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Promises and Challenges of Radio Weak Lensing

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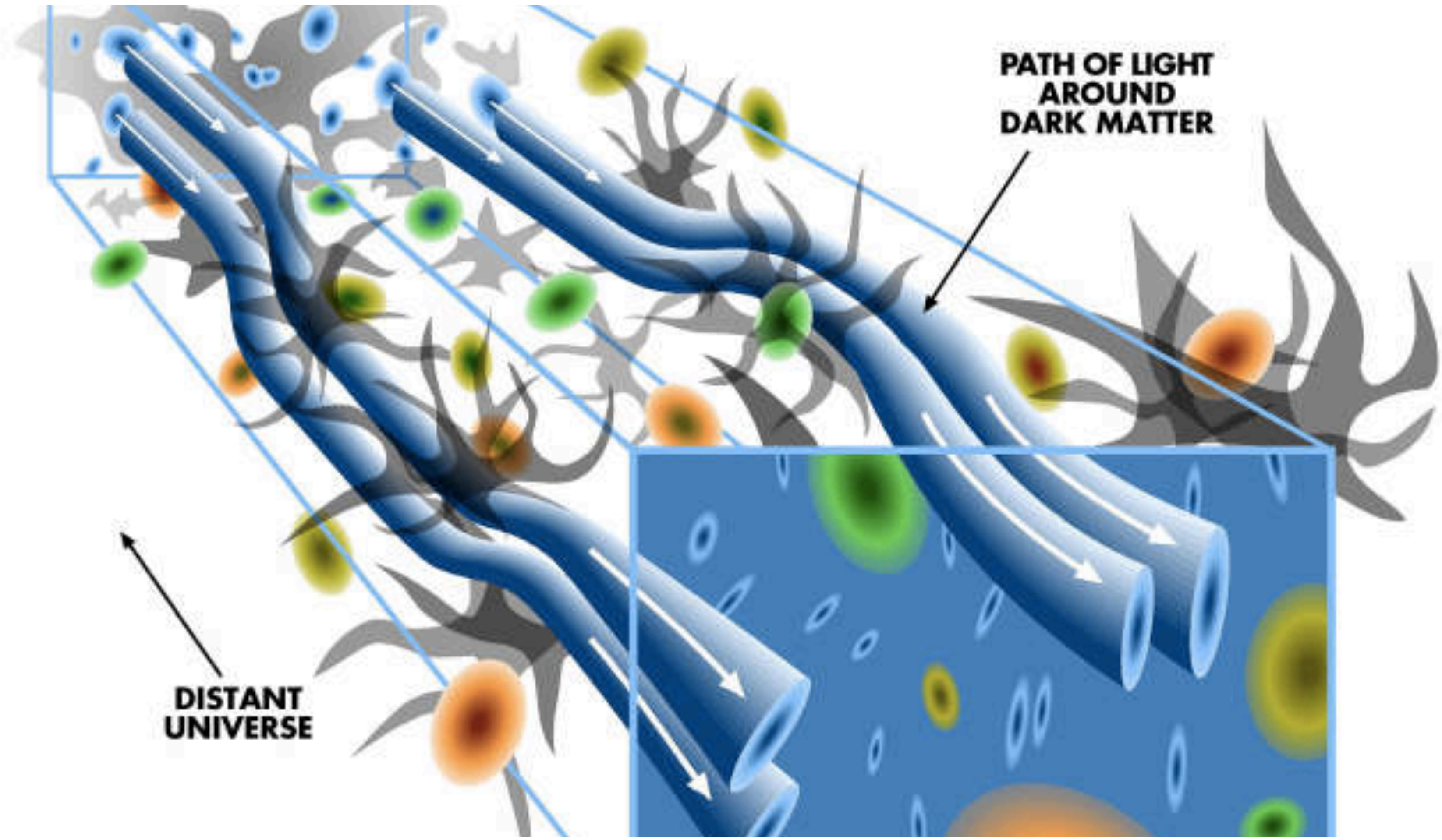
RAS National Astronomy Meeting
Llandudno

6 July 2015

Gravitational Lensing Cosmology

Basic Principle

Weak Lensing Cosmology
Basic Principle



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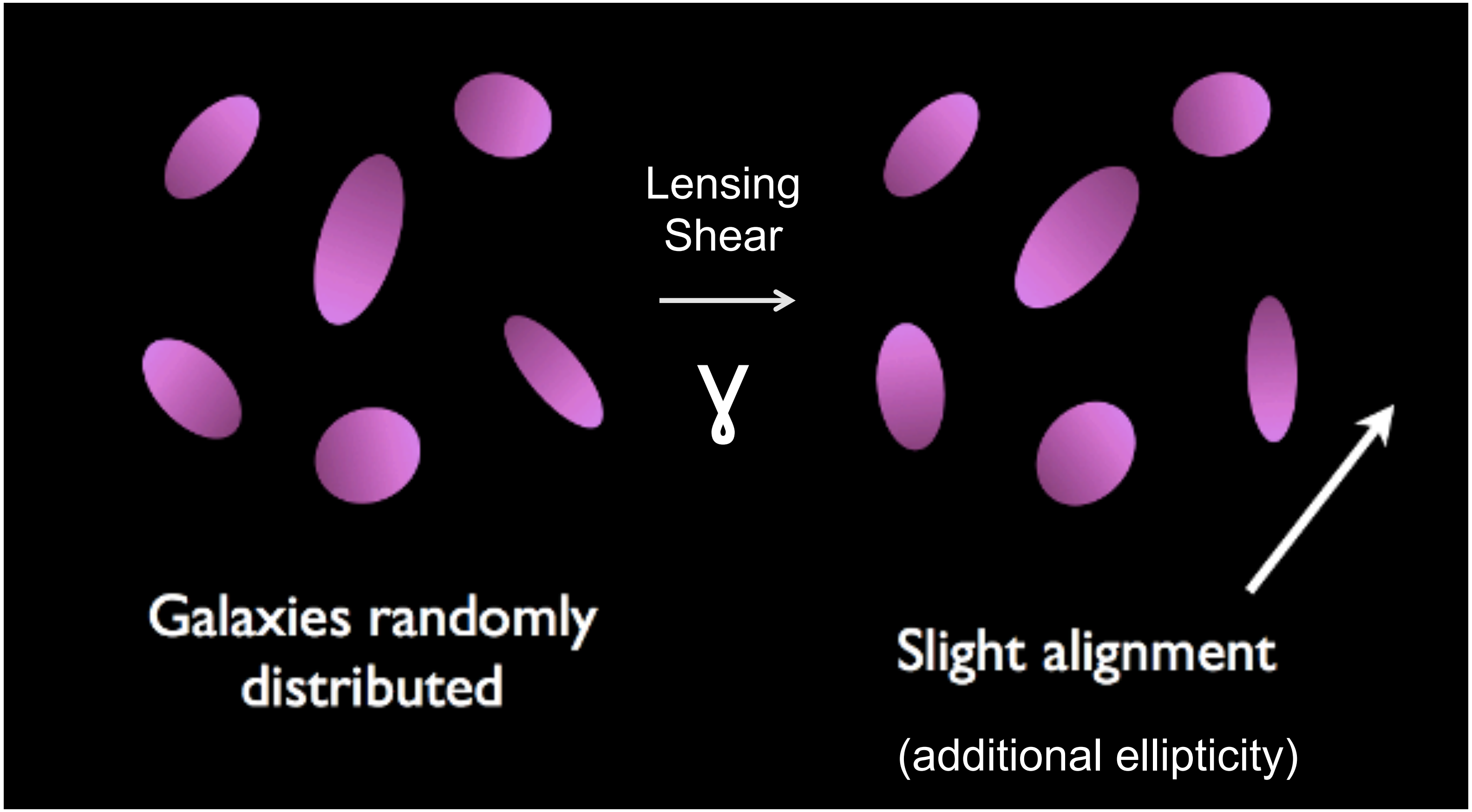
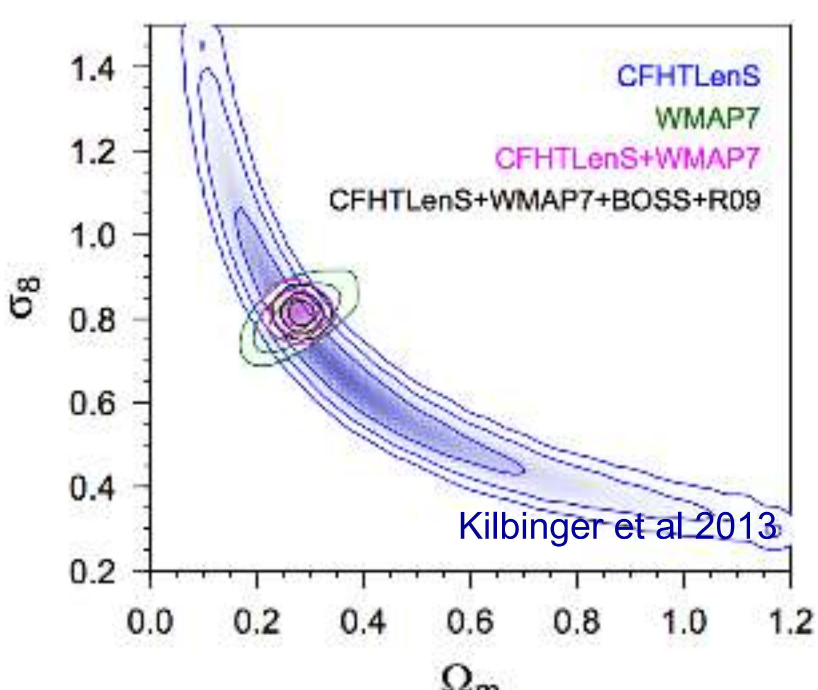
Weak Lensing Cosmology
Basic Principle

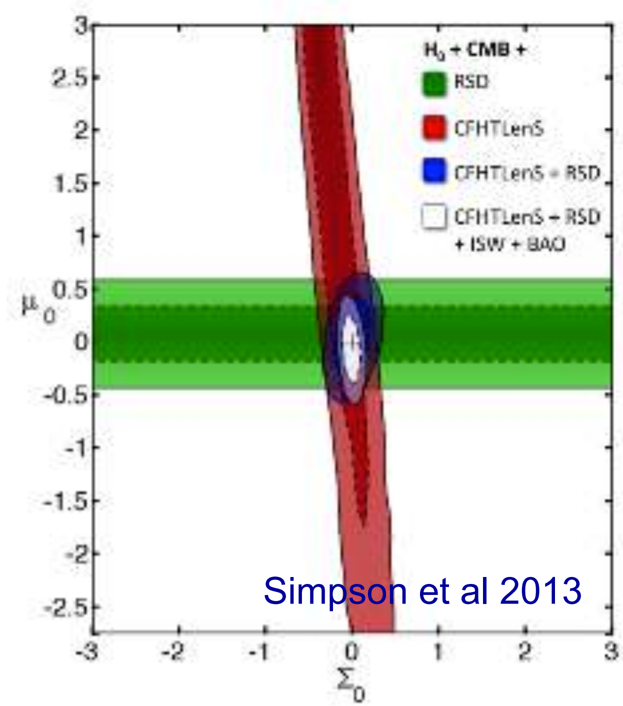


$$e_{\text{obs}} = e_{\text{intrinsic}} + \gamma$$
$$\langle e_{\text{obs}} \rangle = \hat{\gamma}$$

