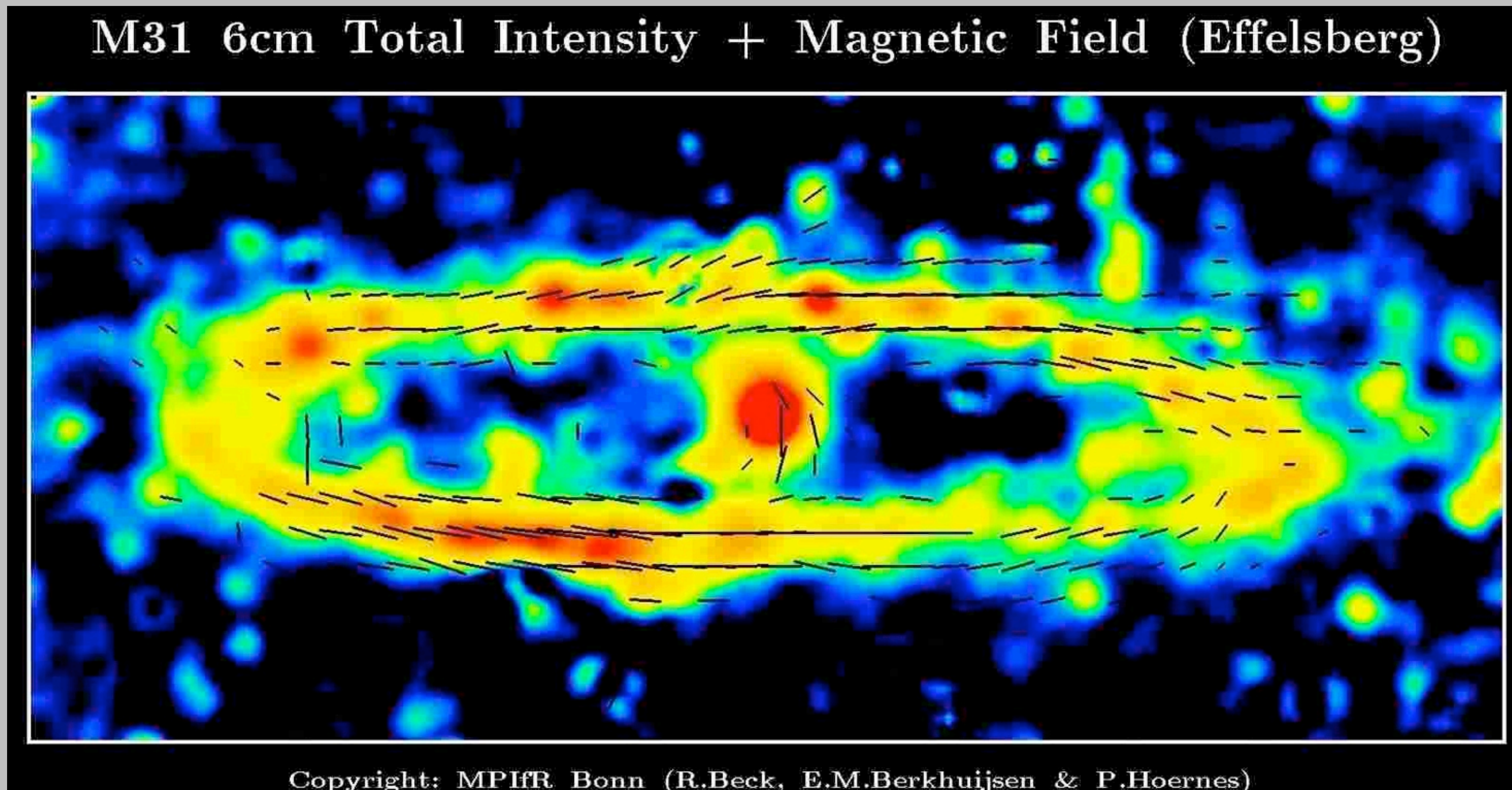
Polarization as an indicator of intrinsic alignment in radio weak lensing (arXiv:1005.1926)



Berkhuijsen, Beck & Hoernes (2003)

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Talk outline

- Using polarization to remove intrinsic alignments.
- Current knowledge of polarization properties of radio galaxies.
- Demonstration of technique on simulations.
- Prospects for lensing in the radio band with forthcoming surveys.

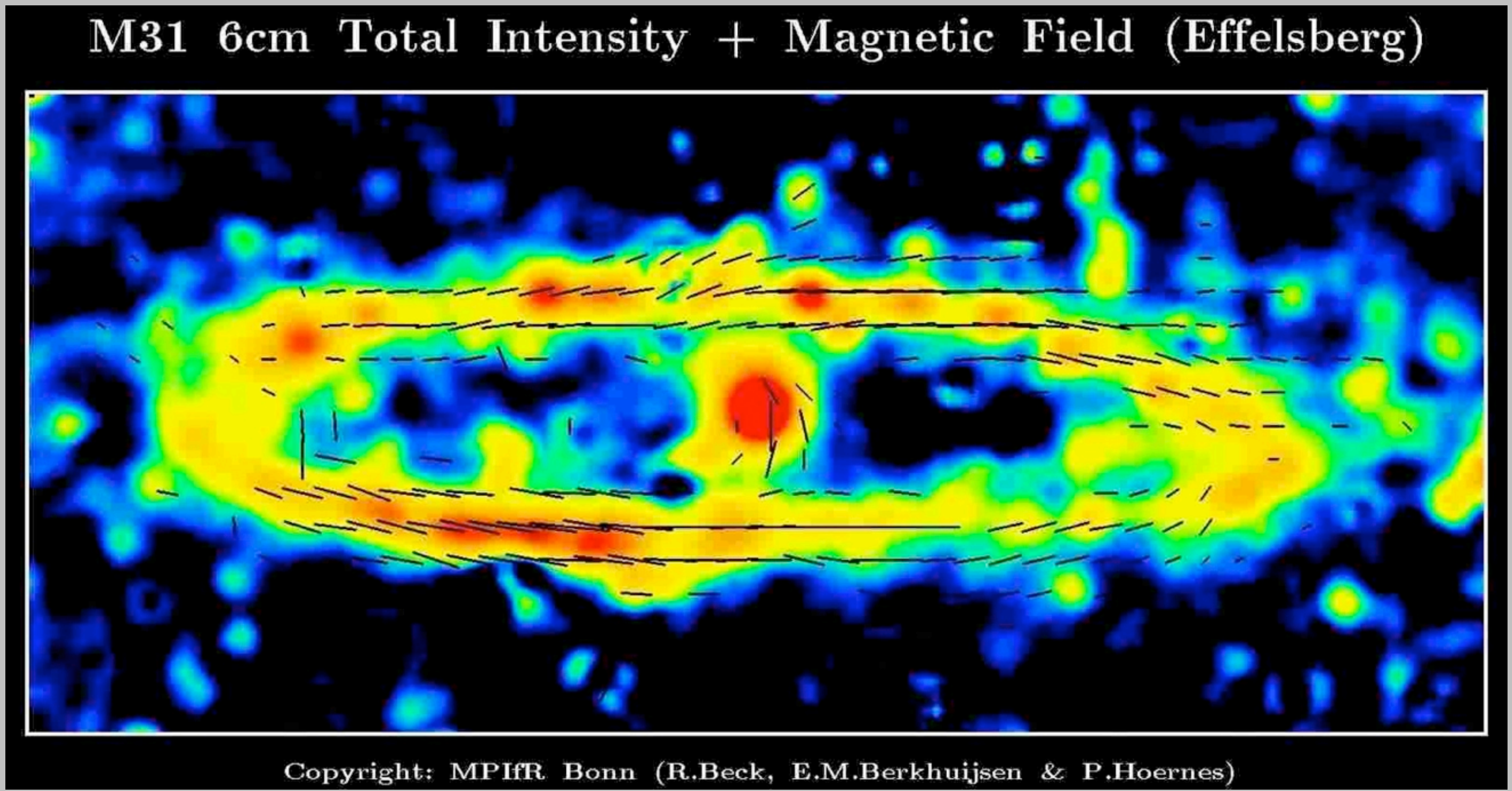
Polarization as an estimate of the intrinsic position angle

- Lensing is just a re-mapping of Stokes parameters from source → image plane. Orientation of polarized emission unaffected by lensing.

