# Mass reconstruction and tests for systematics

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# Outline

- You have a shear catalogue with photometric redshifts. What are you going to do with it?
- Mass reconstruction
- Systematics
- Todays Practical

# Lensing + photometric redshifts

- With a shear catalogue and a photo-z catalogue you could:
  - Investigate the shear-ratio test (constrain cosmology)

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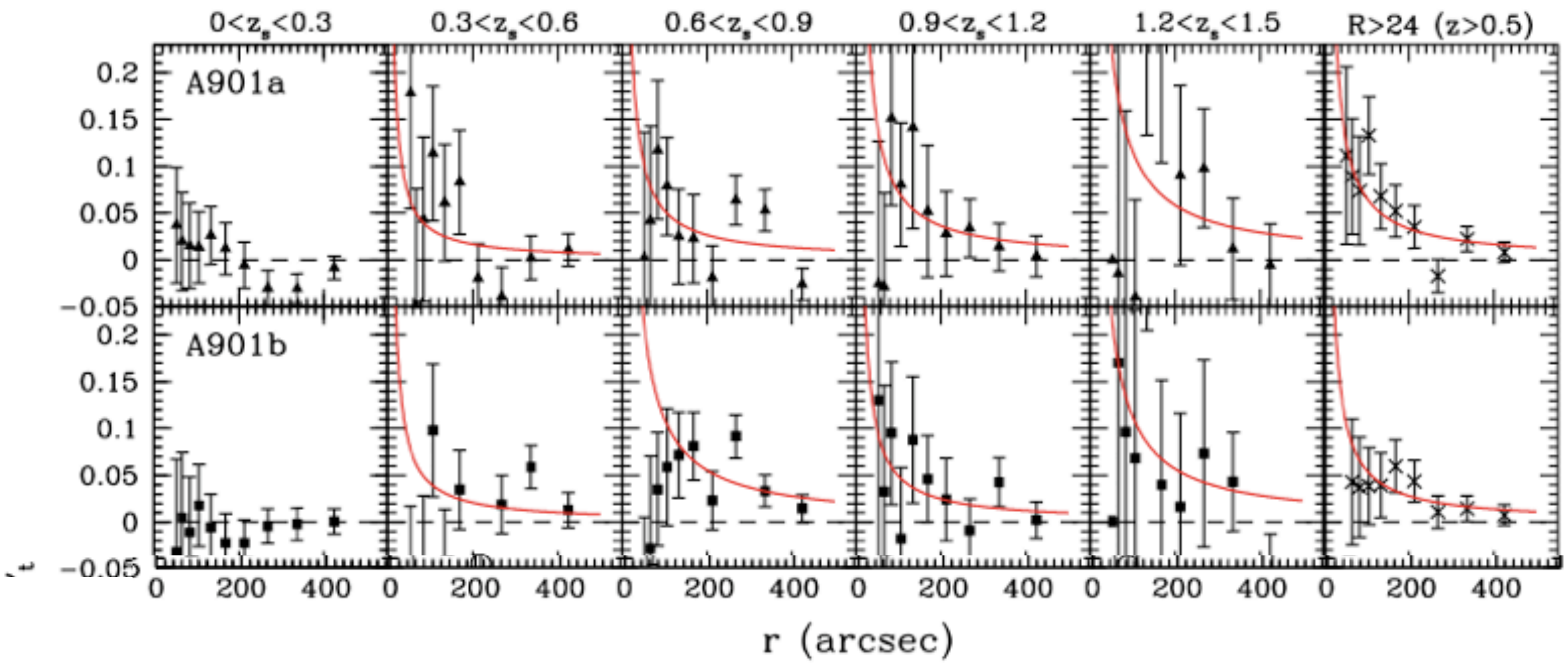
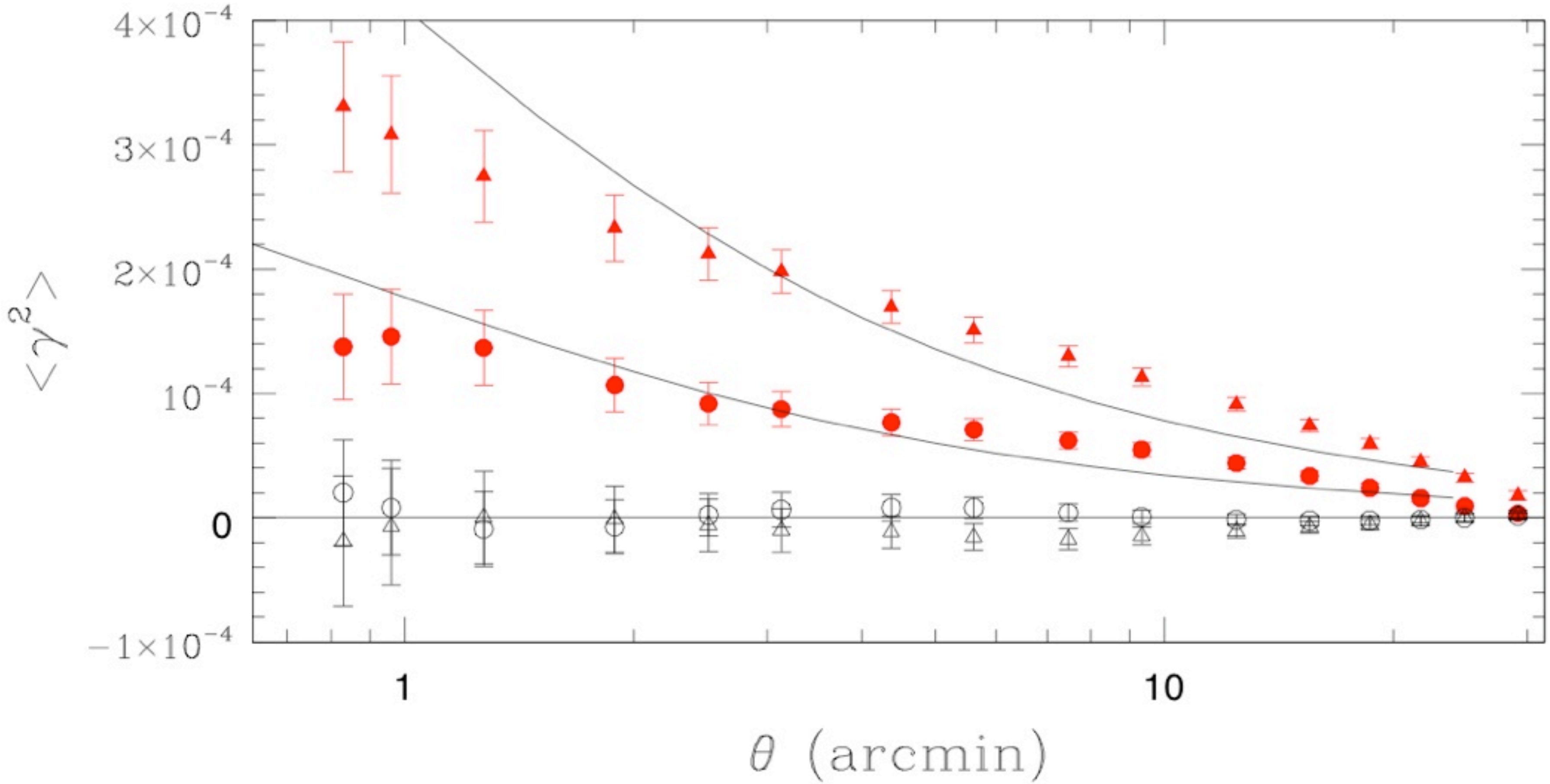