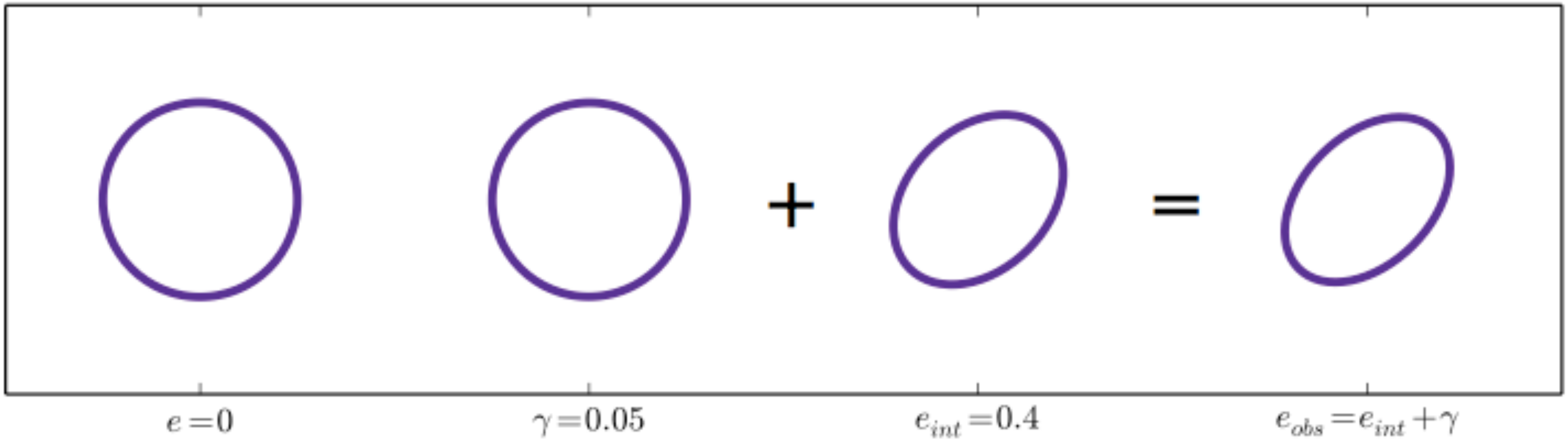
Weak Lensing Cosmology
Cosmological Constraints

- WL observables (i.e. map of shear ɣ) probe gravitational potential along line of sight
  - Map mass
  - Easily relate to matter power spectrum → cosm. parameters
    - redshift binning allows 3D tomography





Weak Lensing Cosmology
Typical Ellipticity



No ellipticity	Cosmic shear	Galaxy ellipticity	Observed ellipticity
$e = 0$	$\gamma \sim 0.05$	$e \sim 0.4$	Galaxy + Cosmic shear

σ_{sys}<1% for detection

σ_{sys}<0.01% for useful cosmology

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Radio Weak Lensing Requirements from a Survey

- High number densities
- …of resolved, high redshift sources
- Wide fields
- Exquisite control of systematics (e.g. PSF ellipticity)

$$e^{obs} = (1+m)e^{true} + c$$

Requirements on systematics

	Experiment	A_{sky}	n_{gal}	z_m	$m <$	$c <$	$Q >$
Optical	DES	5000	12	0.8	0.004	0.0006	260
	Euclid	20000	35	0.9	0.001	0.0005	990
SKA-MID	SKA1-early	5000	1.2	0.8	0.012	0.0011	79
	SKA1	5000	2.7	1.0	0.0067	0.00082	140
	SKA2	30940	10	1.3	0.0012	0.00035	825

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Radio Weak Lensing Requirements from a Survey

- High number densities
- …of resolved, high redshift sources
- Wide fields
- Exquisite control of systematics (e.g. PSF ellipticity)

All theses should be achievable with a μJy depth, ~10^3 deg^2, sub-arcsecond SKA-MID continuum survey (probably Band 2)

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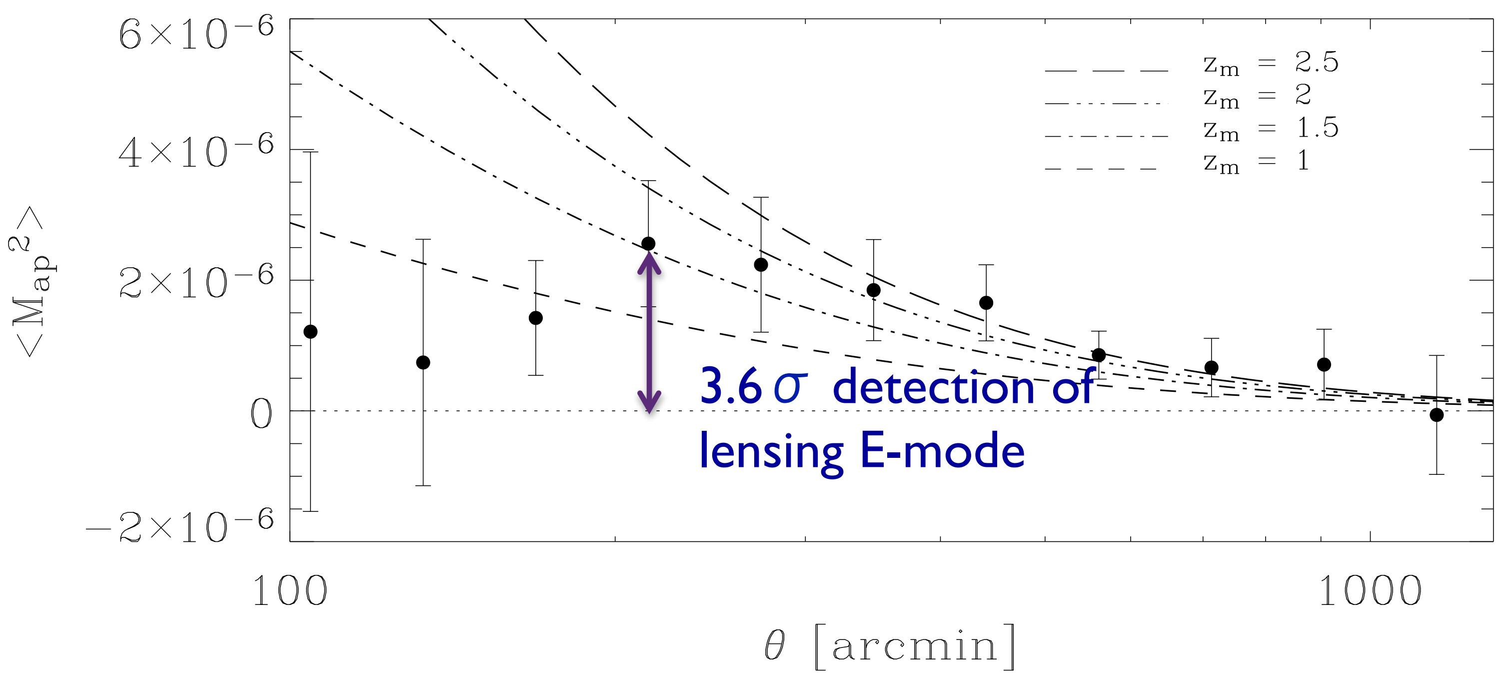
Advantages of Radio Weak Lensing

- PSF Errors
  - Radio interferometer beams are (in principle) precisely known, highly deterministic
- Higher redshift source distribution than optical
- Intrinsic alignments
  - Radio polarisation angle (Brown & Battye 2011)
  - HI rotational velocity measurements (e.g. Morales 2005)
- Redshift uncertainties
  - Large 21cm line surveys (i.e. with SKA2) give spec-z for sources
- Cross-correlating shear maps with other wavebands
  - wavelength dependent systematics drop out!

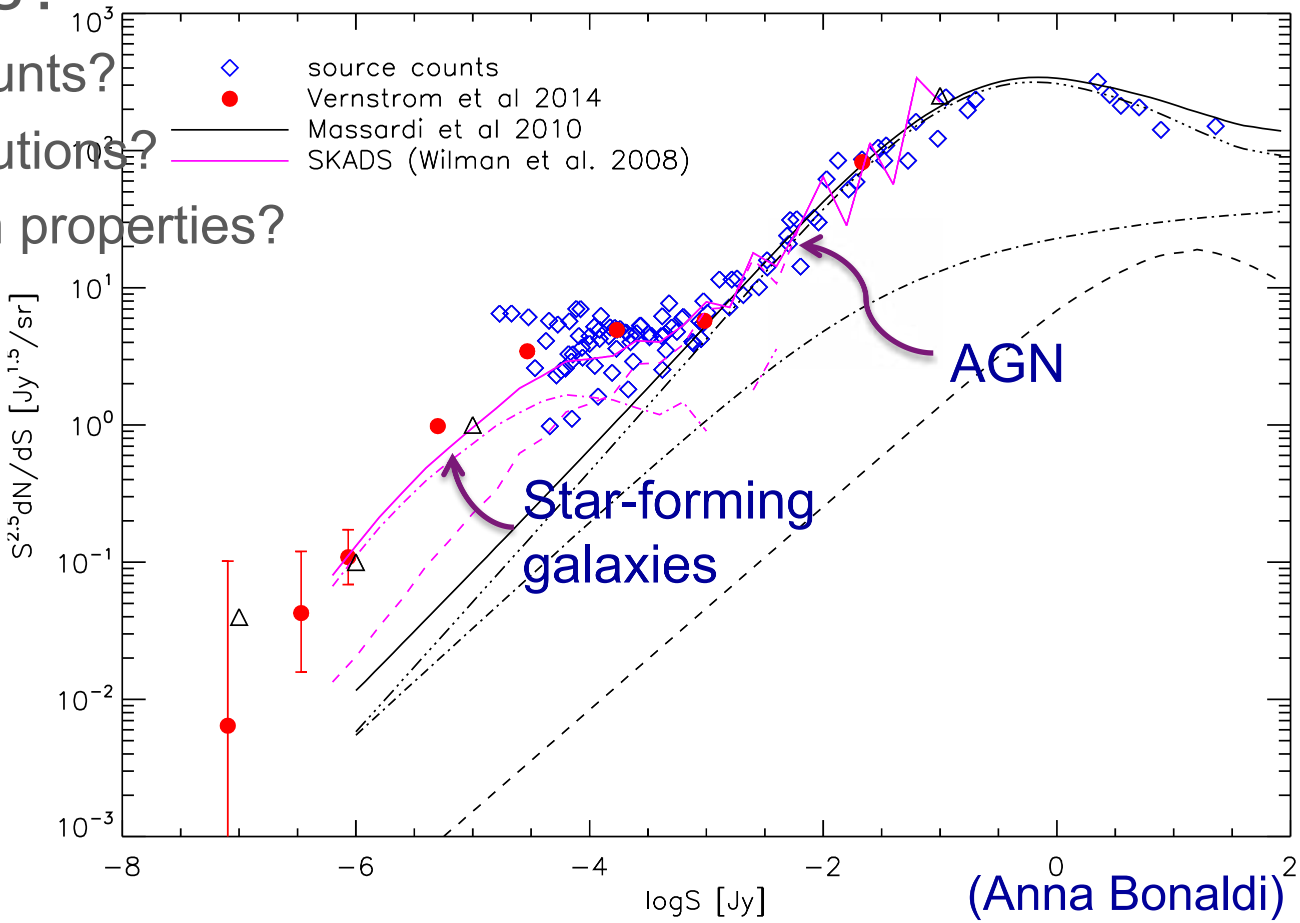
Radio Weak Lensing Studies to Date

- In HDF-N (Patel et al 2010)
  - no detection (tiny sample size)
- In FIRST (Chang, Refregier & Helfand 2004)



Radio Weak Lensing Challenges – Source Population?

