Separating weak lensing and intrinsic alignment signals using radio observations

Lee Whittaker

MANCHESTER 1824
The University of Manchester

The intrinsic alignment problem

- Assuming we are working well within the weak lensing regime, the observed ellipticity can be expressed as

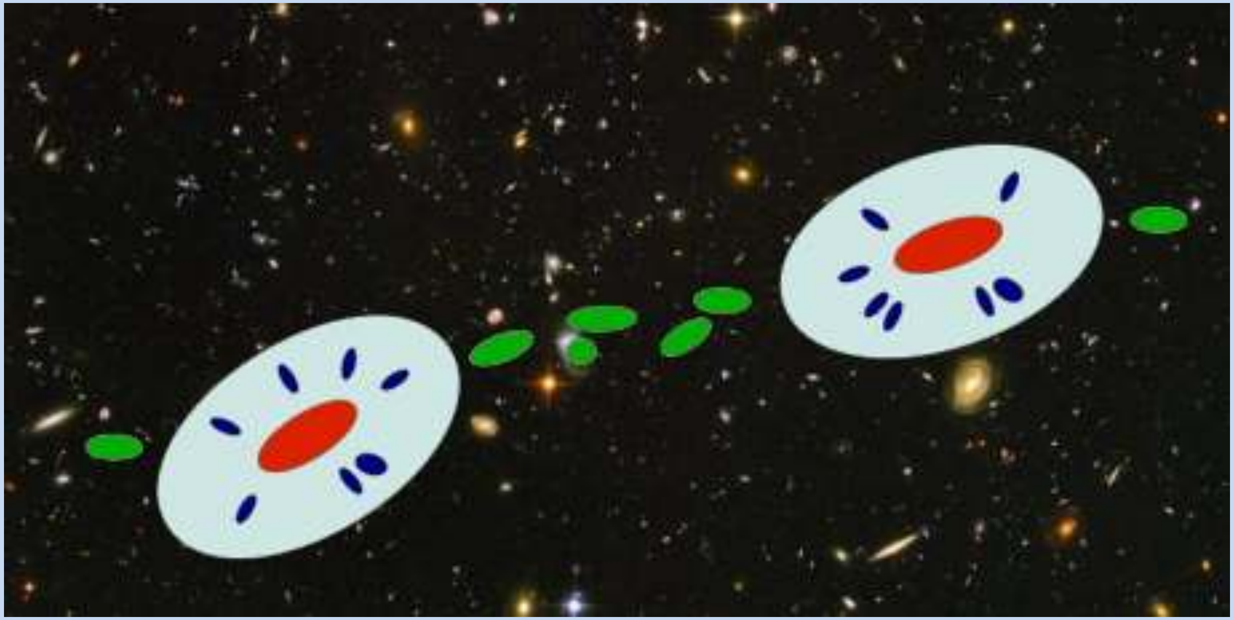
$$\boldsymbol{\epsilon}^{\mathrm{obs}} = \boldsymbol{\epsilon}^{\mathrm{int}} + \boldsymbol{\gamma} + \boldsymbol{\epsilon}^{\mathrm{error}}$$

- Further assuming that the average intrinsic ellipticity is zero, the standard shear estimator is

$$\widehat{\boldsymbol{\gamma}} = \frac{1}{N}\sum_{i=1}^{N} \boldsymbol{\epsilon}_i^{\mathrm{obs}}$$

- The error on the estimator is

$$\sigma_{\widehat{\gamma}} = \sqrt{\frac{\sigma_\epsilon^2 + \sigma^2}{N}}$$



- During formation, tidal effects can cause galaxies to form such that, on average, they radially align with the large scale structure.
- This "intrinsic alignment" of the galaxies mimics a shear signal.

$$\boldsymbol{\epsilon}^{\mathrm{obs}} = \boldsymbol{\gamma}^{\mathrm{IA}} + \boldsymbol{\gamma} + \boldsymbol{\epsilon}^{\mathrm{noise}}$$