Taylor et al 2003

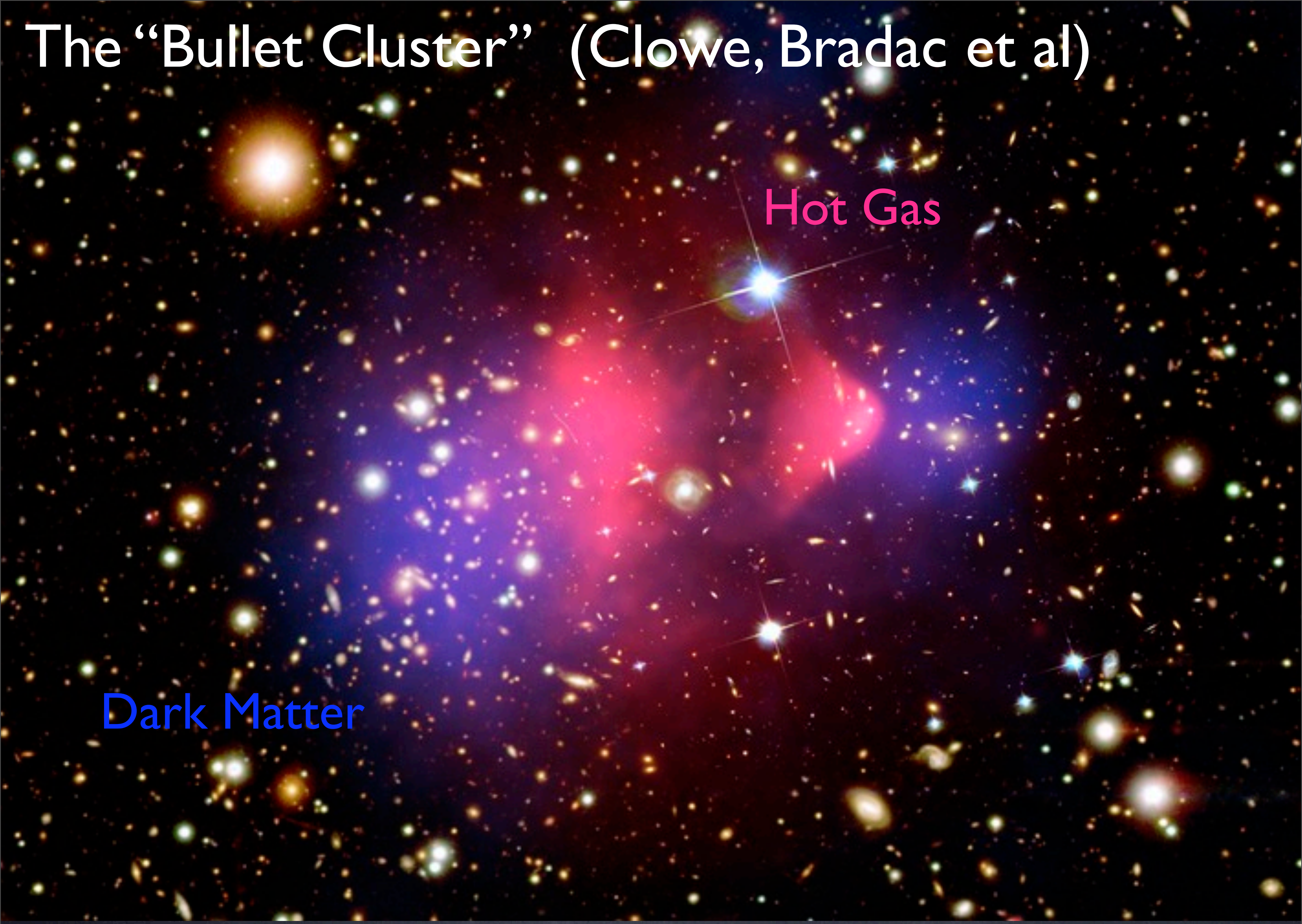
# Lensing + photometric redshifts

- Cosmic shear tomography




Sembolini et al. First results from CFHTLS Deep data

# The "Bullet Cluster" (Clowe, Bradac et al)



# From shapes to mass

From week 1 we know the relationship between

- convergence ($\kappa$ - the projected surface mass density)
- shear($\gamma$ - the measurable lensing distortion)
- lensing potential ($\psi$)

