Weak Lensing with Radio Continuum Surveys

Prina Patel
University of the Western Cape, South Africa

21st October 2015

The many facets of extragalactic radio continuum surveys
Bologna, 2015.

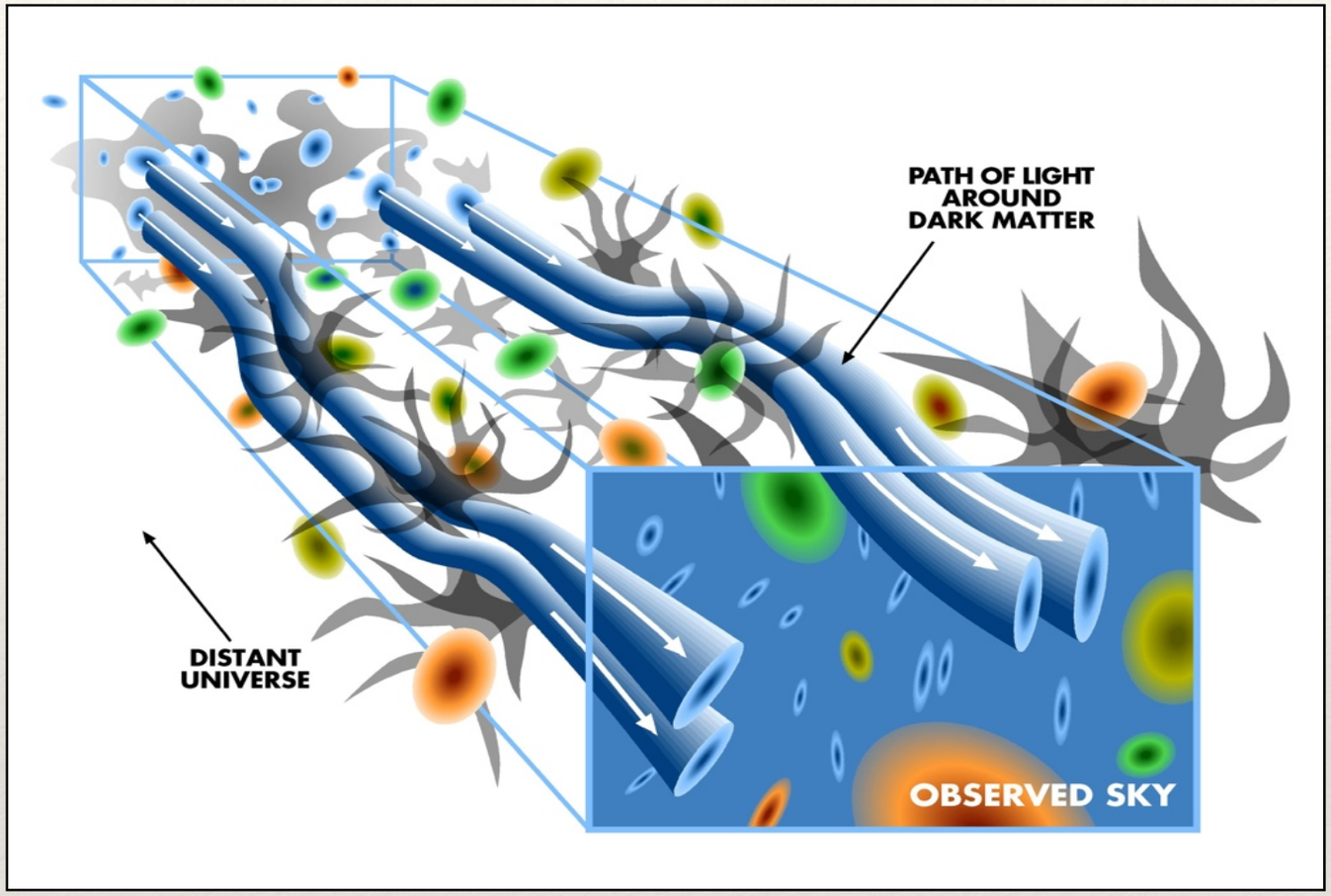
Weak Gravitational Lensing

GR —> Light deflection

Small deflections on cosmological scales

Distortions —> slight changes to galaxy ellipticities

Depends on geometry and large scale structure



Distances Power spectrum

$$\kappa_{eff}(\vec{\theta}, w) = \frac{3H_0^2\Omega_m}{2c^2}\int_0^w \frac{(w-w')\,w'}{w}\frac{\delta(w'\vec{\theta}, w')}{a(w')}\mathrm{d}w'$$

Both depend on Dark Matter and Dark Energy

Prospects

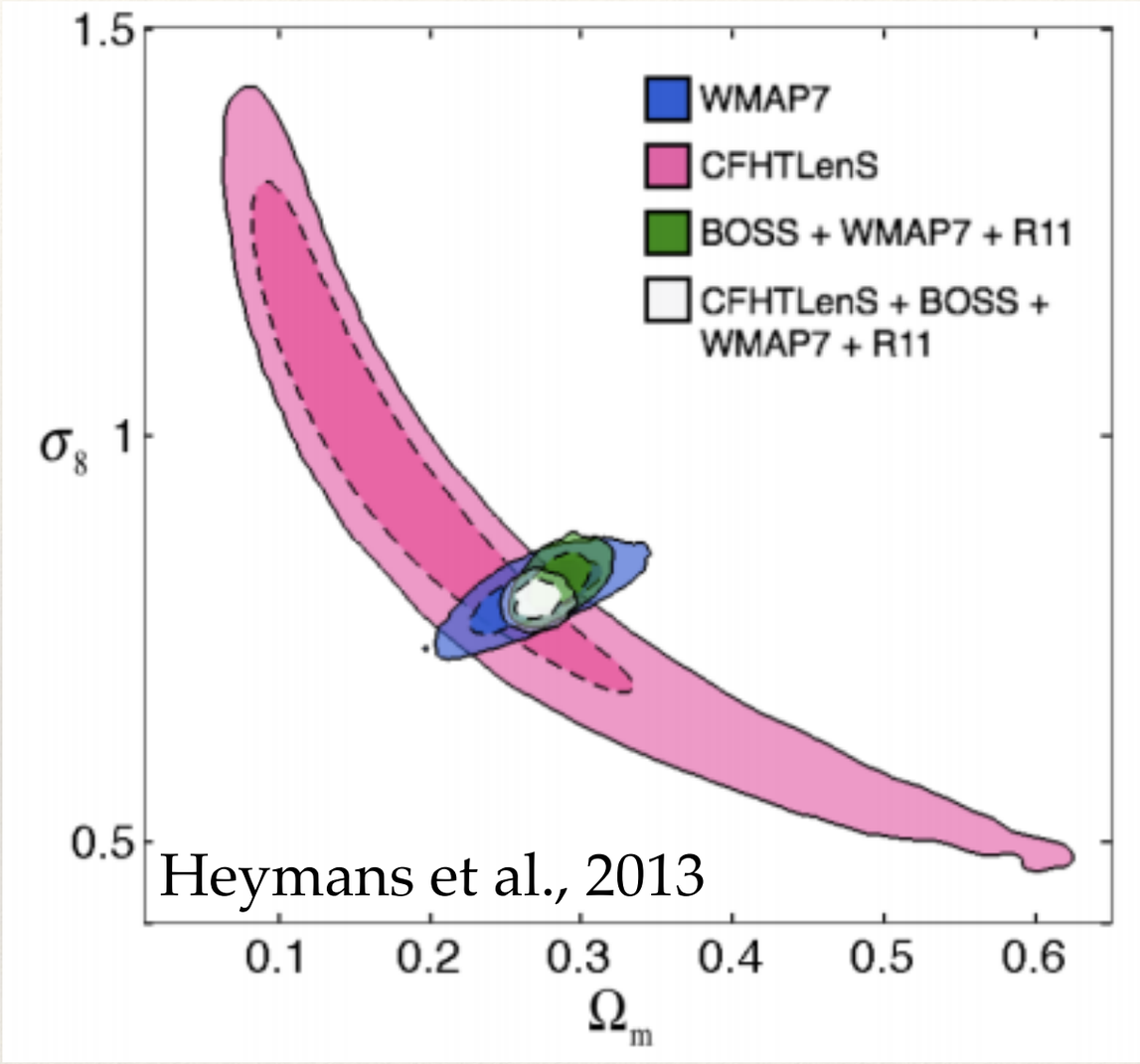
Sensitive to the dark matter distribution