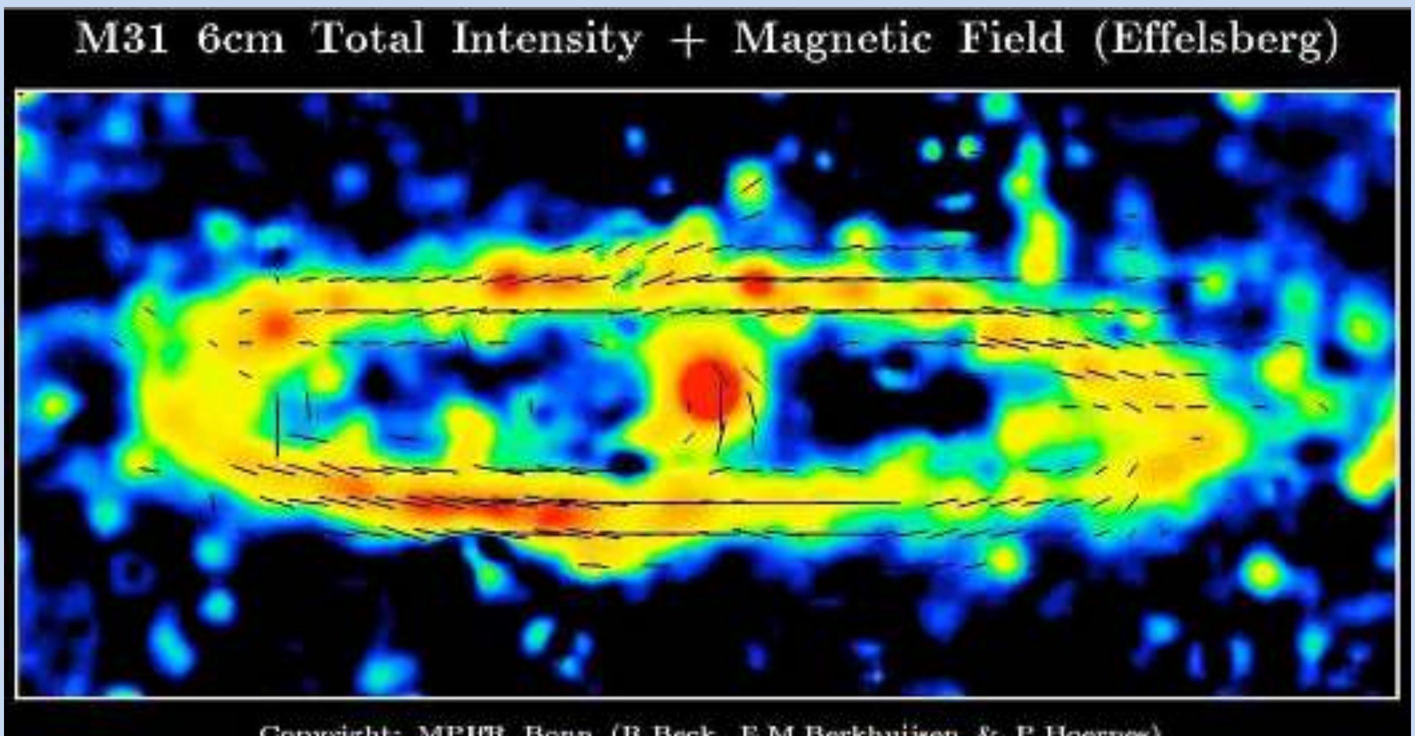
- There is an anti-correlation between the shear and IA signals.
- The measured shear power spectrum is

$$\hat{C}_l^{\mathrm{GG}} = C_l^{\mathrm{GG}} + C_l^{\mathrm{II}} + C_l^{\mathrm{GI}} + C_l^{\mathrm{IG}} + C_l^{\mathrm{NN}}$$

Polarization as an indicator of intrinsic alignment in radio weak lensing

Michael L. Brown[1,2★] and Richard A. Battye[3★] (2011)

- Electrons orbiting in the galactic plane emit polarized synchrotron radiation.
- The integrated polarization position angle is unaffected by lensing (e.g. Kronberg et. al. 1991).