$$\kappa(\boldsymbol{\theta}) = \frac{1}{2}(\psi_{,11} + \psi_{,22}) \quad \gamma_1(\boldsymbol{\theta}) = \tfrac{1}{2}(\psi_{,11} - \psi_{,22}) \quad \gamma_2(\boldsymbol{\theta}) = \psi_{,12}$$

We want to reconstruct the mass distribution($\kappa$) but can only measure the shear ($\gamma$)

Invert these equations to recover the mass from the shear

# From shapes to mass

We solve these equations in Fourier Space:

$$\psi(\theta) = \int dk\, e^{ik.\theta} \hat{\psi}(k)$$

recalling:

$$\psi_{,j} \rightarrow i k_j \hat{\psi}(k)$$

$$\kappa(\boldsymbol{\theta}) = \frac{1}{2}(\psi_{,11} + \psi_{,22}) \quad \gamma_1(\boldsymbol{\theta}) = \tfrac{1}{2}(\psi_{,11} - \psi_{,22}) \quad \gamma_2(\boldsymbol{\theta}) = \psi_{,12}$$

The Fourier pairs are therefore:

$$\hat{\kappa}(\mathbf{k}) = -\frac{1}{2}(k_1^2 + k_2^2)\hat{\psi}(\mathbf{k}) \quad \hat{\gamma}_1(\mathbf{k}) = -\tfrac{1}{2}(k_1^2 - k_2^2)\hat{\psi}(\mathbf{k}) \quad \hat{\gamma}_2(\mathbf{k}) = -k_1 k_2 \hat{\psi}(\mathbf{k})$$

# From shapes to mass

Finally:

$$\hat{\kappa} = \frac{(k_1^2 - k_2^2)\,\hat{\gamma}_1 + 2k_1 k_2\,\hat{\gamma}_2}{k^2}$$

- One therefore simply takes the Fourier transform of the shear fields, multiply by the coefficients, and take the inverse Fourier transform to get a mass map.

1. How do we create a continuous shear field from a galaxy catalogue?
2. How do we take a FT of a finite field?
3. We measure the reduced shear [$g = \gamma / (1+\kappa)$] not the true shear $\gamma$

# Mass reconstruction methods

- There are many mass reconstruction methods in the literature
- They differ in how they;

1. Solve the equations (Fourier with zero-padding, or maximum likelihood lensing potential analysis)
2. Smooth the data (Gaussian, adaptive, wavelets)
3. Include the reduced shear (assume $g = \gamma$ or calculate it exactly)

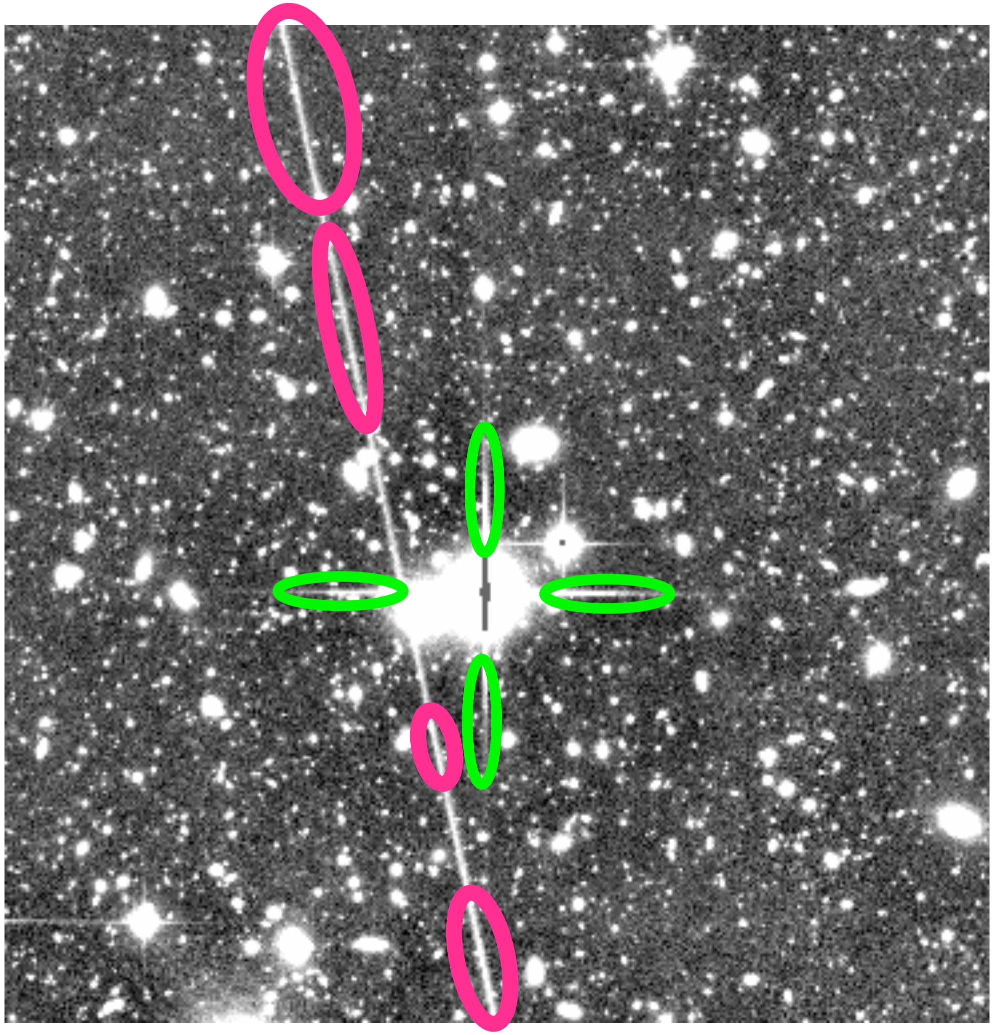
- Some References: Kaiser & Squires 1993, Seitz and Schneider 1995 and 1996, Lombardi & Bertin 1998, Van Waerbeke 2000, Starck et al 2006, Khiabanian & Dell'Antonio 2008

