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The SuperCLASS (SuperCLuster Assisted Shear Survey) Weak Lensing Survey

Ian Harrison

on behalf of the SuperCLASS collaboration

e-MERLIN and the EVN in the SKA Era Workshop II

11 September 2017

SuperCLASS
The Collaboration

Rob Beswick, Sarah Bridle, Michael Brown, Ian Browne, Simon Garrington, Ian Harrison, Neal Jackson, Scott Kay, Paddy Leahy, Tom Muxlow, Anita Richards, Anna Scaife, Dan Thomas, Ben Tunbridge, Peter Wilkinson, Lee Whittaker, Bob Watson (JBCA, Manchester)
David Bacon, Bob Nichol (Portsmouth)
Mark Birkinshaw (Bristol)
Caitlin Casey, Sinclaire Manning (UT Austin)
Stefano Camera (UNITO, Turin)
Constantinos Demetroullas (The Cyprus Institute)
Meghan Gray (Nottingham)
Chris Hales (Newcastle)
Steve Myers (NRAO, Socorro)
Chris Riseley (CSIRO)
Ian Smail (Durham)

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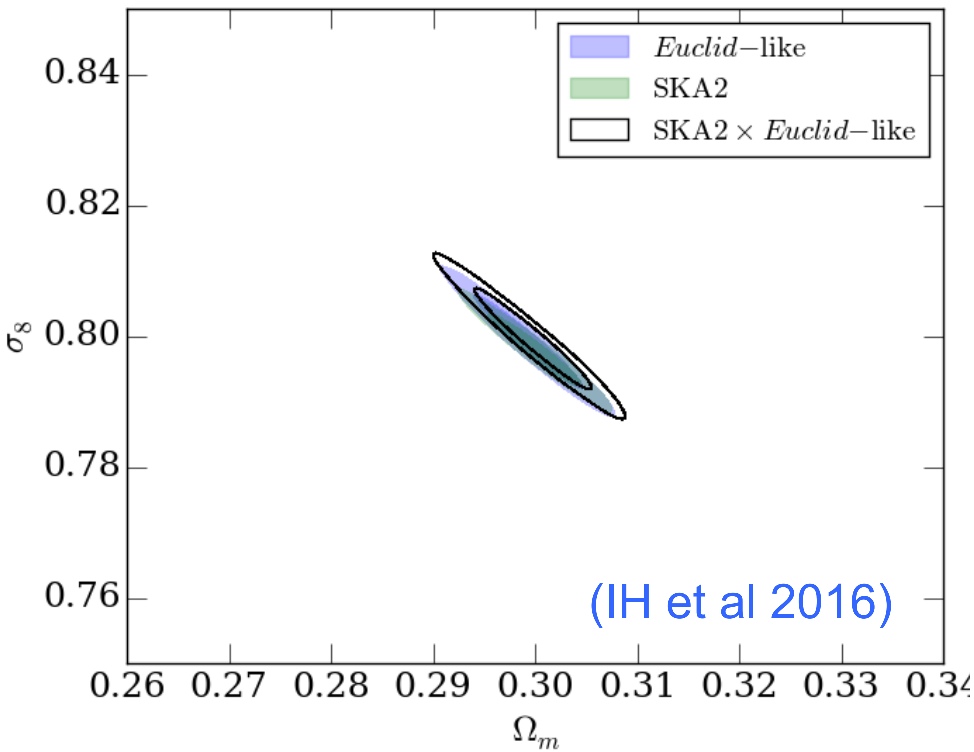
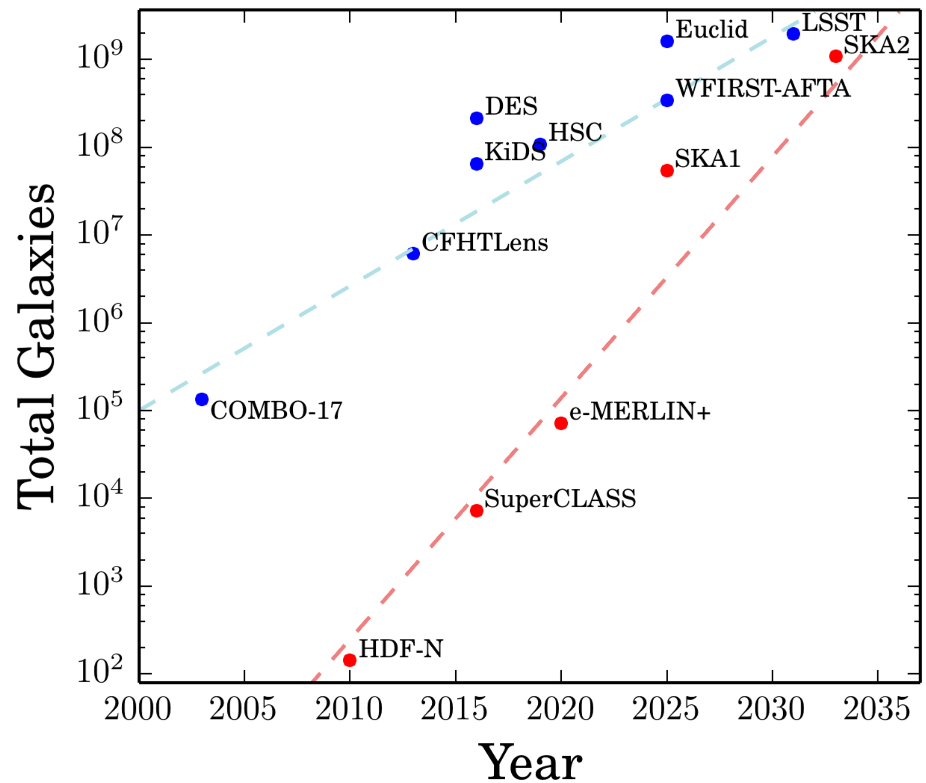
SuperCLASS
The Raison d'Etre

- Full SKA weak lensing cosmology can be as good as *Euclid* or LSST
- …and combining them is even better!

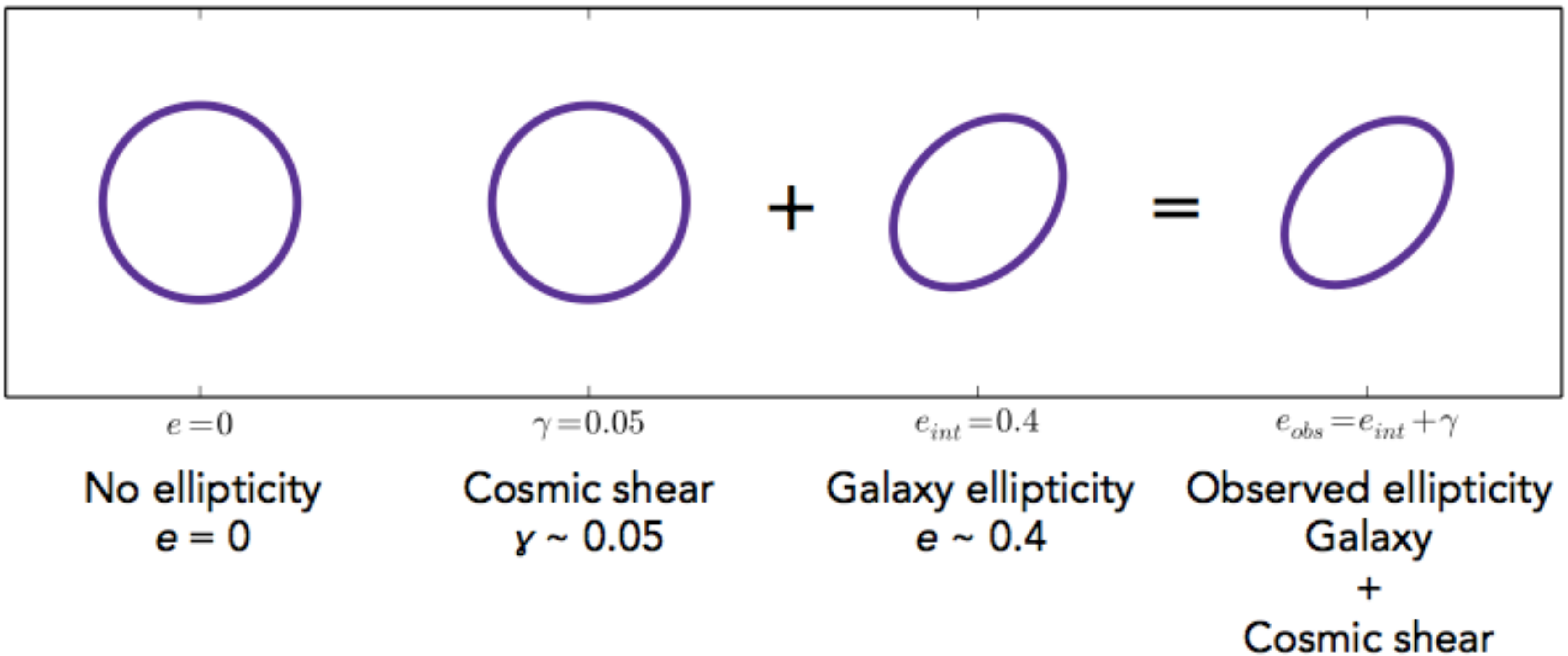


(IH et al 2016)



SuperCLASS
Radio Weak Lensing

- Measure ellipticity of >1 starforming galaxies $arcmin^{-2}$ over >1 deg^2
- Map ~1% changes in shape due to gravitational lensing by dark matter



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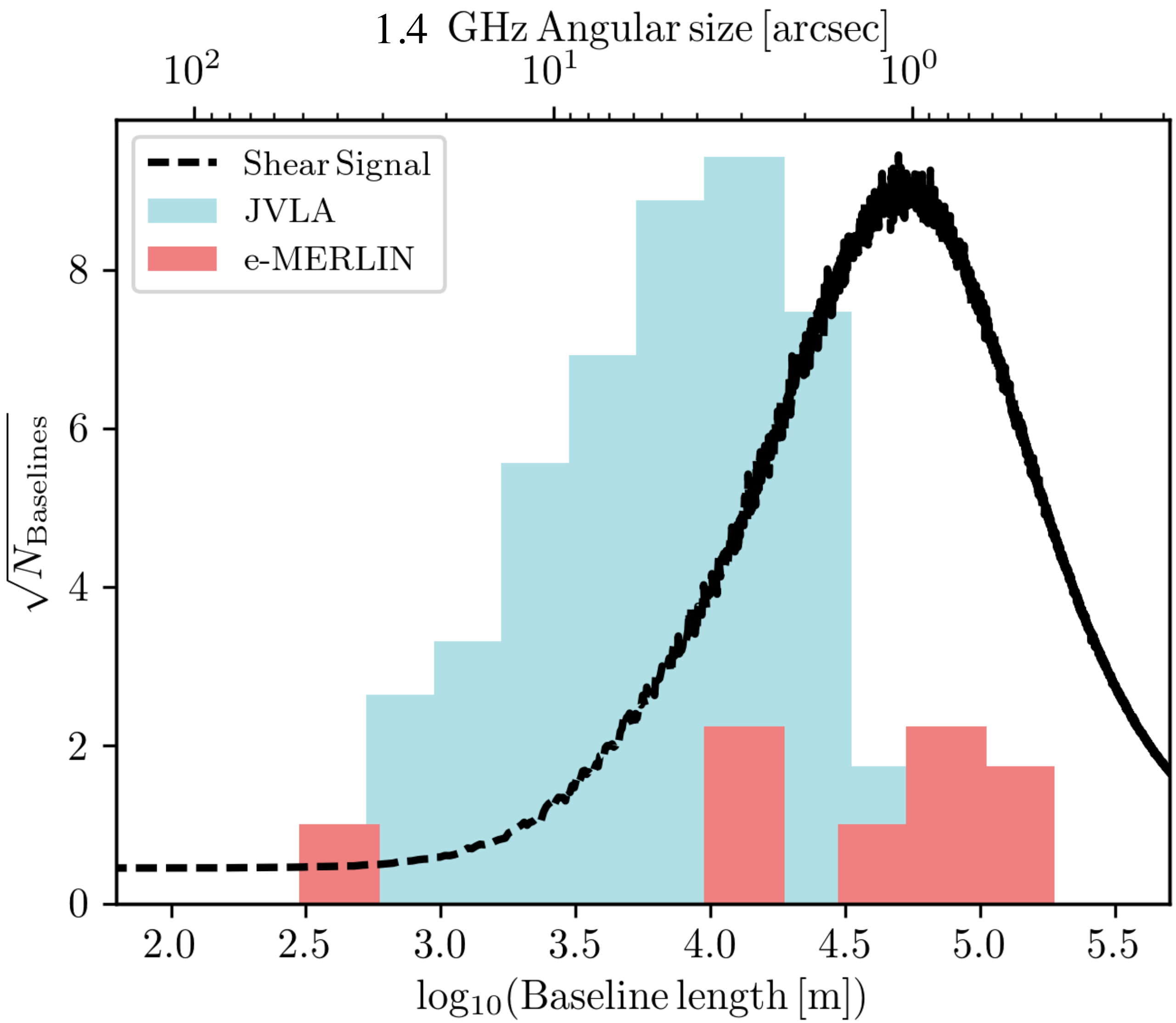
SuperCLASS
Scales of Interest



