Separating weak lensing and intrinsic alignment signals using radio polarization information

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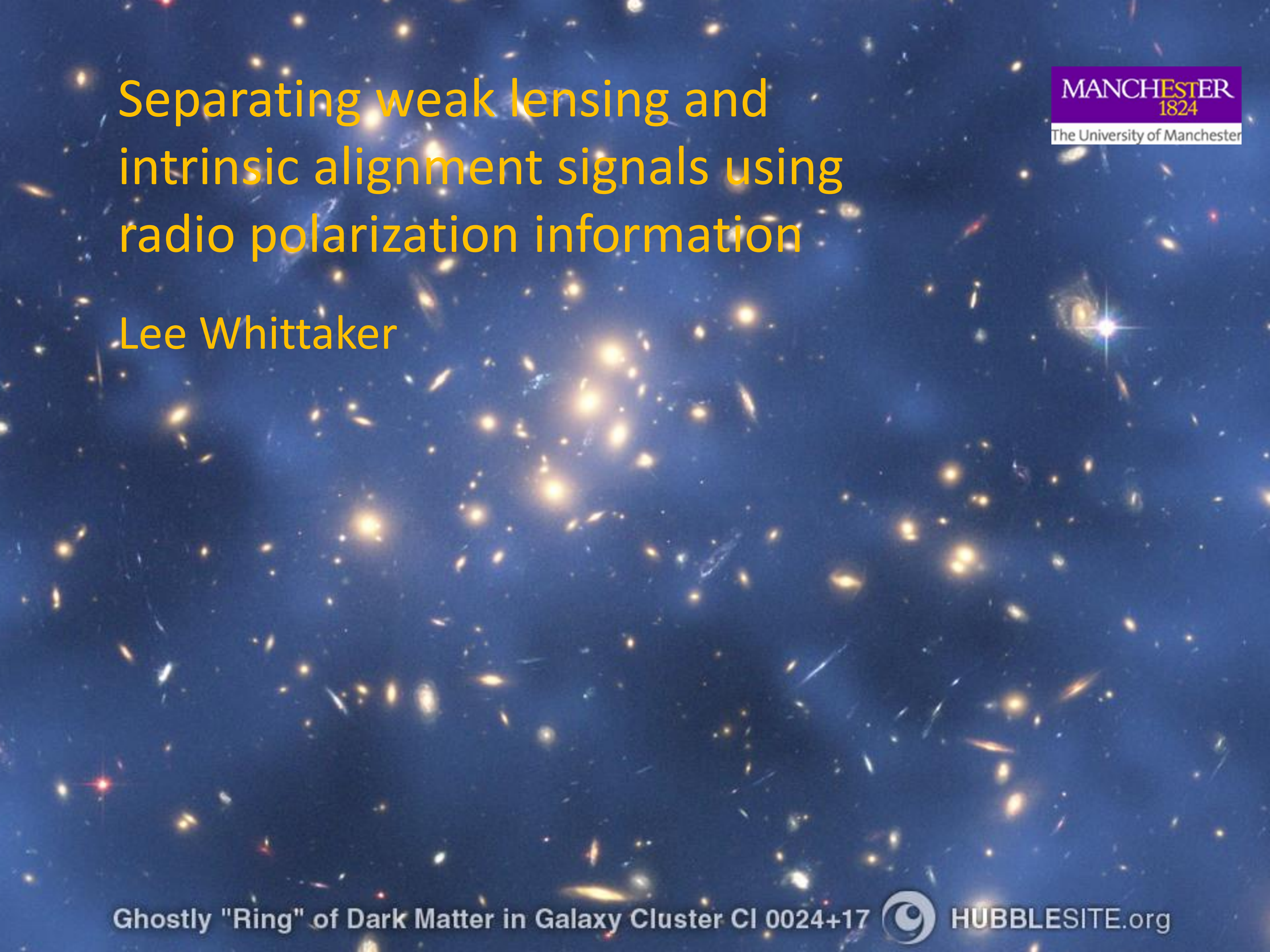


The Intrinsic alignment problem

- Assuming that 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

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

- When $\boldsymbol{\epsilon}^{\mathrm{error}}$ is zero

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

- 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.
- There is an anti-correlation between the shear and IA signals.