Kronberg et al (1991); Dyer & Shaver (1992); Faraoni (1993); Surpi & Harari (1999); Sereno (2005)

- Origin of polarization is large-scale magnetic field of galaxy - on average, will be aligned with galaxy's intrinsic structure.

- What we're interested in is the *integrated polarization* - averaging over galaxy should reduce noise further.



Berkhuijsen, Beck & Hoernes (2003)

Shear estimation with intrinsic position angle estimates

- Effect of lensing is simply $\boldsymbol{\epsilon}^{\mathrm{obs}} = \boldsymbol{\epsilon}^{\mathrm{int}} + \boldsymbol{\gamma}$ or in component form:

$$\begin{aligned} \epsilon_1^{\mathrm{obs}} &= |\epsilon^{\mathrm{int}}| \cos(2\alpha^{\mathrm{int}}) + \gamma_1 \\ \epsilon_2^{\mathrm{obs}} &= |\epsilon^{\mathrm{int}}| \sin(2\alpha^{\mathrm{int}}) + \gamma_2. \end{aligned}$$

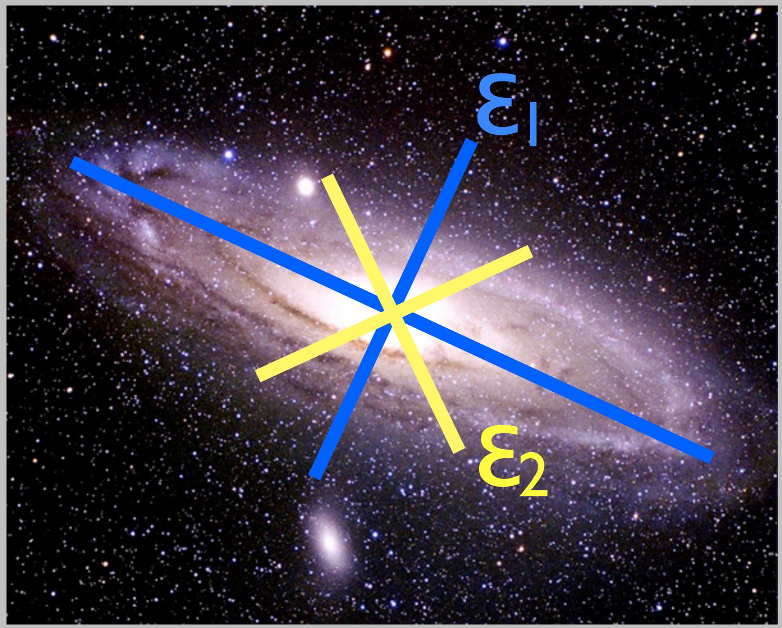
- With estimates of intrinsic position angles (α_{int}) can solve for lensing shear in a pixel regardless of intrinsic correlations.

New shear estimator: $\hat{\gamma} = \mathbf{A}^{-1}\boldsymbol{b}$

$$\begin{aligned} \mathbf{A} &= \sum_i w_i \hat{\boldsymbol{n}}_i \hat{\boldsymbol{n}}_i^T, \\ \boldsymbol{b} &= \sum_i w_i (\boldsymbol{\epsilon}_i^{\mathrm{obs}} \cdot \hat{\boldsymbol{n}}_i) \hat{\boldsymbol{n}}_i. \end{aligned}$$

$$\hat{\boldsymbol{n}}_i = \begin{pmatrix} \sin 2\hat{\alpha}_i^{\mathrm{int}} \\ -\cos 2\hat{\alpha}_i^{\mathrm{int}} \end{pmatrix}$$

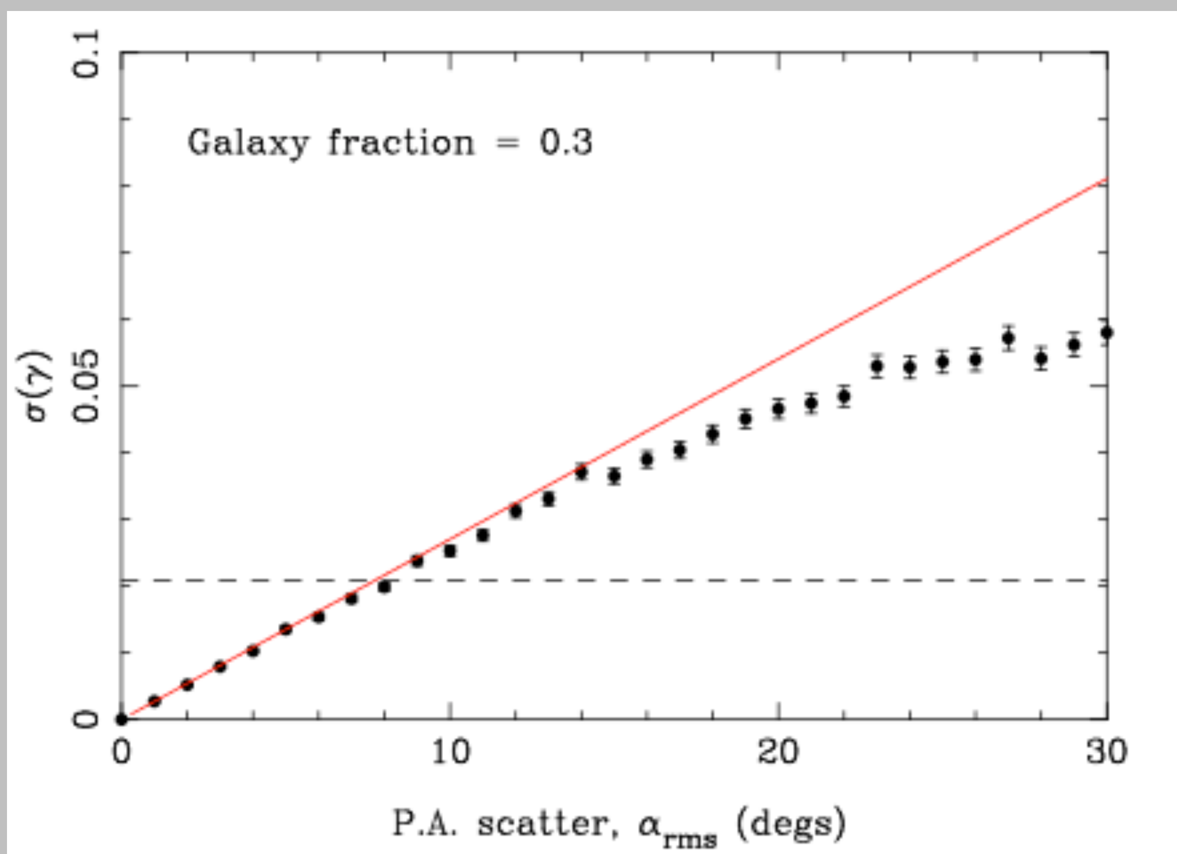
Brown & Battye (2010)