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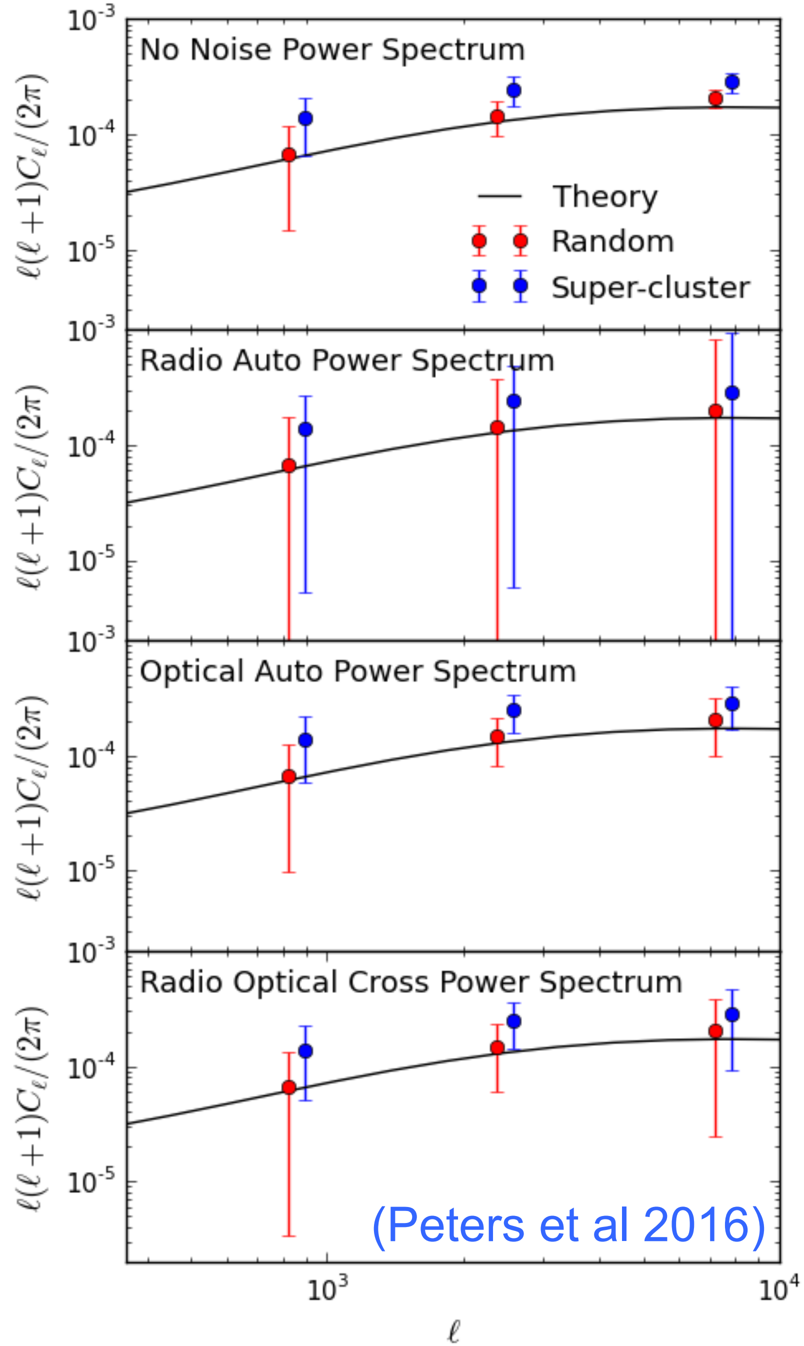
SuperCLASS
The Raison d'Etre

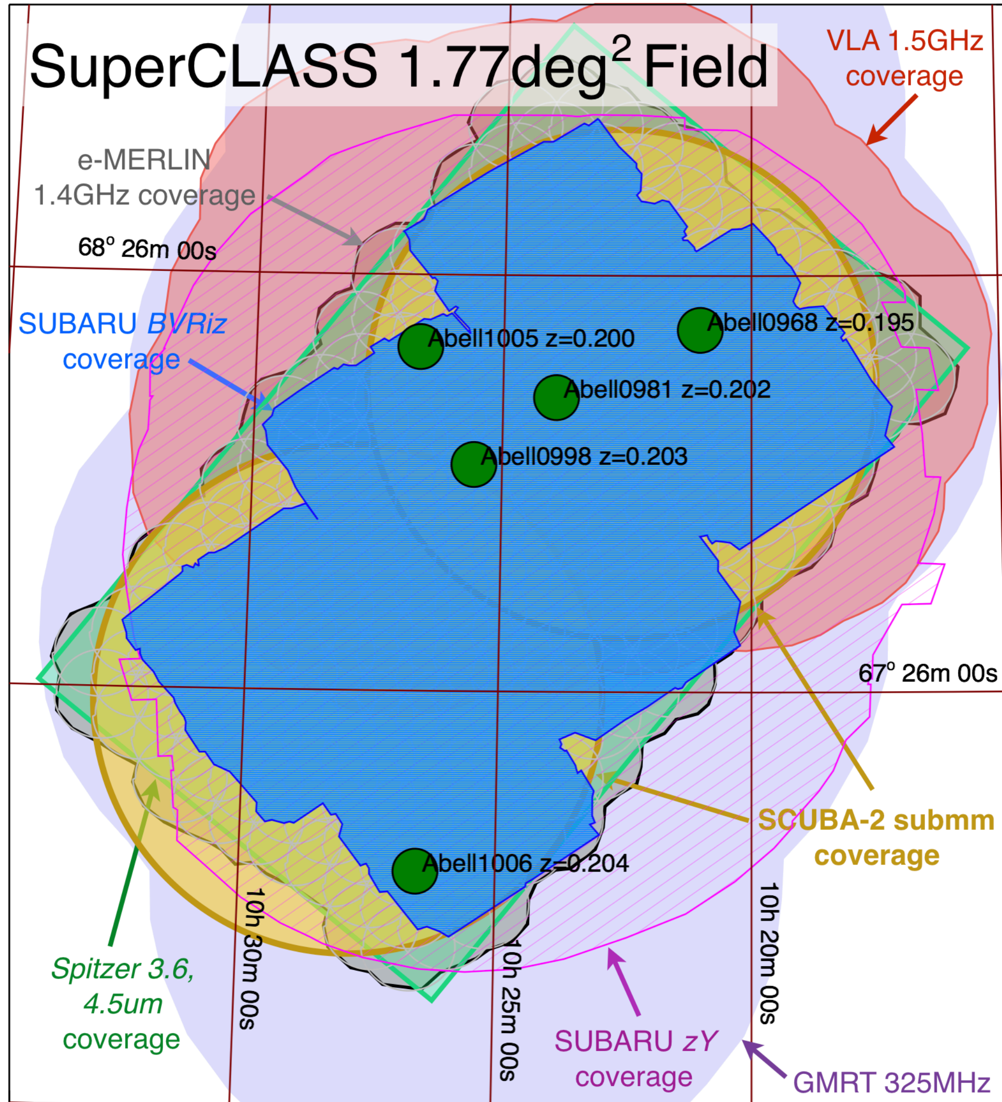
- Targeted supercluster region for enhanced lensing signal
- Can make first convincing detections of radio-optical, radio-radio weak lensing
- Test bed for radio weak lensing techniques



SuperCLASS
The Survey

(Caitlin Casey)

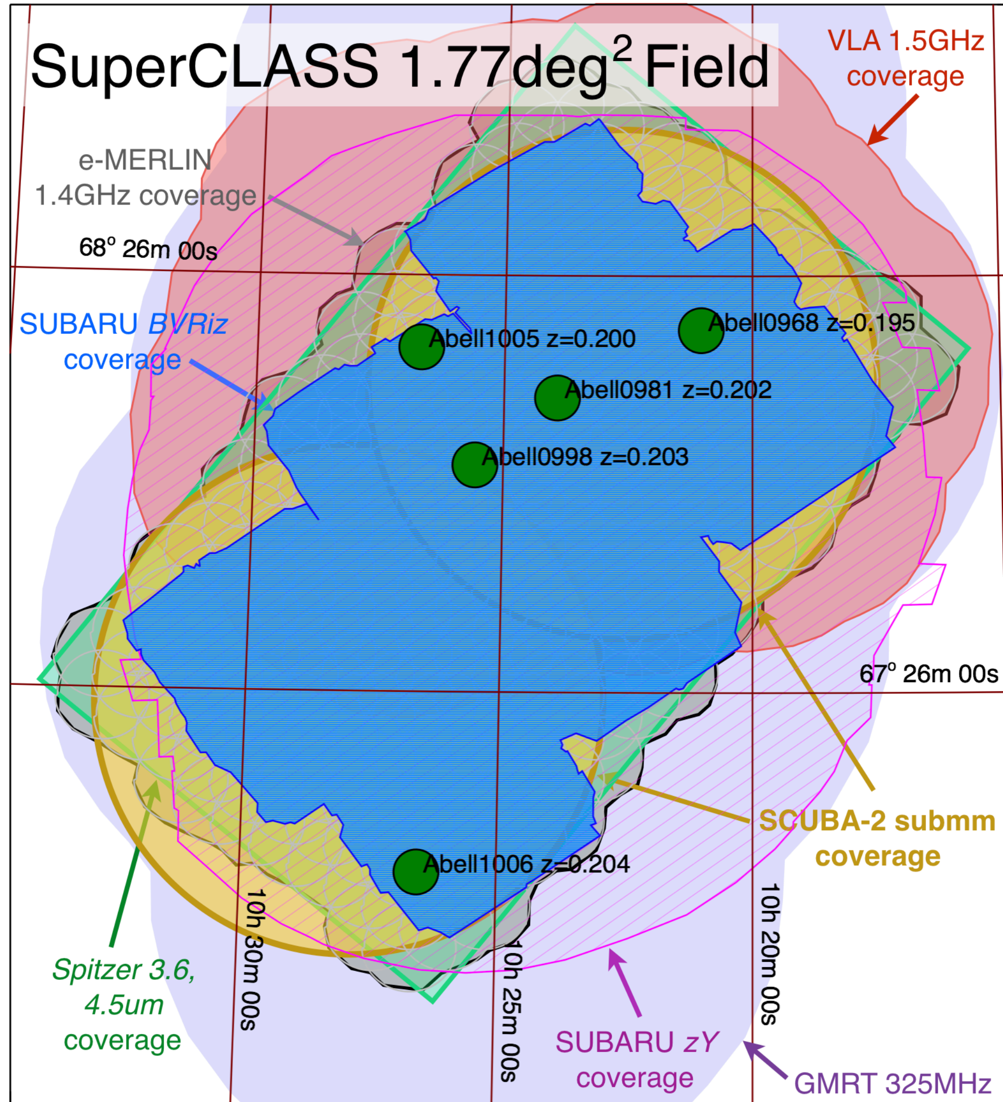
- Radio shear:
  - e-MERLIN (1.4 GHz)
  - JVLA (1.5 GHz)
- Optical shear, photo-zs:
  - Subaru (BVRIz)
  - CFHT (near-IR)
- Source classification, RM-synthesis:
  - GMRT (325 MHz)
  - LOFAR (150 MHz)
- Source classification:
  - Spitzer (3.6, 4.5 um)
  - SCUBA-2 (submm)
  - AMI (15 GHz)



SuperCLASS
The Survey

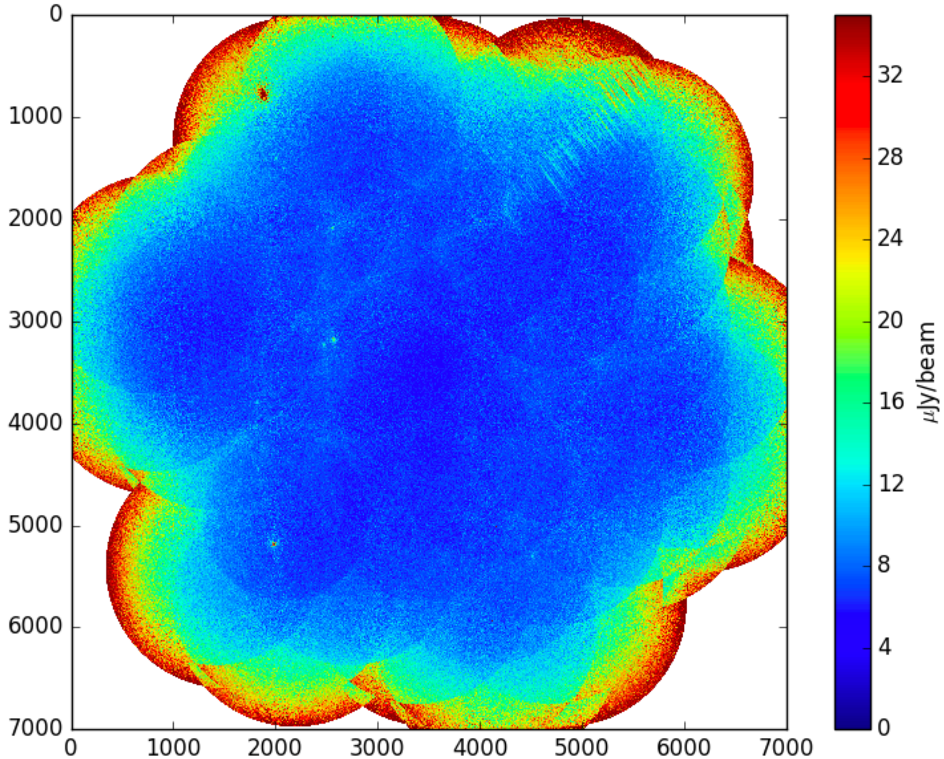
(Caitlin Casey)

- Currently have 'Half Field to Full Depth'
  - 0.6 deg^2 to ~7uJy
- Current plan is for first data release in ~autumn
  - Survey description paper
  - Radio x Optical lensing paper – detection expected
  - Radio-only lensing paper – will be lucky!