Can measure the evolution of structure

Complementarity with other probes breaks degeneracies

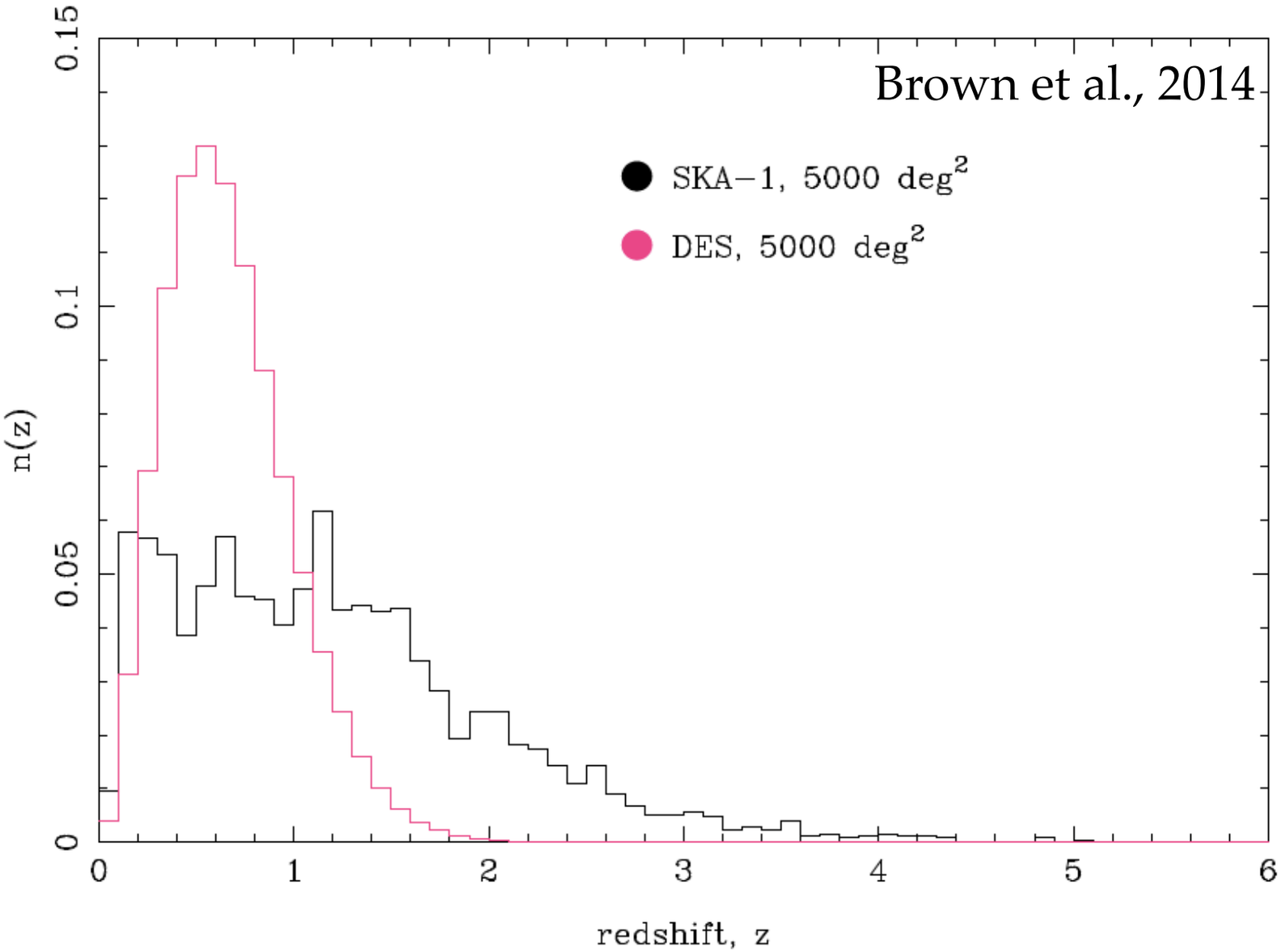
Upcoming: DES, KiDS, Pan-STARRS, EUCLID, LSST, SKA (eMERLIN and JVLA)

Chang et al., 2004 (FIRST), Patel et al., 2010 (HDFN) & Patel et al., 2014 demonstrated feasibility