# Kaiser and Squires 1993

- In the practical we'll be using the simplest Fourier method from Kaiser and Squires 1993
- Reasons to use it:
  - It's very fast and relatively easy to use
  - It's public software available in Nick Kaisers imcat package (http://www.ifa.hawaii.edu/~kaiser/imcat/)
- Reasons not to use it:
  - It assumes $g = \gamma$ which is not a good assumption in the cores of clusters
  - It does not include any knowledge of a mask
- Typically this method is used to provide the "first guess" of the mass distribution which is then iterated on using a maximum likelihood method

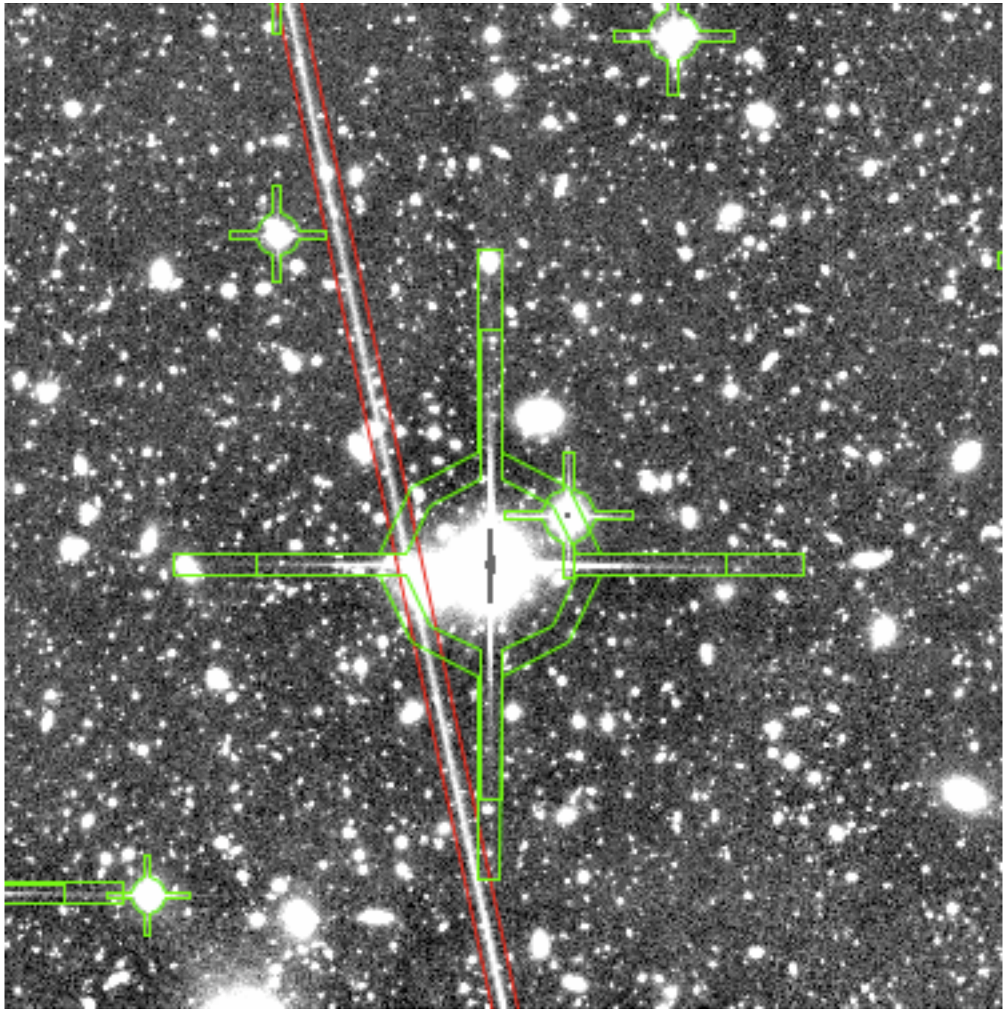
# A reminder about masks

- A common mistake in weak lensing analyses is to include objects in the catalogue that aren't galaxies
- Satellite trails are detected by source extraction software as many discrete aligned objects
- Diffraction spikes from bright stars give a negative cluster signal!
- These objects need to be detected and removed