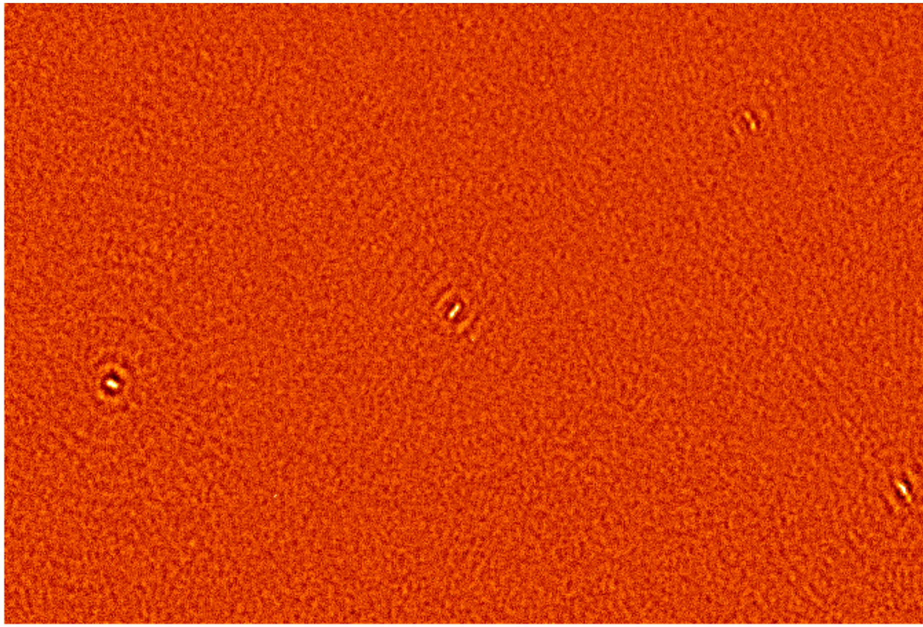


Results So Far
e-MERLIN Mosaic

Noise map (since improved)

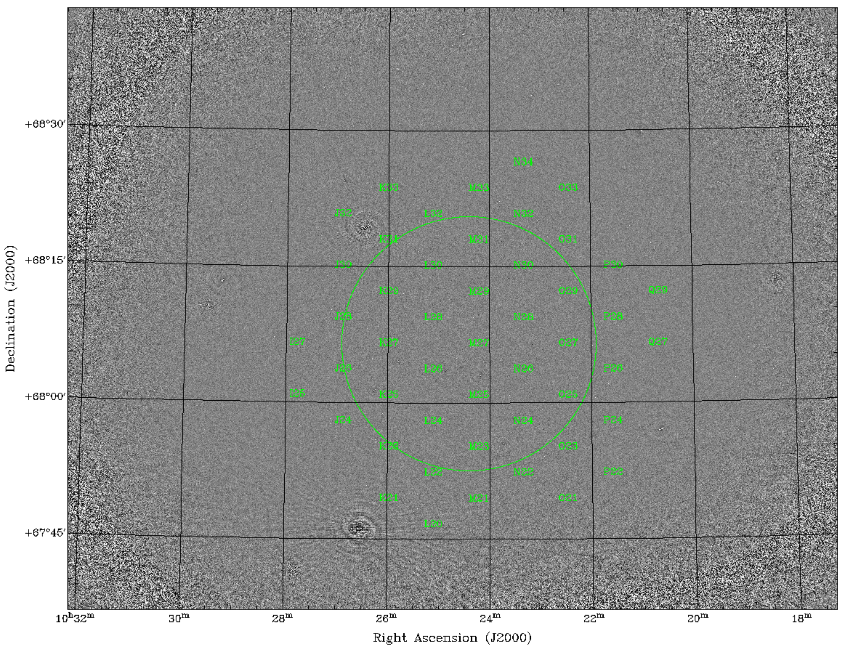


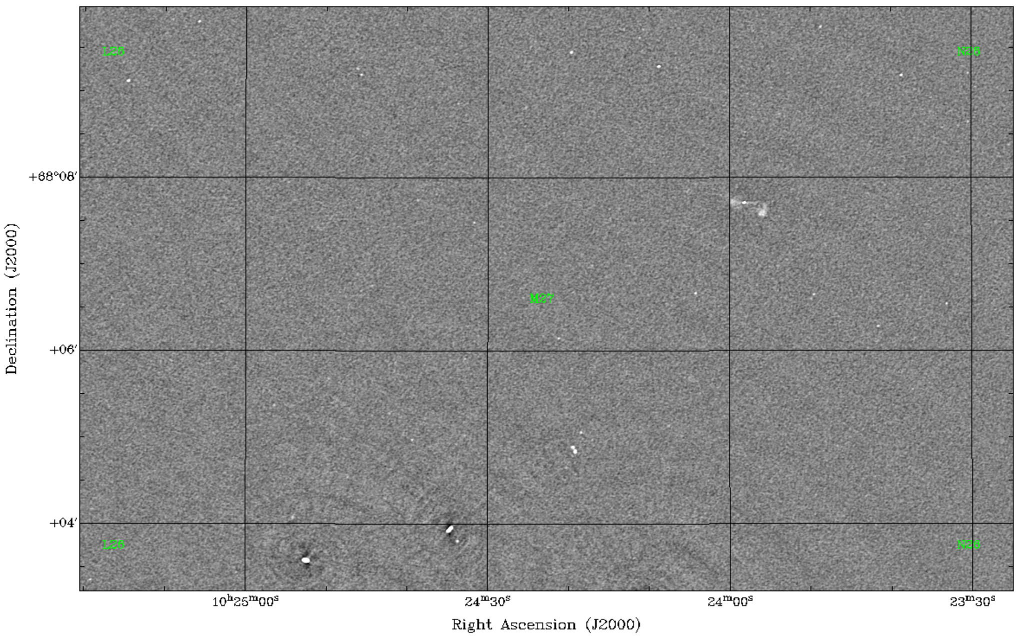
Some sources



(Bob Watson)
(video: Neal Jackson)

Results So Far
JVLA Mosaic

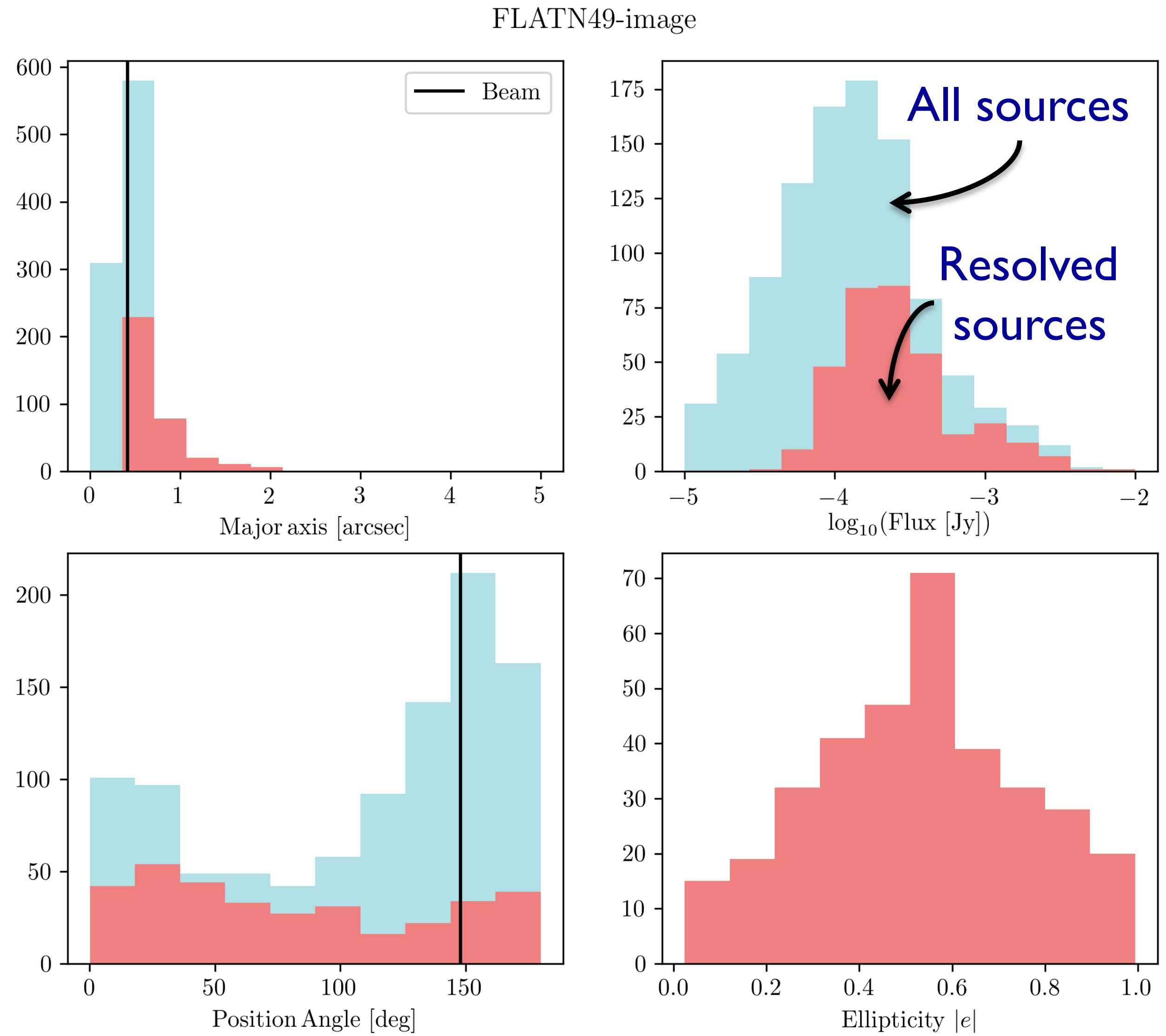




(Chris Hales)

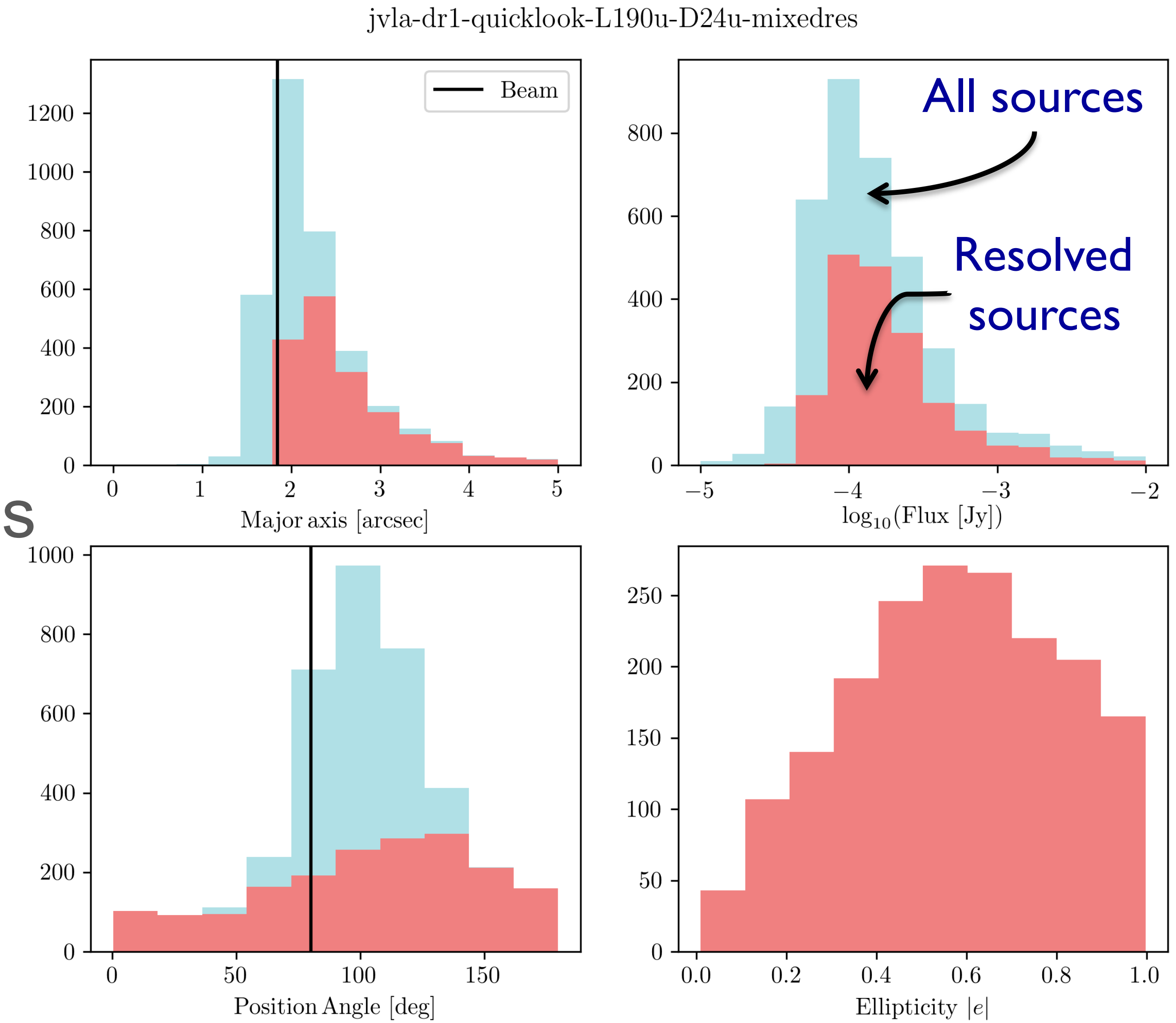
Results So Far
Source Catalogues – e-MERLIN

- pyBDSF source catalogue
- ~7 uJy RMS image
- ~900 sources at SNR>5
  - in 0.6 deg^2
  - ~0.4 $arcmin^{-2}$

