e_2) = \int dr \mathcal{L}(e_1, e_2, r) \approx \sum_{r_{\min}}^{r_{\max}} \mathcal{L}(e_1, e_2, r) \Delta r$$

End results: <1 sec processing time per galaxy

Problem 2: What about that prior?

- For a Bayesian method to work you need to know a prior. In this case it is the distribution of intrinsic ellipticities before they have been lensed.

Likelihood (of data given ellipticity)

(Intrinsic ellipicity) Prior

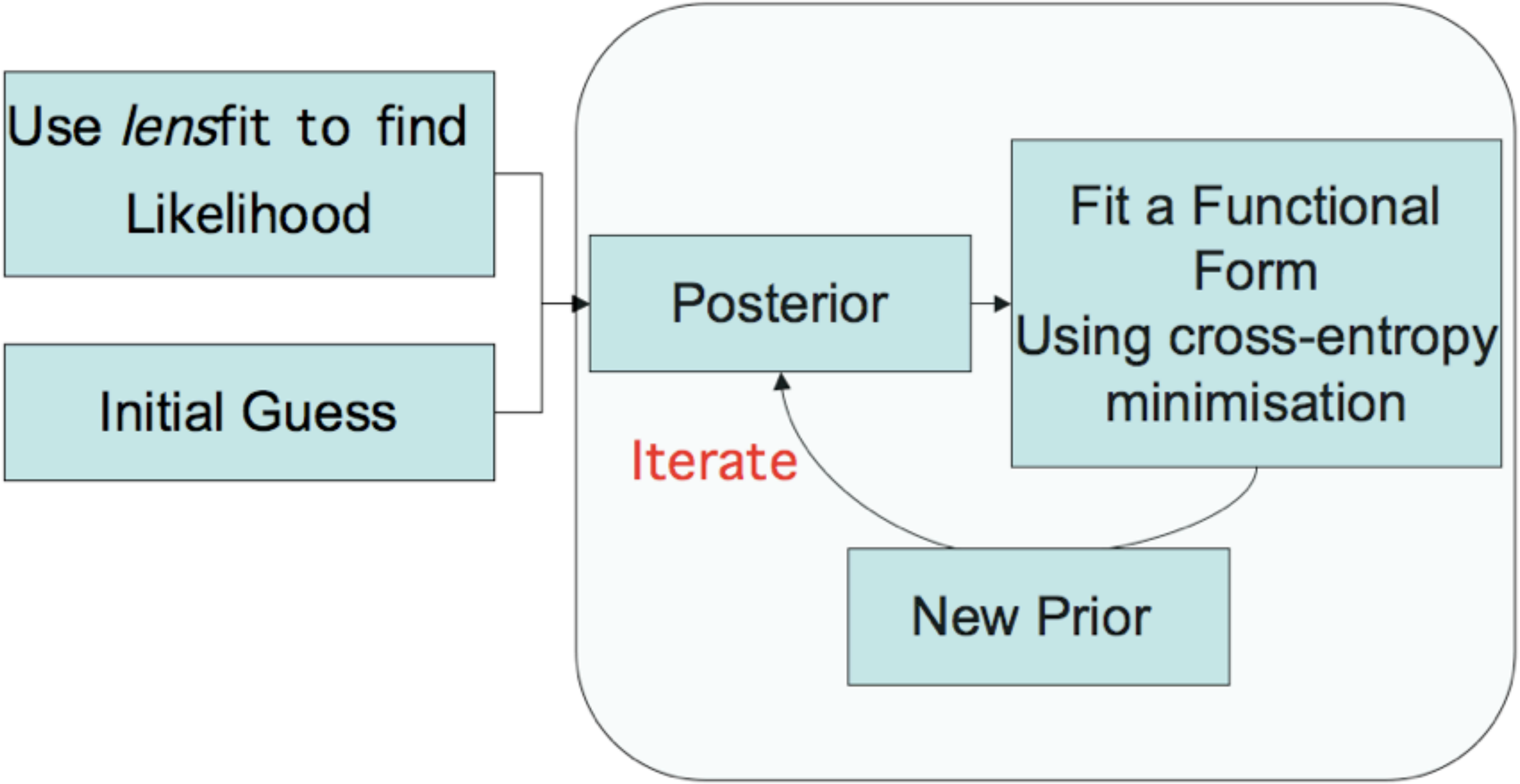
$$p_i(\boldsymbol{e}|\boldsymbol{y}_i) = \frac{\mathcal{P}(\boldsymbol{e})\,\mathcal{L}(\boldsymbol{y}_i|\boldsymbol{e})}{\int \mathcal{P}(\boldsymbol{e})\,\mathcal{L}(\boldsymbol{y}_i|\boldsymbol{e})\,d\boldsymbol{e}}$$

Miller et al 2008

Posterior (likelihood of ellipticity given data)