- What are μJy star-forming galaxy source populations?
  - Number counts?
  - Size distributions?
  - Polarisation properties?



(Anna Bonaldi)

Radio Weak Lensing

Solution – μJy depth, small areas

- Existing data (Ben Tunbridge poster on COSMOS)
- e-MERLIN Legacy Projects
  - e-MERGE (Tom Muxlow talk Thursday)
  - SuperCLASS (Constantinos Demetroullas talk Thursday)
    - Dedicated ~1 deg^2 WL survey of supercluster field
    - ~150/800 hours observed so far
- CHILES-con-pol
  - Deep continuum, polarisation survey with JVLA
- VLASS on upgraded JVLA
  - WIDE and to be submitted deep proposal
- Plus surveys on ASKAP, MeerKAT, LOFAR

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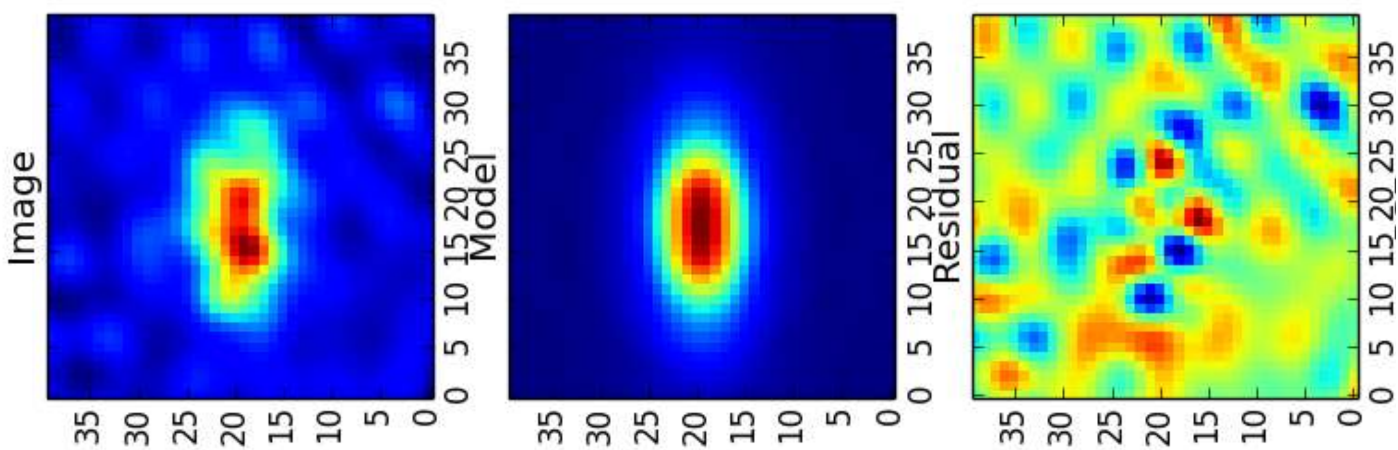
Radio Weak Lensing Challenges – Shape Measurement

- How can we best measure shearing of sources from radio interferometer data?
  - Image plane or visibility plane?
  - Bespoke imaging methods, shape measurement methods
- Accuracy achievable with CLEAN on SKAI sims not looking great (Patel, IH et al 2015)
  - Q ~ 0.4 vs. Q ~ 140 required



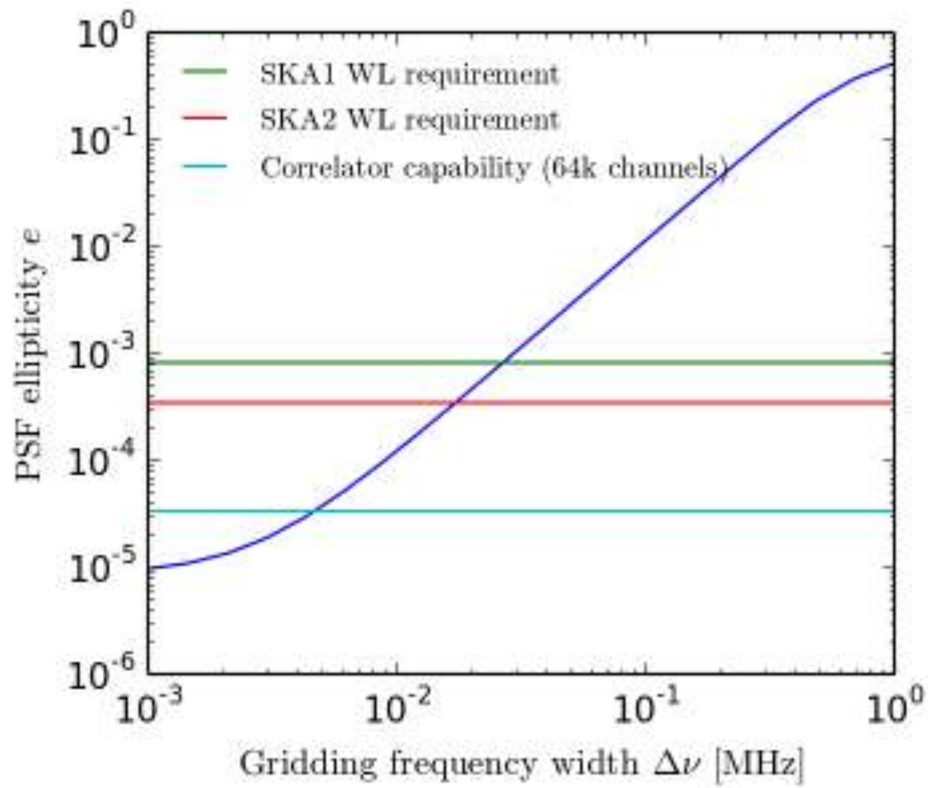
Radio Weak Lensing Solution – radioGREAT

- Expect need bespoke tools for radio WL
- Optical WL gained much from STEP and GREAT
- Community-wide blind data challenge
  - benchmark current methods
  - identify areas necessary for development
- Both image and UV plane data supplied
- Like inference challenges?
  Image analysis?
  SKA data simulation?
  - http://radiogreat.jb.man.ac.uk

Radio Weak Lensing Challenges – Requirements from SKA

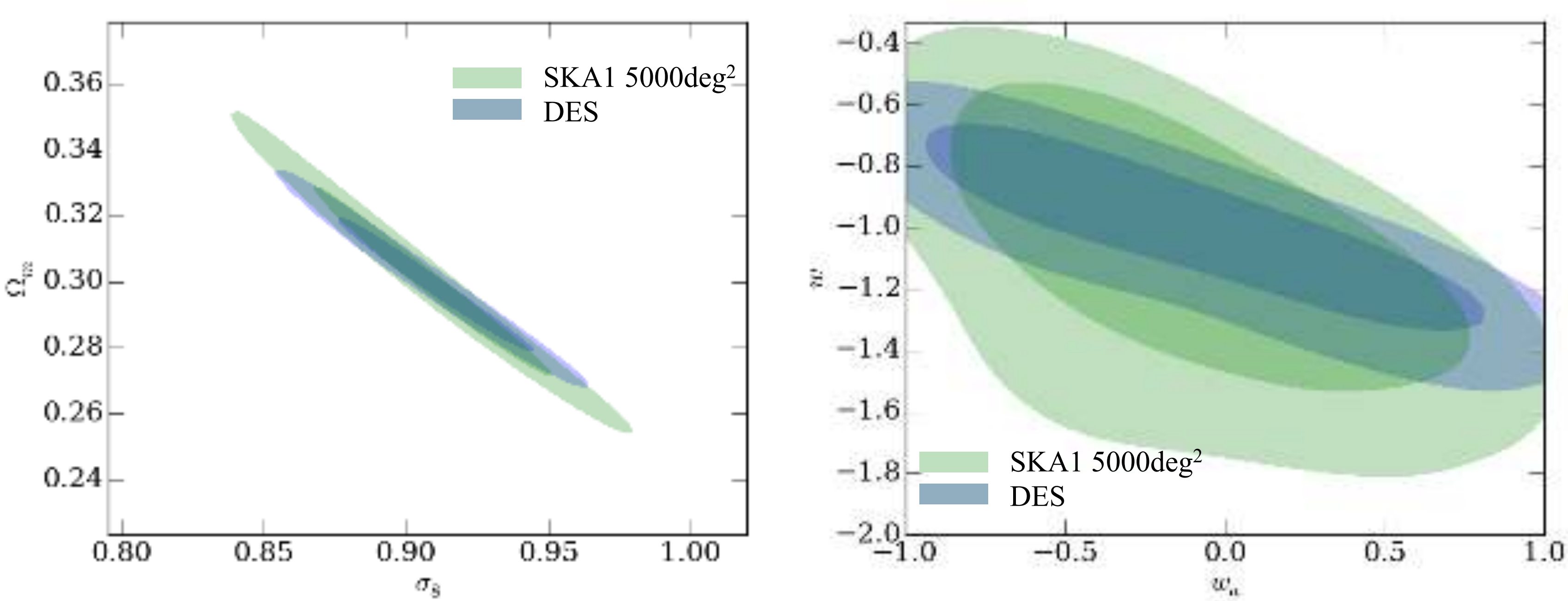
- Bespoke imaging or shape measurement methods need gridded vis. as SKA output
  - current pipelines iterative deconvolved images only!