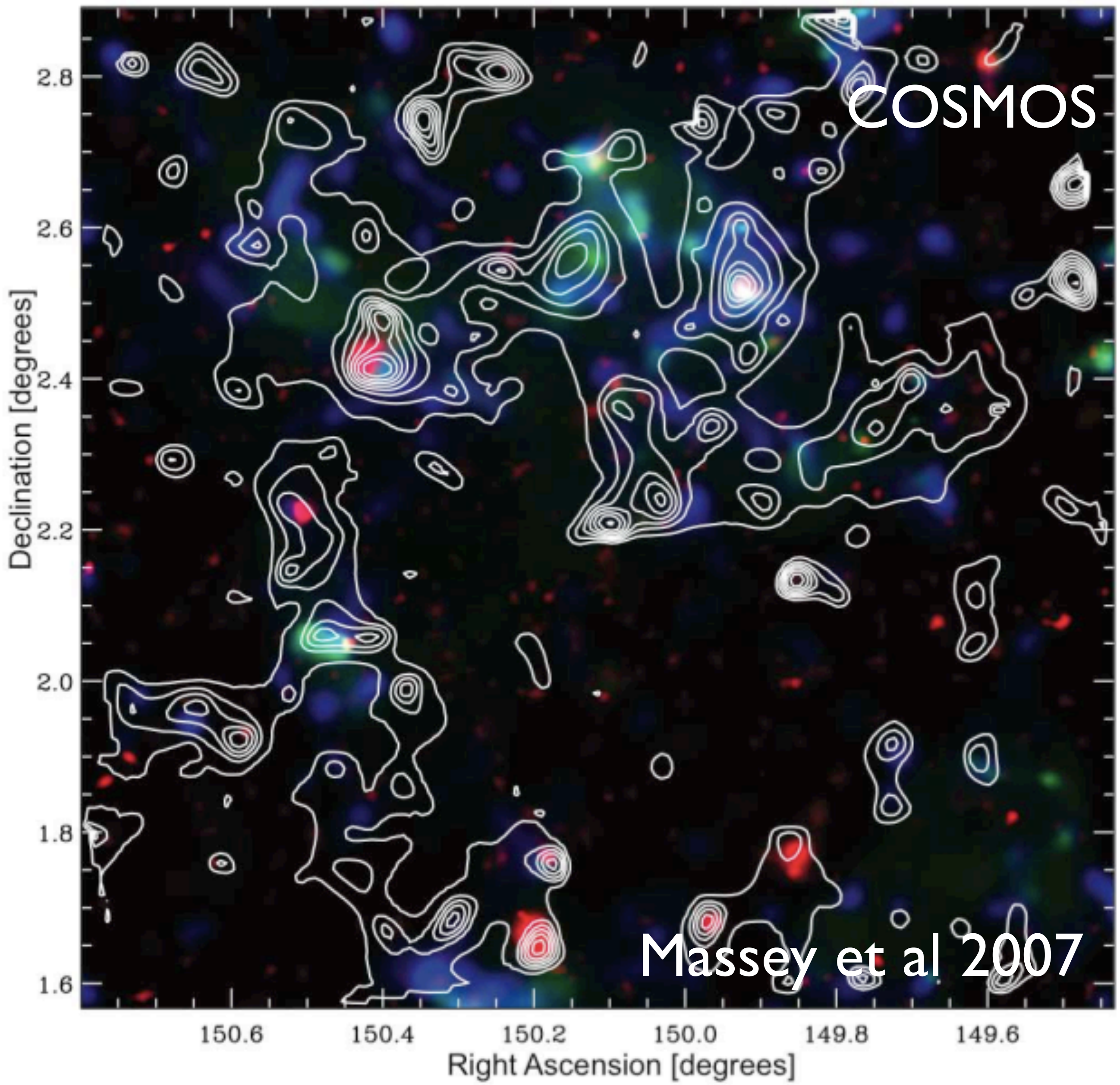
# Theli automated masking

- Masking is automated within Theli (to some level)
  - Stellar catalogues can be used to identify bright stars and a default mask can be scaled based on its magnitude
  - Bright satellite trails can be identified by a series of connected objects
- Remember to mask your data, objects like these will seriously degrade your lensing analysis



# Systematics, noise or is that a dark halo?

“We may need to fine-tune our ideas of how galaxies form” Eric Linder in USA Today ?



# PSF residuals

- The distortion induced by the atmosphere and telescope is more than an order of magnitude larger that the distortion that you're trying to measure - have you correctly removed it?

$$\gamma_i' = \gamma_i + a_i e_i^* \tag{3.65}$$

An estimate of the shear correlation measures the true shear correlation plus a systematic PSF component,

$$\langle \gamma_i' \gamma_j' \rangle = \langle \gamma_i \gamma_j \rangle + a_i a_j \langle e_i^* e_j^* \rangle \,. \tag{3.66}$$