Slide from Tom Kitching see http://www.physics.ox.ac.uk/lensfit

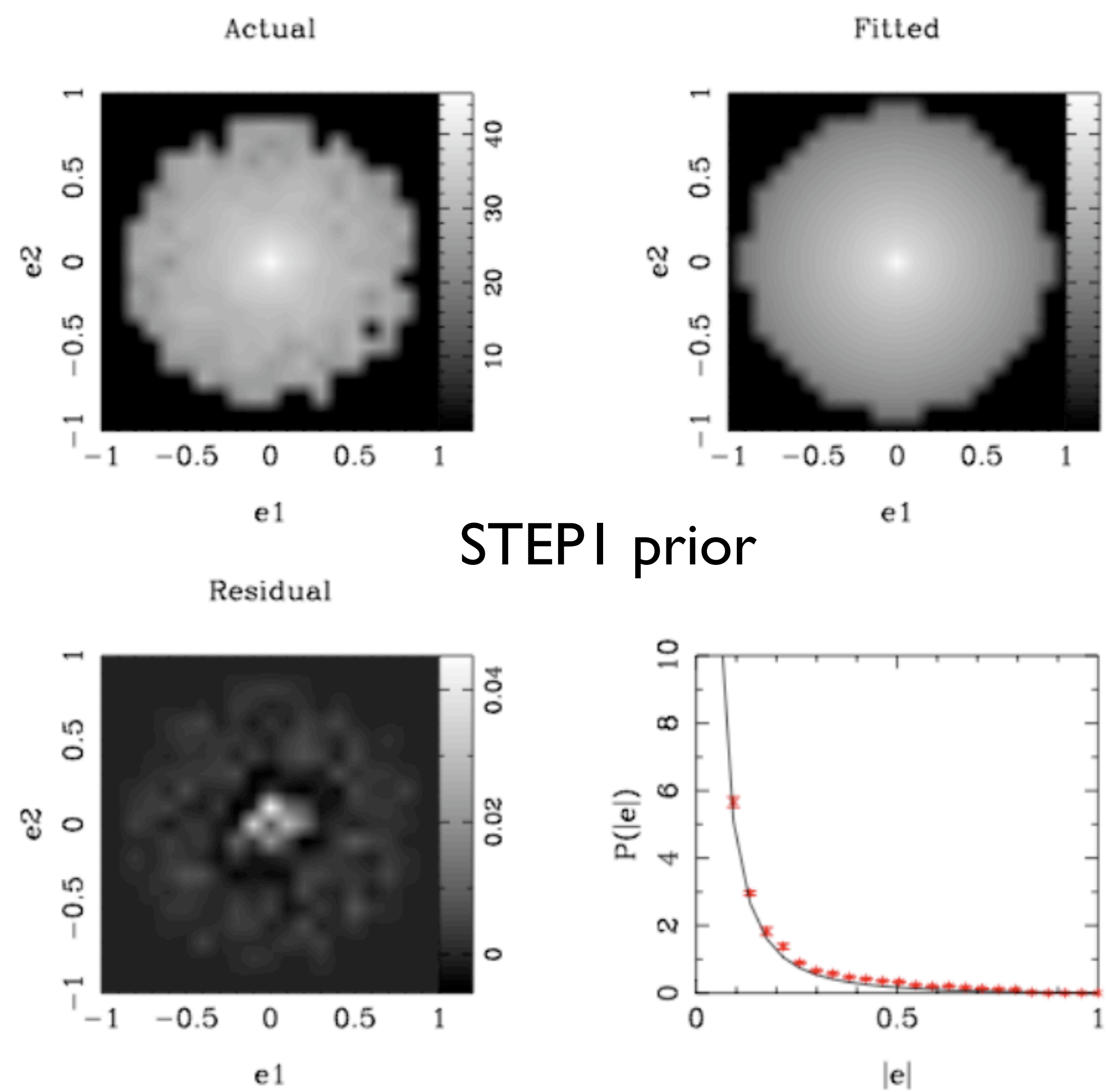
How to determine the prior



Slide from Tom Kitching see http://www.physics.ox.ac.uk/lensfit

Problem 2: What about that prior?

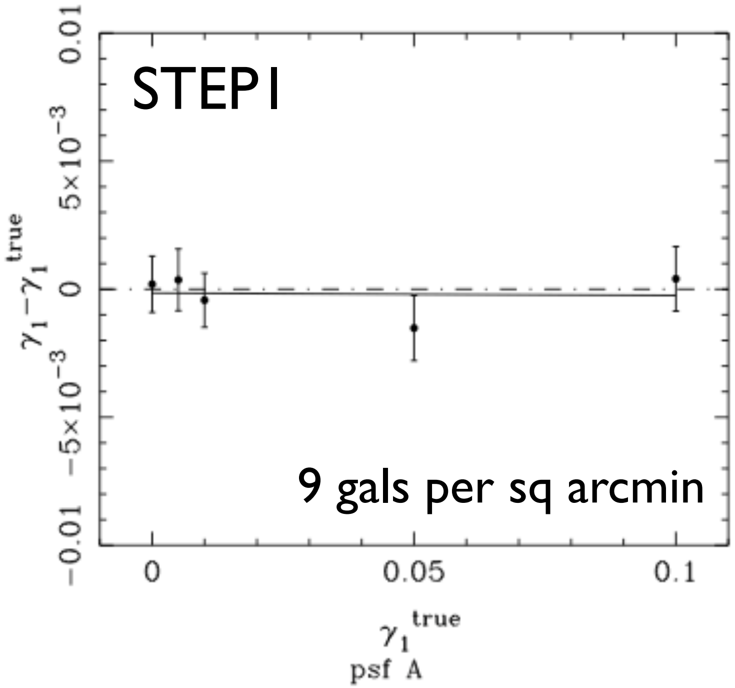
- On average across the whole sky the shear=0, so with deep and wide enough data it is possible to use lensfit iteratively to get a good measure of the prior