- Have written ECP to request gridded vis. as output (IH, Michael Brown)
- Specify 10000 hr, 5000 deg^2, Band 2 survey with ~10kHz channels, 0.1 arcsec pixels
  - Require this spectral resolution to avoid bandwidth smearing
  - …around 500PB for entire survey!
  - Commensal with continuum, HI spectral line surveys? ☺



Radio Weak Lensing
Predictions for Stage III Surveys

- SKA1-early already ~5x better than CFHTLens
- SKA1 competitive with DES



(IH, Joe Zuntz, CosmoSIS)

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Radio Weak Lensing Predictions for Stage III Surveys

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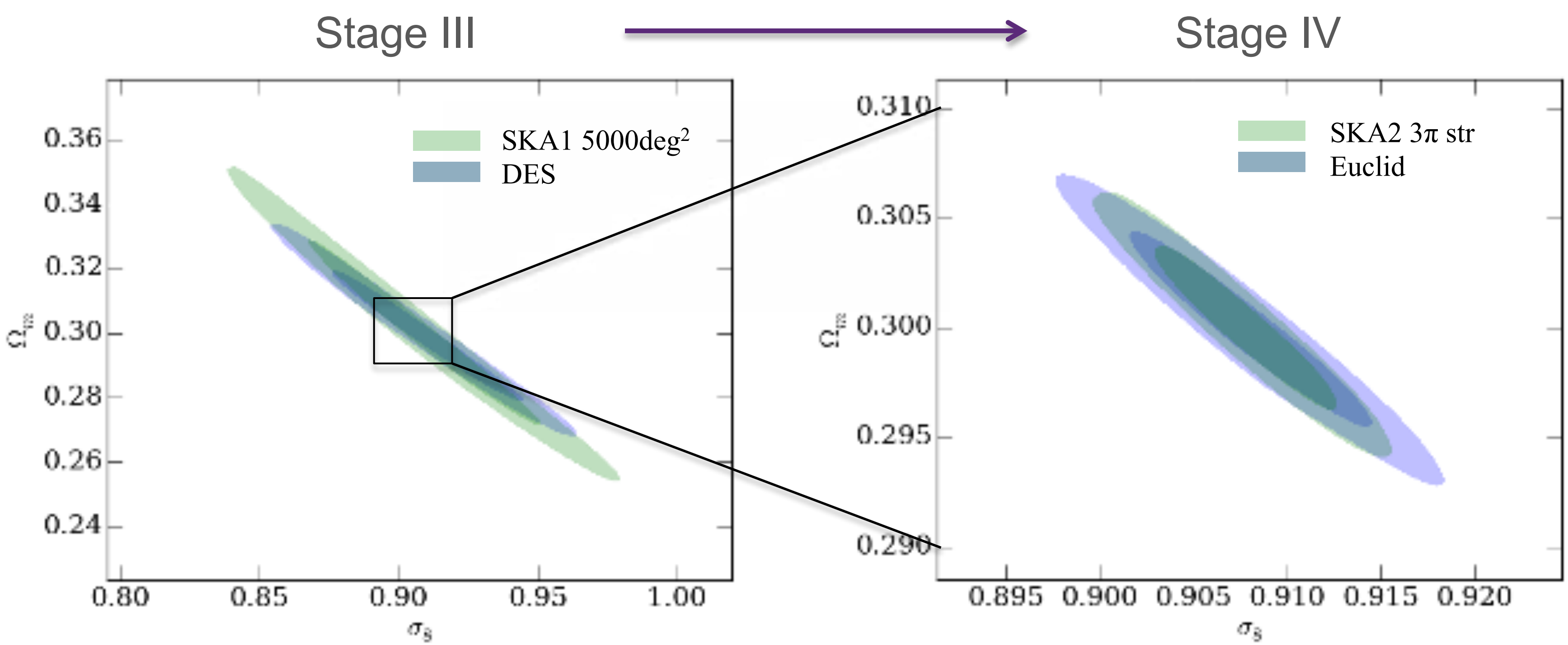
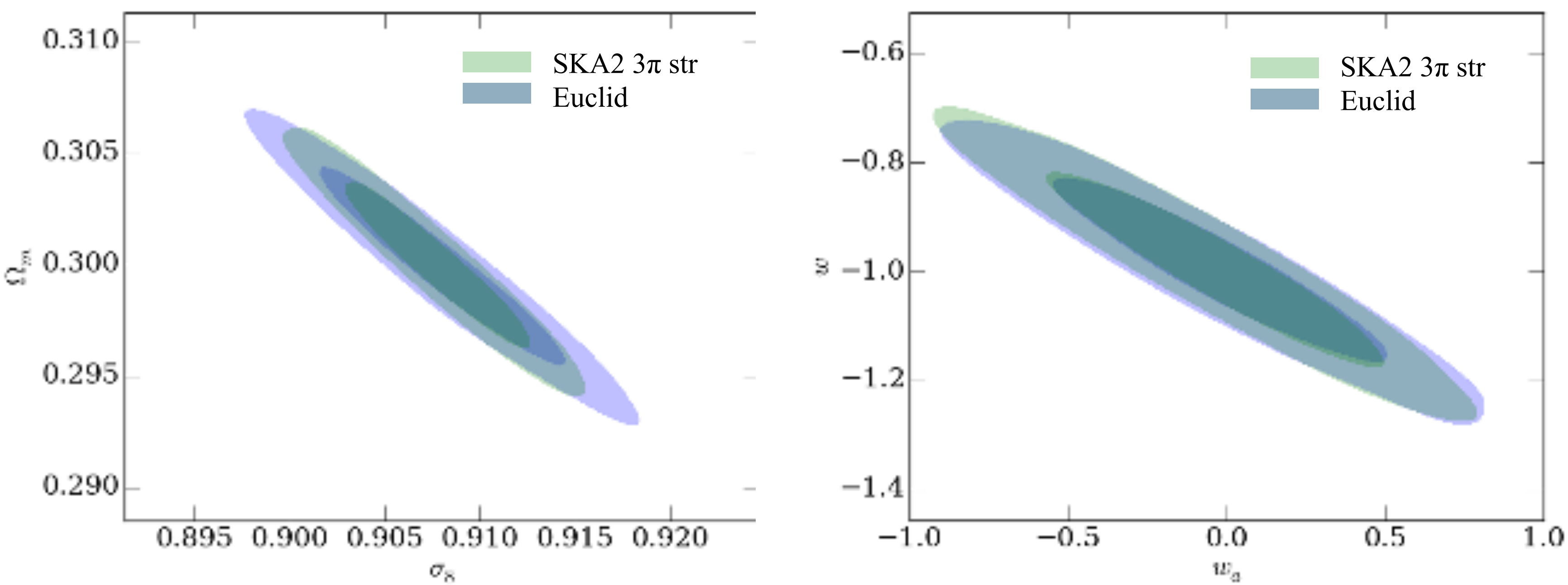


(IH, Joe Zuntz, CosmoSIS)

Radio Weak Lensing Predictions for Stage IV Surveys

- SKA2 competitive with Euclid
- Cross-correlations can be even better!



(IH, Joe Zuntz, CosmoSIS)

Radio Weak Lensing
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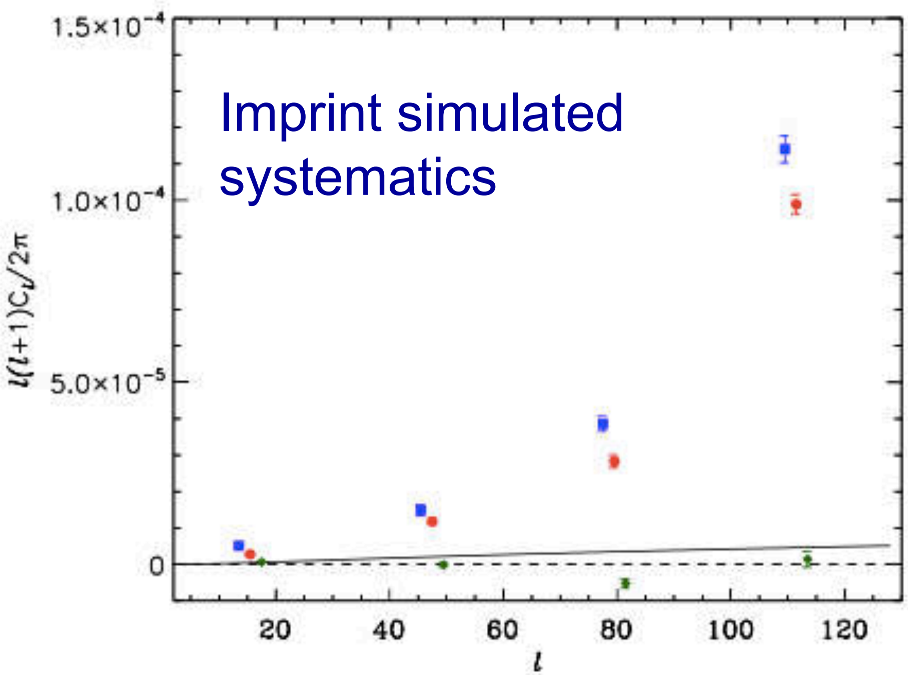

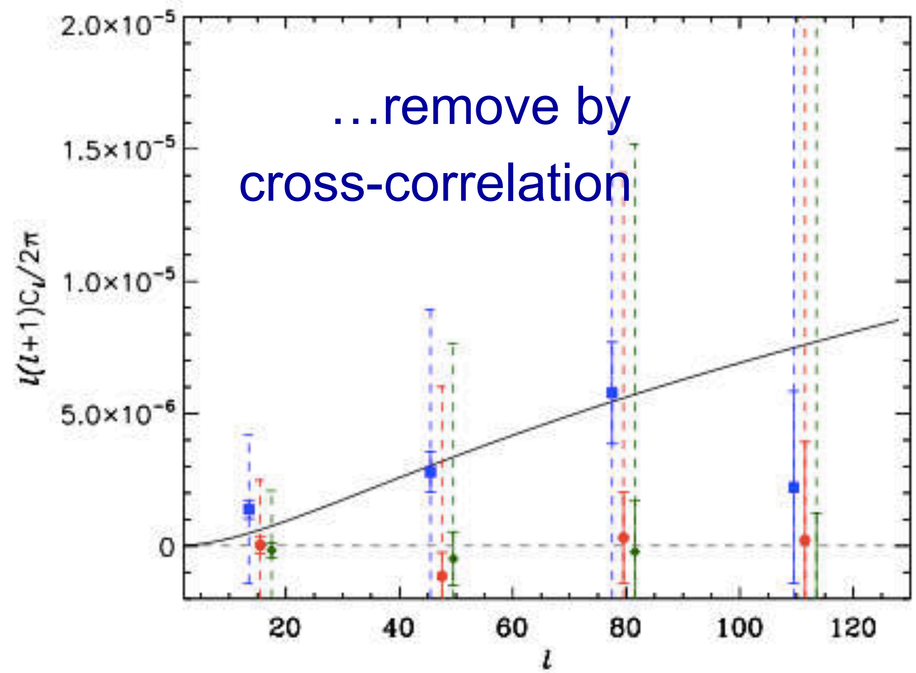

(SDSSxFIRST, Demetroullas & Brown, in prep)

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Radio Weak Lensing
Summary

- SKA can do WL competitive with premier optical surveys
- Radio can be panacea for many WL systematics
  - Polarisation/rotational velocities for Intrinsic Alignments
  - PSF systematics
  - Spec-zs from HI line surveys
- Radio weak lensing will be hard
  - shear measurement from interferometer an open question
- Ongoing efforts with simulations, pathfinder experiments and algorithm challenges
  - SuperCLASS, e-MERGE, CHILES-con-pol, VLASS
  - radioGREAT