Current state of the art from CFHTLS

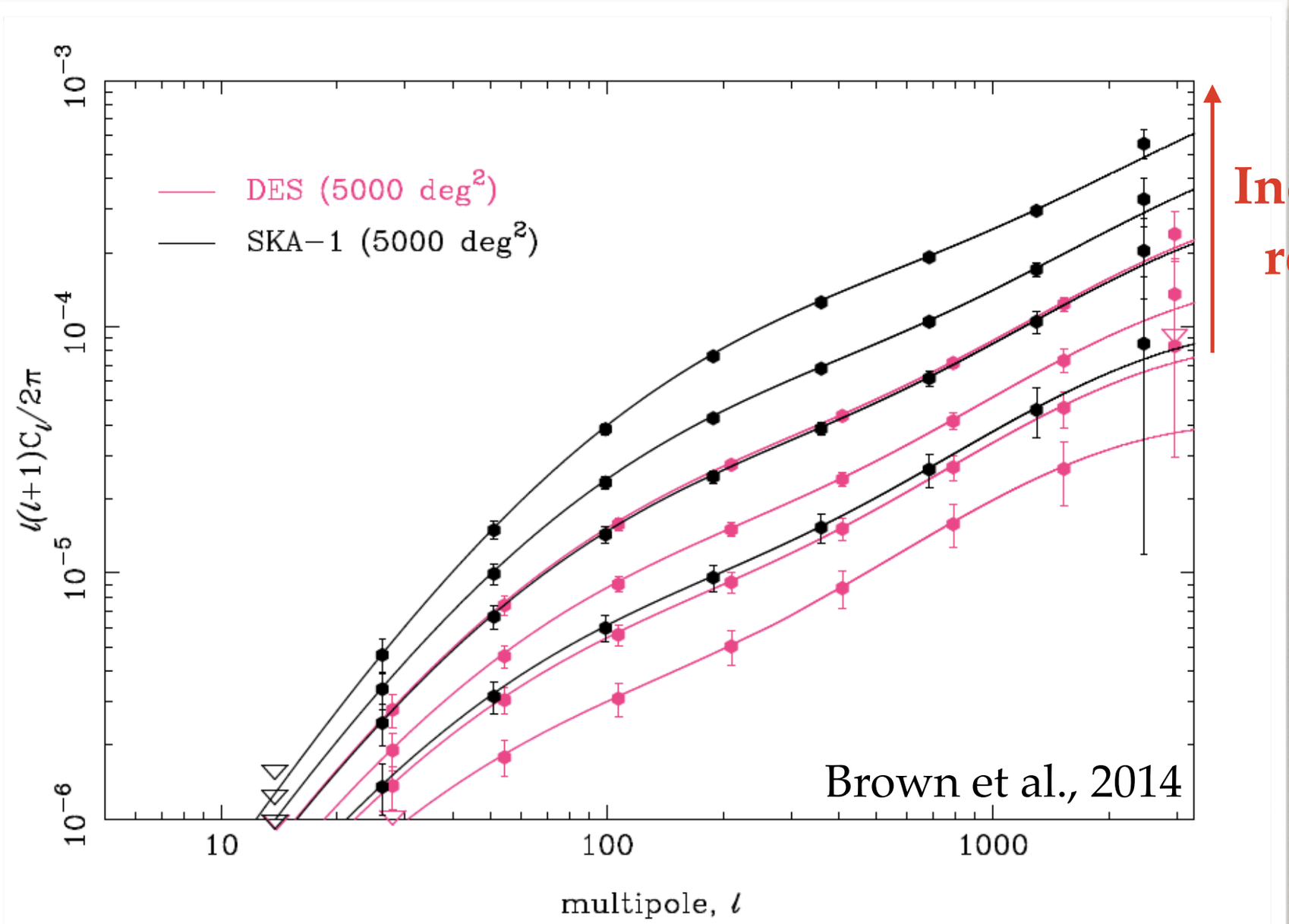
Why Radio Continuum?



Assumes a two year (on-sky) survey covering 5000 sq. degrees with SKA-MID array.

Can push lensing to higher redshifts!

Why Radio Continuum?



Increasing redshift

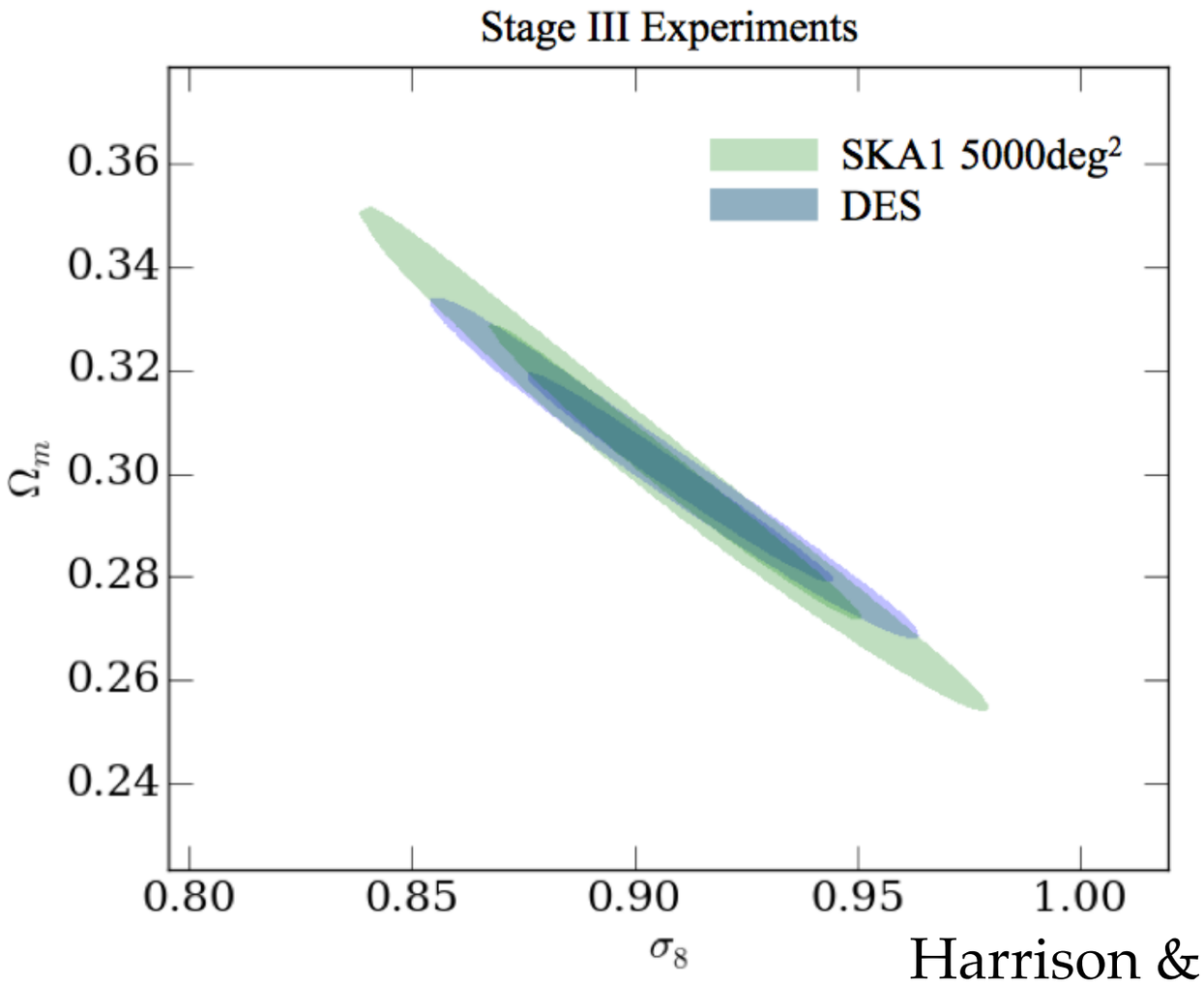
Can push lensing to higher redshifts!