- We can construct a direct shear estimator that includes information about the polarization position angle.
- The estimator is given as

$$\hat{\boldsymbol{\gamma}} = \mathbf{A}^{-1}\boldsymbol{b} \qquad \hat{\boldsymbol{n}}_{\boldsymbol{i}} = \begin{pmatrix} \sin 2\hat{\alpha}_i^{\text{int}} \\ -\cos 2\,\hat{\alpha}_i^{\text{int}} \end{pmatrix}$$

- Where

$$\mathbf{A} = \sum_i \omega_i \hat{\boldsymbol{n}}_i \hat{\boldsymbol{n}}_i^T \quad \text{and} \quad \boldsymbol{b} = \sum_i \omega_i \left(\boldsymbol{\epsilon}_i^{\text{obs}} \cdot \hat{\boldsymbol{n}}_i\right)\hat{\boldsymbol{n}}_i$$

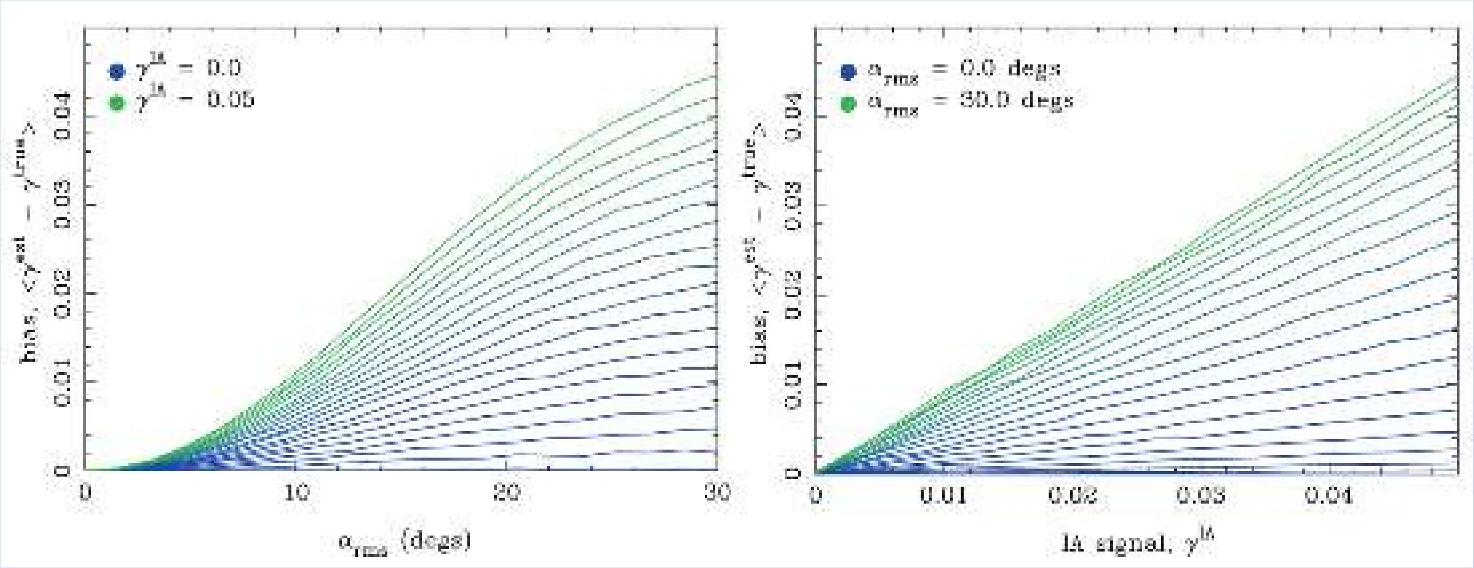
- The IA signal can then be estimated as

$$\hat{\boldsymbol{\gamma}}^{\text{IA}} = \frac{1}{N}\sum_i \boldsymbol{\epsilon}_i^{\text{obs}} - \hat{\boldsymbol{\gamma}}$$

- Assuming a small IA signal, the measurement error on this estimator is

$$\sigma_{\hat{\gamma}} = \sqrt{\frac{2\sigma_\epsilon^2(1-\beta_4) + 2\sigma^2}{N}} \quad \text{where} \quad \beta_4 = \langle \cos(4\delta\alpha^{\text{int}}) \rangle$$

- In the presence of a non-zero IA signal and non-zero measurement errors on α_i^{int}, there is a small bias in the estimator:

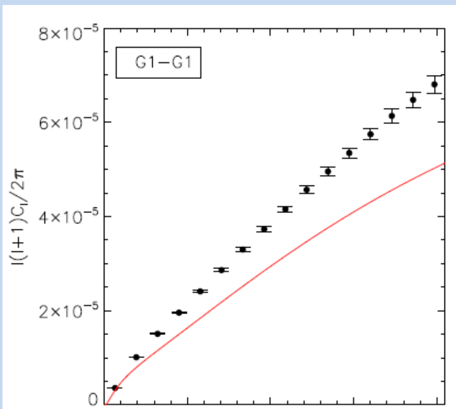


Brown & Battye 2011

Tests on simulations

- We constructed shear and IA maps using a ΛCDM model, which takes into account all possible auto and cross-correlations.