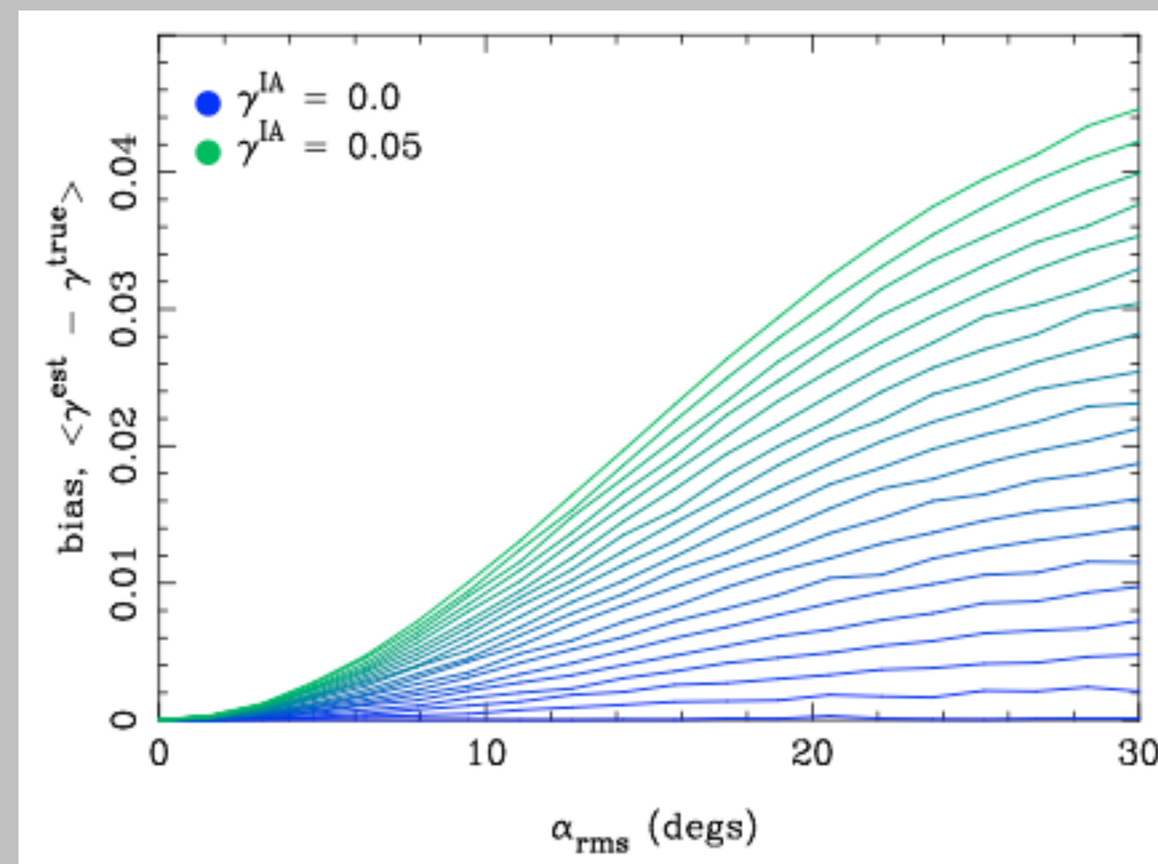


- In rotated co-ordinate system aligned with intrinsic orientation, new estimator rejects ε_1 component and retains ε_2 component.

Properties of estimator

- In limit of perfect estimates of intrinsic position angle, estimator is shot noise free and removes all effects of intrinsic alignments.
- If position angle estimates are noisy but unbiased, still get impressive improvements over standard lensing estimator:





- Dispersion in estimator: $\sigma_{\hat{\gamma}} \approx 4 \frac{\alpha_{\rm rms}\, \epsilon_{\rm rms}}{\sqrt{N}}$

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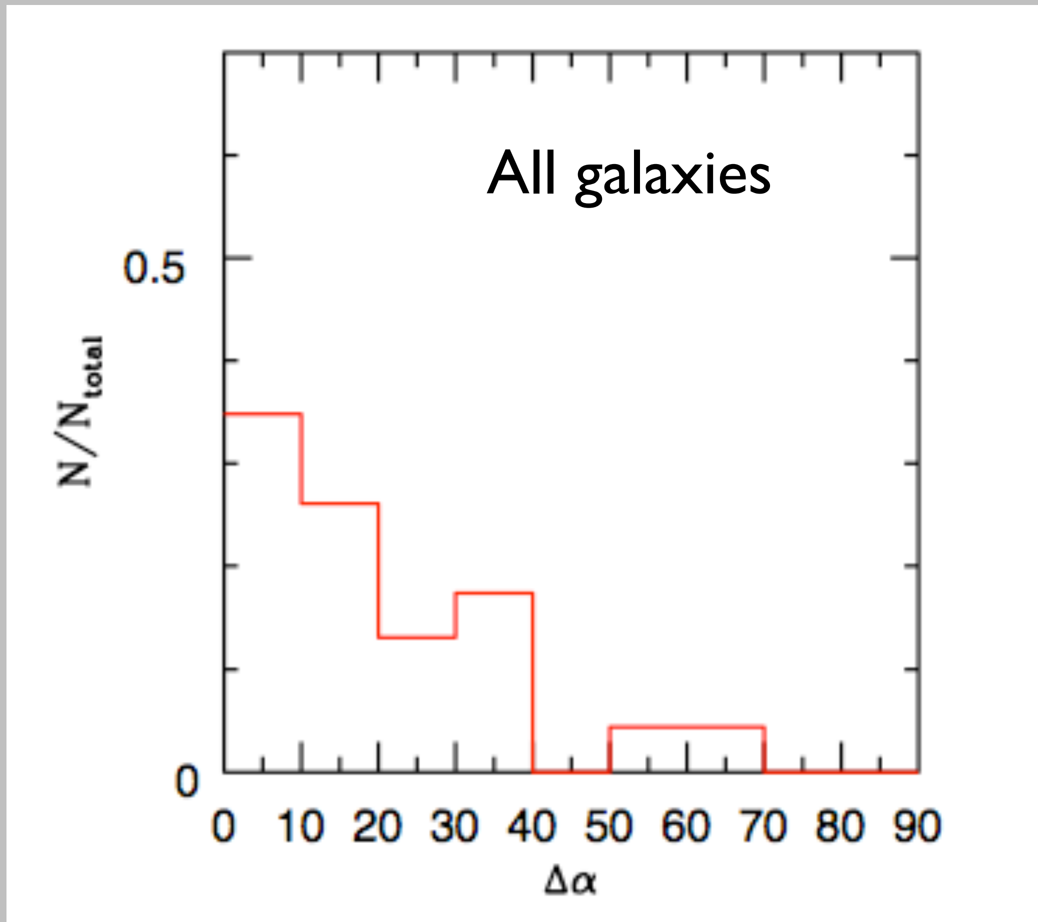
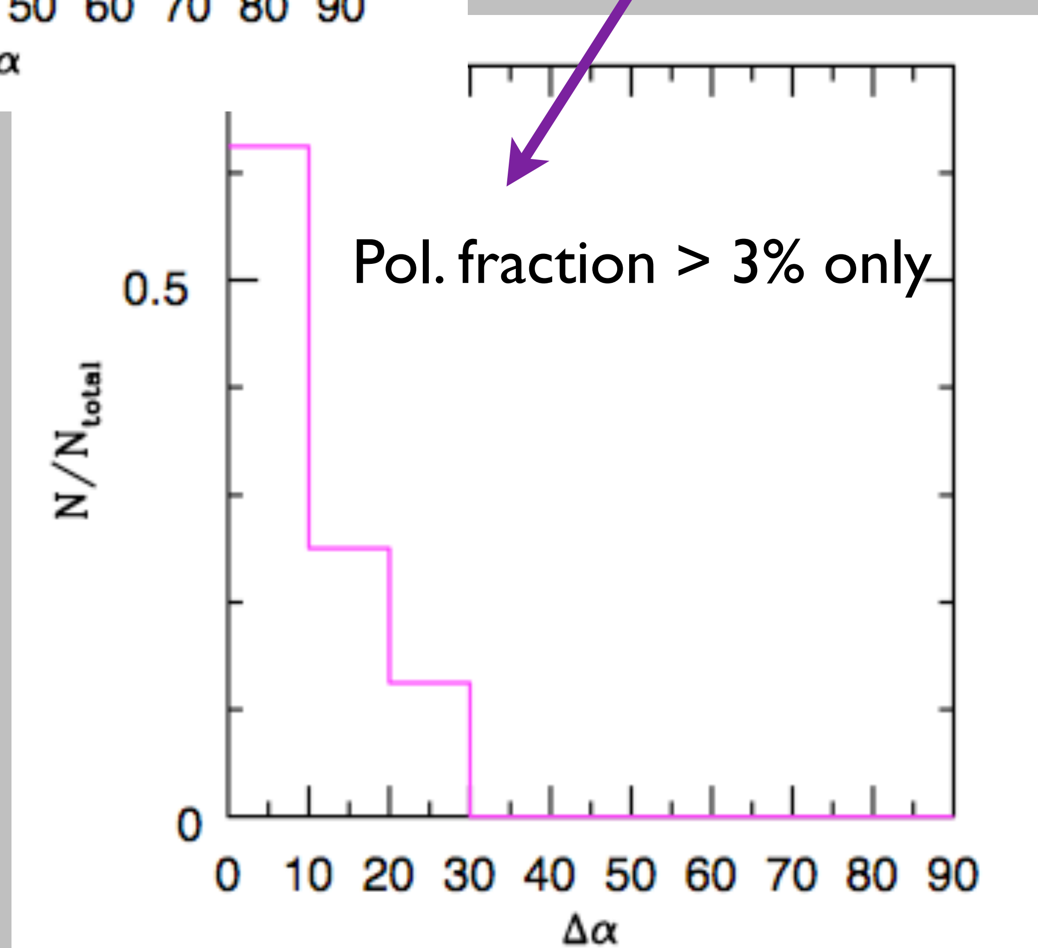
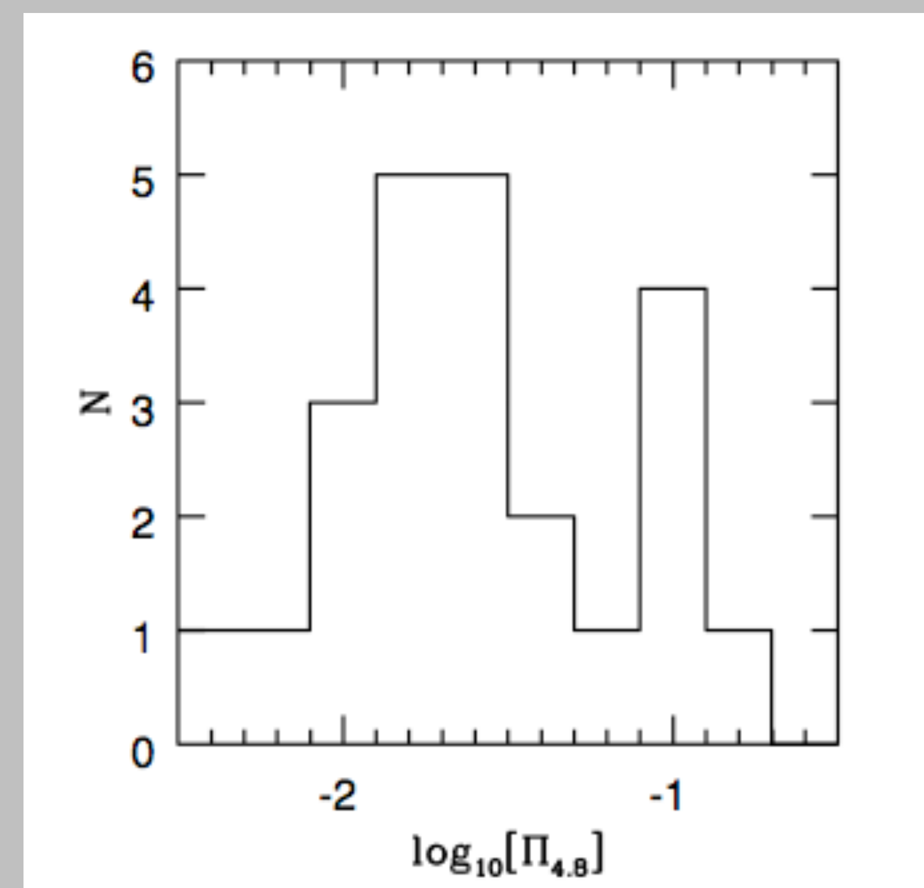
Integrated polarization of local radio galaxies