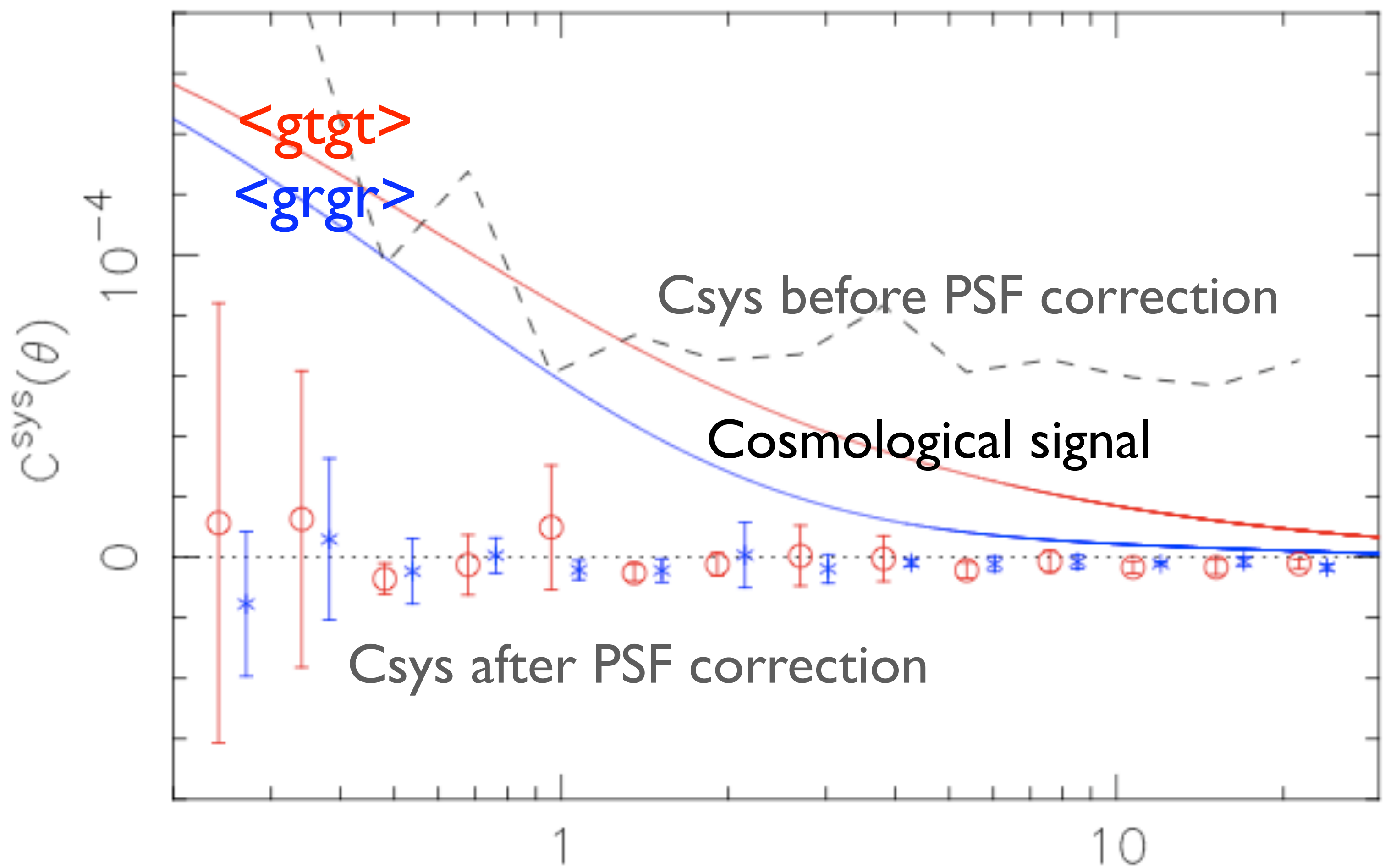
Noting that

$$\langle \gamma_i' e_j^* \rangle = a_i \langle e_i^* e_j^* \rangle \,, \tag{3.67}$$

as $\langle \gamma_i e_j^* \rangle = 0$, we find that uncorrected ellipticities add a component to the measured correlation function $c_k^{\rm sys}$ where

$$c_k^{\rm sys} = a_i a_j \langle e_i^* e_j^* \rangle = \frac{\langle \gamma_i' e_j^* \rangle \langle \gamma_j' e_i^* \rangle}{\langle e_i^* e_j^* \rangle}. \tag{3.68}$$