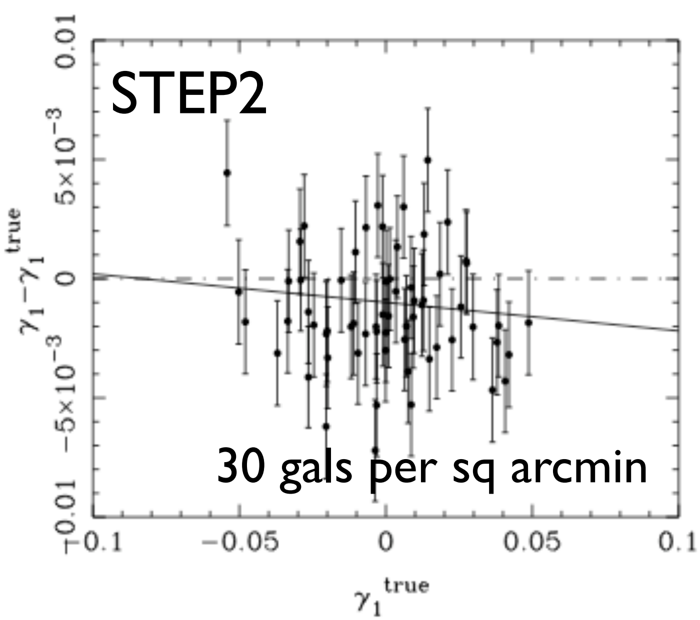


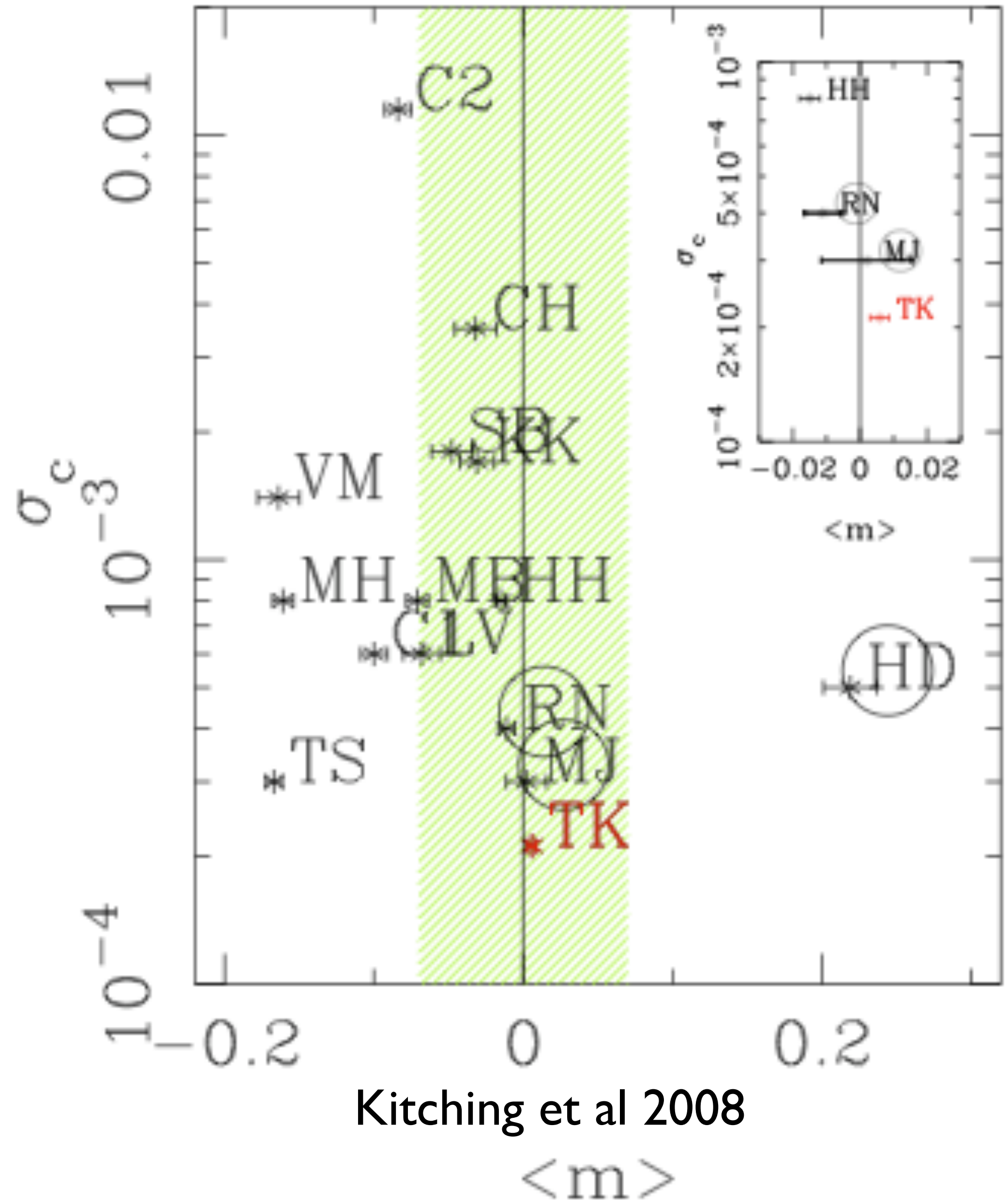
STEP1 prior

Kitching et al 2008

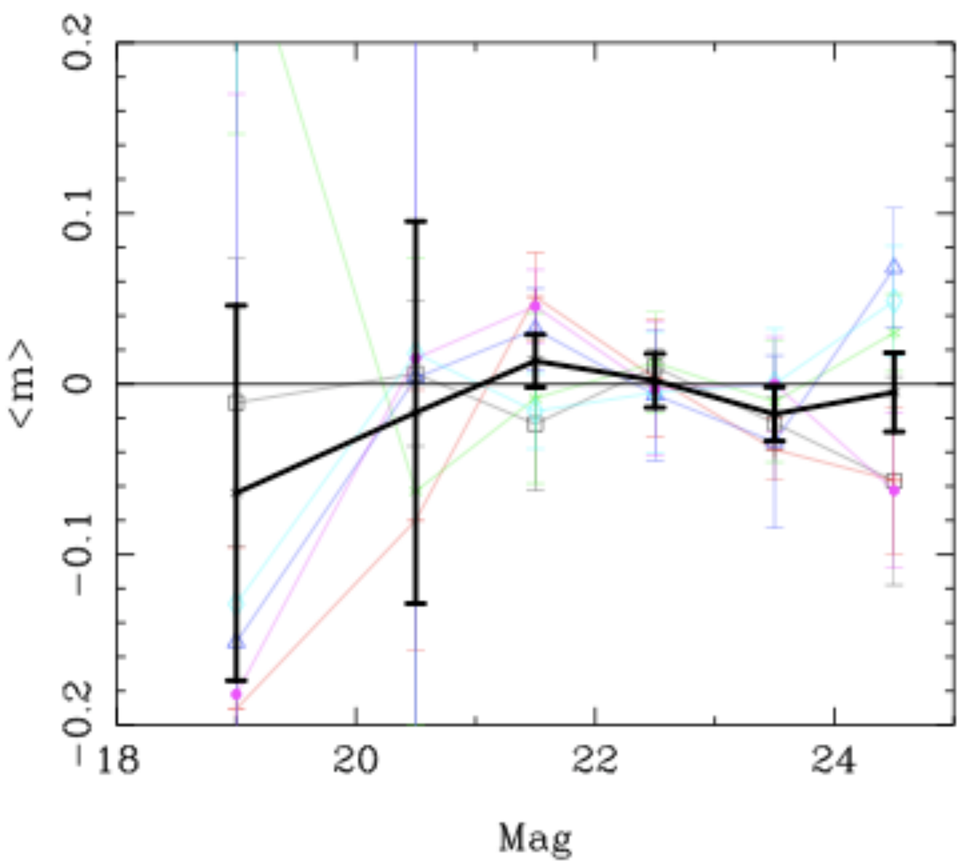
Lensfit - very promising performance on STEP