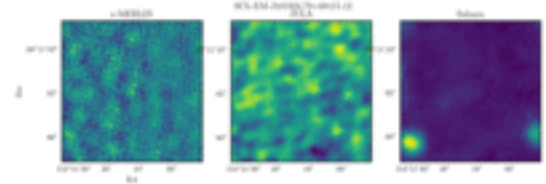


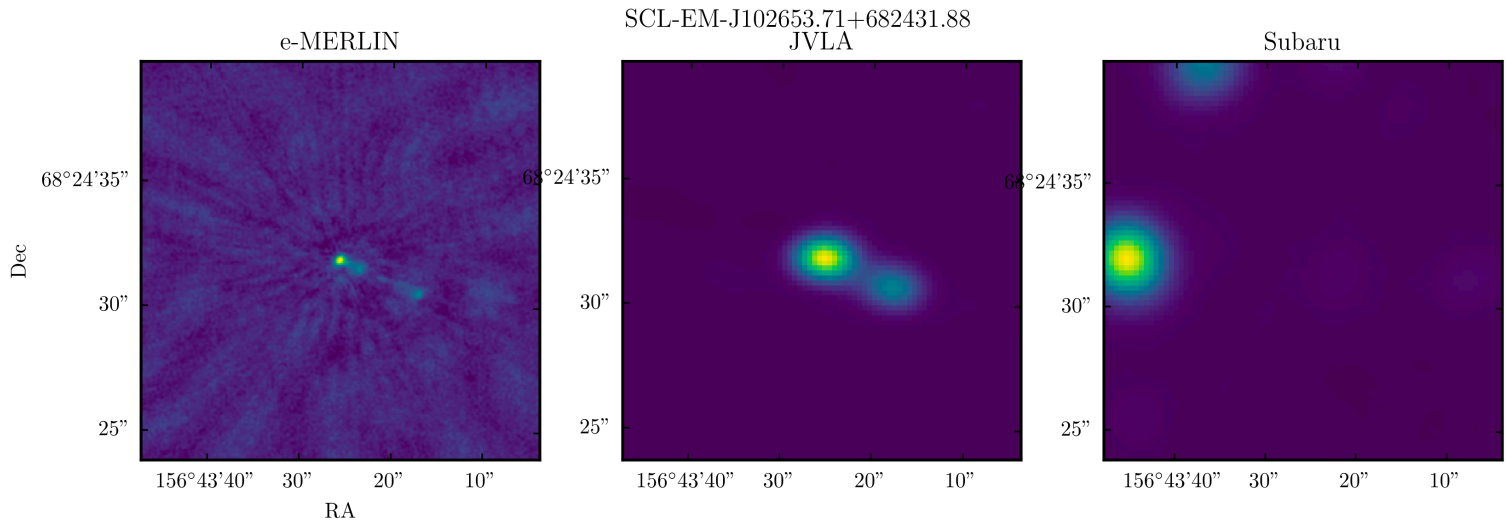
Results So Far
Source Catalogues – JVLA

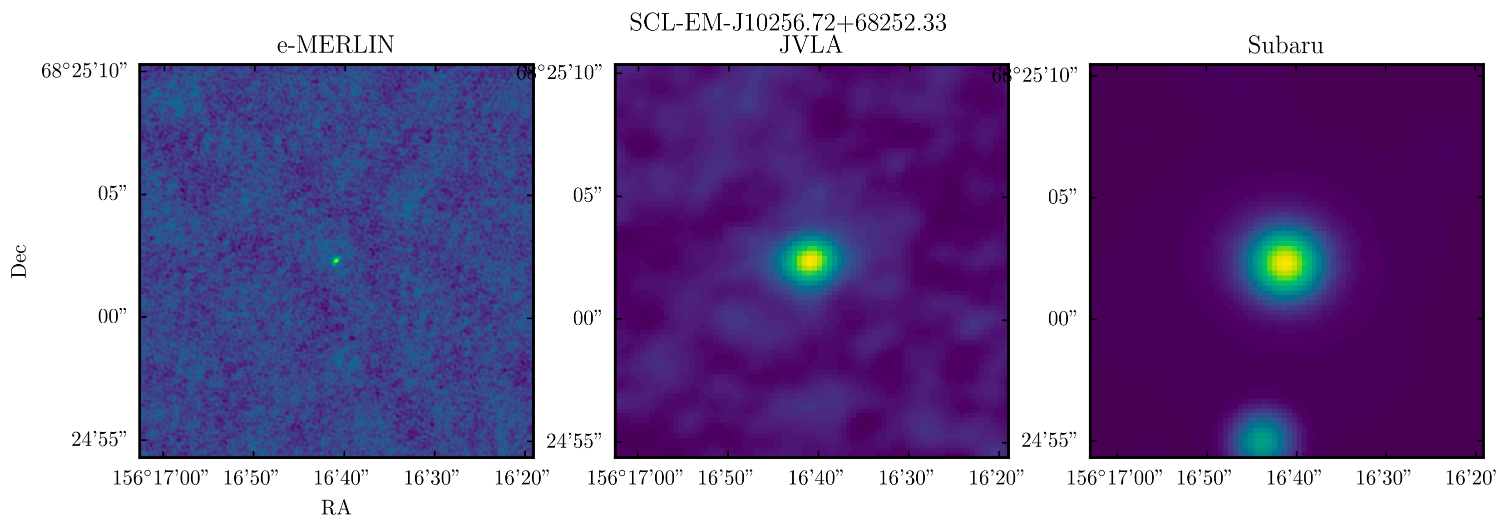
- pyBDSF source catalogue
- ~7 uJy RMS image
- ~3500 sources at SNR>5
  - in 1.75 deg^2
  - ~0.55 arcmin^{-2}



Results So Far
Source Thumbnails







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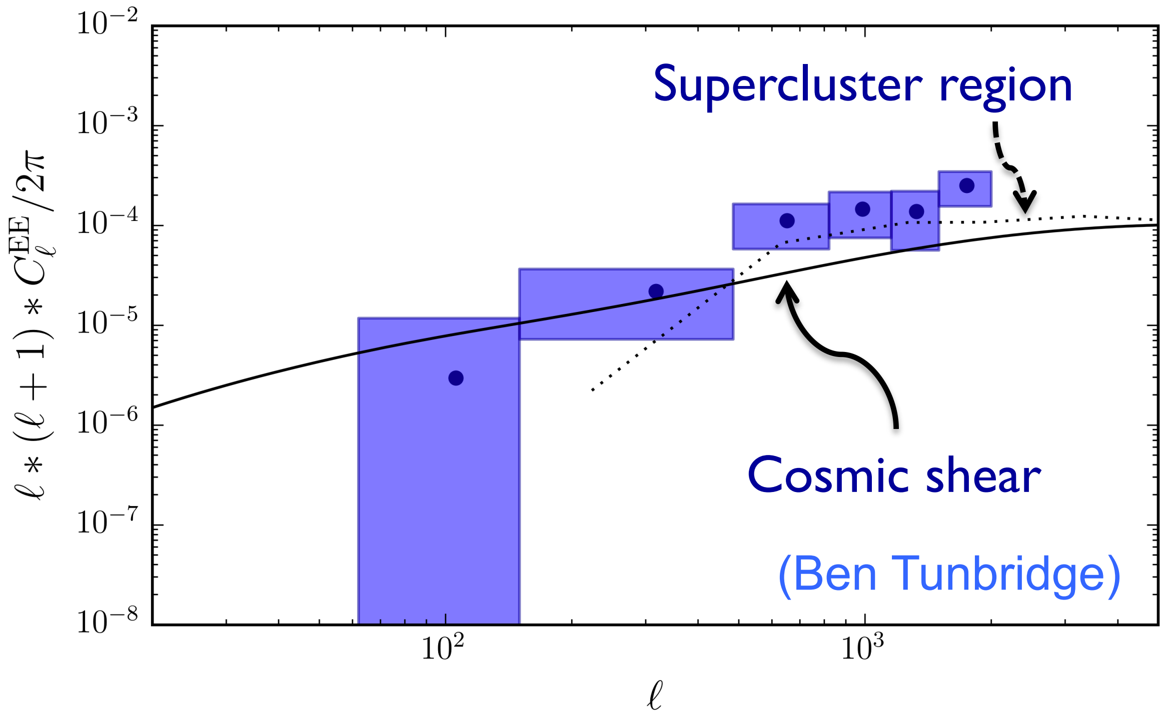
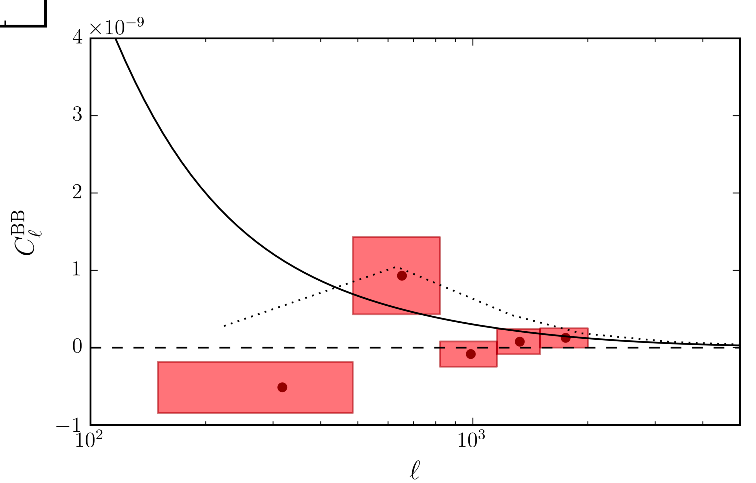
Results So Far
Subaru Shear Power Spectrum



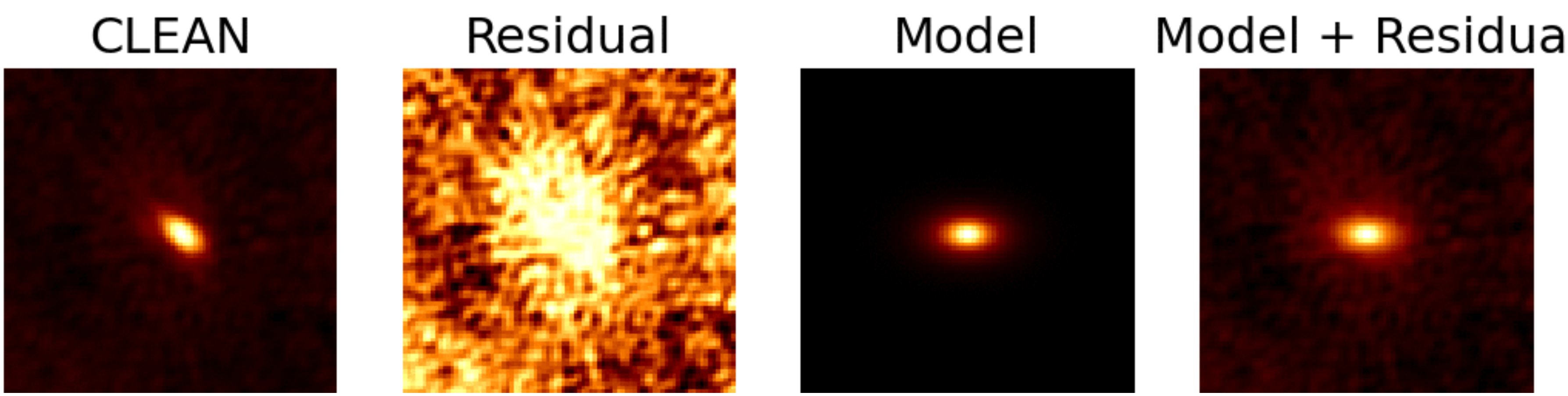
- E-mode power spectrum detected at 9.3σ
- Consistent with expected signal for supercluster region

- B-mode power spectrum consistent with zero



Work Still Ongoing
Shape Measurement

- Three shape measurement pipelines:
  1. Image-plane 'super calibration' (SuperCALS)
  2. UV-plane phase shift and average
  3. UV-plane brute force



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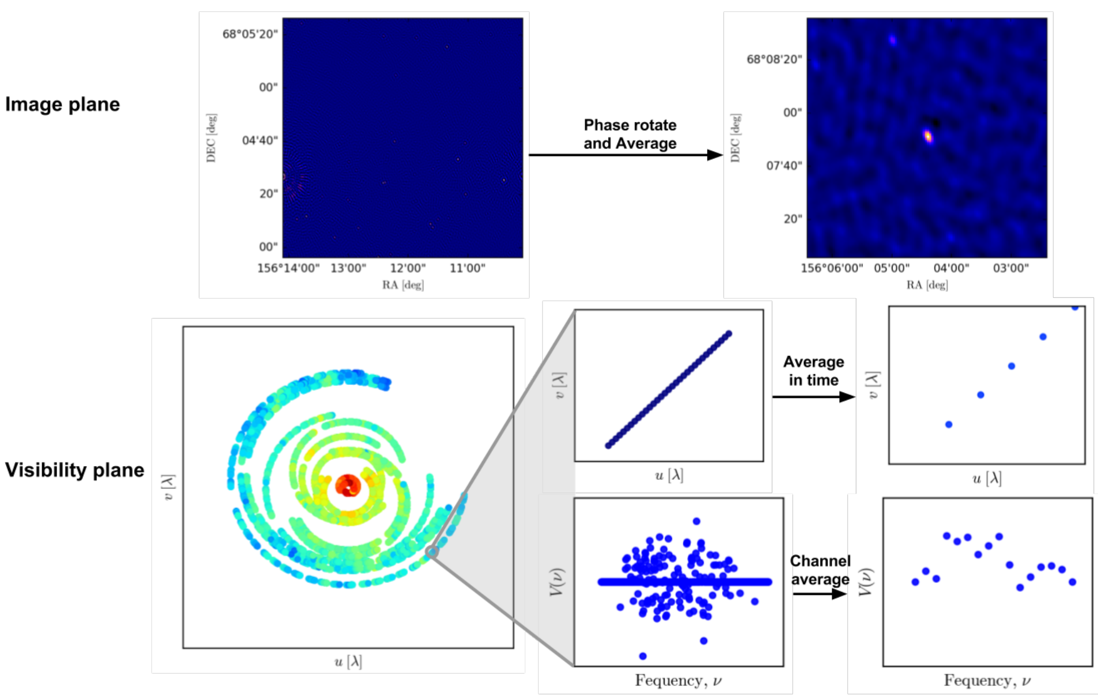

(Ben Tunbridge)