# PSF residuals

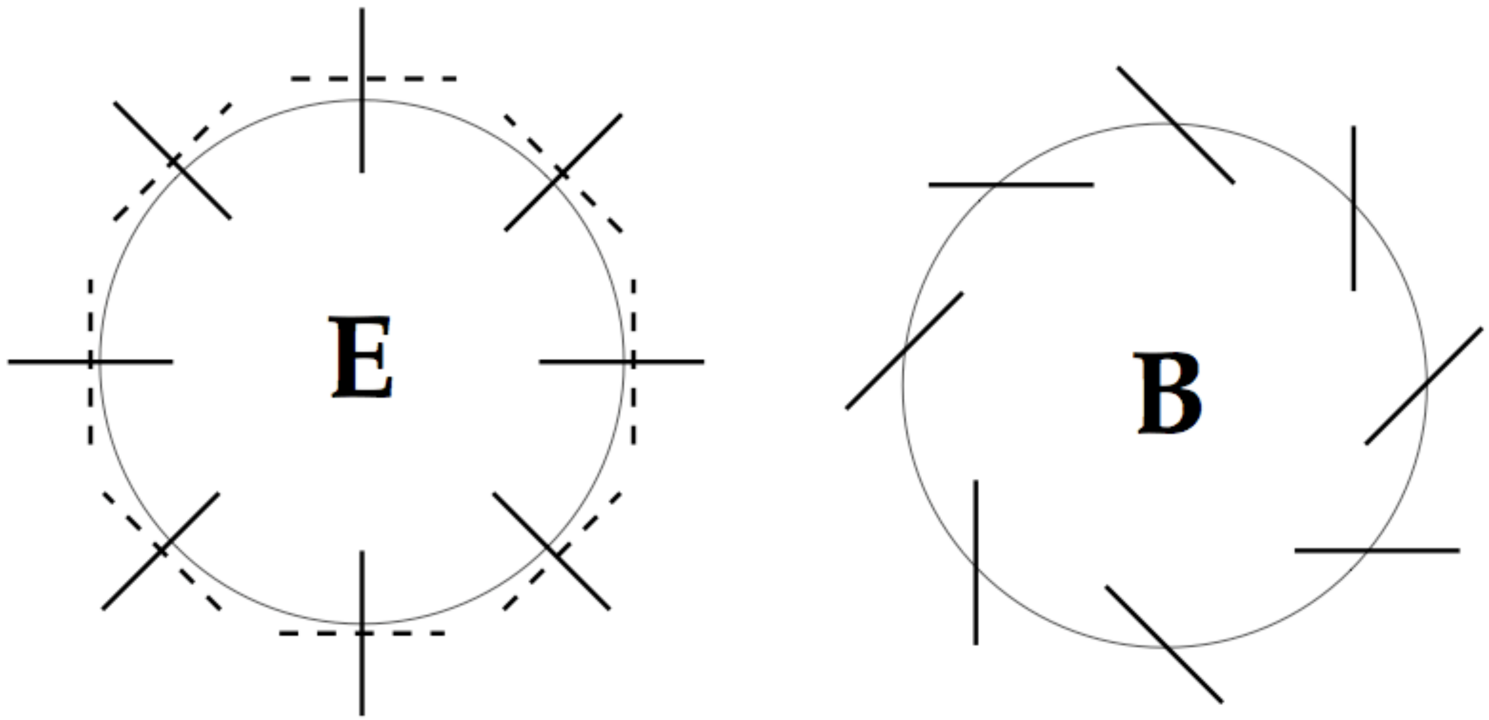



This is a very useful statistic

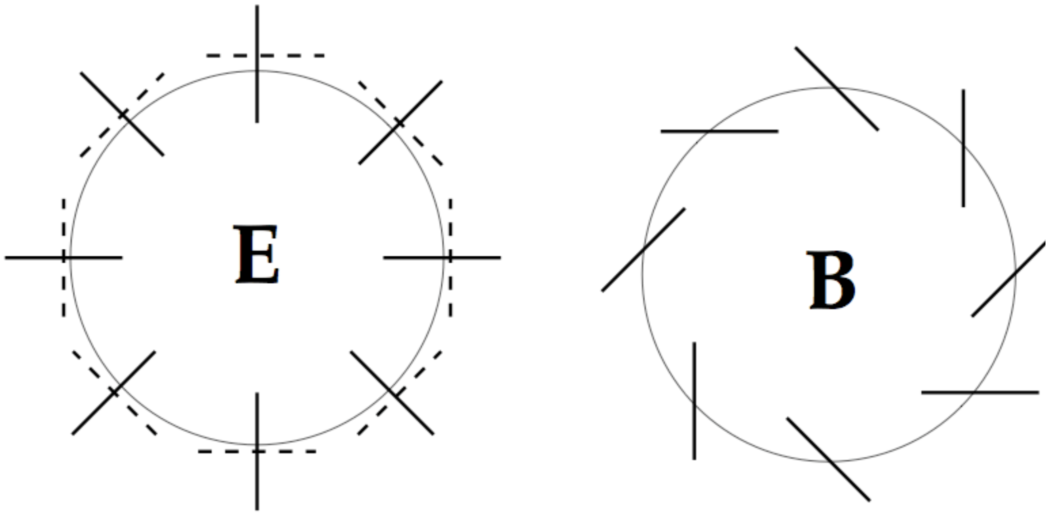
$$c_k^{\rm sys} = a_i a_j \langle e_i^* e_j^* \rangle = \frac{\langle \gamma_i' e_j^* \rangle \langle \gamma_j' e_i^* \rangle}{\langle e_i^* e_j^* \rangle}.$$

# E and B modes

Pure lensing only produces E-modes. If there are Bmodes in your analysis on large scales these can only arise from systematics