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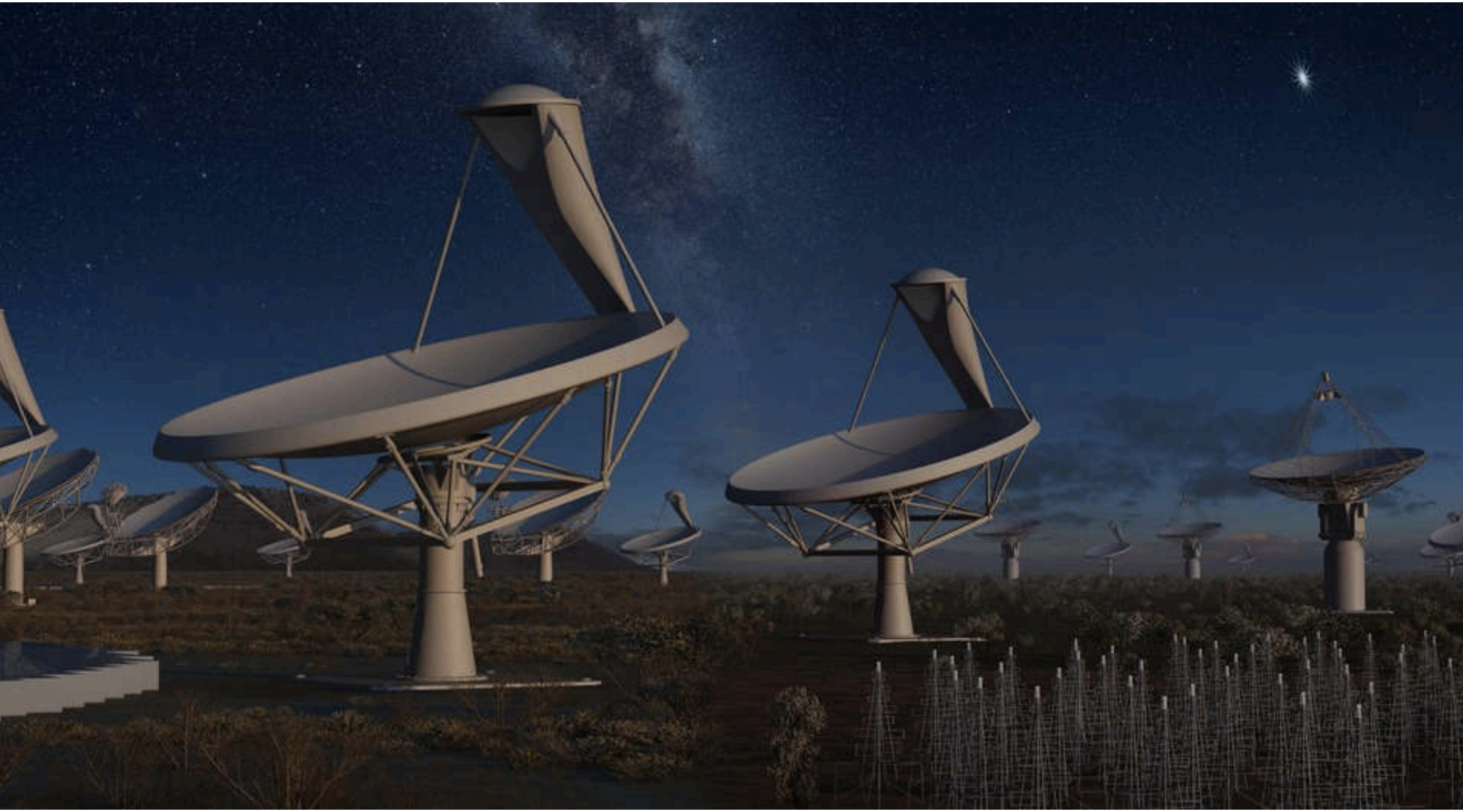
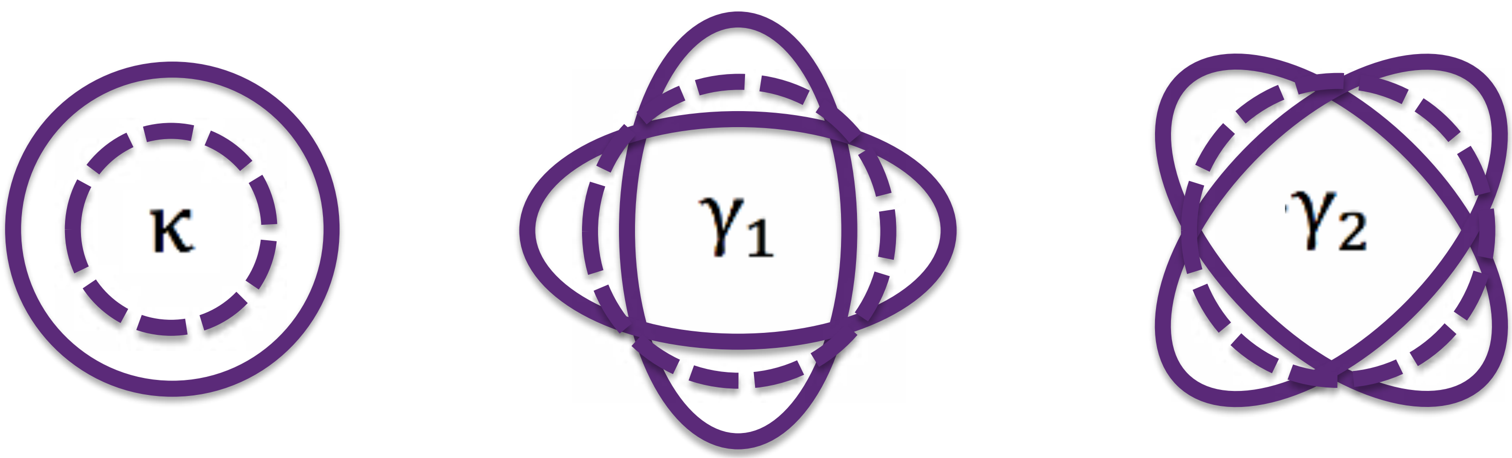
Bonus Slides



Weak Lensing Cosmology
Shear Transformation

- Source profile in the image plane transformed by lensing matrix:

$$G_{\text{lens}} = \begin{pmatrix} 1-\gamma_1-\kappa & -\gamma_2 \\ -\gamma_2 & 1+\gamma_1-\kappa \end{pmatrix}$$



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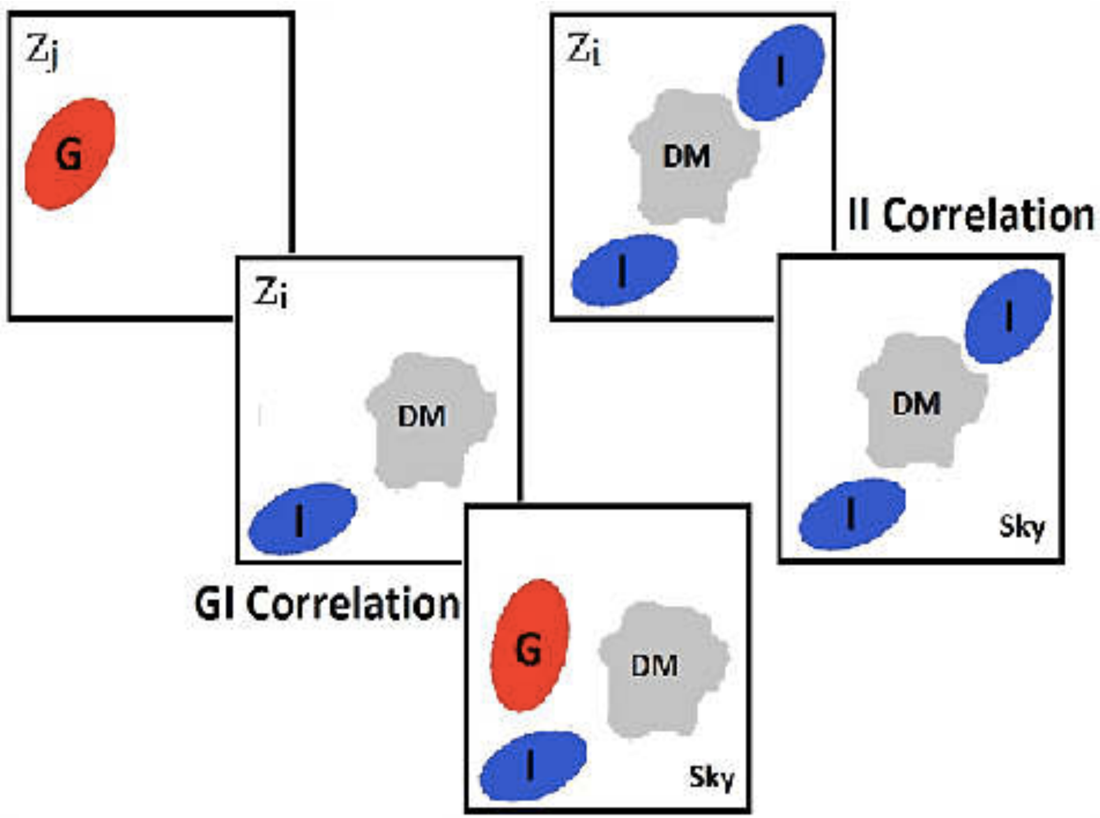
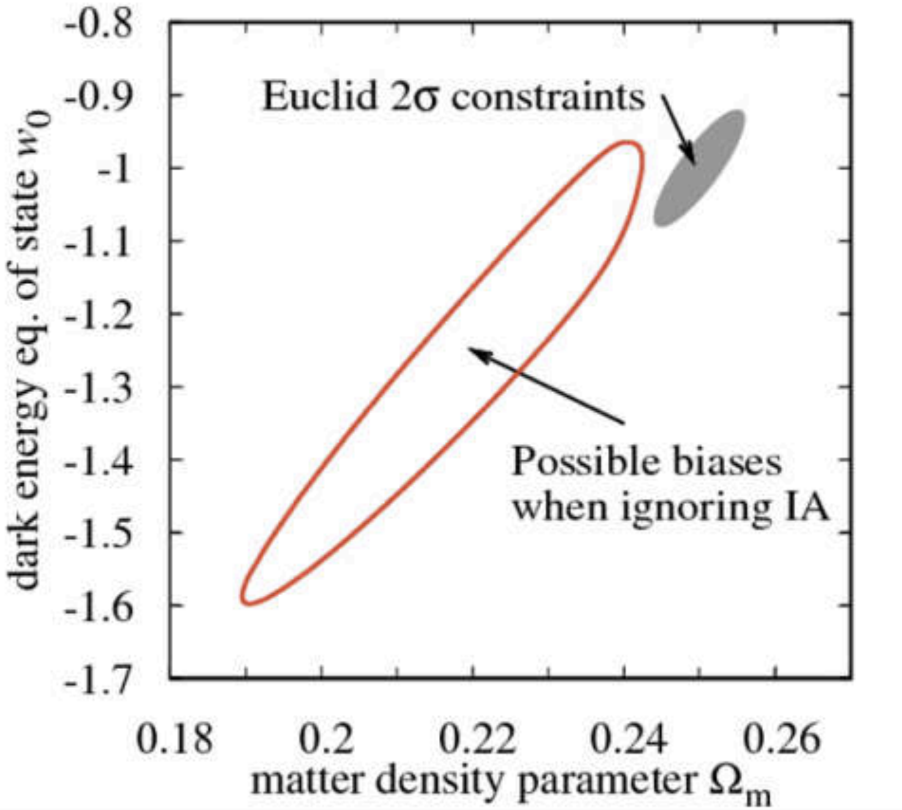
Weak Lensing Cosmology
Intrinsic Alignment Systematics

- Assumed $\langle e_{intrinsic} \rangle = 0$ BUT galaxies have intrinsic alignments due to structure formation process



Weak Lensing Cosmology
Intrinsic Alignment Systematics

- Such systematics are potentially a BIG problem
  - (this is only one example)