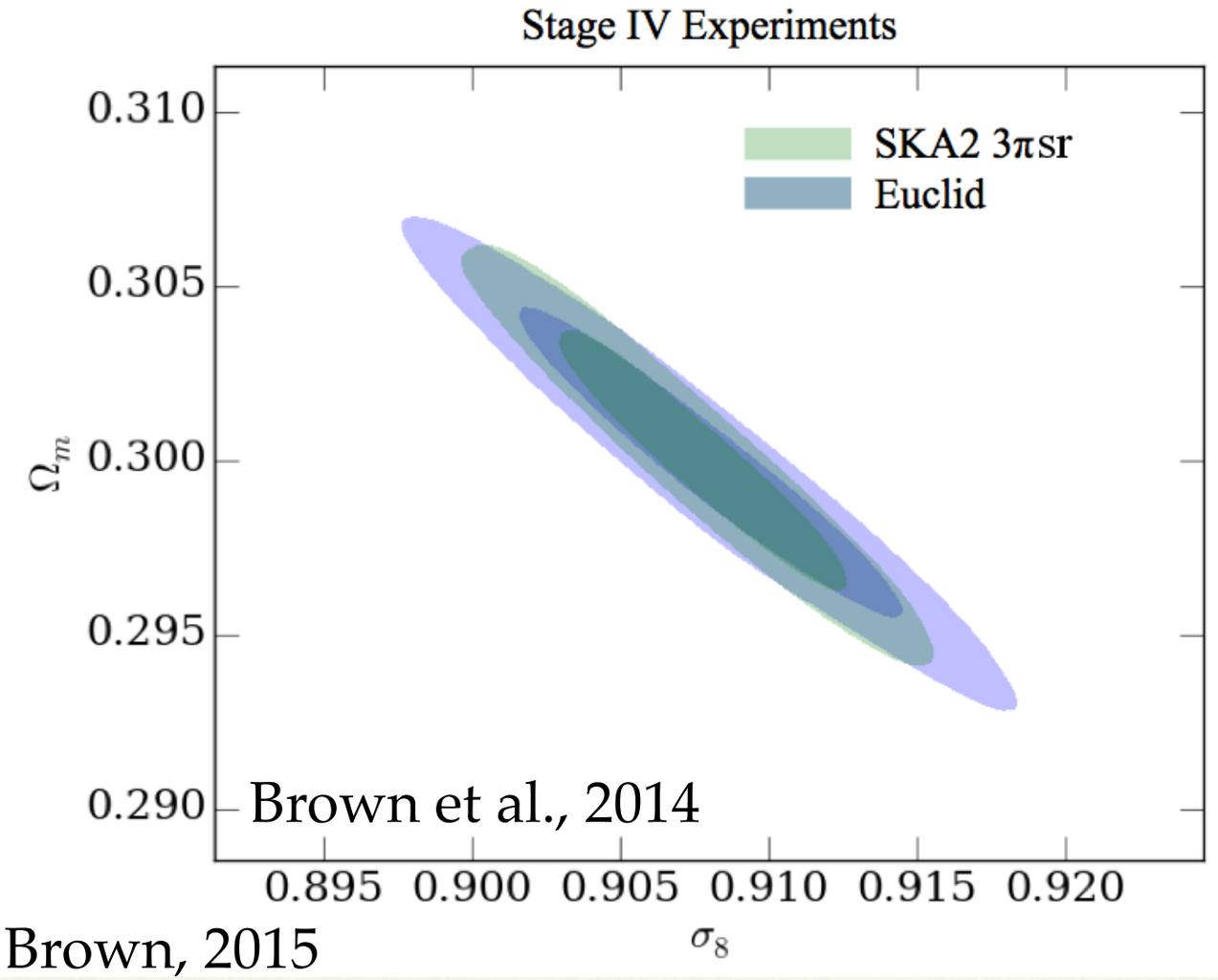
Measure lensing power at different epochs!

Assumes a two year (on-sky) survey covering 5000 sq. degrees with SKA-MID array.

Why Radio Continuum?

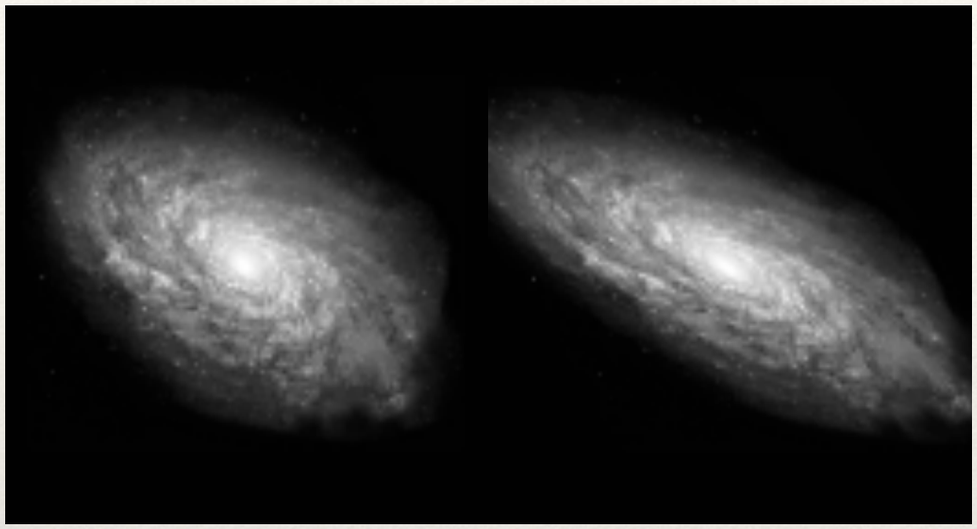
SKA has constraining power comparable to DES and EUCLID.