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Work Still Ongoing
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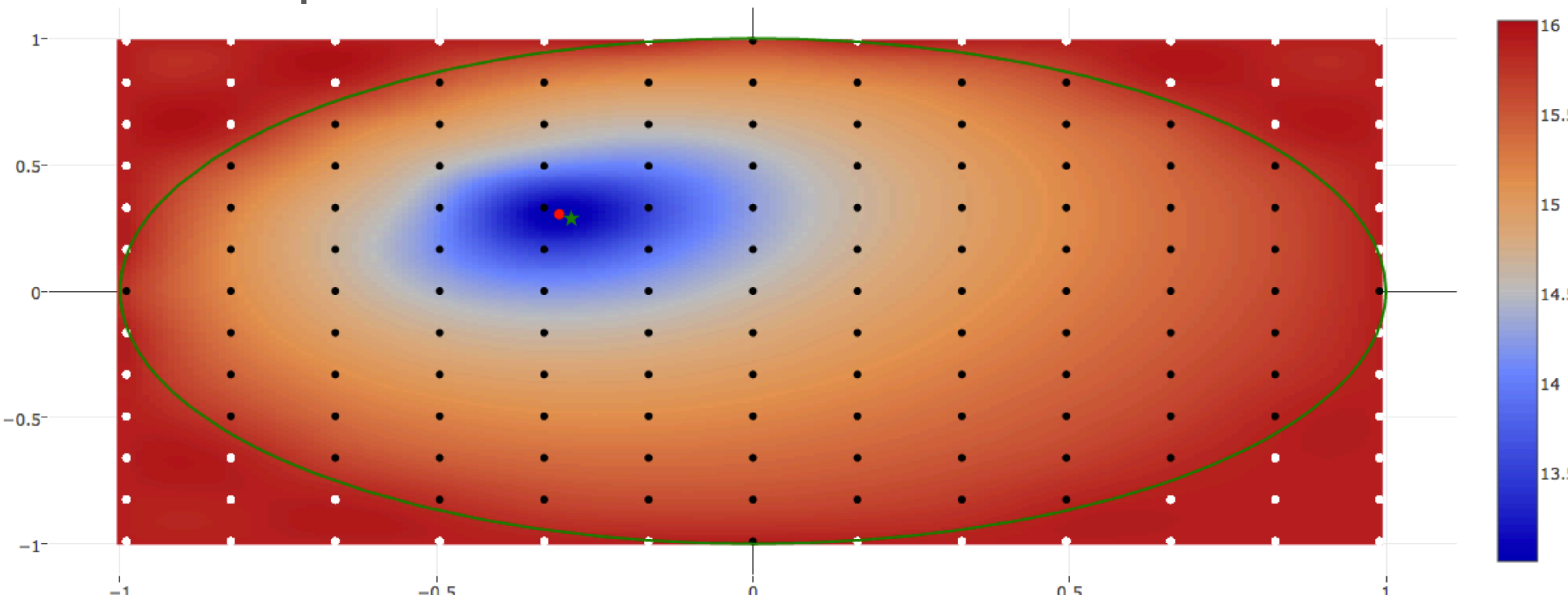

(Dan Thomas)

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Pipeline Components

- Have pushed the capabilities of current software!
- Current pipeline:
  - Bob Watson homebrew flagger (upcoming SerBob)
  - AIPS for calibration
    - Export to MS
  - WSCLEAN for wide-field imaging
  - …back to AIPS for mosaicing with FLATN
  - pyBDSF for source finding
  - Our own shape measurement methods
    - Involved pipelines themselves
- See all our software! https://bitbucket.org/superclass-shear/

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Pipeline Issues

- Have pushed the capabilities of current software!
- Found multiple issues:
  – Efficiency of auto-flaggers
  – Accuracy of phase rotation in CASA *and* AIPS
  – Channel labelling offsets
  – Accuracy of Primary Beam model
  – WSCLEAN CLEAN beam fitting
- Ended up with a hybrid monster 👾

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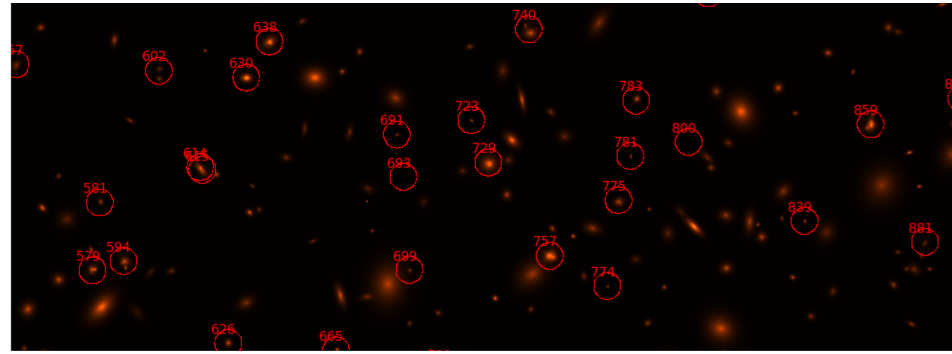
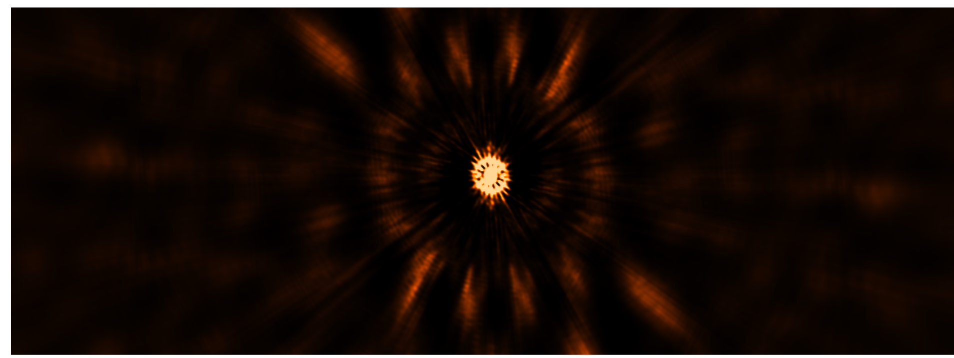
Pipeline Simulations

- Simulations *crucial* to quantify precision, accuracy of shape measurements
- Source populations
  - T-RECS (Bonaldi et al) (SKADS replacement)
- Sky model
  - GalSim
- Full visibility simulation
  - CASA sm tool
- Imaging
- Source finding

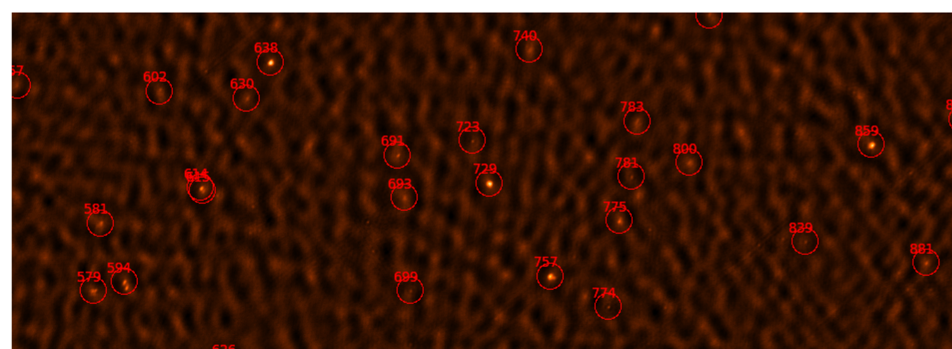
Input sky model:



e-MERLIN PSF:

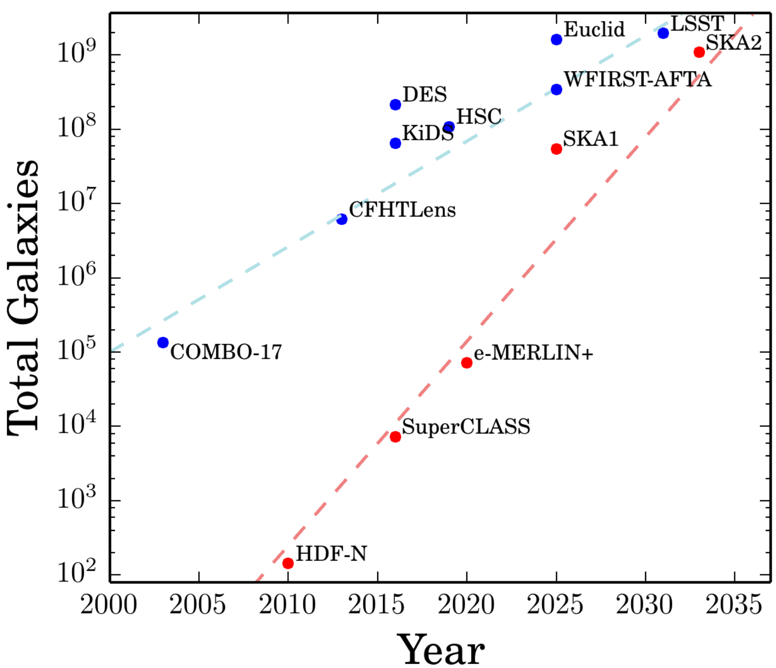


Recovered sources:

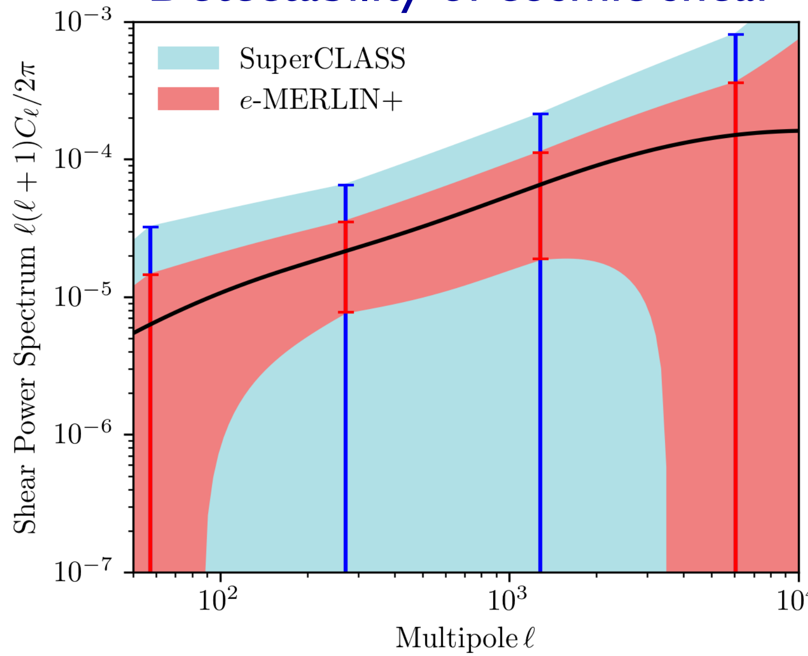


Work Still Ongoing
Looking to the Future

- Survey with e-MERLIN+PAF can fill gap in pre-SKA era
  - ~10 deg^2 to ~5 uJy
- Pipeline development on SDP software would be invaluable



Detectability of cosmic shear



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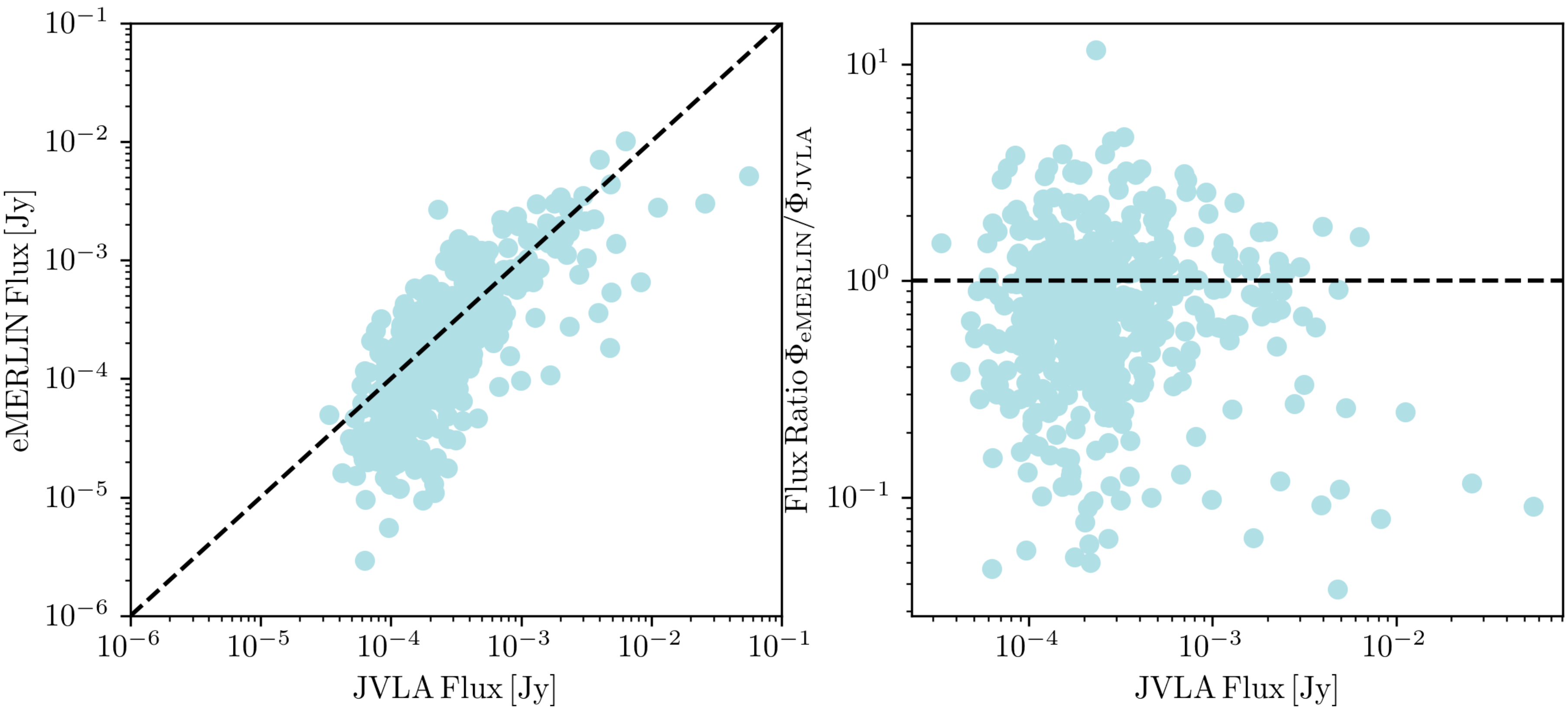
SuperCLASS
Summary