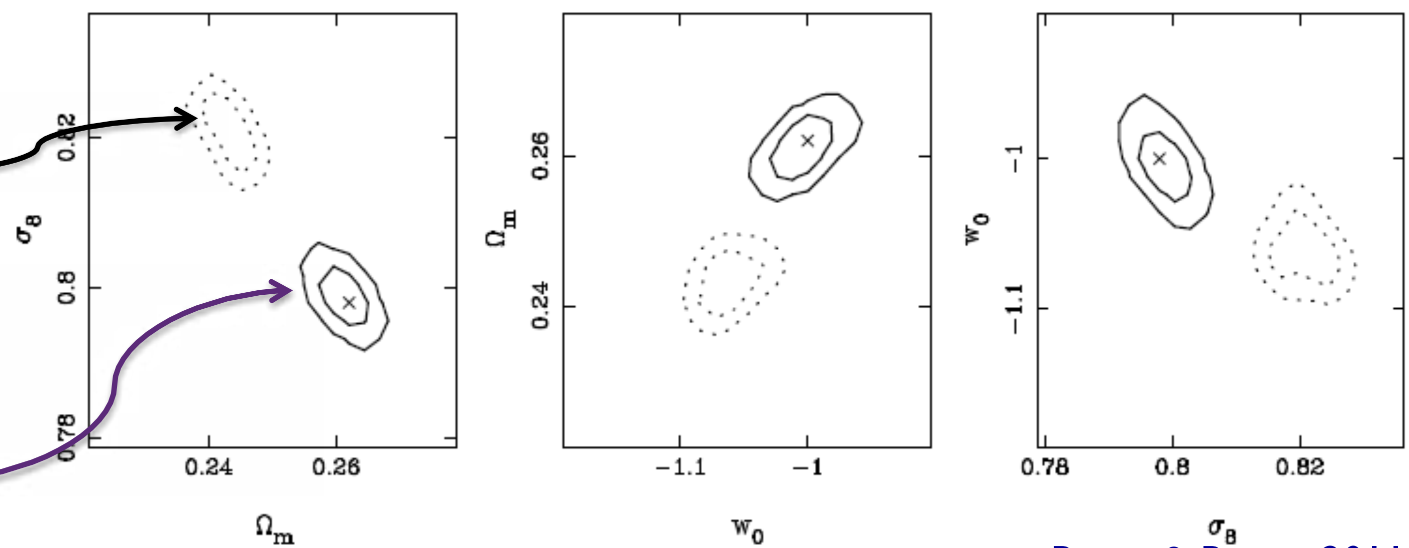
Joachimi et al 2011

Radio Weak Lensing
Intrinsic Alignment Systematics

- Radio can help with this!
  - Polarisation unaffected by lensing
  - Can expect relationship between integrated polarisation angle and true galaxy position angle
  - Can form map of intrinsic alignments

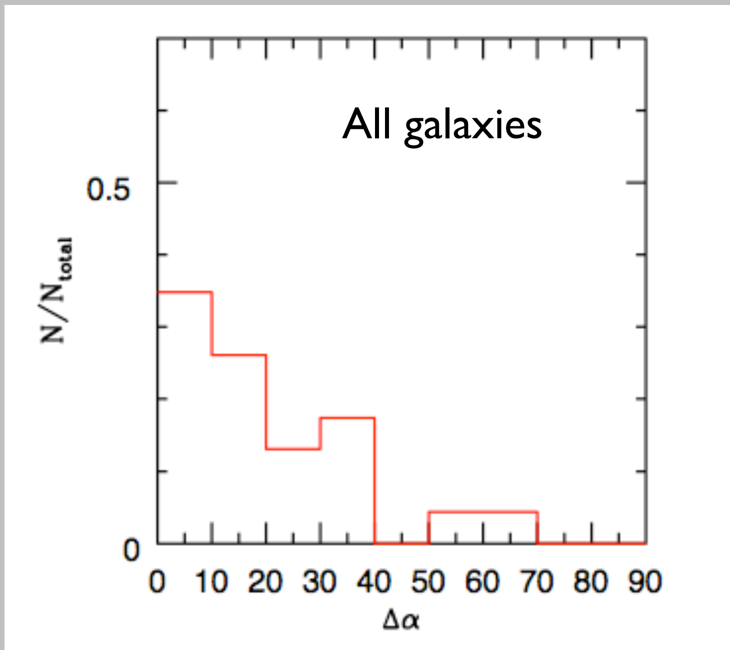
Standard analysis biased by intrinsic alignment contamination

Contamination removed using new technique with no degradation in constraining power

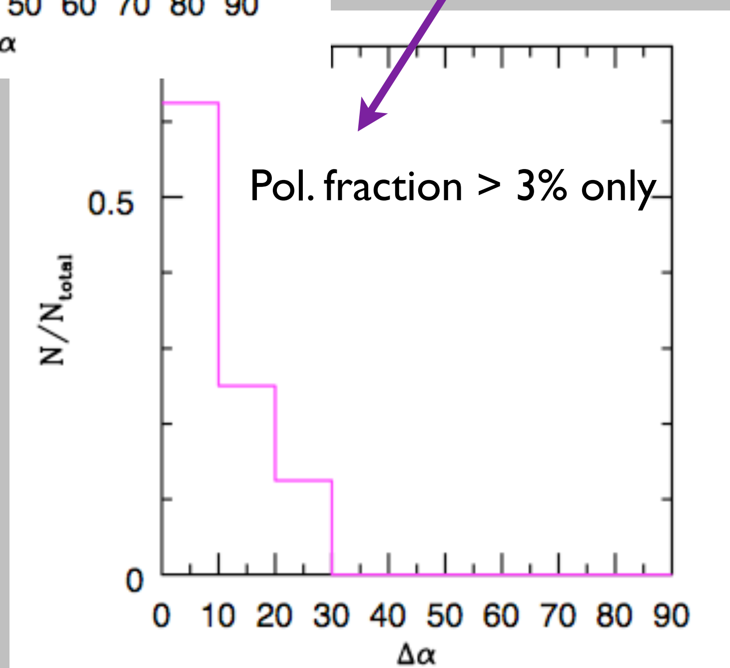


Bown & Battye 2011

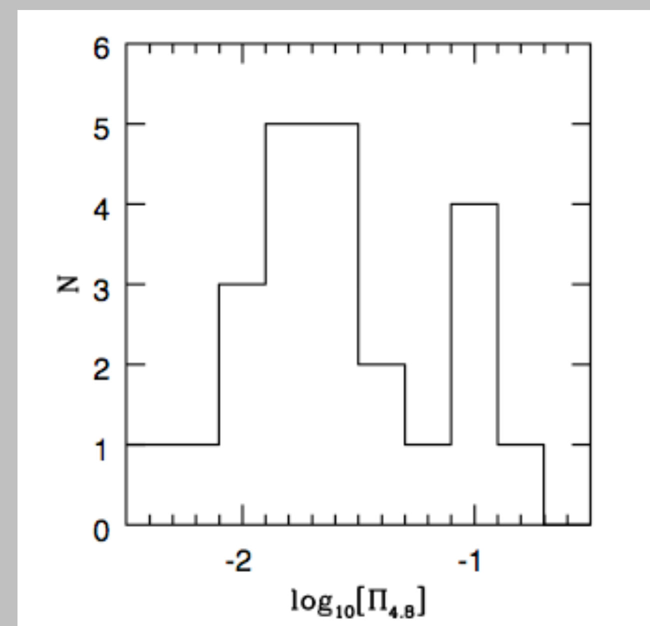
Integrated polarization of local radio galaxies



Alignment of polarization orientation with intrinsic position angle



Distribution of polarization fraction:

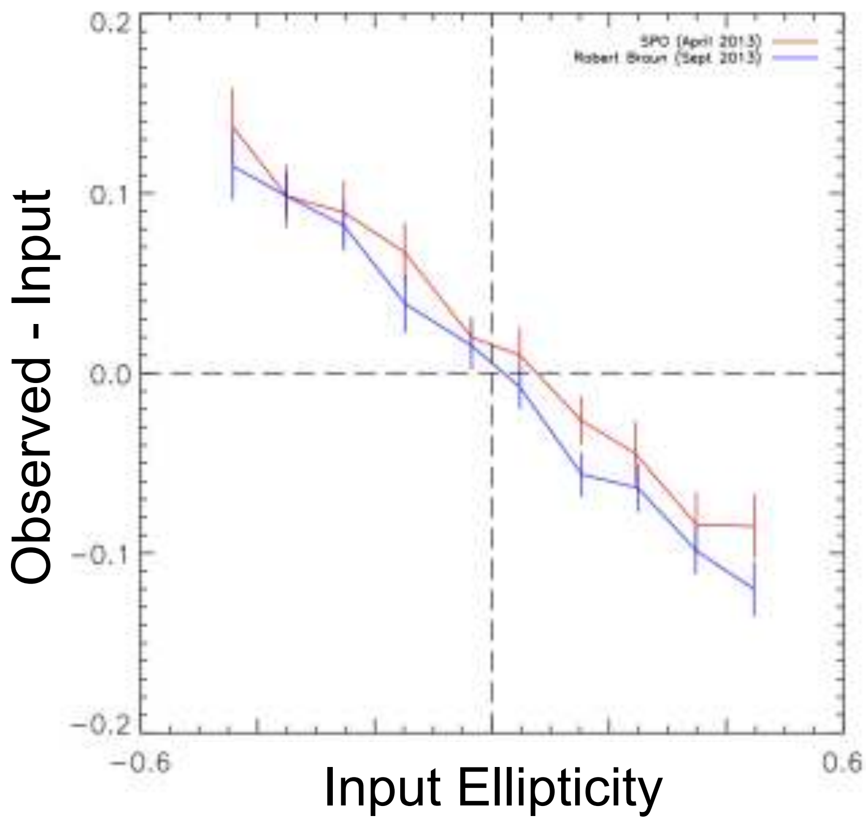


Data from Stil et al. (2009)

(Michael Brown's slide)

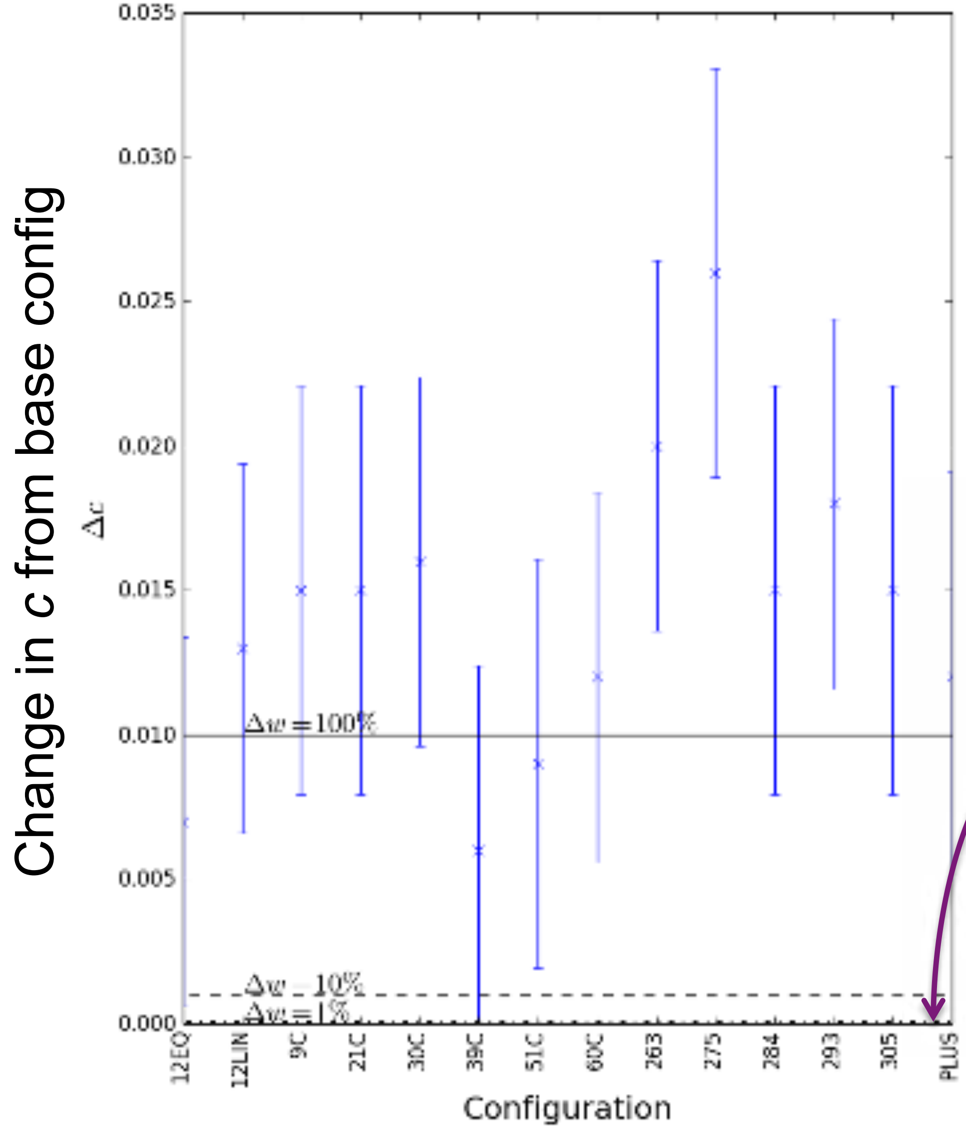
Radio Shape Measurement
Current State of the Art