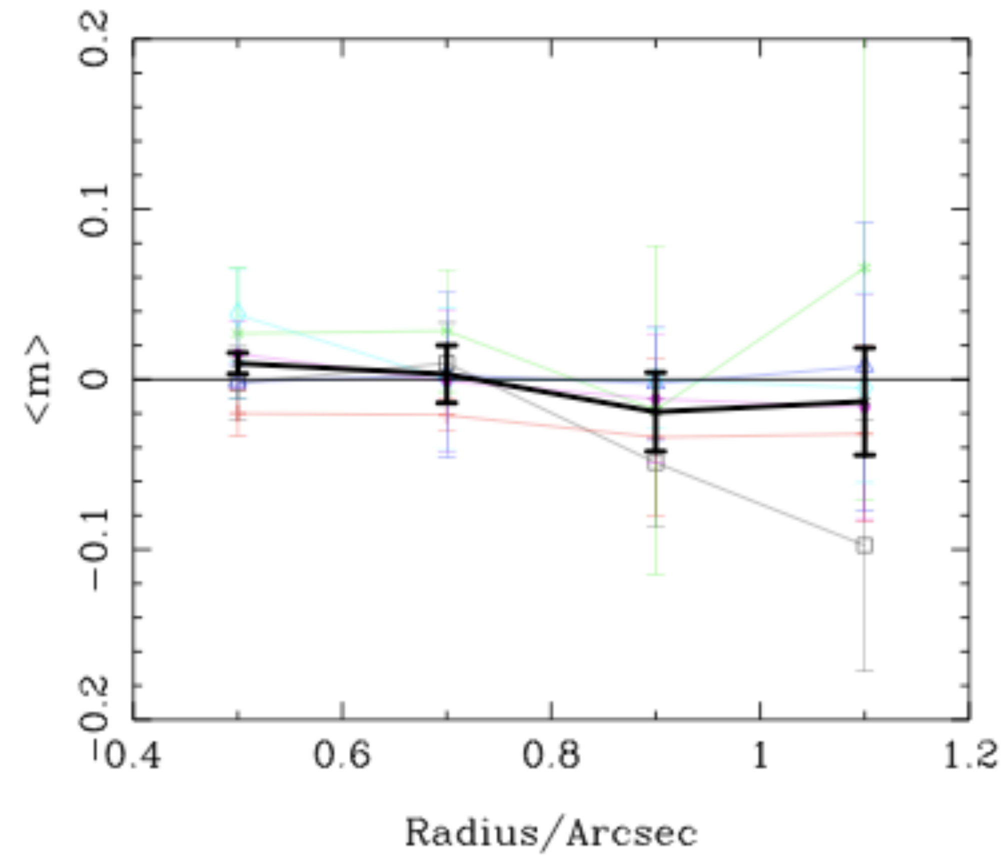






Lensfit - no bias with magnitude or size





Kitching et al 2008

- Lensfit is very promising on simulated data
- It is by far the best method tested by the CFHTLS systematics collaboration
- This new way of thinking is a real breakthrough in shear measurement

Summary

- For the next generation of surveys we much higher accuracy in shear measurement than we can get with KSB.
- This has prompted many new methods to be proposed.
- The most promising is a Bayesian model fitting method called lensfit. The evolving code is available on request to Lance Miller and Tom Kitching

This shear analysis is all too tricky - why should I bother?