- Expressing $\boldsymbol{\epsilon}^{\mathrm{obs}}$ as

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

- The standard estimator is then biased, such that

$$\langle \widehat{\boldsymbol{\gamma}} \rangle = \boldsymbol{\gamma}^{\mathrm{IA}} + \boldsymbol{\gamma}$$

- The measured shear power spectrum is

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

- The first term on the RHS is the sought after shear power spectrum.

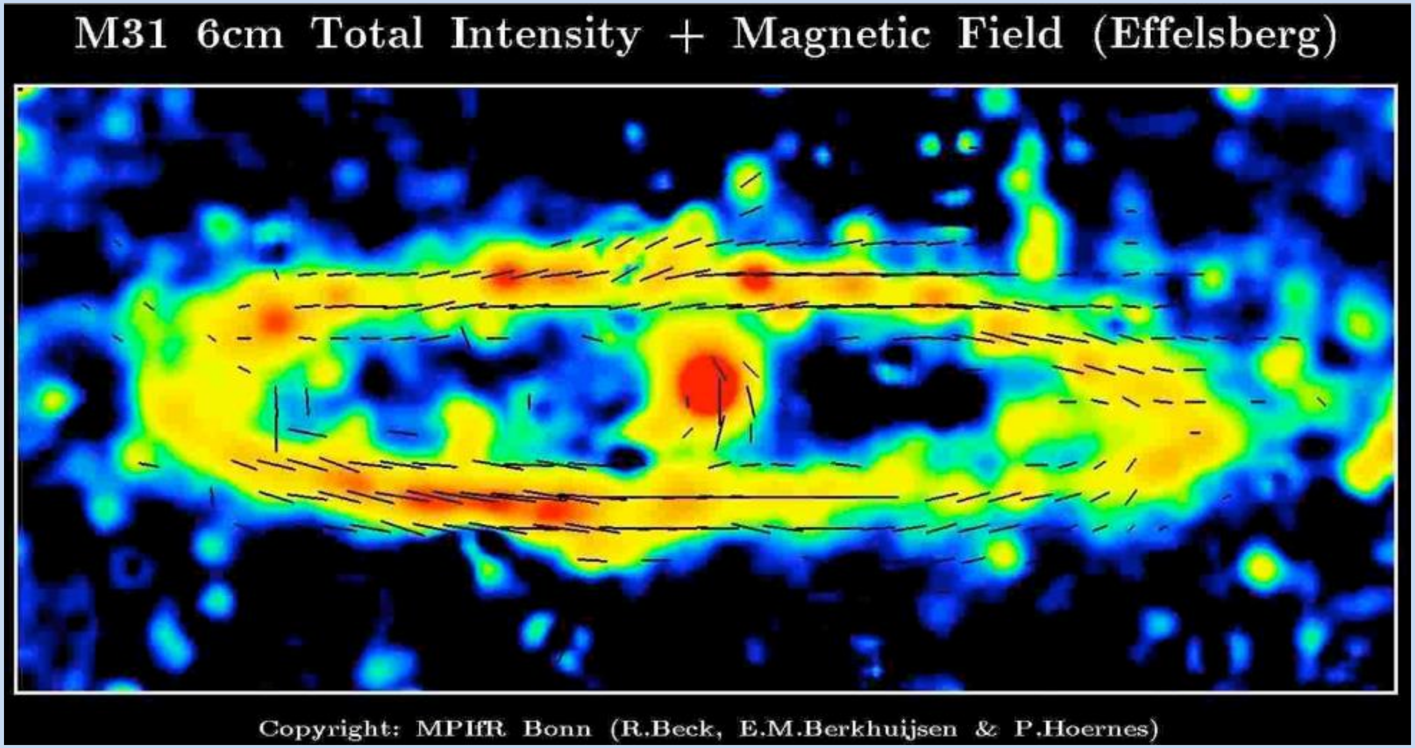
$$\hat{C}_l^{\mathrm{GG}} = C_l^{\mathrm{GG}} + C_l^{\mathrm{II}} + C_l^{\mathrm{GI}} + C_l^{\mathrm{IG}} + C_l^{\mathrm{NN}}$$

- The second term is the “II” signal.
- The next two terms are the “GI” signal.
- The last term is the contribution from noise.
- The II term is the dominant systematic for shallow surveys and can even dominate over the shear signal. A number of methods have been used to remove this signal.
- For deeps surveys the GI term is the dominant systematic. The removal of this signal is more problematic.