Alignment of polarization orientation with intrinsic position angle



Distribution of polarization fraction:



Data from Stil et al. (2009)

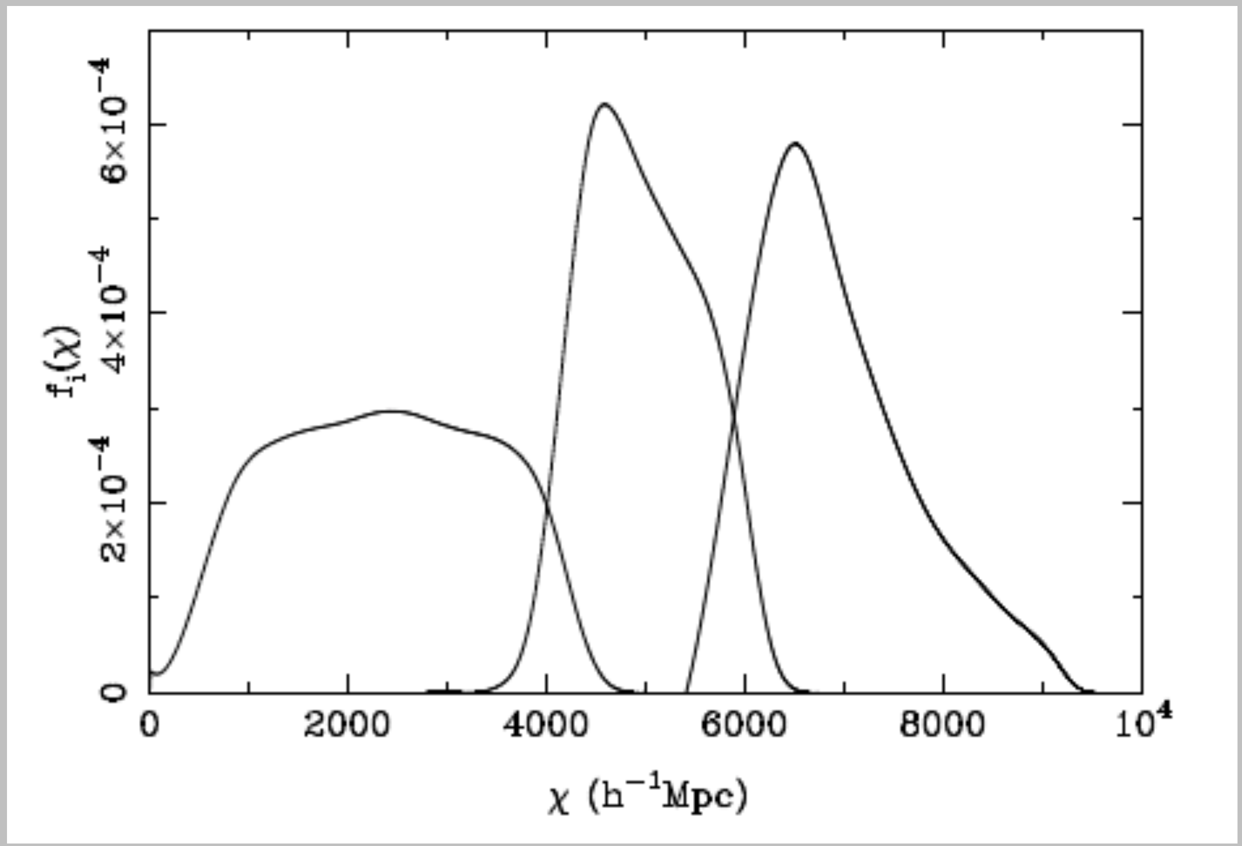
Investigated impact on cosmology through simulations

- Simple (Gaussian) simulations of a lensing survey with future radio telescope (approximating the Square Kilometer Array).