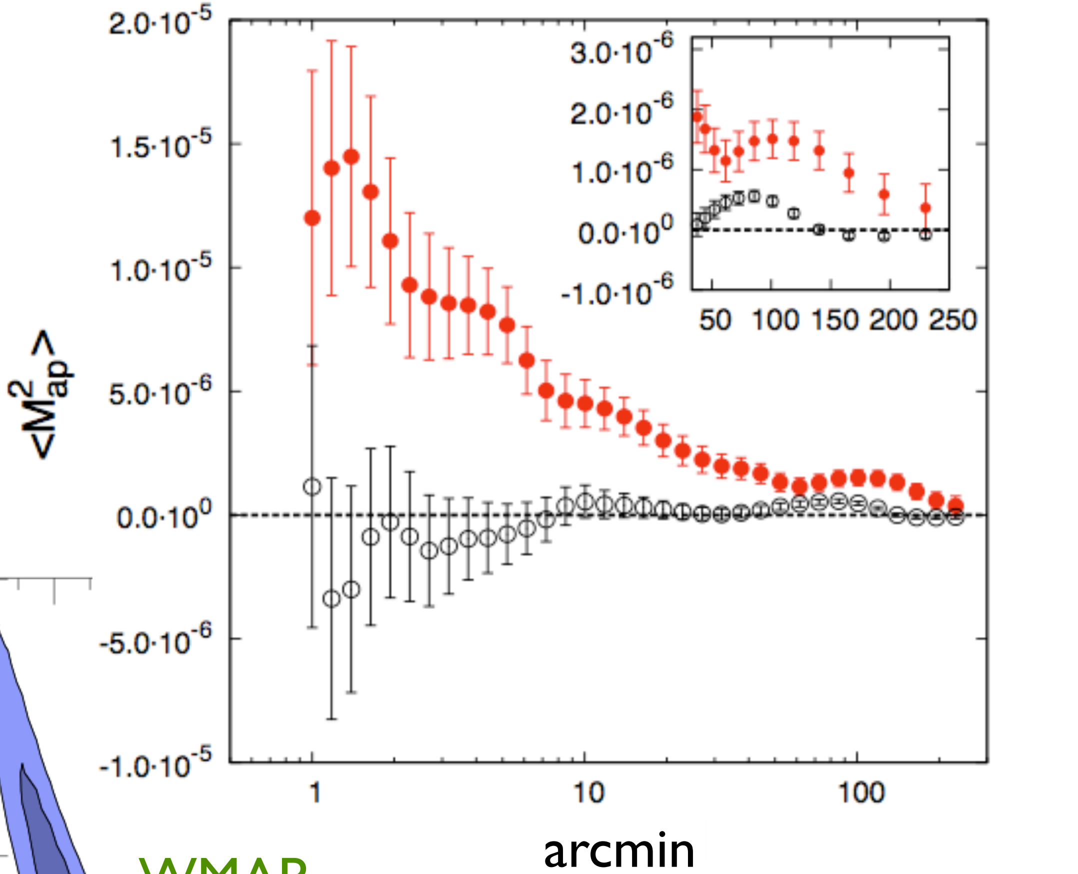
Now is a great time to get into lensing

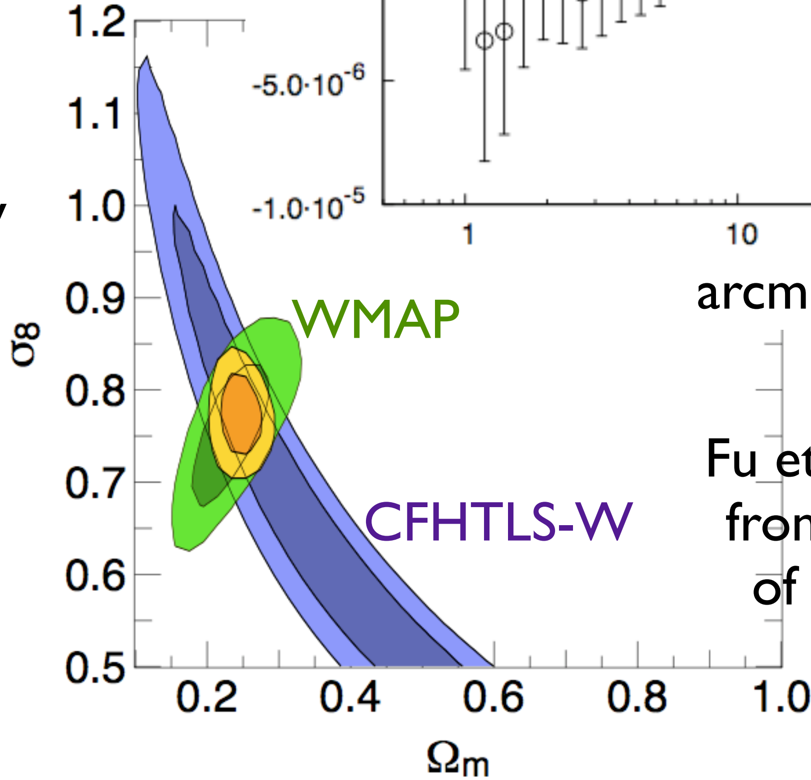
NASA, ESA, C. Heymans (University of British Columbia), M. Gray (University of Nottingham), and the STAGES Collaboration STScI-PRC08-03

CFHTLS Wide: completed early 2009

PI: Y. Mellier

- 4m class telescope
- 1 square degree field of view
- 170 square degree survey
- 5 optical colours u,g,r,i,z
- I<24.5, zm ~ 0.8
- Data is public!





Fu et al 2008: results from 3rd year data of 50 sq degrees

PanSTARRS: started summer 2009

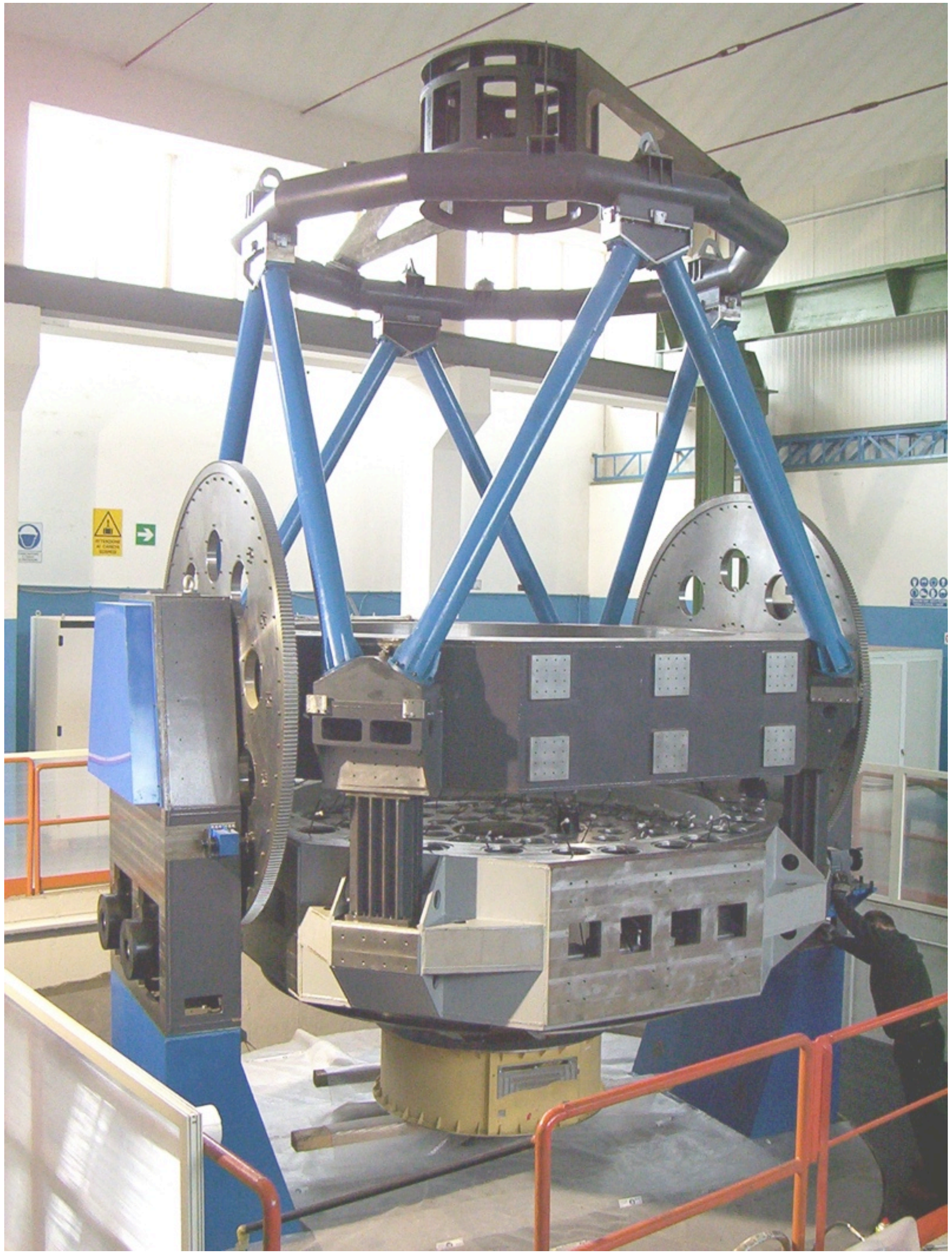
PI: N. Kaiser

- 1.8m class telescope
- 7 square degree field of view
- All sky survey
- 4 optical colours g,r,i,z
- r<24, zm ~ 0.6 (building up over many years)
- Very wide but shallow