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 synchrotron radiation. The integrated polarization position angle is unaffected by lensing (e.g. Kronberg et. al. 1991).



- We can obtain a direct shear estimator, which includes information about the polarization position angle.
- The estimator is given as

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

- Where

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

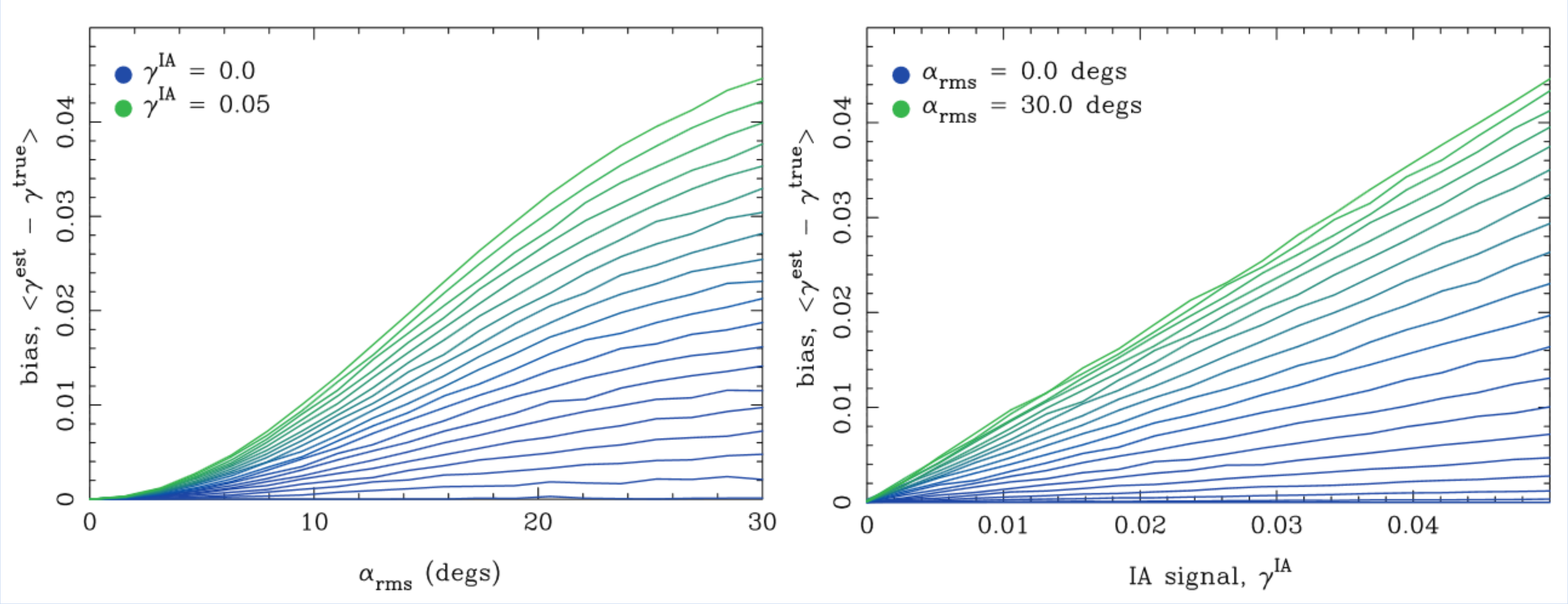
- The IA signal can the be estimated as

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

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

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

- In the presence of a non-zero IA signal and non-zero measurement error on $\alpha^{\rm int}$, there is a small bias in the estimator:



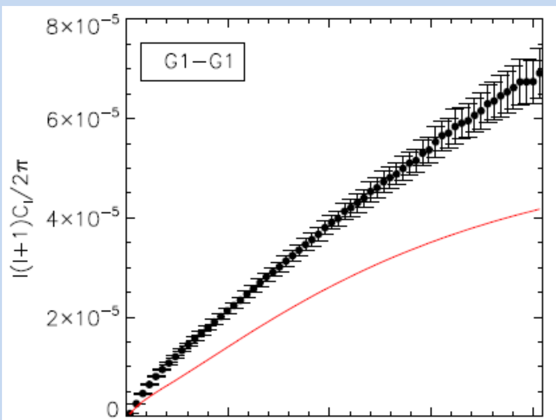
Tests on simulations

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

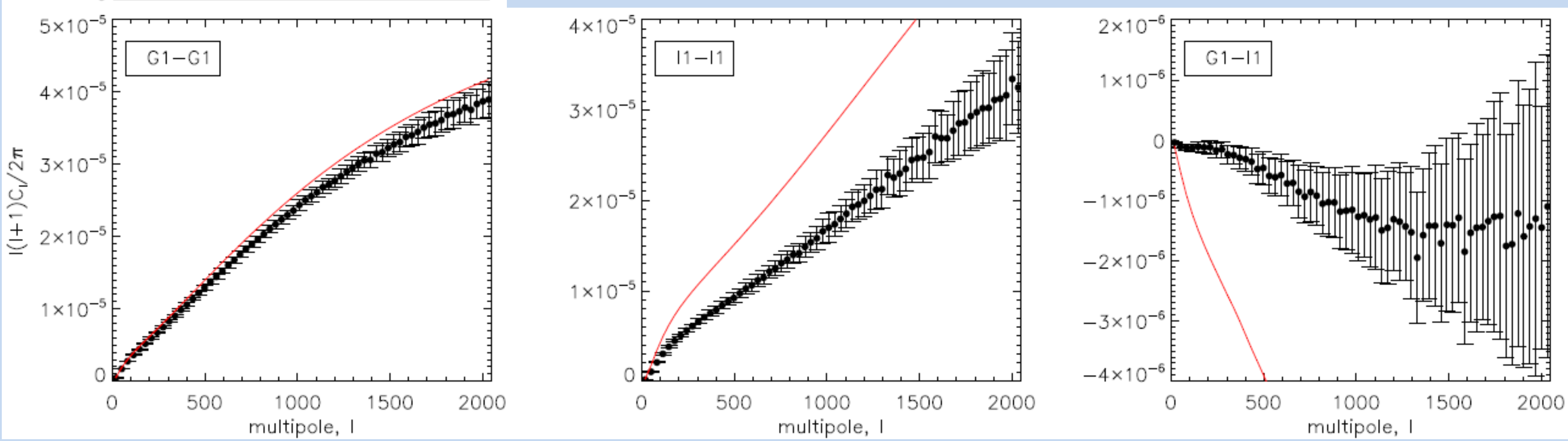
- The estimated shear power spectra using the standard method (ST) and the Brown & Battye estimator (BB).