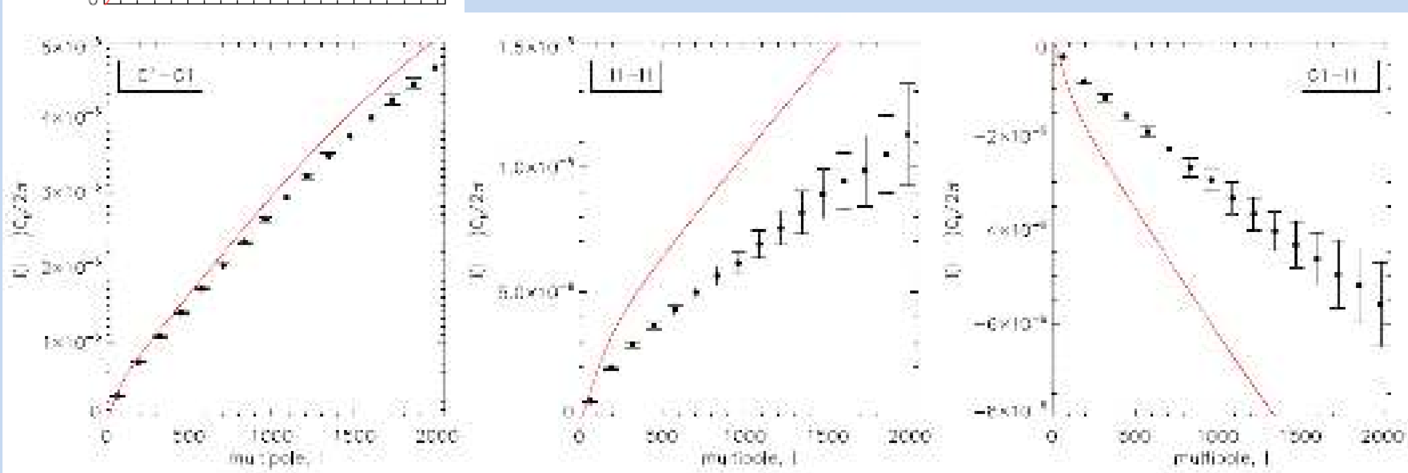
ST



- We reconstructed the shear power spectra using the standard method (ST) and the Brown & Battye estimator (BB).

$$\hat{C}_l^{\mathrm{GG}} = C_l^{\mathrm{GG}} + C_l^{\mathrm{II}} + C_l^{\mathrm{GI}} + C_l^{\mathrm{IG}} + C_l^{\mathrm{NN}}$$