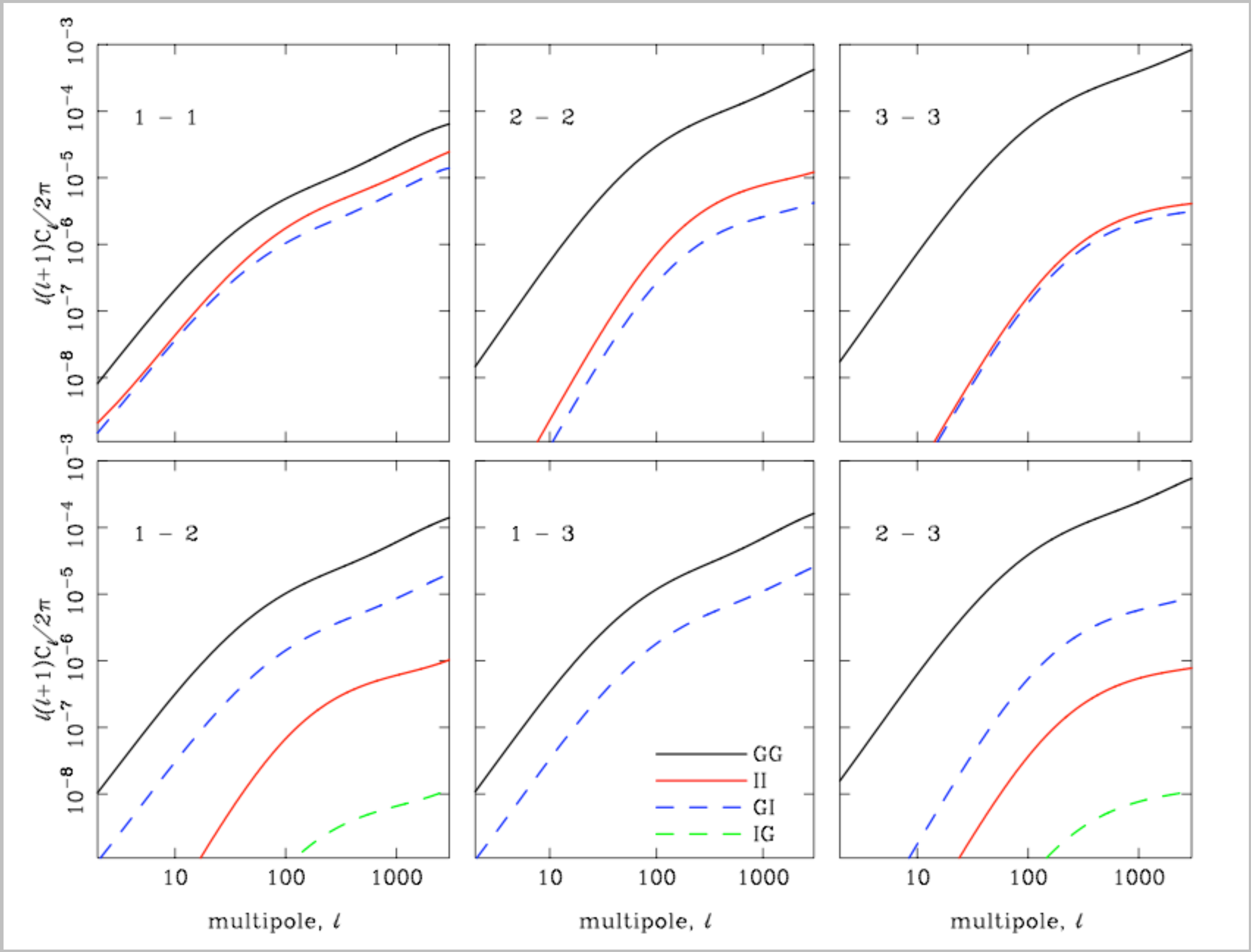
- For sake of simulations, have assumed we can measure polarization for 10% of galaxies in sample and the scatter in the polarization direction/intrinsic orientation relation is ~5 degrees.

- Realistic redshift distribution (from SKADS, Wilman et al. 2009), ΛCDM cosmic shear signal and intrinsic alignment signal based on linear alignment model with amplitude matched to 1x and 5x SuperCOSMOS amplitude.

- Attempt to reconstruct lensing (and intrinsic alignment) power spectra in three overlapping redshift bins.



Lensing and intrinsic alignment power spectra



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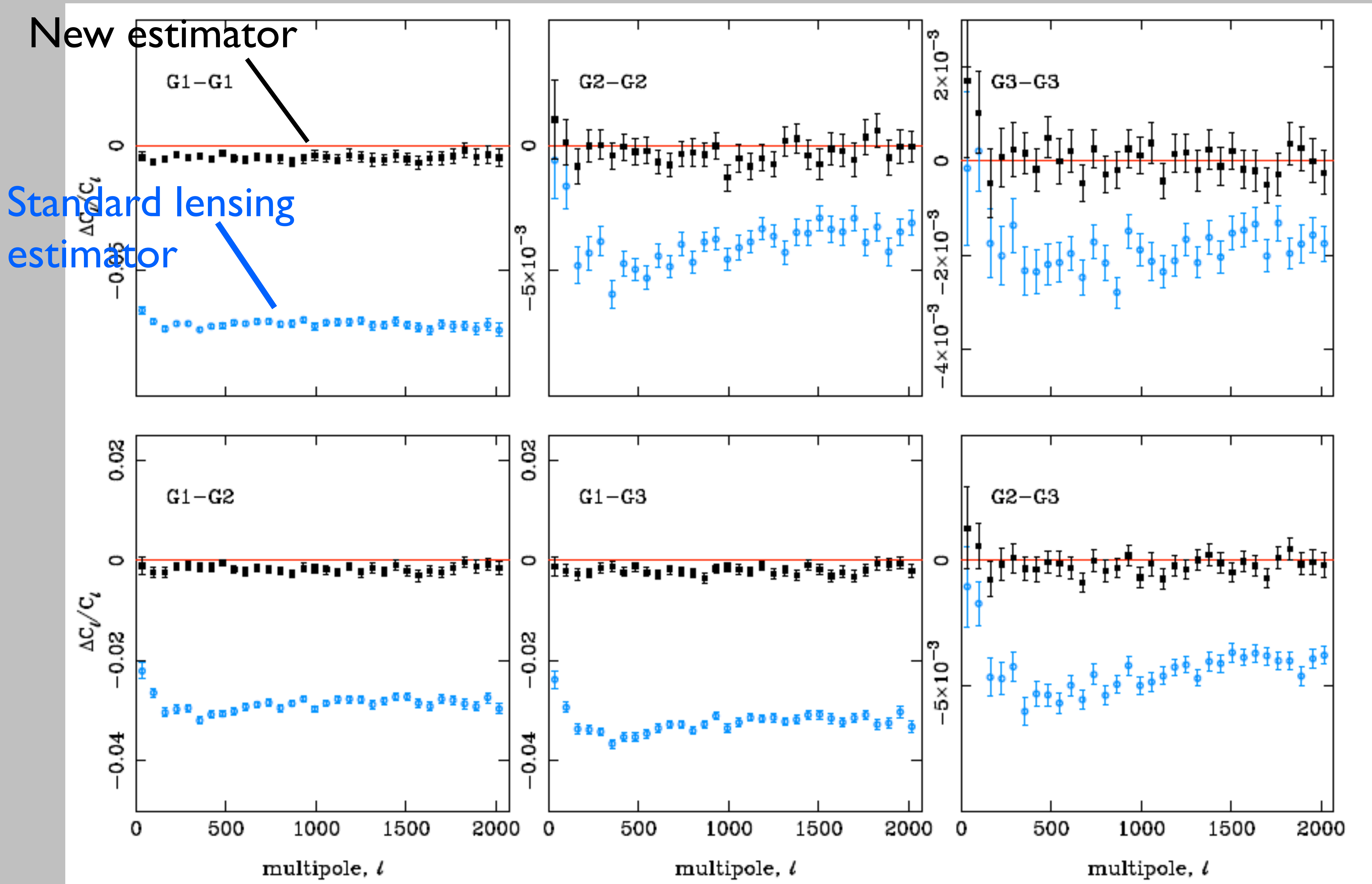
Intrinsic alignment bias in recovered power spectra