Harrison & Brown, 2015

Radio Optical Complimentarily



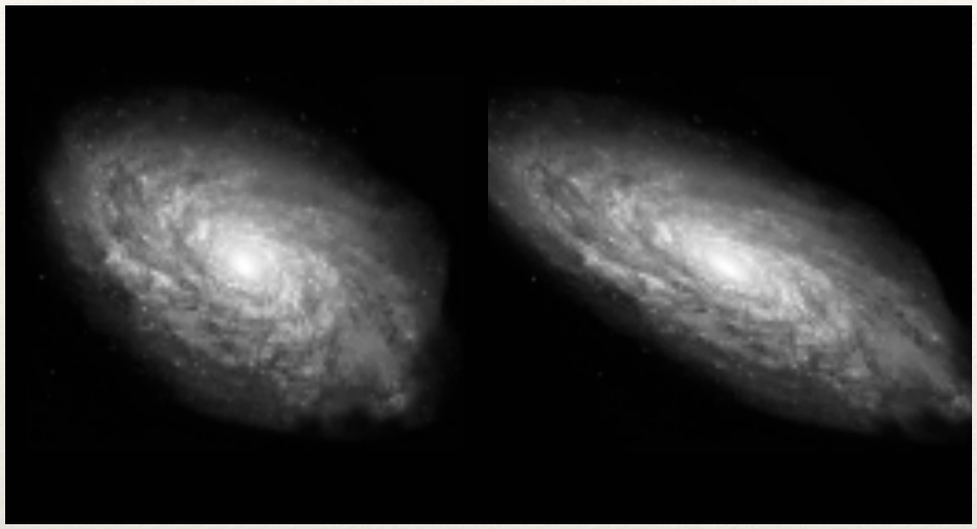
Measured ellipticity of a galaxy = intrinsic shape + instrumental systematics + lensing

$$\tilde{\gamma} = \gamma + \gamma^s$$

Extract a cleaner signal by cross-correlating:

$$\langle \tilde{\gamma}_o \tilde{\gamma}_r \rangle = \langle \gamma\gamma \rangle + \langle \gamma\gamma_o^s \rangle + \langle \gamma\gamma_r^s \rangle + \langle \gamma_o^s \gamma_r^s \rangle$$

Radio Optical Complimentarily



Measured ellipticity of a galaxy = intrinsic shape + instrumental systematics + lensing

$$\tilde{\gamma} = \gamma + \gamma^s$$

Extract a cleaner signal by cross-correlating:

$$\langle \tilde{\gamma}_o \tilde{\gamma}_r \rangle = \langle \gamma\gamma \rangle + \langle \gamma\gamma_o^s \rangle + \langle \gamma\gamma_r^s \rangle + \langle \gamma_o^s \gamma_r^s \rangle$$

Jarvis & Jain, 2008, Patel et al., 2010

↑Demonstrated this CC technique with HDFN data from optical and radio

Surveys

All continuum surveys can be used to do weak lensing provided you have the sensitivity and resolution

Lensing shear analysis will aim to make use of gridded visibility data so resolution of the standard continuum maps not a factor

Overlap with optical fields for cross correlation

Exact optimal survey design depends on the chosen figure-of-merit

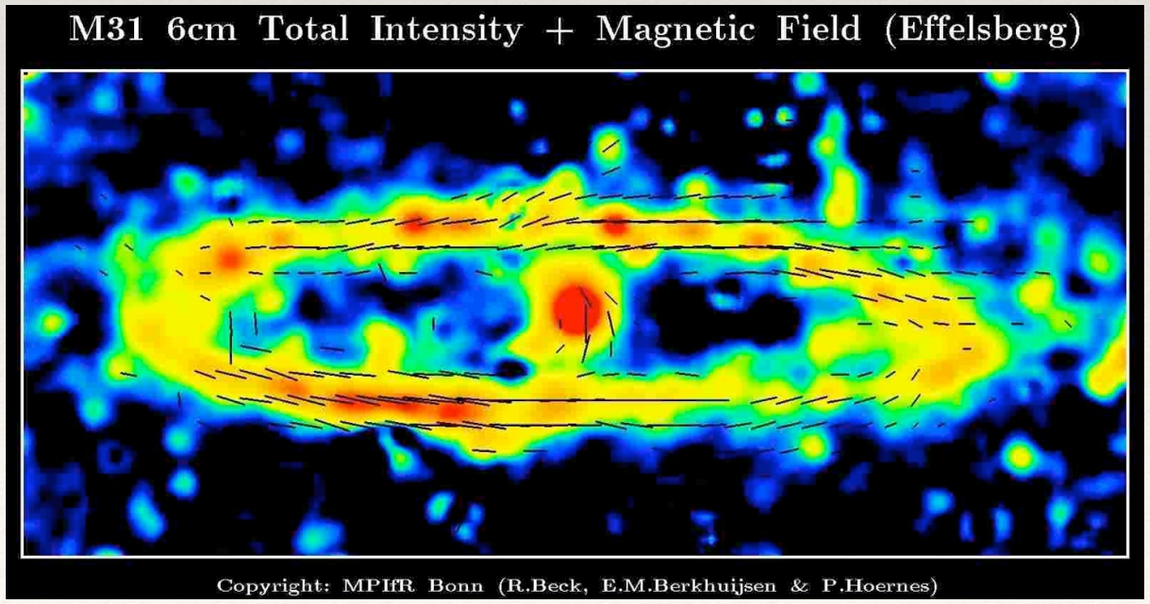
Uniqueness: Polarisation

Intrinsic galaxy shapes are not random —> intrinsic alignments are major systematic in weak lensing surveys

Polarisation angle unaffected by lensing —> unlensed galaxy shapes

Use polarisation information to reduce noise and remove intrinsic alignment

Promising BUT depends on as yet uncertain quantities, e.g. fractional polarisation, correlation between the polarisation and galaxy structure