BB

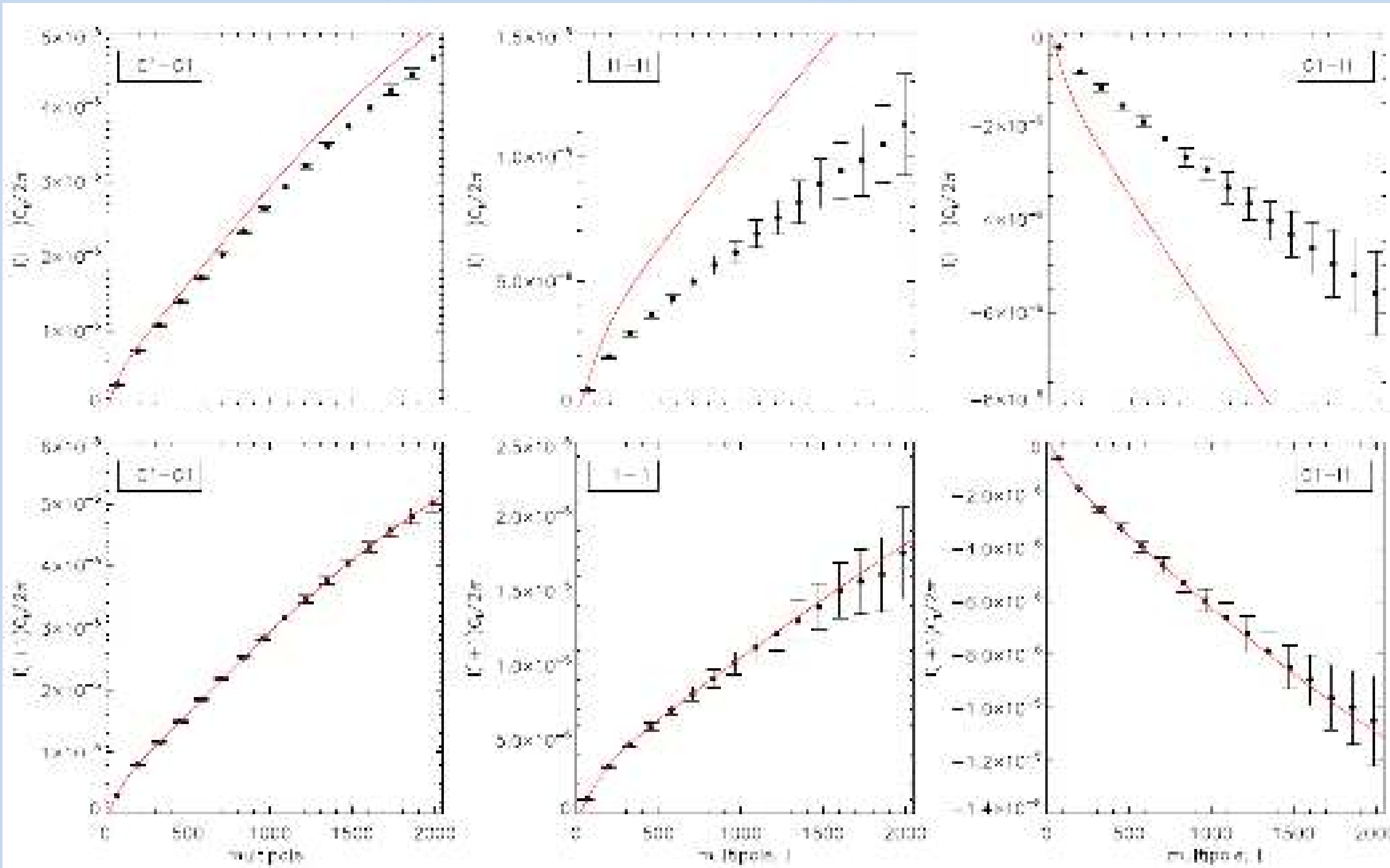


Whittaker et al. 2015

- This bias can be corrected for by examining how errors on the α_i^{int} propagate through the trig functions.

BB

CBB



- This correction requires a threshold number of galaxies.
- Noise in the shear estimates is model dependent.

An IA estimator using a knowledge of the intrinsic ellipticity distribution

- If we have an estimate of the intrinsic ellipticity distribution, we can estimate the IA signal using only measurements of α_i^{int}, such that (Whittaker et. al. 2014)

$$F_1\left(\left|\hat{\boldsymbol{\gamma}}^{\mathrm{IA}}\right|\right) = \frac{1}{\beta}\sqrt{\left(\frac{1}{N}\sum_i \cos 2\hat{\alpha}_i^{\mathrm{int}}\right)^2 + \left(\frac{1}{N}\sum_i \sin 2\hat{\alpha}_i^{\mathrm{int}}\right)^2}$$

And

$$\hat{\alpha}^{\mathrm{IA}} = \frac{1}{2}\tan^{-1}\left(\frac{\sum_i \sin 2\hat{\alpha}_i^{\mathrm{int}}}{\sum_i \cos 2\hat{\alpha}_i^{\mathrm{int}}}\right)$$