- SKAI antenna configurations
- Measure recovered shape from lwimager images
  - (IM3SHAPE, shapelets give comparable results)



Patel, IH et al 2015

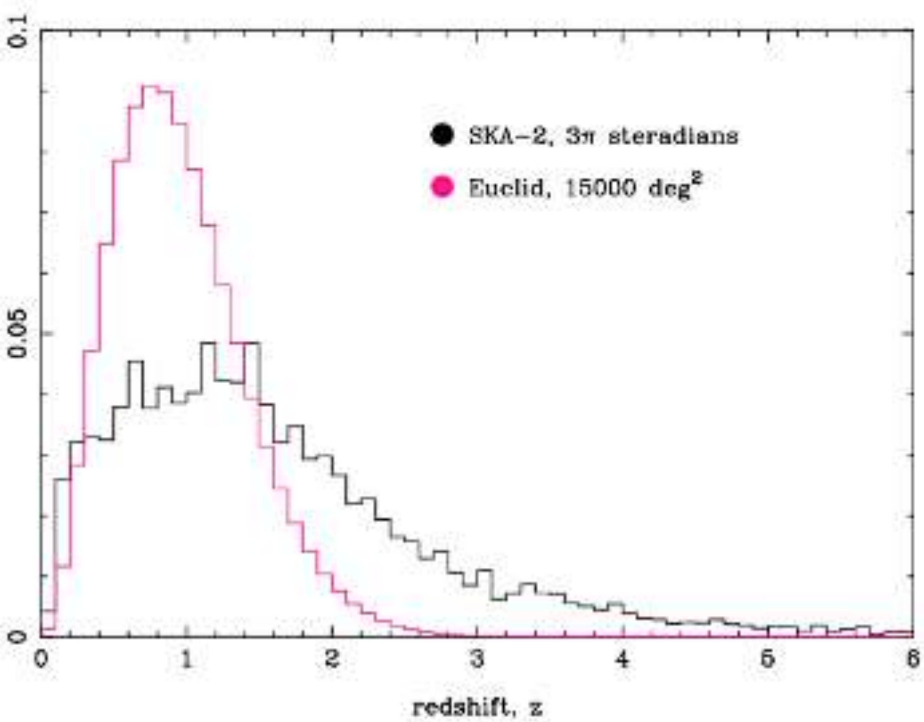
Radio Shape Measurement
Effect of Antenna Configuration

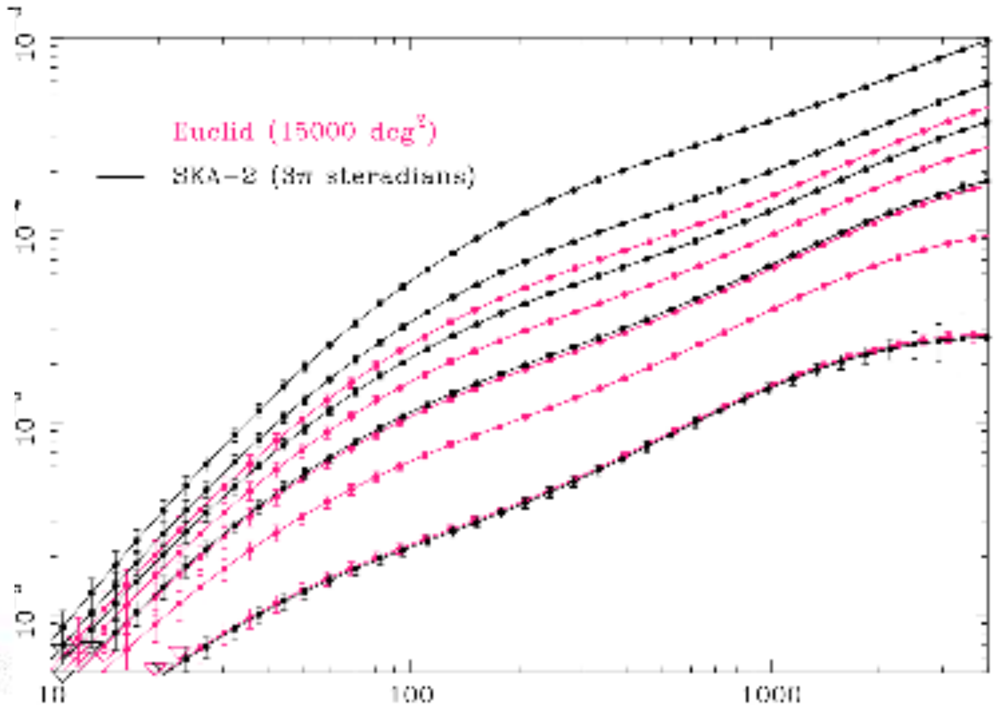


Goal

Patel, IH et al 2015

Survey Design
Redshift distributions





Brown, IH et al 2015

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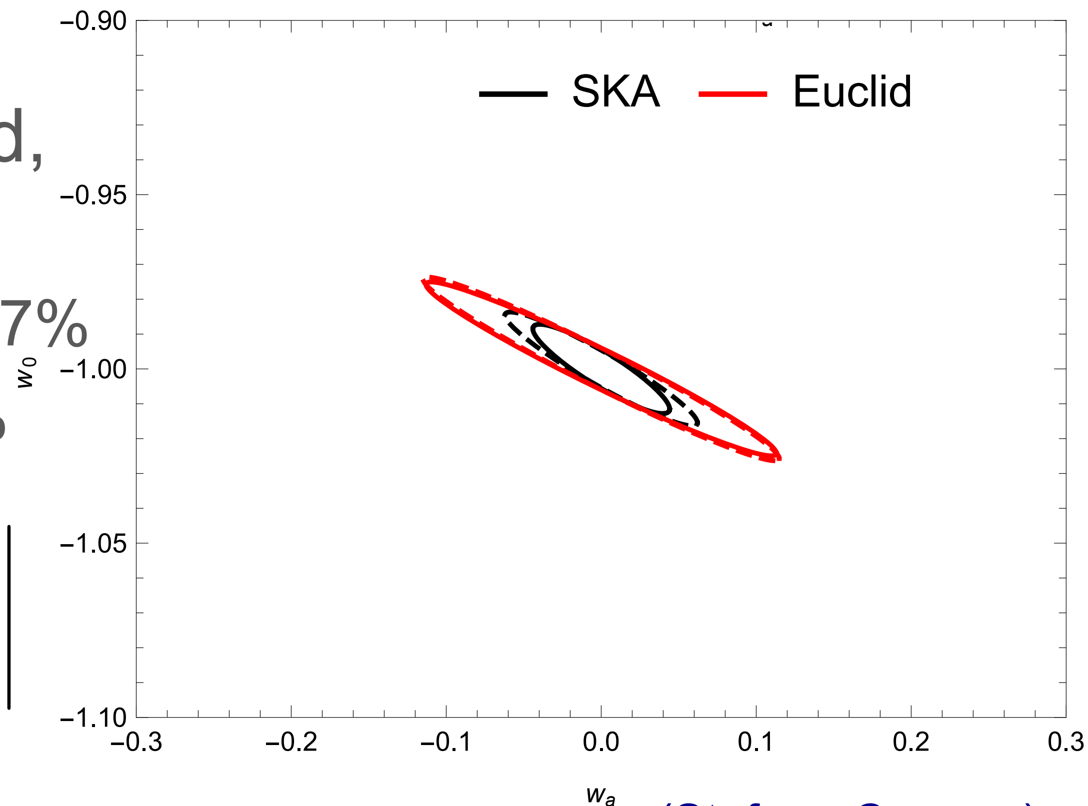
Radio Weak Lensing
Accuracy of Fisher Forecasts

- Compare CosmoSIS MCMC (accurate!) chains to Fisher forecasts (fast!)

- For un-marginalised, full sky case:
  - Euclid: 5.6% and 1.7%
  - SKA: 22% and 29%

$$\left|\frac{\sigma_{\text{Fisher}}(\vartheta_\alpha)}{\sigma_{\text{CosmoSIS}}(\vartheta_\alpha)} - 1\right|$$

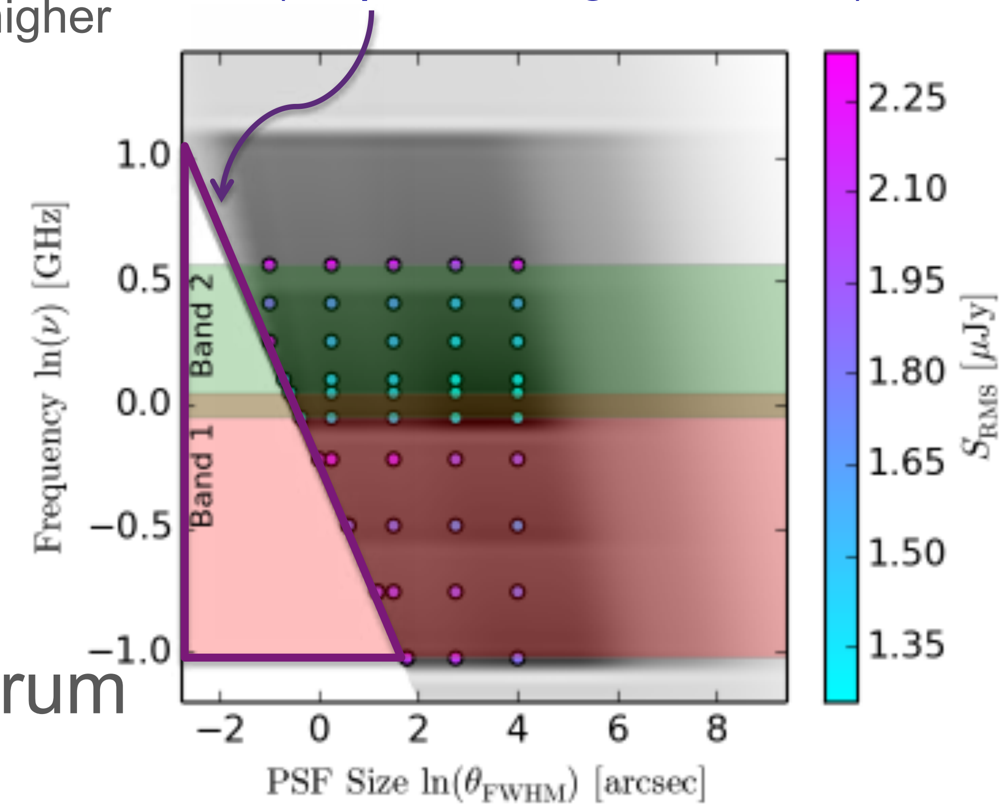


(Stefano Camera)