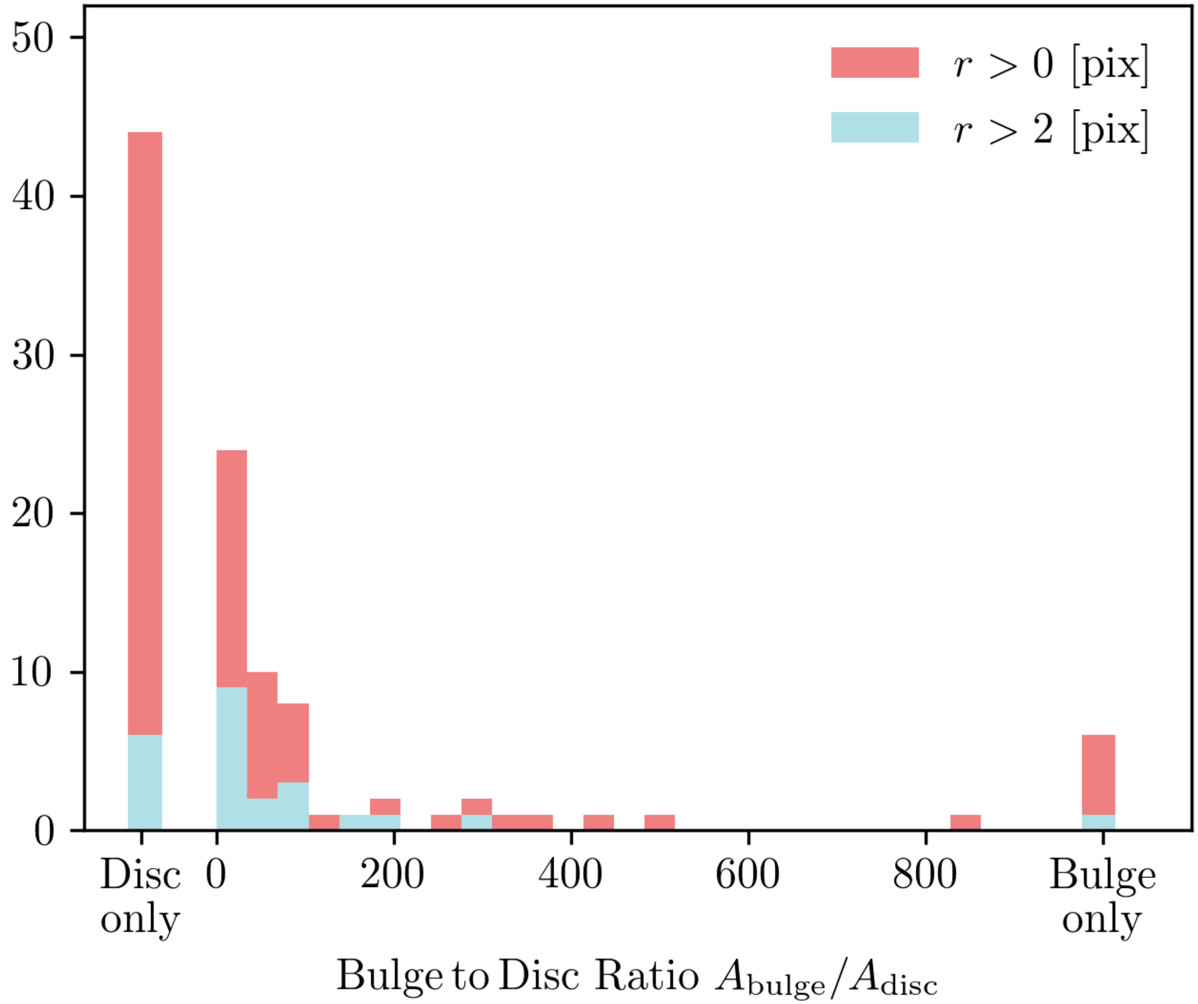
- Weak lensing in radio hugely powerful
  - SKA comparable to optical, huge worth in cross-correlations
- SuperCLASS has achieved a ~7 uJy e-MERLIN mosaic across 0.6 deg^2
- Developing methods to measure cosmic shear
- Integrated simulations & pipeline crucial in quantifying biases and doing cosmology
- 10 deg^2 survey can fill gap in pre-SKA era

Bonus Slides

Results So Far
Source Classification

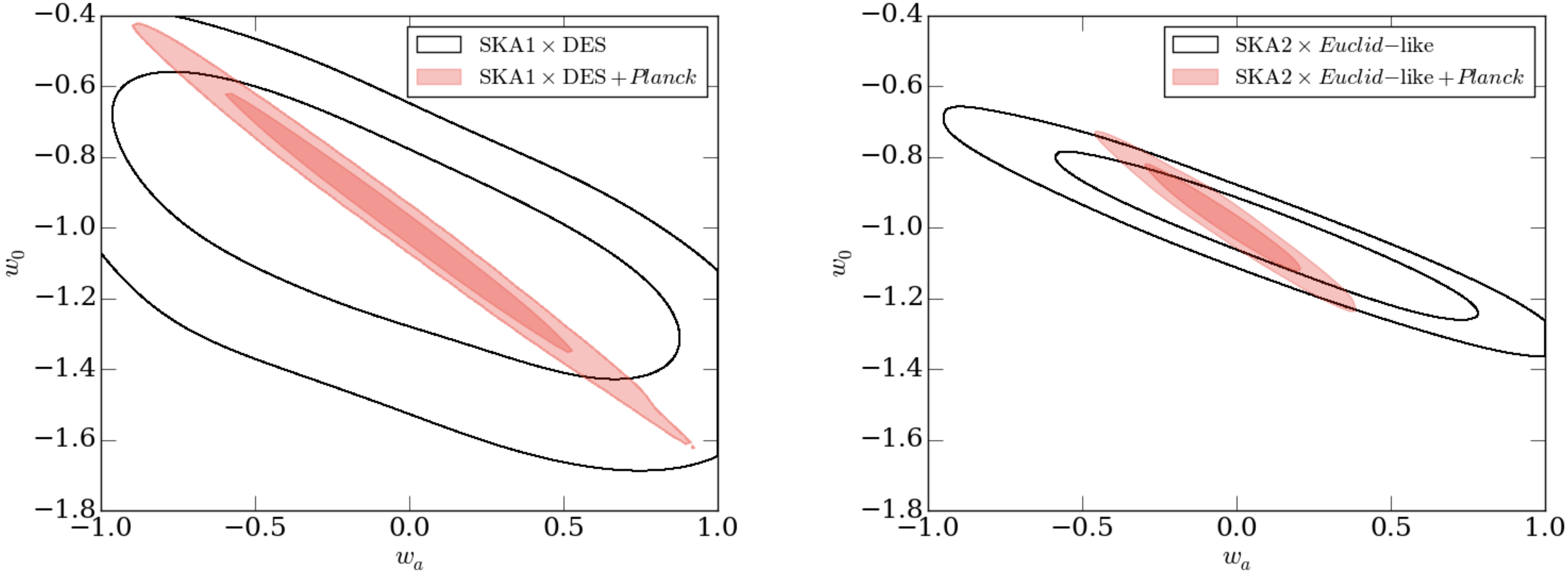


e-MERGE
Source Profiles



Radio Weak Lensing
SKA Forecasts

- With Planck Priors:



(IH et al arXiv:1601.03947)

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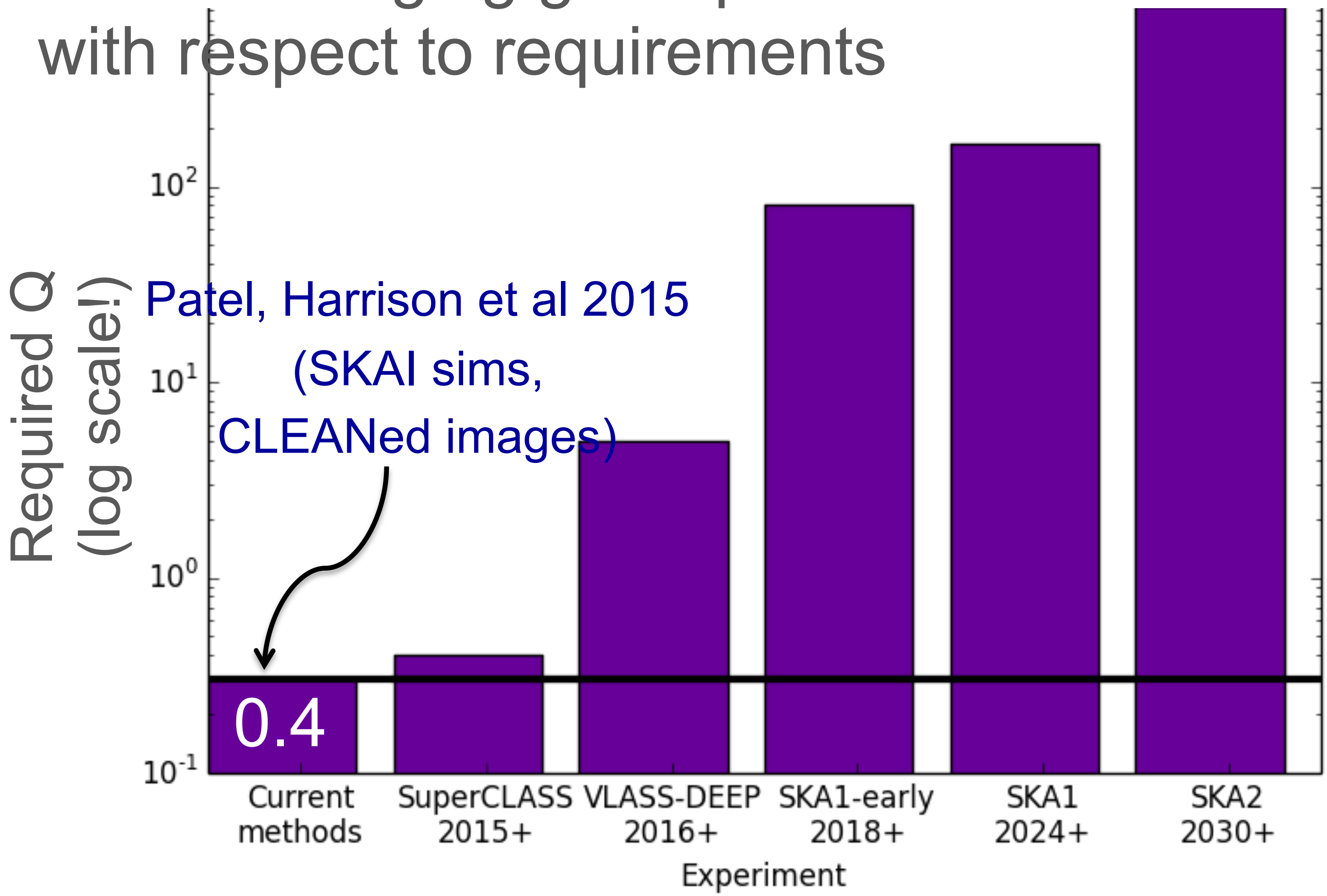
Radio Weak Lensing
SKA Forecasts

Experiment	$(\sigma_{\Omega_m}/\Omega_m,$	$\sigma_{\sigma_8}/\sigma_8)$	$(\sigma_{w_0},$	$\sigma_{w_a})$	$(\sigma_{\Sigma_0}/\Sigma_0,$	$\sigma_{Q_0}/Q_0)$	DETF FoM
SKA1	0.083	0.040	0.36	0.54	0.19	0.43	5.8
SKA1 + *Planck*	0.084	0.040	0.28	0.43	-	-	77
DES	0.056	0.032	0.25	0.54	0.13	0.43	9.8
DES + *Planck*	0.058	0.033	0.22	0.33	-	-	89
SKA1×DES	0.046	0.024	0.28	0.54	0.13	0.39	8.8
SKA1×DES + *Planck*	0.046	0.024	0.23	0.36	-	-	106
SKA2	0.010	0.0046	0.14	0.42	0.04	0.13	51
SKA2 + *Planck*	0.010	0.0047	0.086	0.15	-	-	305
Euclid-like	0.011	0.0058	0.13	0.38	0.053	0.17	54
Euclid-like + *Planck*	0.012	0.059	0.095	0.16	-	-	244
SKA2×*Euclid*-like	0.013	0.0064	0.15	0.43	0.053	0.17	45
SKA2×*Euclid*-like + *Planck*	0.013	0.0064	0.10	0.17	-	-	240

(IH et al arXiv:1601.03947)