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

ST



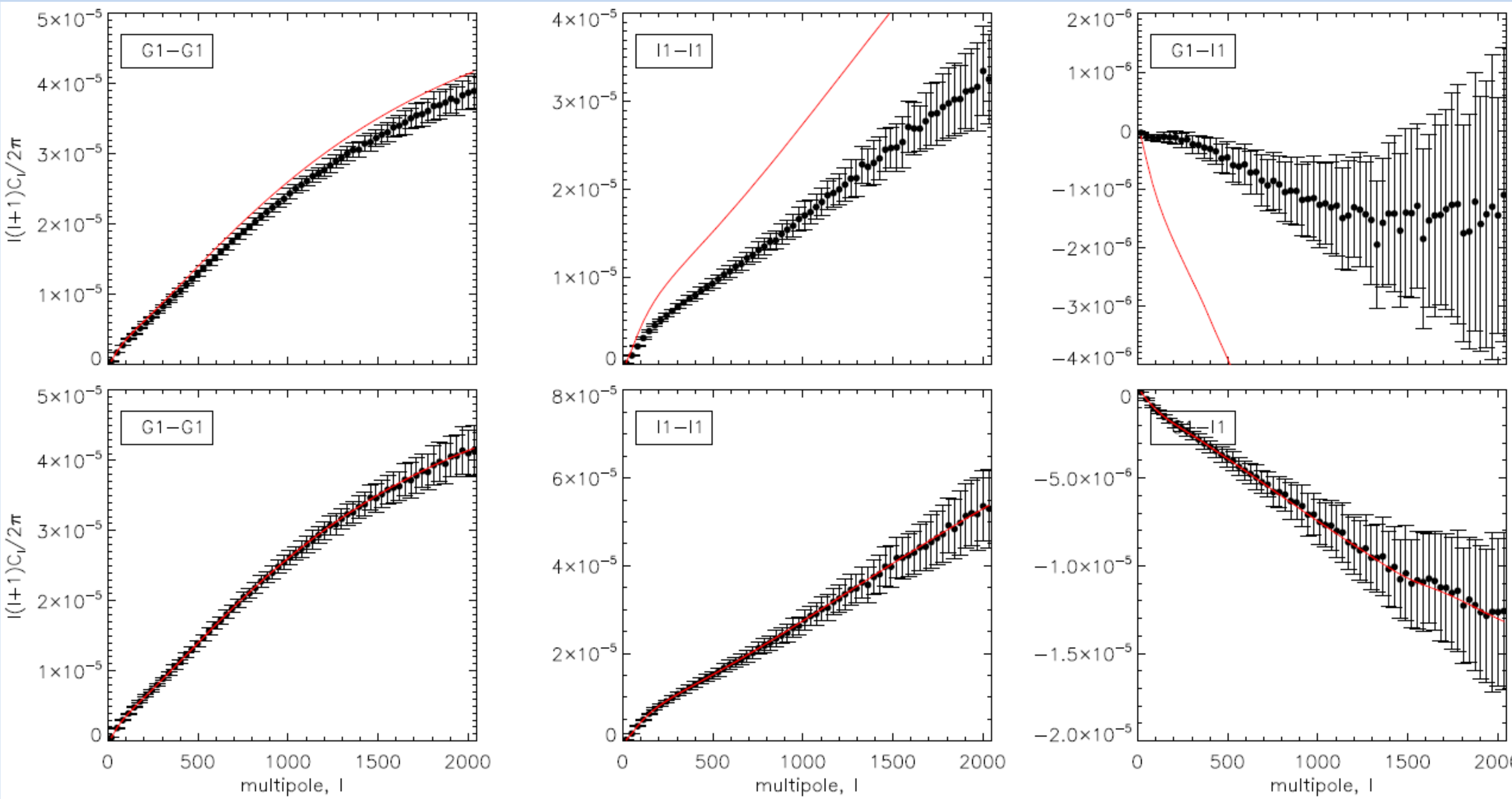
BB



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

BB

CBB



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

Methods which use a knowledge of the intrinsic ellipticity distribution

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

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

And