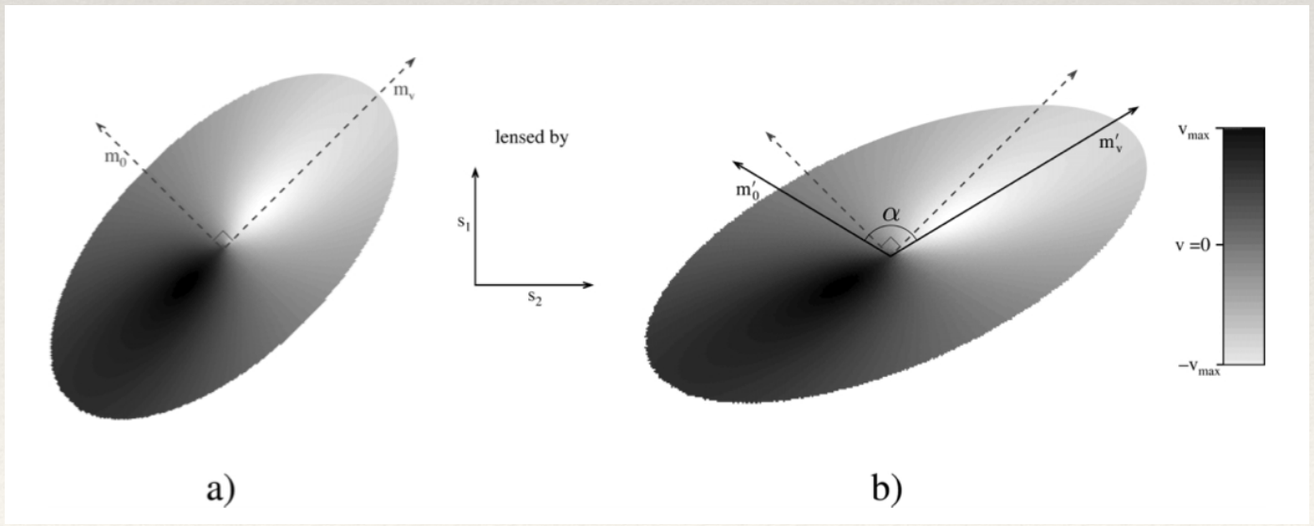
see Brown & Battye 2011

Uniqueness: Rotational Velocities

Rotational velocity measure - similar idea. Rotation axis and orientation axis should be perpendicular. Departure from perpendicularity —> experienced shear field

Again, depends on as yet uncertain quantities

Both ideas being investigated with SuperCLASS and CHILES projects

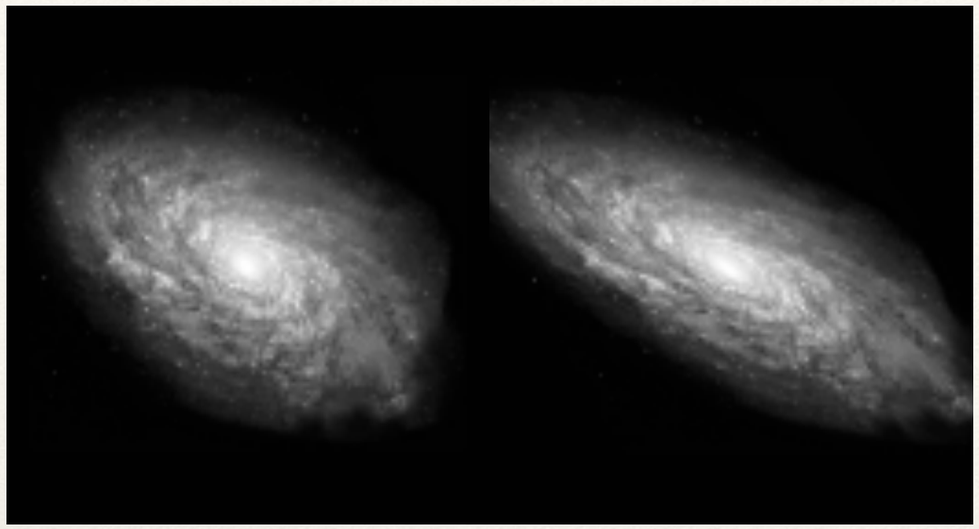


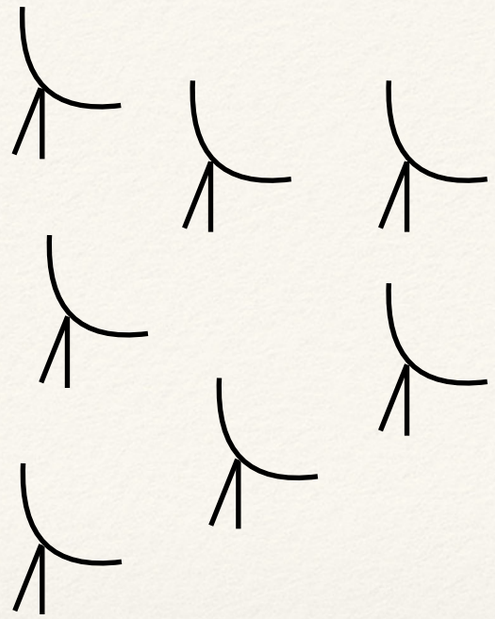
see Blain 2002, Morales 2006

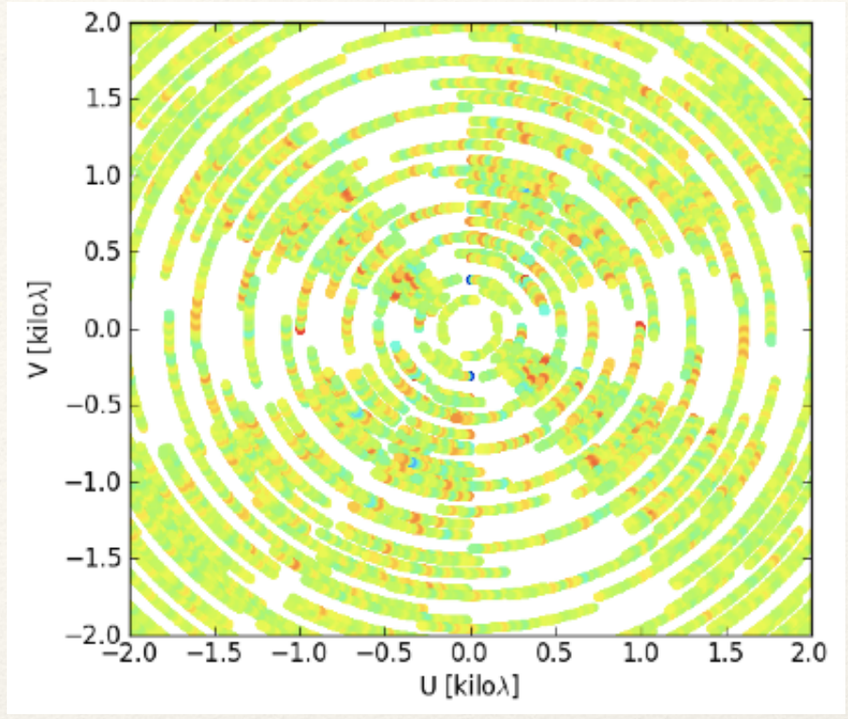
Weak lensing with radio continuum is promising…