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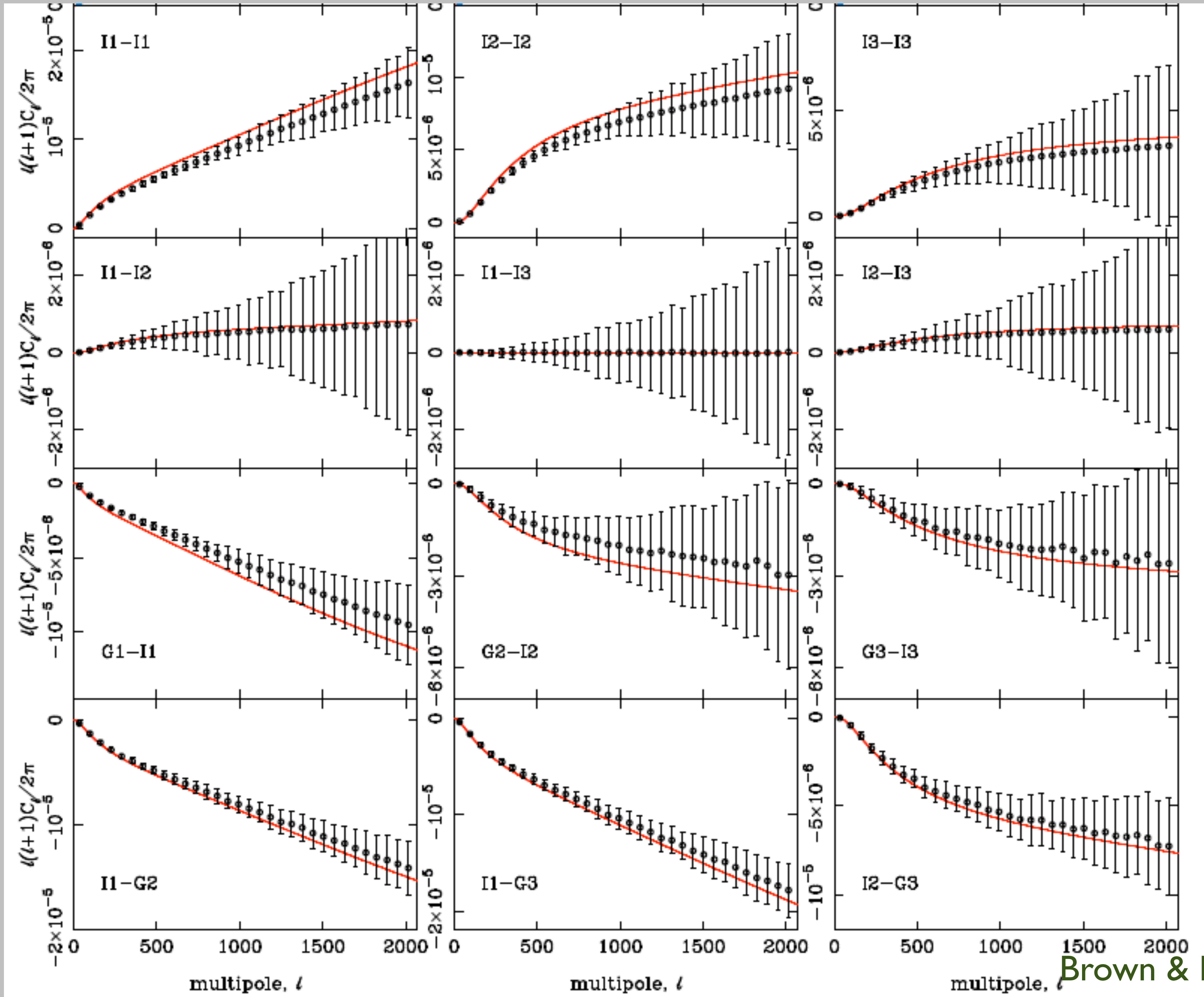
Can also reconstruct intrinsic signal and intrinsic-lensing cross-correlations with new estimator



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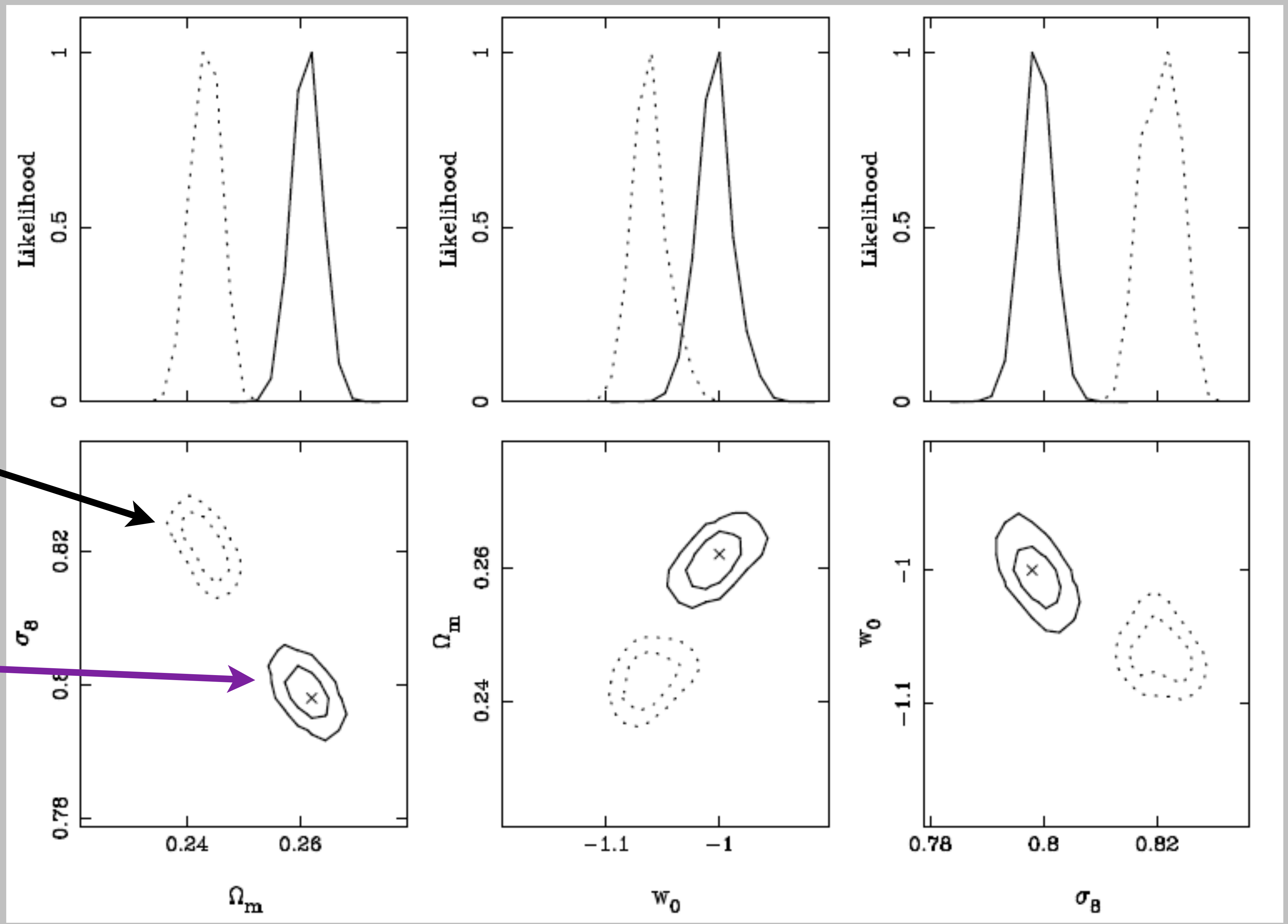
Mitigating biases in cosmological parameter estimates



Standard analysis biased by intrinsic alignment contamination

Contamination removed using new technique with no degradation in constraining power

x = input model

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Advantages of future radio surveys (e.g. SKA) for weak lensing

- Precisely determined beam reconstruction (as opposed to complicated telescope point-spread functions in optical).
- Large surveys (e.g. 20,000 sq. degs with SKA).
- High resolution - as good as space-based optical surveys.
- Higher median redshift of sources (lensing signal stronger).
- With SKA, will get precise redshifts from H1 detections.