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

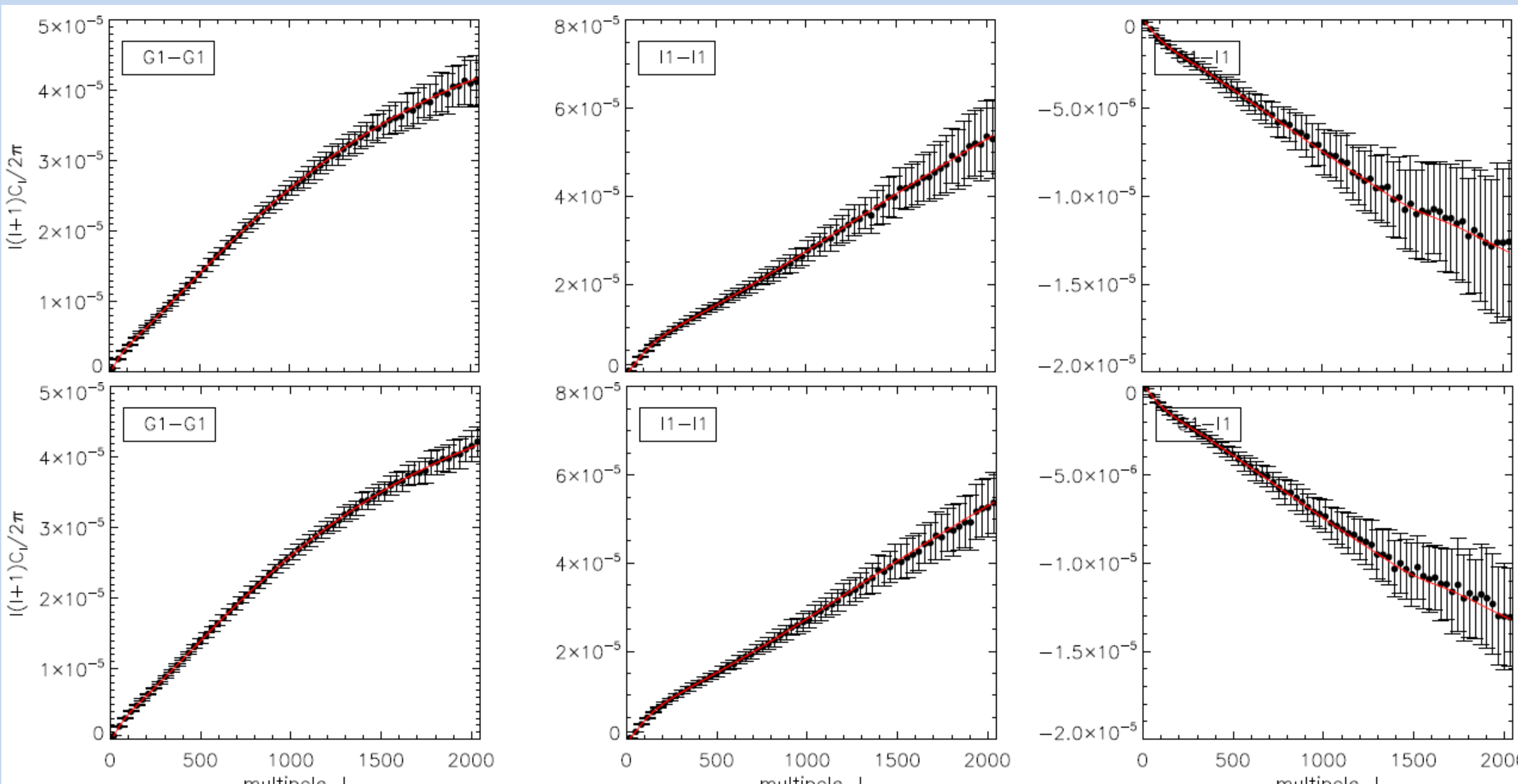
Where $\beta = \left\langle \cos\left(2\delta\alpha^{\text{int}}\right)\right\rangle$

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

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

CBB

STAO



- It is also possible to derive an estimator which compares the orientation of the galaxy before and after lensing.