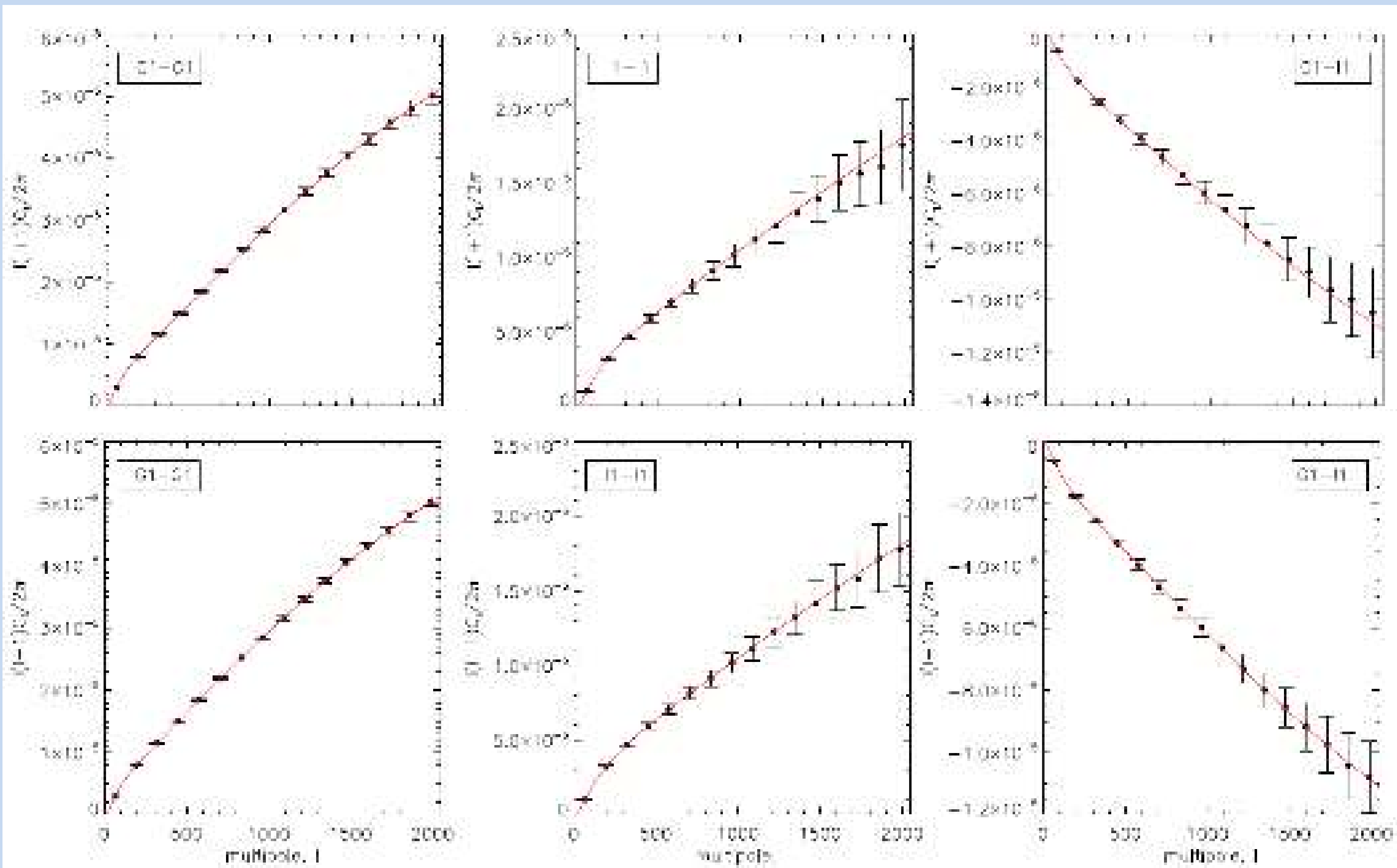
Where $\beta = \langle\cos(2\delta\alpha^{\mathrm{int}})\rangle$

- Upon recovering an estimate of the IA signal, we can recover an estimate of the shear:

$$\hat{\boldsymbol{\gamma}} = \frac{1}{N}\sum_{\boldsymbol{i}} \boldsymbol{\epsilon}_i^{\text{obs}} - \hat{\boldsymbol{\gamma}}^{\text{IA}}$$

CBB

STAO



Whittaker et al. 2015

Conclusions

- We can correct for the bias in the Brown & Battye estimator. However, we require a threshold number of galaxies for a given measurement error, and noise in the shear estimates is dependent on the input signal.
- We can recover IA estimates using measurements of α_i^{int} provided we have an accurate knowledge of the intrinsic ellipticity distribution.
- We can combine the angle only IA estimator with full ellipticity information to recover estimates of the shear.
- We hope that future observations, such as the SuperCLASS observations made by e-MERLIN and the VLA, will address some of the outstanding issues, including the fraction of galaxies with useful polarization information and the expected rms error on α_i^{int} measurements.