Challenge: Shape Measurement

Radio:







A CLEANed image is a MODEL of your sky, the visibilities are the real data

Need to understand the effect of each data processing step on the signal

Unlikely that standard radio imaging techniques (e.g. CLEAN) are suitable for this kind of work

—> radio weak lensing will require dedicated techniques to measure galaxy shapes probably directly from the *uv* data

—> require expertise from both weak lensing and radio community

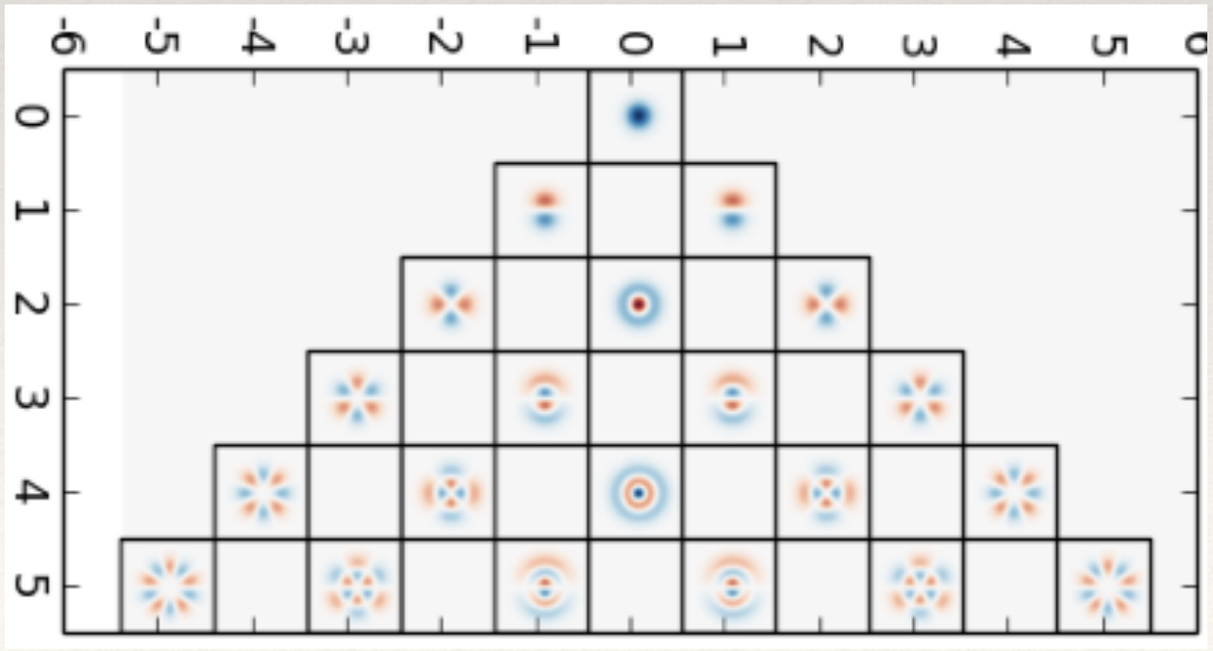
Simulations

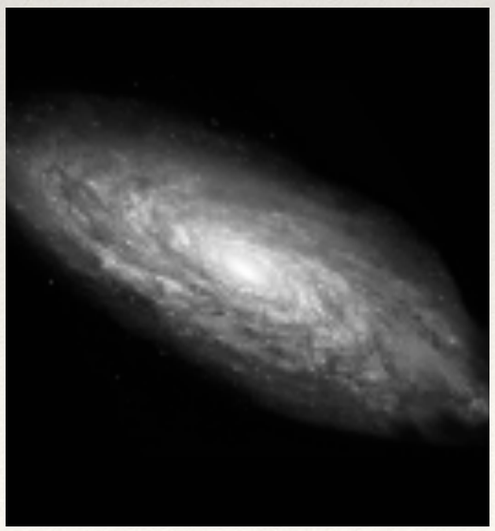
Telescope & Observation Parameters

Shapelet based sky models

Meqtrees Software

Model visibilities or Images





Patel et al., 2014

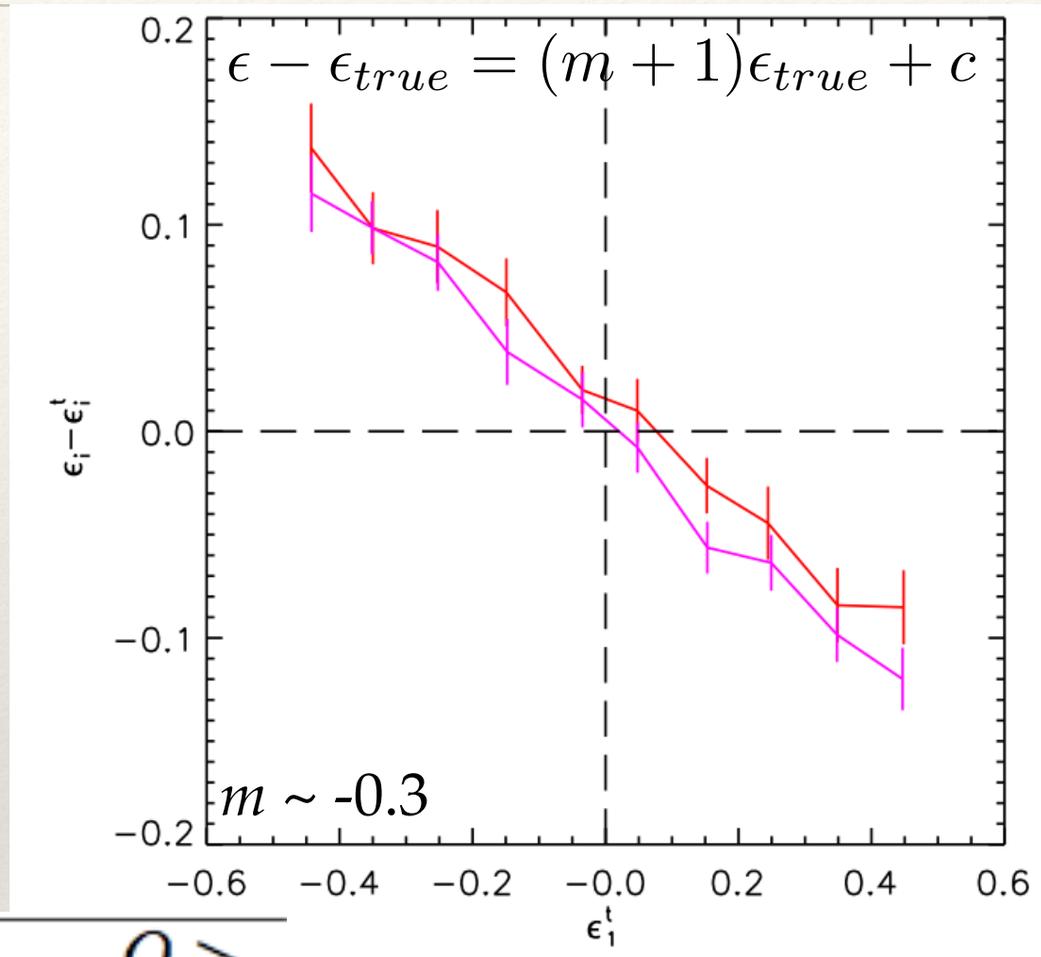
Current Status

Simulate SKA observations of galaxies with known ellipticities (8 hours, 700 MHz)