Prospects in the near/medium term

• SKA precursor telescopes, MeerKAT (South Africa) and ASKAP (Australia).... large surveys but relatively poor resolution.

• e-MERLIN (UK): much smaller surveys but excellent resolution (~0.15 arcsec at 1.5 GHz).

• All will include full polarization capabilities so will be ideal for investigating polarization properties of faint radio sources and testing new lensing technique.

Summary

- Intrinsic galaxy alignments are a serious astrophysical systematic for future lensing surveys. Existing techniques for mitigating these are either lossy or are dependent on details of highly uncertain models.

- Have developed a new technique using polarization orientation as a proxy for intrinsic morphological orientation. Potentially powerful for reducing shot noise and mitigating effects of intrinsic alignments in future radio lensing surveys.

- We have plans to use forthcoming observations from e-MERLIN and MeerKAT to investigate polarization properties of faint radio sources and to test new lensing estimator on real data.

- Definitive radio lensing surveys with the advent of the SKA (2016 - 2020).

Intrinsic shape correlations: theory

- Linear alignment model (ellipticals): Ellipticity of a galaxy determined in part by ellipticity of parent DM halo. Ellipticity of DM halo in turn perturbed by local tidal field from large scale structure:

$$\gamma^I = -\frac{C_1}{4\pi G}(\nabla_x^2 - \nabla_y^2, 2\nabla_x\nabla_y)\mathcal{S}[\Psi_P]$$

Catelan, Kamionkowski & Blandford (2001)

- Quadratic alignment model - tidal torque theory (spirals): Ellipticity of galaxy determined by orientation (and hence angular momentum) of disk. Angular momentum originates from external tidal fields perturbing collapsing galaxy:

$$\gamma^I = C_2(T_{x\mu}^2 - T_{y\mu}^2, 2T_{x\mu}T_{y\mu})$$

$$T_{\mu\nu} = \frac{1}{4\pi G}\left(\nabla_\mu\nabla_\nu - \frac{1}{3}\delta_{\mu\nu}\nabla^2\right)\mathcal{S}[\Psi_P]$$

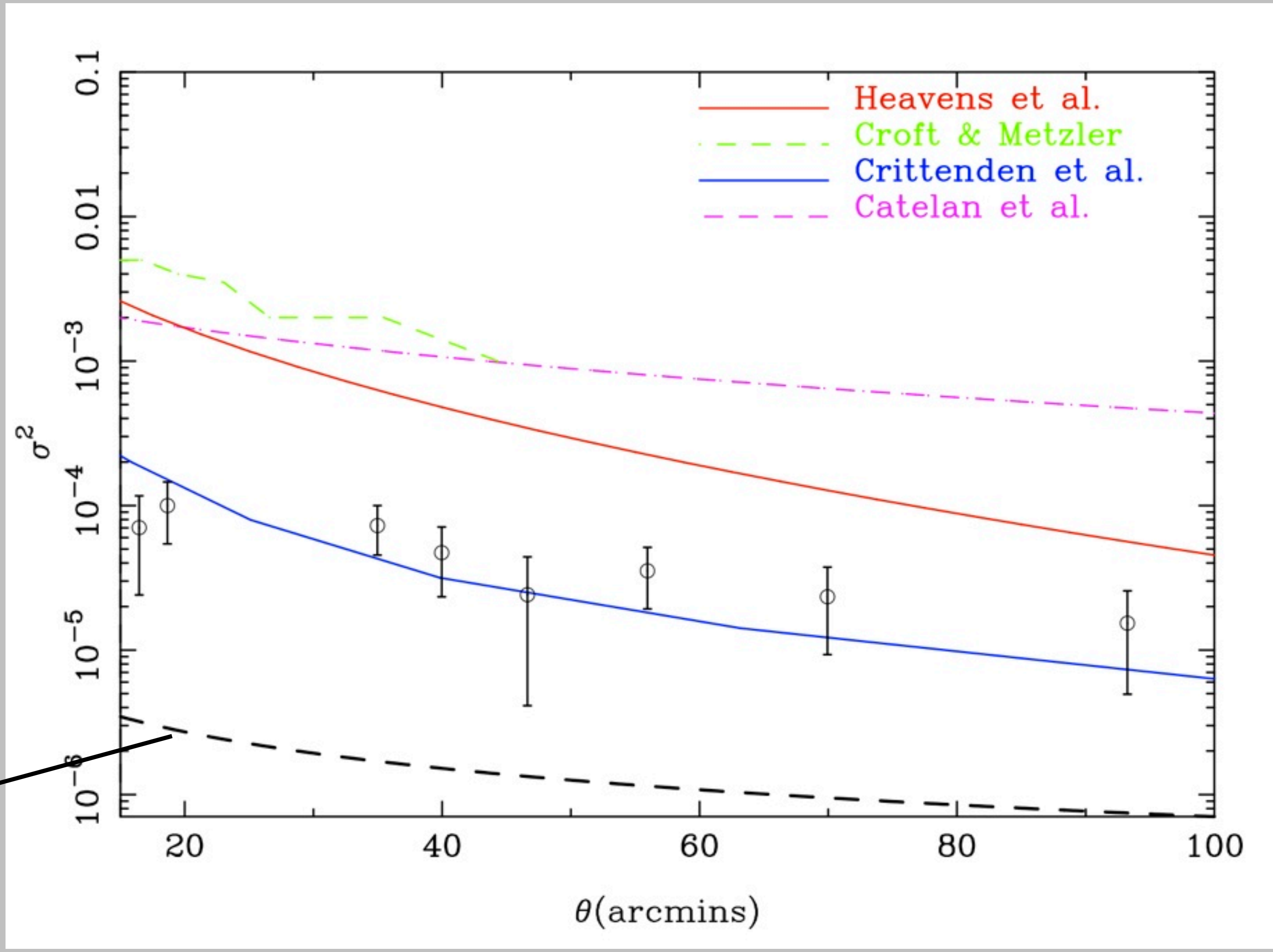
Crittenden, Natarajan, Pen, Theuns (2000); Catelan, Kamionkowski, Blandford (2001); Hui & Zhang (2002); Hoyle (1949); Peebles (1969); Doroshkevich (1970); White (1984); Peacock & Heavens (1985); Barnes & Efstathiou (1987); Heavens & Peacock (1988); Porciani et al (2002).

Intrinsic shape correlations: observations

- Can measure intrinsic alignment signal in low redshift surveys for which the efficiency of lensing is very low.

Predictions of intrinsic alignment signal from theory/simulations span ~2 orders of magnitude

Expected lensing signal



SuperCOSMOS Sky Survey; Brown et al. (2002)

- See also constraints from SDSS (Hirata et al. 2007) and WiggleZ (Mandelbaum et al. 2010).