KIDS: starting 2010

PI: K. Kuijken

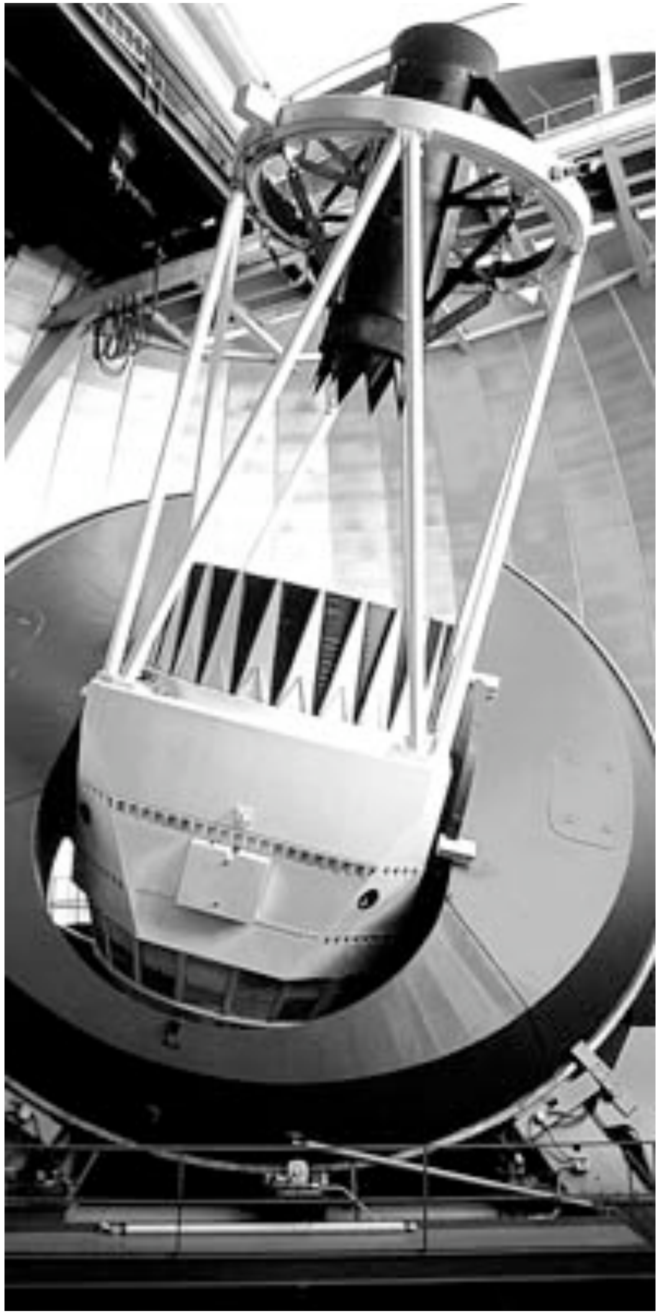
- 2.6m class telescope
- 1 square degree field of view
- 1500 sq degree survey
- 4 optical colours u,g,r,i,z + NIR from VISTA
- I<24.0, zm ~ 0.7



DES: starting 2010?

PI: J. Carlstrom

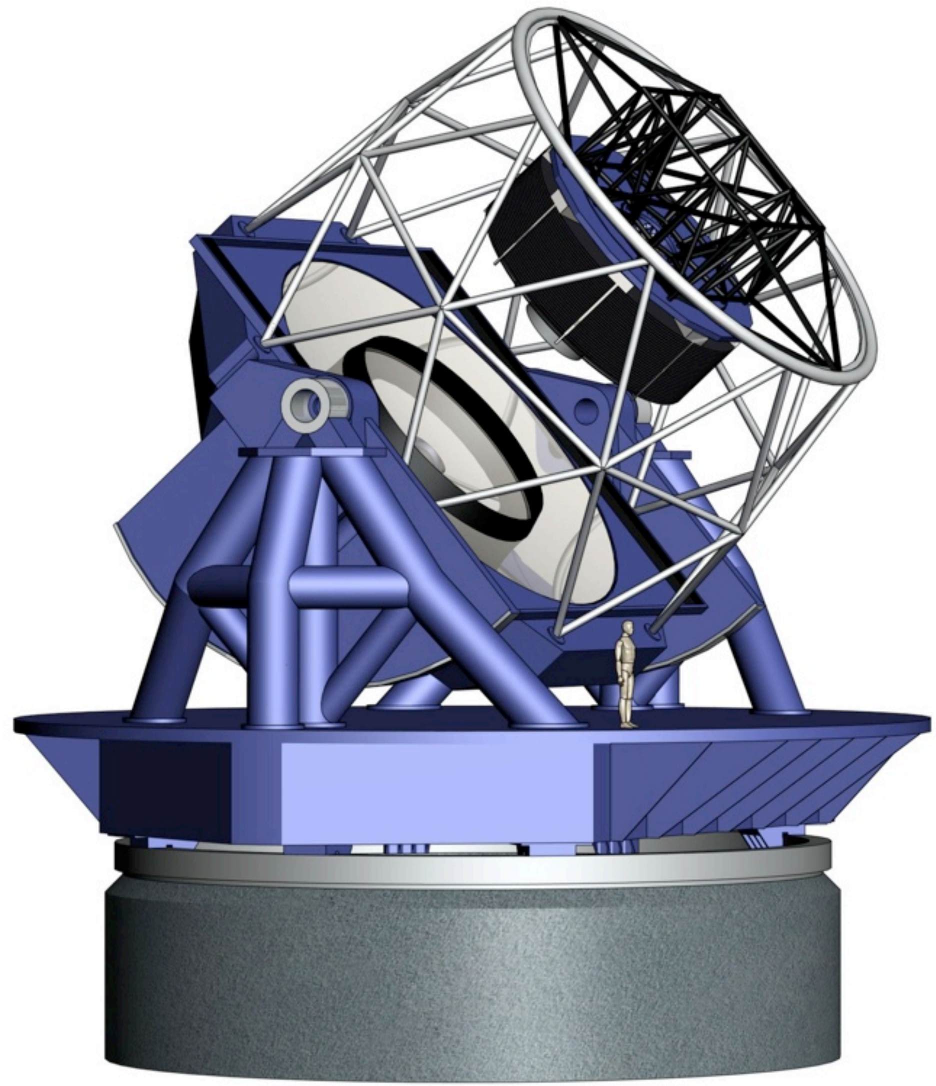
- 4m class telescope
- 3 square degree field of view
- 5000 sq degree survey
- 4 optical colours g,r,i,z + NIR from VISTA
- I<24.0, zm ~ 0.7
- Very similar to KIDS but bigger!