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

And

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

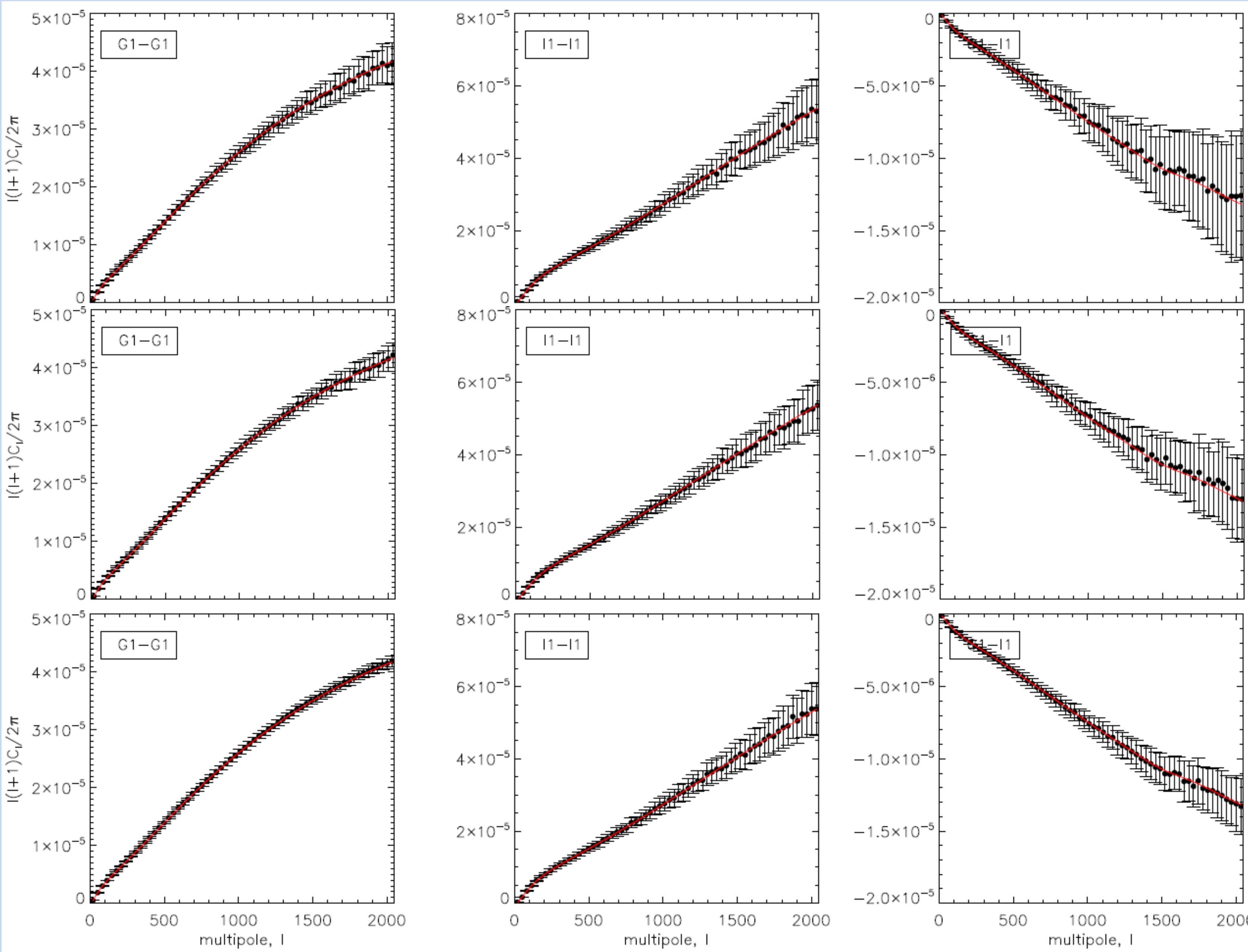
Where $\beta^{\mathrm{tot}}=\langle\cos(2\delta\alpha)\rangle$

- An estimate of the shear can be recovered by first obtaining an estimate of $\hat{\boldsymbol{\gamma}}^{\mathrm{IA}}$ using the previous method and then solving the above equations for $\hat{\boldsymbol{\gamma}}$.

CBB

STAO

AO



G1−G1
I1−I1
l(l+1)C$_l$/2π
multipole, l
0
500
1000
1500
2000
0
1×10^{-5}
2×10^{-5}
3×10^{-5}
4×10^{-5}
5×10^{-5}
2×10^{-5}
4×10^{-5}
6×10^{-5}
8×10^{-5}
−5.0×10^{-6}
−1.0×10^{-5}
−1.5×10^{-5}
−2.0×10^{-5}

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 the noise in the estimator 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 have developed a purely angle-only method using measurements of the observed galaxy position angles. However, we again require an iterative method using simulations to remove noise bias.
- We hope that future observations, such as the SuperCLASS observations made by e-MERLIN and the VLA, will address some of the outstanding issues, such as the fraction of galaxies with useful polarization information and the expected rms error on α_i^{int} measurements.