Challenges – Shape Measurement Requirements from a Survey

- CLEAN imaging gives poor results with respect to requirements



Challenges – Shape Measurement Requirements from a Survey

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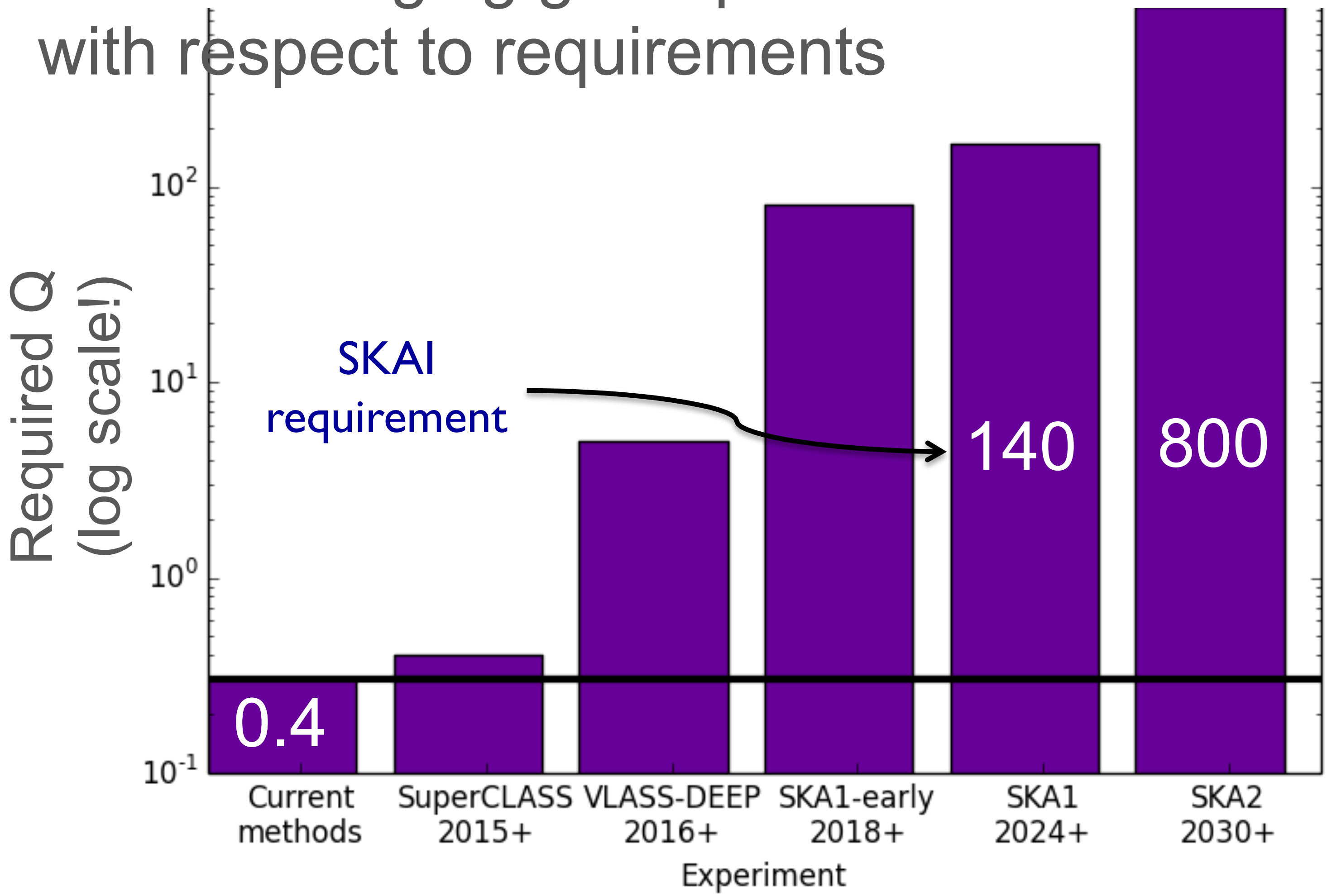
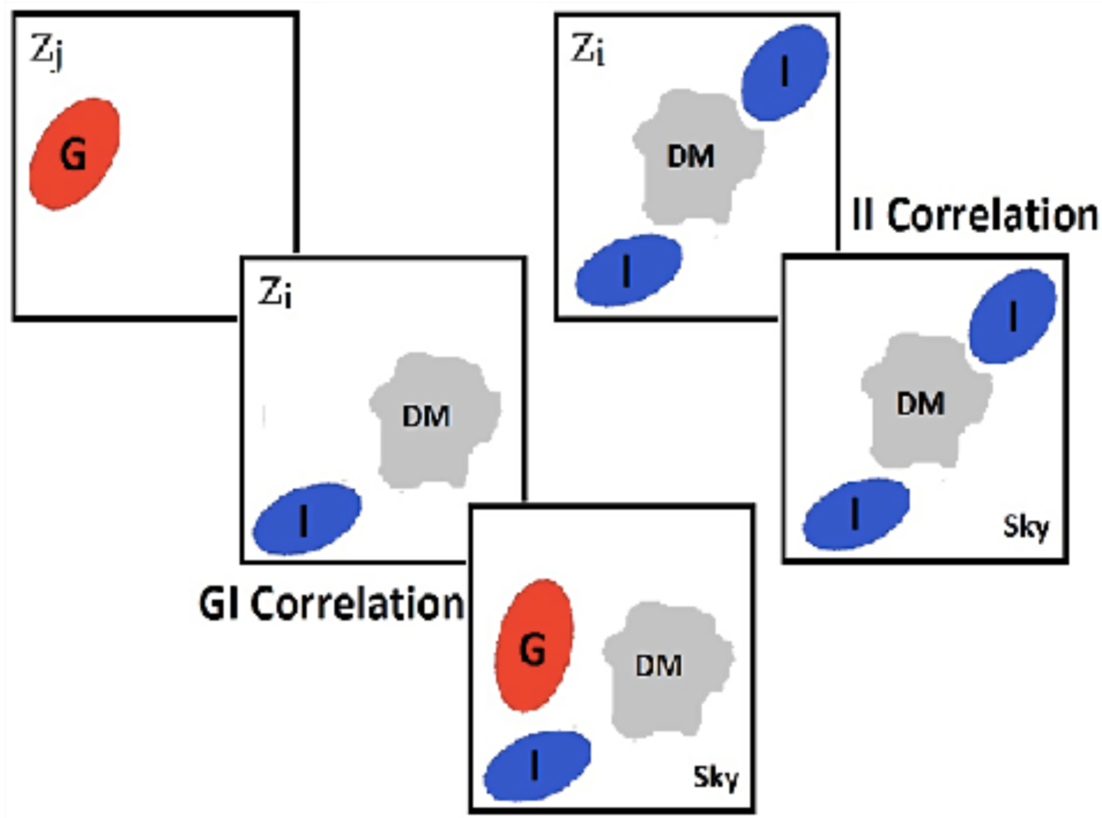


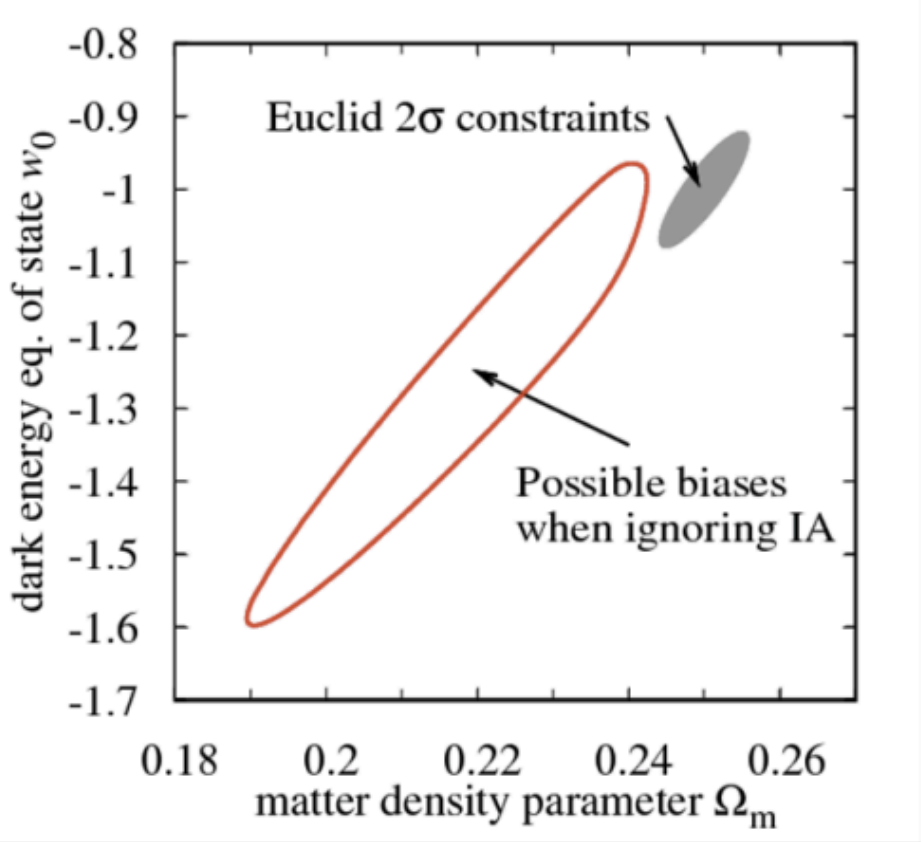
Additional Information from Radio WL
Intrinsic Alignment Systematics

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



Additional Information from Radio WL
Intrinsic Alignment Systematics

- Many such physical systematics are wavelength independent (so cross-correlations don't help)



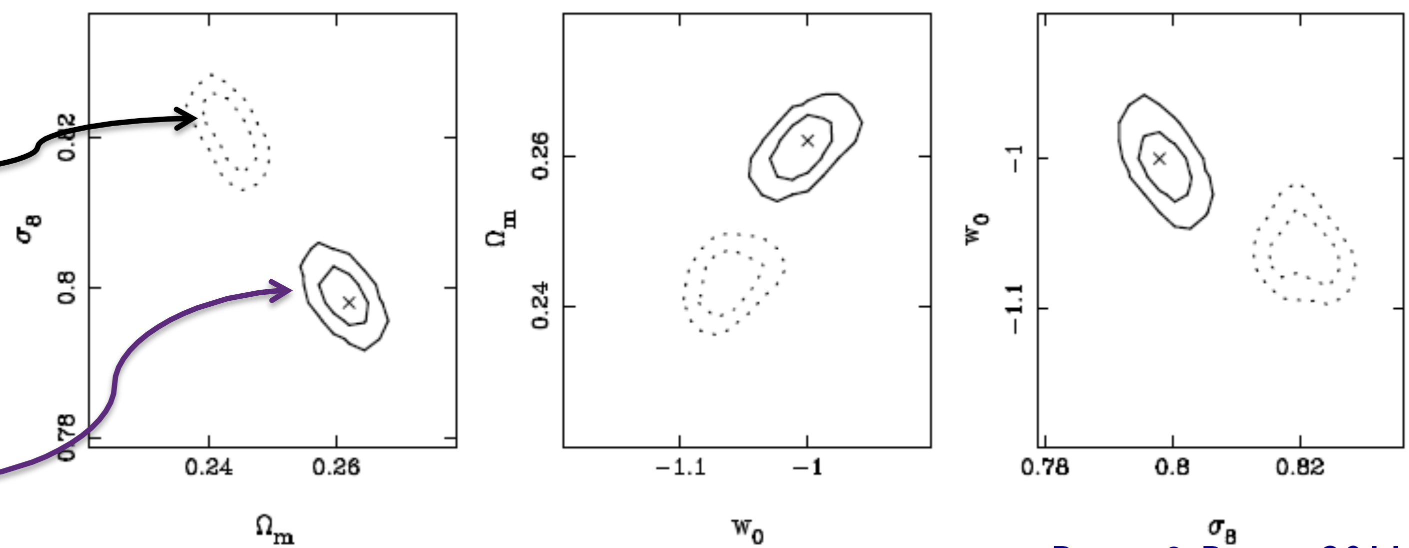
Joachimi et al 2011

Additional Information from Radio WL 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

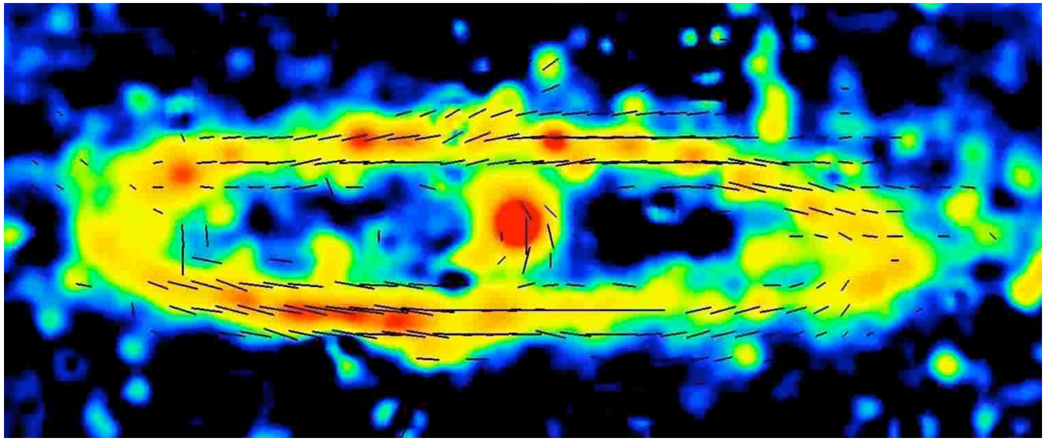
Contamination removed using new technique with no degradation in constraining power



Bown & Battye 2011

Additional Information from Radio WL
Shape Noise and Polarisation

- Can also use polarisation angle as tracer of pre-lensing intrinsic position angle
  - Will have some astrophysical scatter α_{int}
- Error on shear estimation reduced
  - if $\alpha_{int} \lesssim 12°$ (Whittaker et al 2015)