Based on Patel et al., 2014 simulation pipeline

Make standard CLEAN images

Compare input and output shapes using shapelets, done for ~10,000 galaxies



Experiment	A_{sky}	n_{gal}	z_m	$m <$	$c <$	$Q >$
SKA1	1000	10.75	1.2	0.0067	0.00082	140
SKA1	5000	4.2	1.0	0.0054	0.00073	177
SKA1	30940	1.1	0.7	0.0052	0.00072	182
SKA2	1000	75	1.6	0.0022	0.00046	456
SKA2	5000	44	1.4	0.0014	0.00037	726
SKA2	30940	20	1.3	0.00085	0.00029	1170

Calibration is some way off!

radioGREAT

Key question: shears from images or visibilities?

Harrison & Brown, 2015: SKA ECP to have gridded visibility data (with appropriate time and frequency resolutions)

Provide community with image and visibility data

Benchmark current methods used in optical

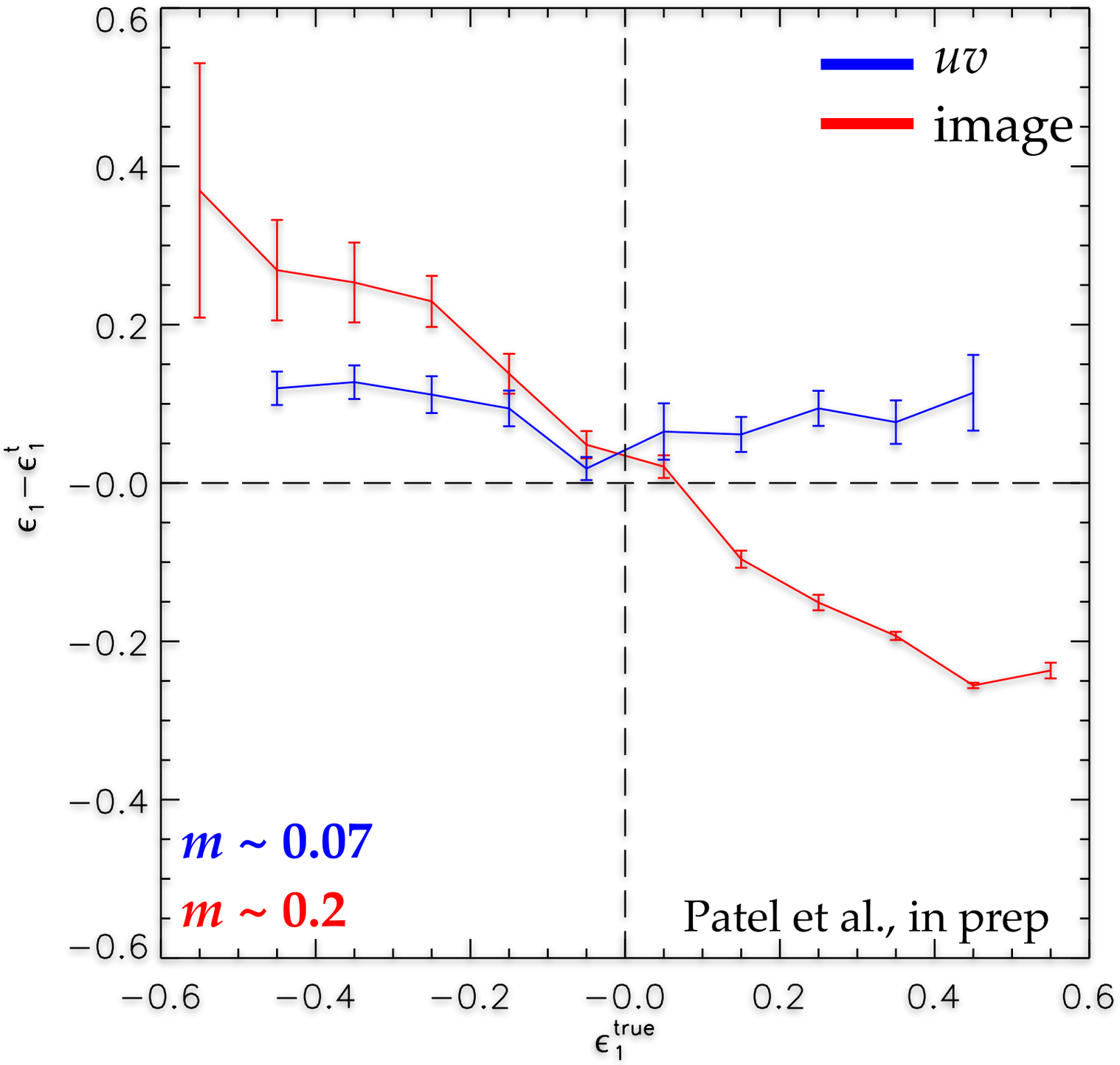
Drive development of suitable *uv* space methods

AWS funded

PP & Ian Harrison

http://radiogreat.pbworks.com/

Shapelets: real vs *uv* space



Shapelets are their own Fourier transform

Can compare the method in image and *uv* space

Applying this to HDFN data (image analysis already done in Patel et al., 2010)

(See Marzia Rivi's poster on RadioLensfit)

Conclusions

Weak lensing is a powerful probe for cosmology, allowing us to map the dark matter distribution over cosmic time

Many optical missions are underway or planned with weak lensing as a major component (DES, EUCLID, LSST)

Radio WL has potential to be game changing by breaking through the systematic floor with CC techniques and radio specific ideas

Will require dedicated effort on how to do the shape measurement that will require both existing lensers and radio community

radioGREAT is our first step in trying to address the key questions

http://radiogreat.pbworks.com/