LSST: Starting 2014?

PI: T. Tyson

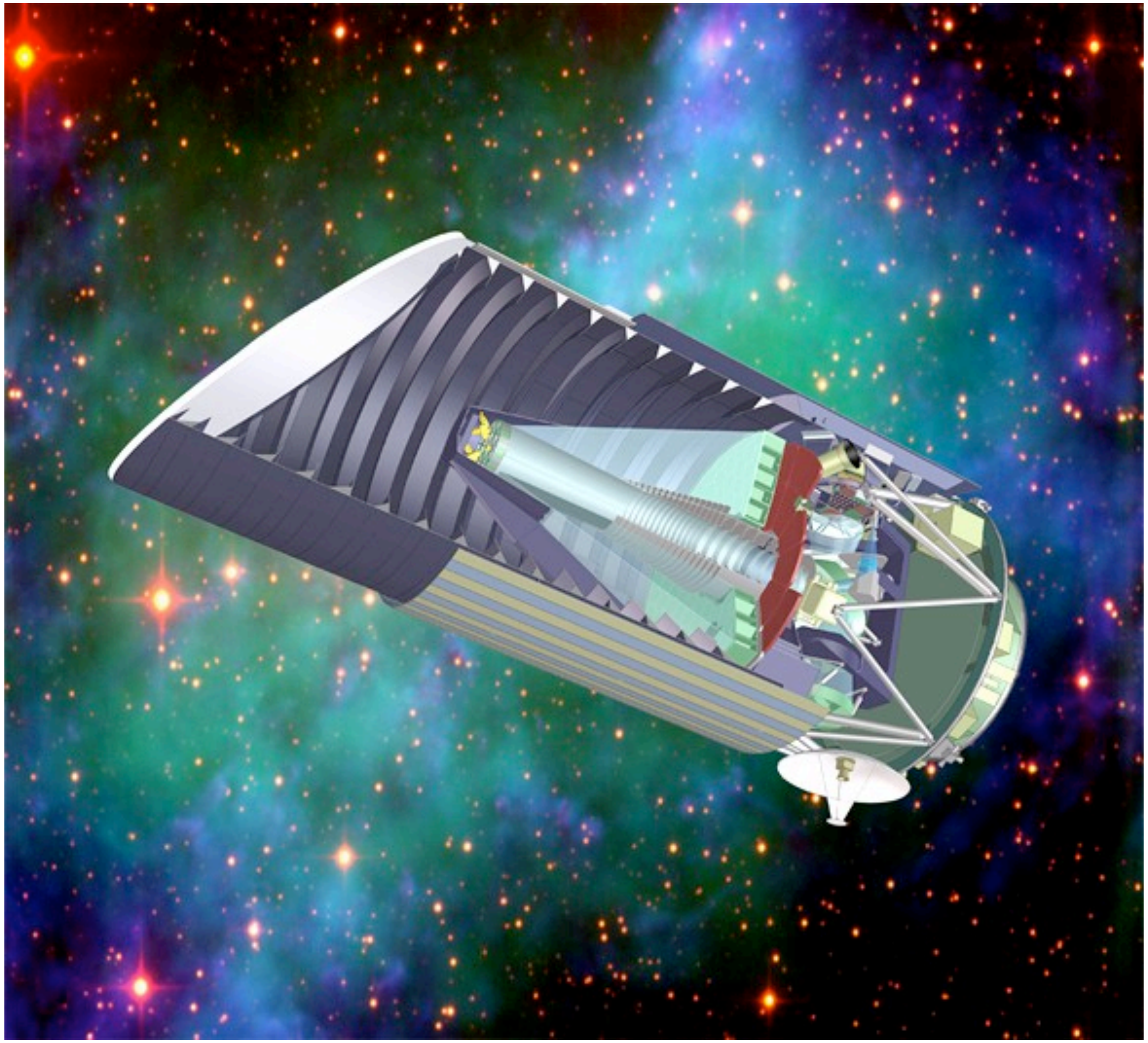
- 8.4m ground-based telescope
- 10 square degree field of view
- All sky survey
- 5 optical filters ugriz
- r<27, useable zm~1.0
- Very wide and very deep - the ultimate ground-based survey!



JDEM: Launch date 2015?