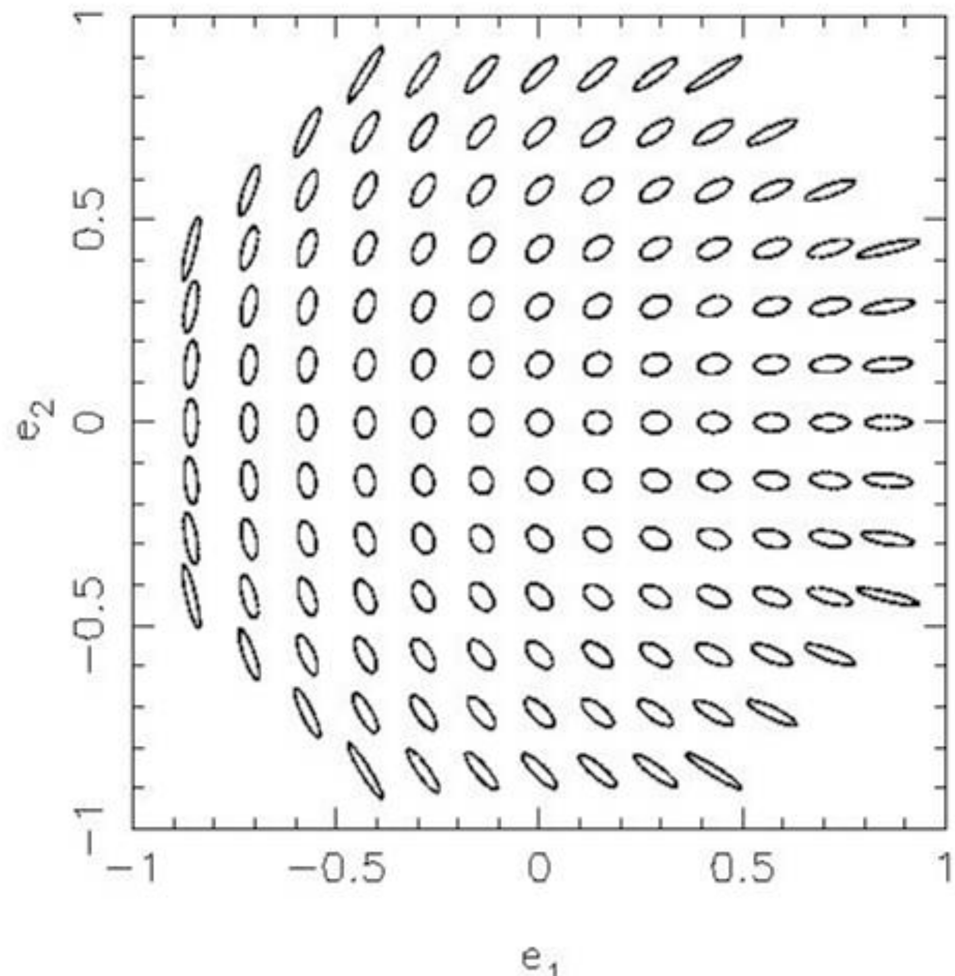
# E/B decomposition the easy way




- If you rotate all your galaxies by 45 degrees you swap your E and B mode.

$$e_1^{rot} = e_2$$
$$e_2^{rot} = -e_1$$

- Repeating your analysis with your rotated catalogue you create a Bmode analysis.



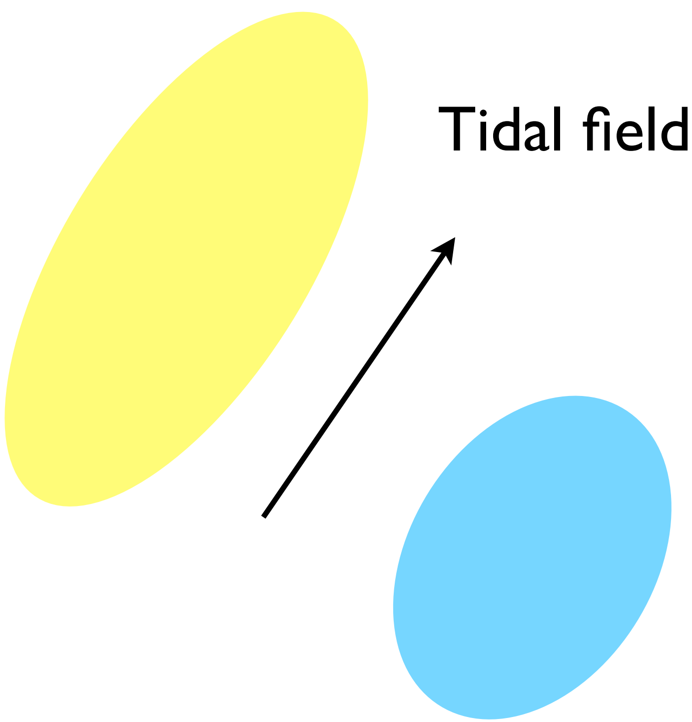

See Schneider, Van Waerbeke & Mellier 2002 for 2pt statistical E/B decomposition

# Physical systematics:

Observed signal — Cosmological signal

$$< e_i^{obs} e_j^{obs} > = < e_i^s e_j^s > + < \gamma_i e_j^s > + < e_i^s \gamma_j > + < \gamma_i \gamma_j >$$

Intrinsic galaxy alignment — Shear-ellipticity correlation




- Weak lensing coherently distorts galaxy images making nearby galaxies appear aligned.
- The process of galaxy formation could however mimic this effect.
- Using N-body simulations we have quantified the amplitude of this effect - with redshift information it should b possible to remove these sources of systematics.

For more info see: Heymans et al 2006 and references within

# Systematics:

- From the Dark Energy Task Force (Albrecht et al)
  - If systematic errors can be controlled, weak lensing is '*likely to be the most powerful individual ... technique, and also the most powerful component in a multi-technique program*' for studying Dark Energy
- It's very important that you understand your systematics and include them in your error budget. Too many lensing papers have been published to date without full systematic error analysis.

http://www.roe.ac.uk/~heymans/KSBf90_for_DUEL/Practical_2.html

DUEL Home | KSBf90.param | findstars.f90 | psffit.f90 | gal_correct.f90 | gal_select.f90
mass recon | Practical 1 | Practical 2 | Download Lecture Notes


## Practical 2:

In this Practical you will use KSBf90 to analyse CFHTLS Deep data and produce a dark matter mass map! It follows the same initial steps (1-6) as Practical 1. Don't forget to edit the fitsname in your scripts to the D1 data name D1_i_V1.6A_Paris.cut.fits!

1) **Download and unpack** KSBf90.tar if you haven't done this already

This contains a Makefile and pre-compiled 32-bit Linux executables. At the IAP only some of the computers have the cfitsio routines installed so the Makefile will not compile on all machines. However you should be able to use the pre-compiled executables.

**2) Set your directories as follows (edit)**

```
setenv dataDIR /Users/heymans/Paris_DUEL/images        # Where your D1 images are
setenv CATDIR /Users/heymans/Paris_DUEL/catalogues     # Where your D1 catalogues
are
setenv KSBDIR /Users/heymans/Paris_DUEL/KSBf90         # Where your KSBf90 software
is
```