Mitigating intrinsic alignments

- In general, observed ellipticity correlations will be "contaminated" by intrinsic and intrinsic-lensing cross-terms:

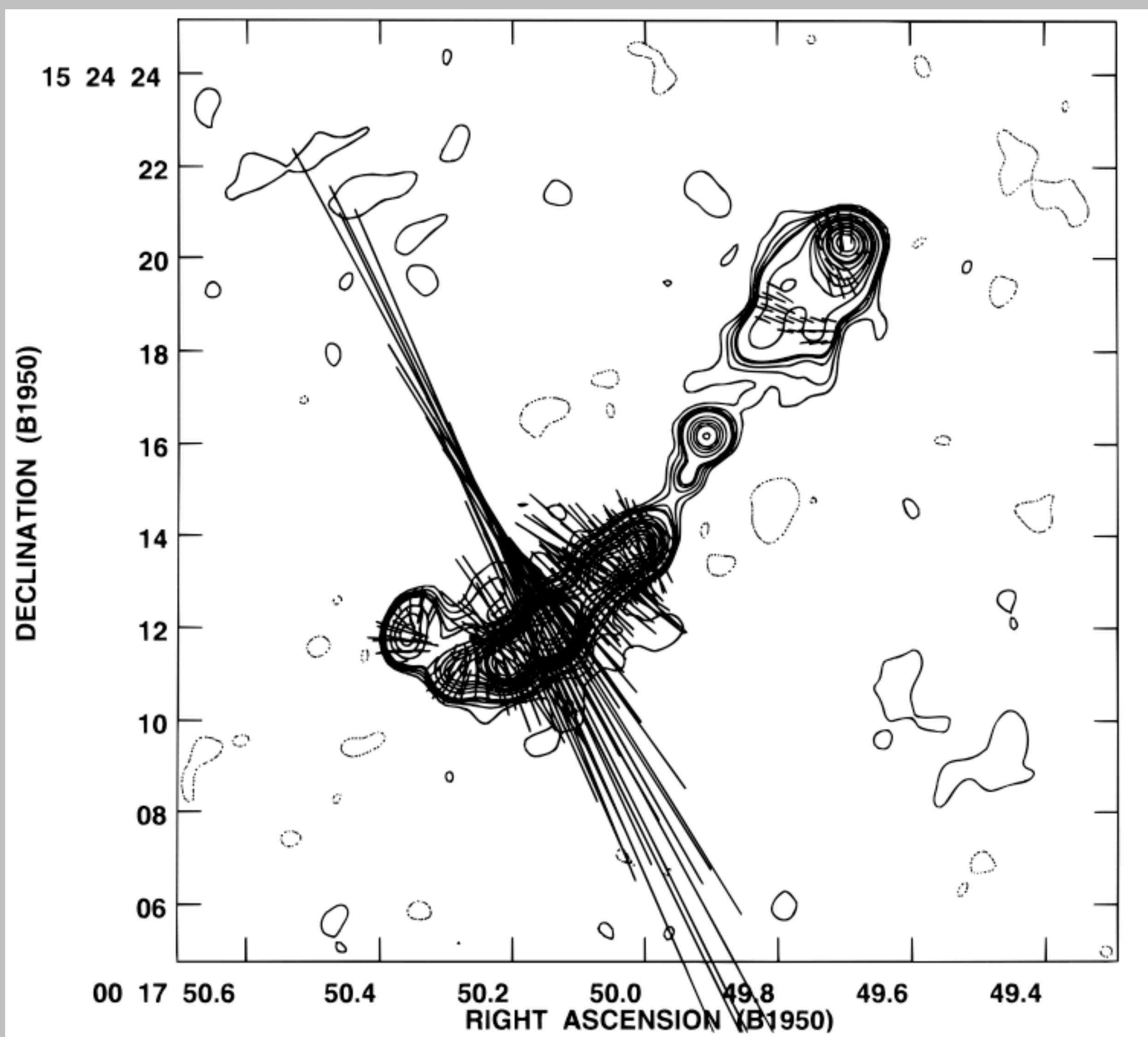
$$\left\langle \epsilon_i \epsilon_j^* \right\rangle = \left\langle \gamma_i \gamma_j^* \right\rangle + \left\langle \epsilon_i^s \epsilon_j^{s*} \right\rangle + \left\langle \gamma_i \epsilon_j^{s*} \right\rangle + \left\langle \epsilon_i^s \gamma_j^* \right\rangle$$

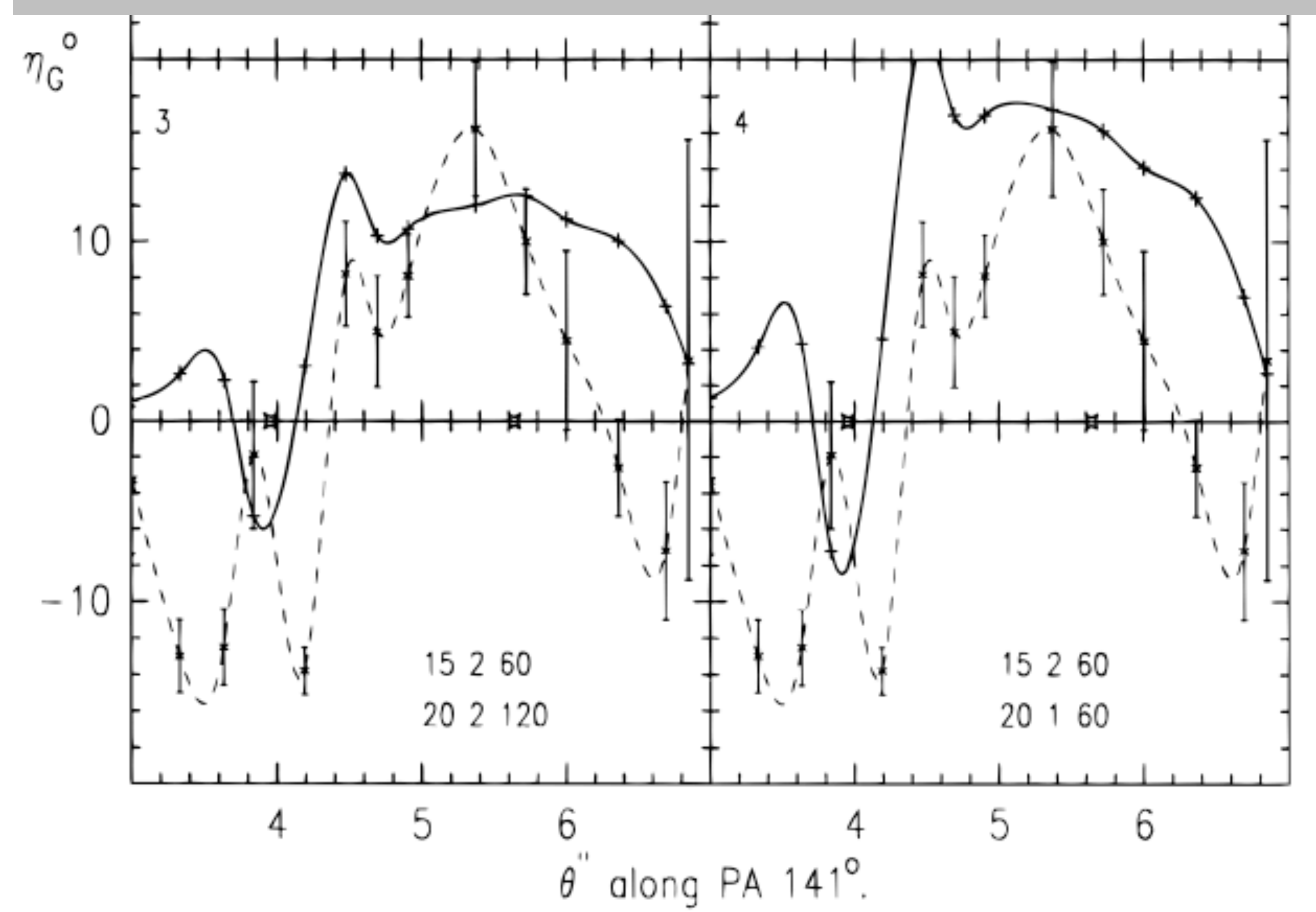
- Two existing approaches to removing contamination:
  - Nulling: downweight galaxy pairs which are physically close and/or use known redshift dependence of lensing and intrinsic signals to distinguish between them. King & Schneider (2002), Heymans & Heavens (2003), Takada & White (2004), Joachimi & Schneider (2008, 2009)
  - Modelling: marginalize over parametrized models of intrinsic alignment signal when doing cosmology. King & Schneider (2003), King (2005), Bridle & King (2007)

BUT: Nulling throws away useful information - degraded cosmological constraints. Modelling dependent on highly uncertain knowledge of physics underpinning the generation of intrinsic correlations.

Gravitational lensing with polarization

- Kronberg et al. (1996) measured the misalignment between polarization and total intensity in two quasars.
- Characterized lensing effect using an alignment breaking parameter, η_G.





Kronberg et al (1996)