PI: S. Perlmutter

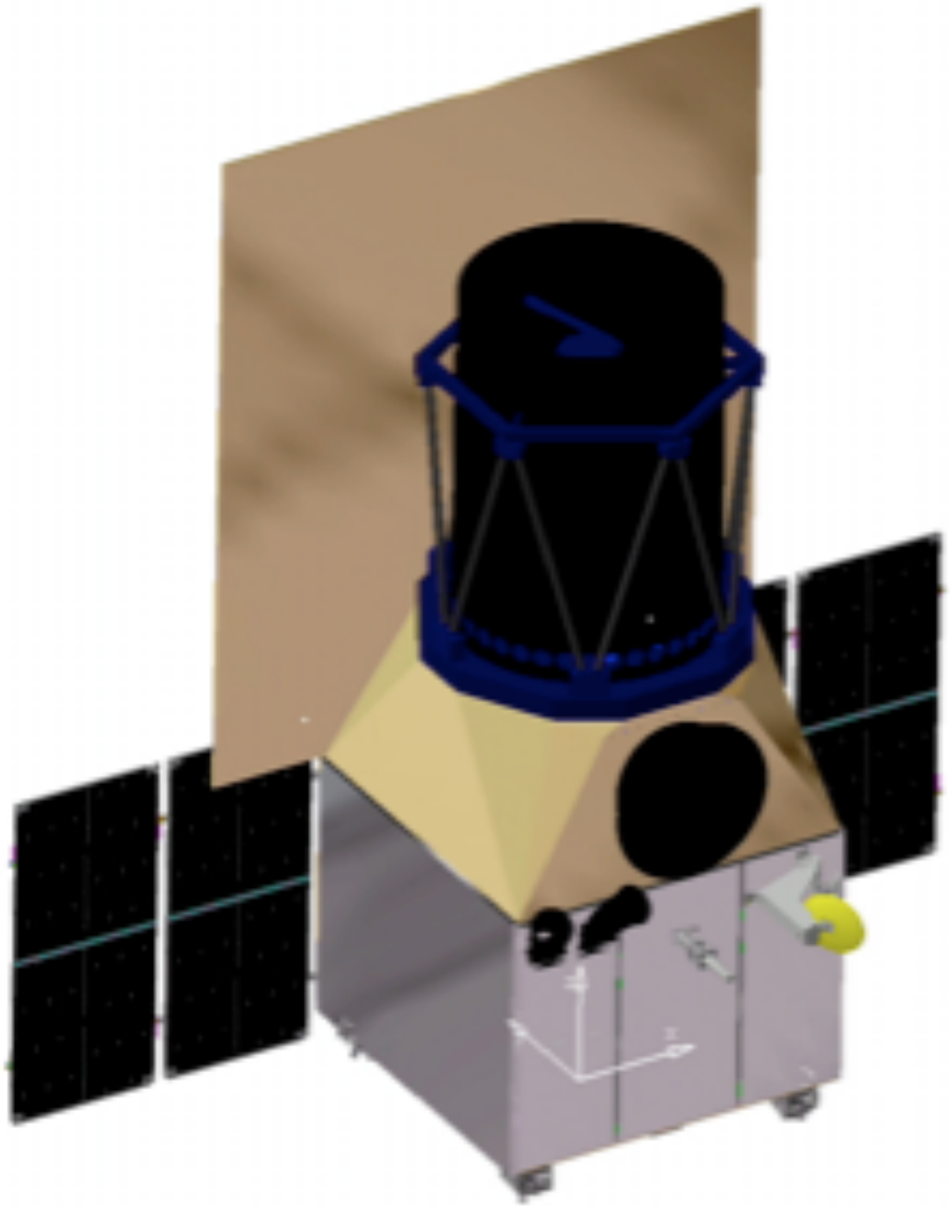
- 2m space-based telescope
- 1 square degree field of view
- 4000 sq degree survey
- 9 filters optical - nearIR
- r<26.6, zm~1.2
- Wide and deep - the ultimate space-based survey!



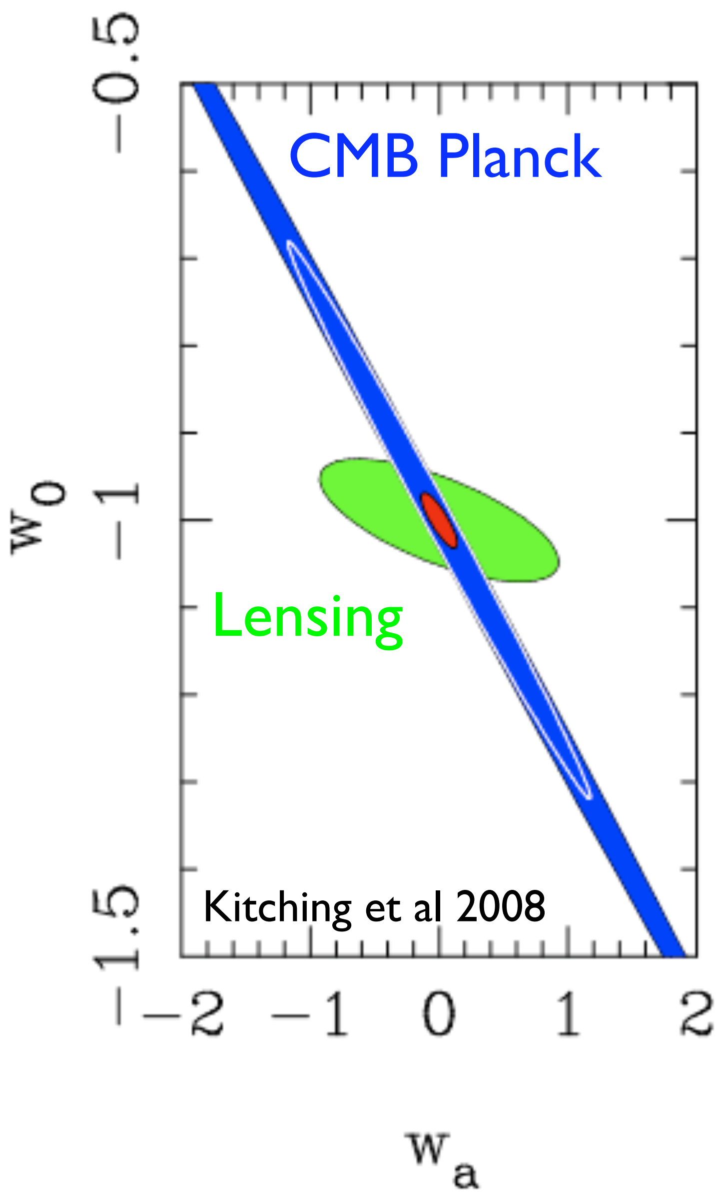
Euclid: Launch date 2015?

PI: A. Refregier

- 1.2m space-based telescope
- 0.5 square degree field of view
- 20000 sq degree survey
- 1-4 filters optical-nearIR
- R<24.5, zm~1.0
- European alternative to SNAP - very wide but shallower



Dark Energy; Cosmological constant?



- Predictions for Euclid (although very similar for the other surveys)
- 3D lensing helps break the degeneracy between a cosmological constant or an evolving dark energy model
- Combining with other cosmological probes such a SN or BAO improve things still further
- This is an exciting time to be getting into weak gravitational lensing - it's tricky but the potential makes it worth the effort!

The END

- Thanks for listening and working so hard throughout the workshop!
- Now we'll listen to your presentations!