Radio Weak Lensing Challenges – Survey Design

- How low in ν can we go?
  - ✓ Synchrotron spectrum gives higher source counts
  - x Ionosphere becomes highly turbulent
- Choose experimental configuration
- Generate realisations of shear catalogues
- Measure power spectrum
- Optimise for best cosmological constraints

Ionosphere PSF dominates (simple Kolmogorov model)



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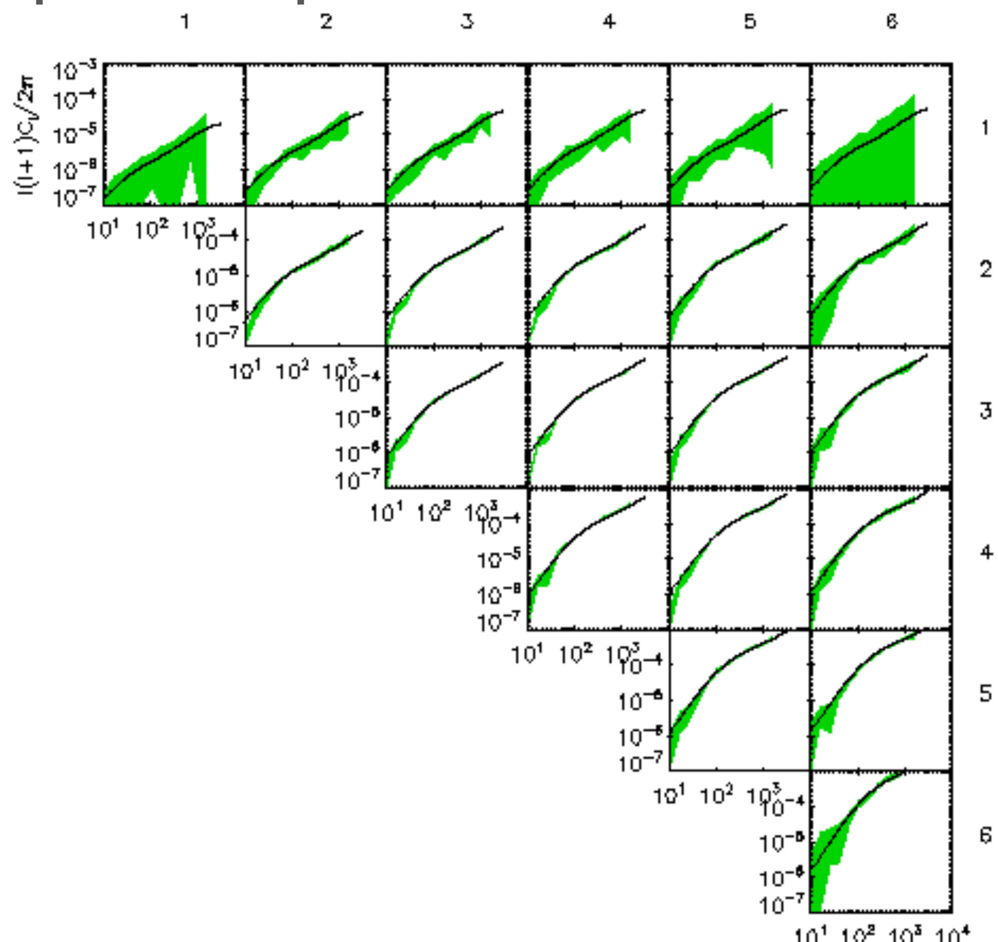
Radio Weak Lensing Challenges – Survey Design

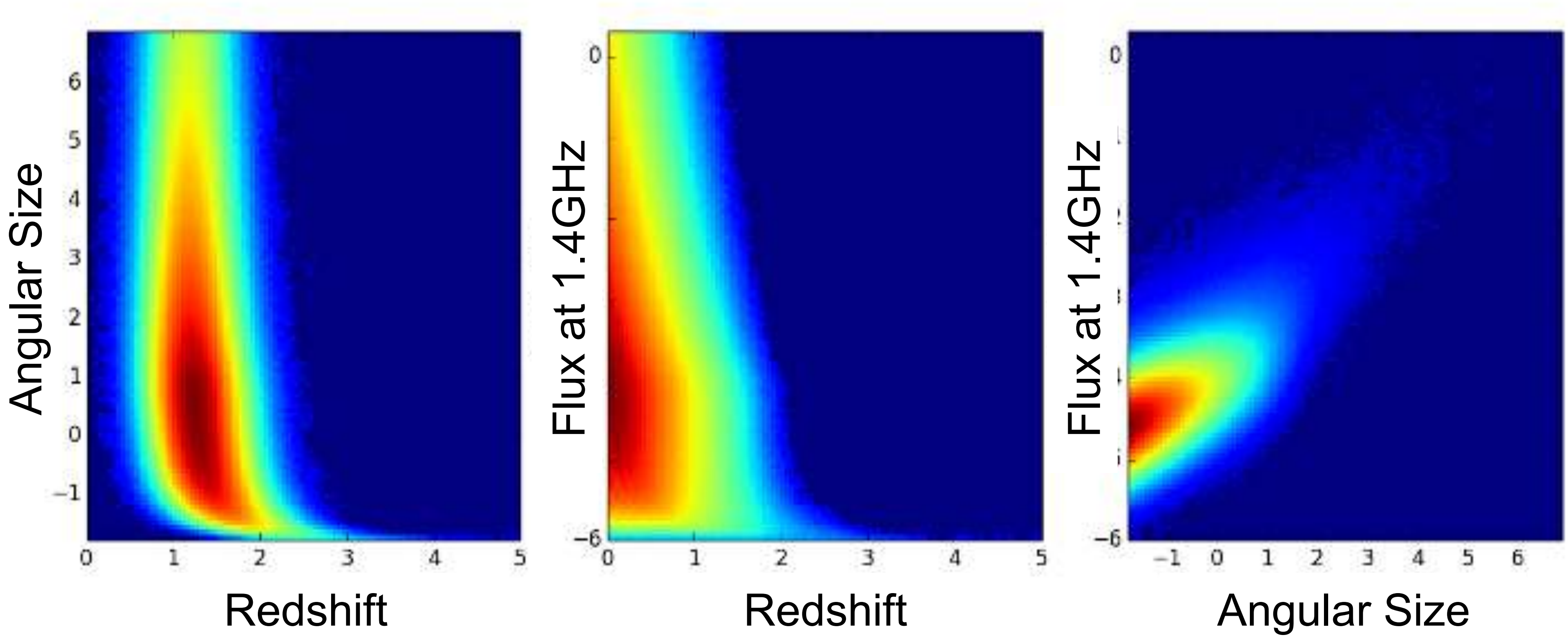
- Example recovered power spectra:
- 6 redshift bins
  - 5 in $0 < z < 2.5$
  - 1 in $z > 2.5$
- 'Canonical' survey
  - 0.5 arcsec PSF
  - 1.4 GHz



(Anna Bonaldi)

Radio Weak Lensing Challenges – Survey Design

- Source (star-forming galaxy) distributions from semi-empirical SKADS simulations



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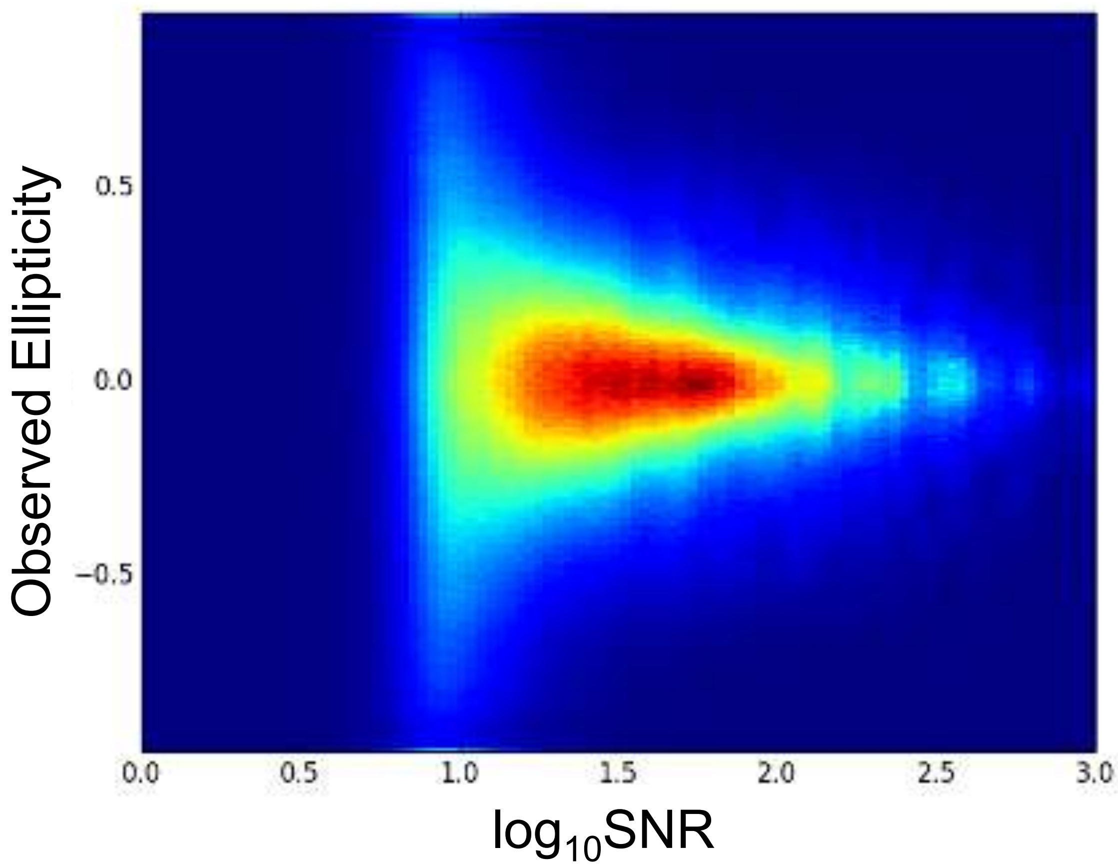
Radio Weak Lensing Challenges – Survey Design

- Shape measurement errors as function of SNR from Tomek Kacprzak's sims with IM3SHAPE



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Additional Probes
21cm Lensing, Galaxy-Galaxy Lensing

- Can also look at lensing of 21cm signal
  - higher redshifts (z ~ 2-3)
- Galaxy-galaxy lensing to constrain DM halo profiles