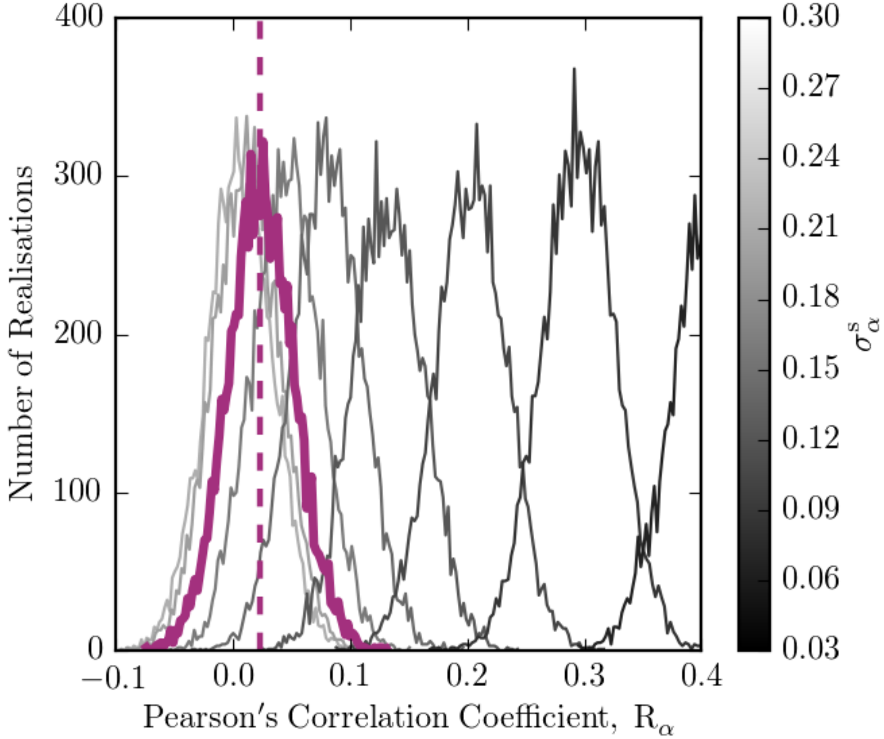
(Berkhuijsen, Beck, Hoernes 2003)

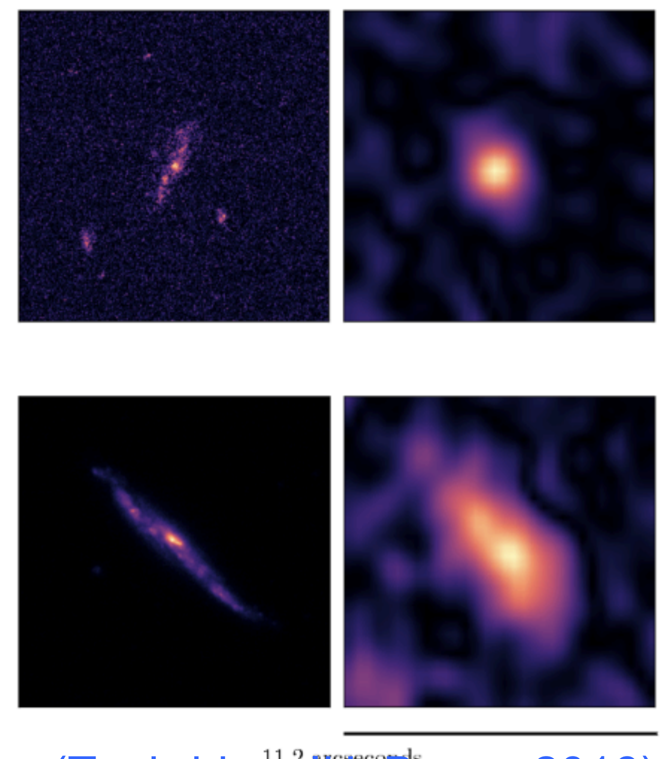
The Present

Shape Covariance in COSMOS

- Quantification of radio-optical shape covariance in VLA COSMOS 1.4 GHz:

$$\sigma_\alpha > 38° \text{ at } 95\%\text{CL}$$

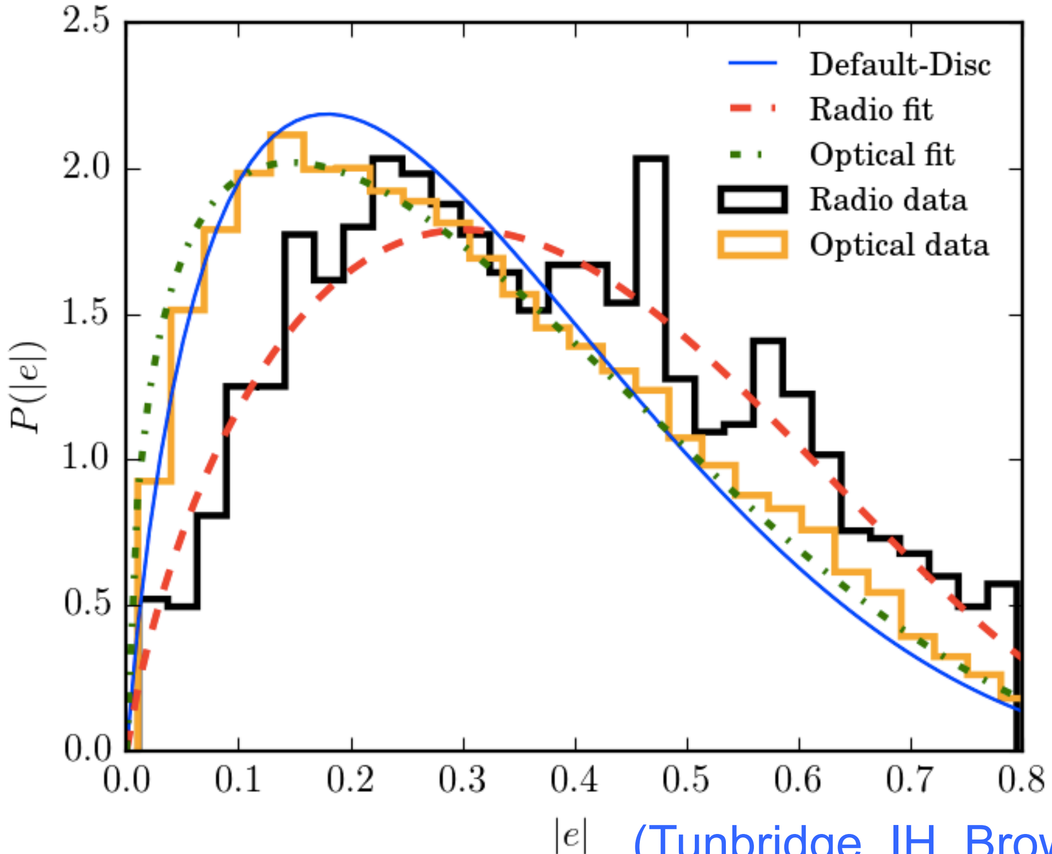




(Tunbridge, IH, Brown 2016)

The Present
Shape Covariance in COSMOS

- Also looked at radio-only shape variance
  - Broadly comparable to optical (good news!)

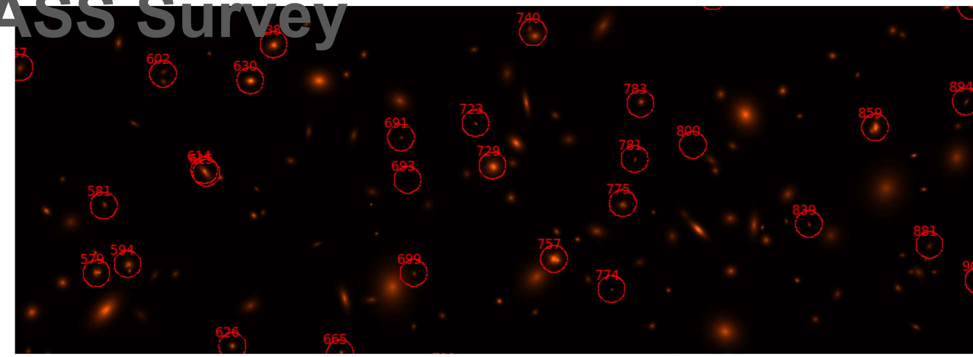


(Tunbridge, IH, Brown 2016)

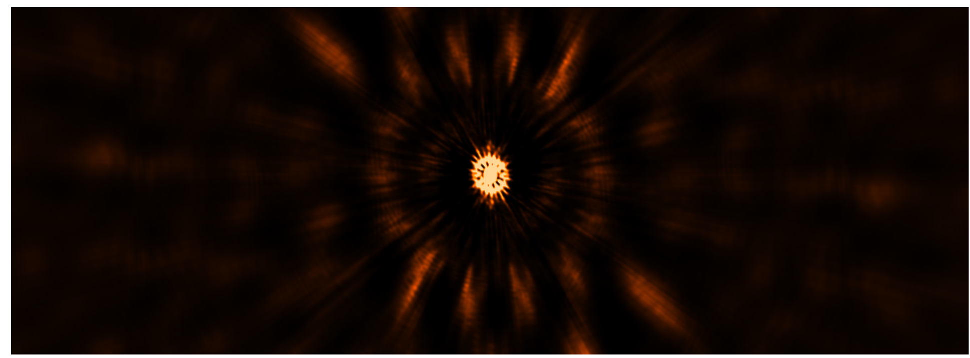
The Present
The SuperCLASS Survey

- Developed full end-to-end pipeline for simulation of radio observations
  - Source populations
  - Sky model (galsim)
  - Full telescope+noise model in visibility plane
  - Imaging
  - Source finding
- Quantify shear biases in pipeline

Input sky model:



e-MERLIN PSF:



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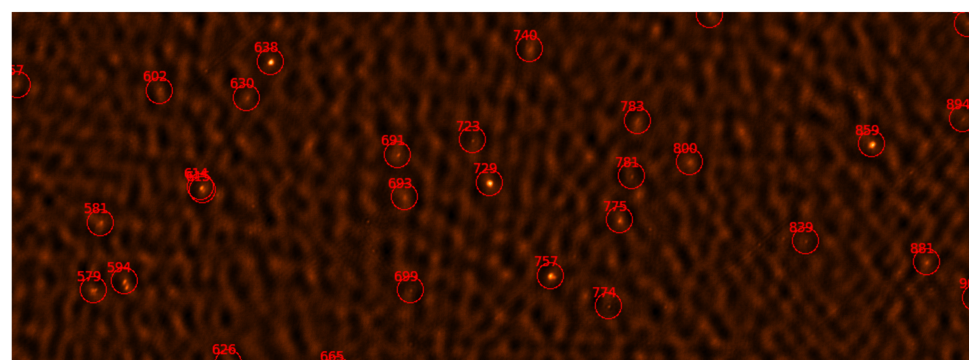
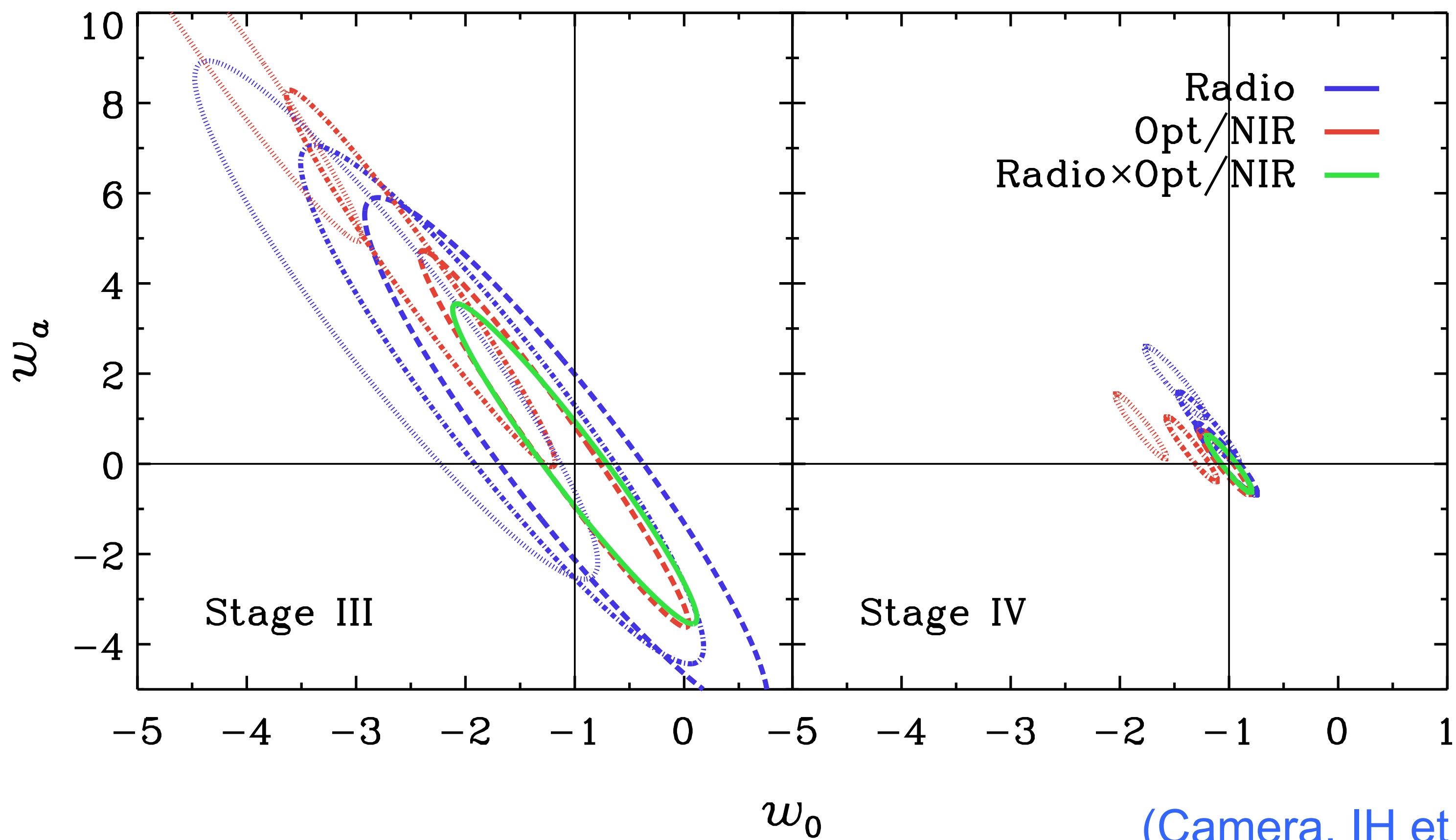


The Future
Cross-Correlations to Mitigate Systematics

- Cross-correlations can remove residual systematics at level important for Stage IV



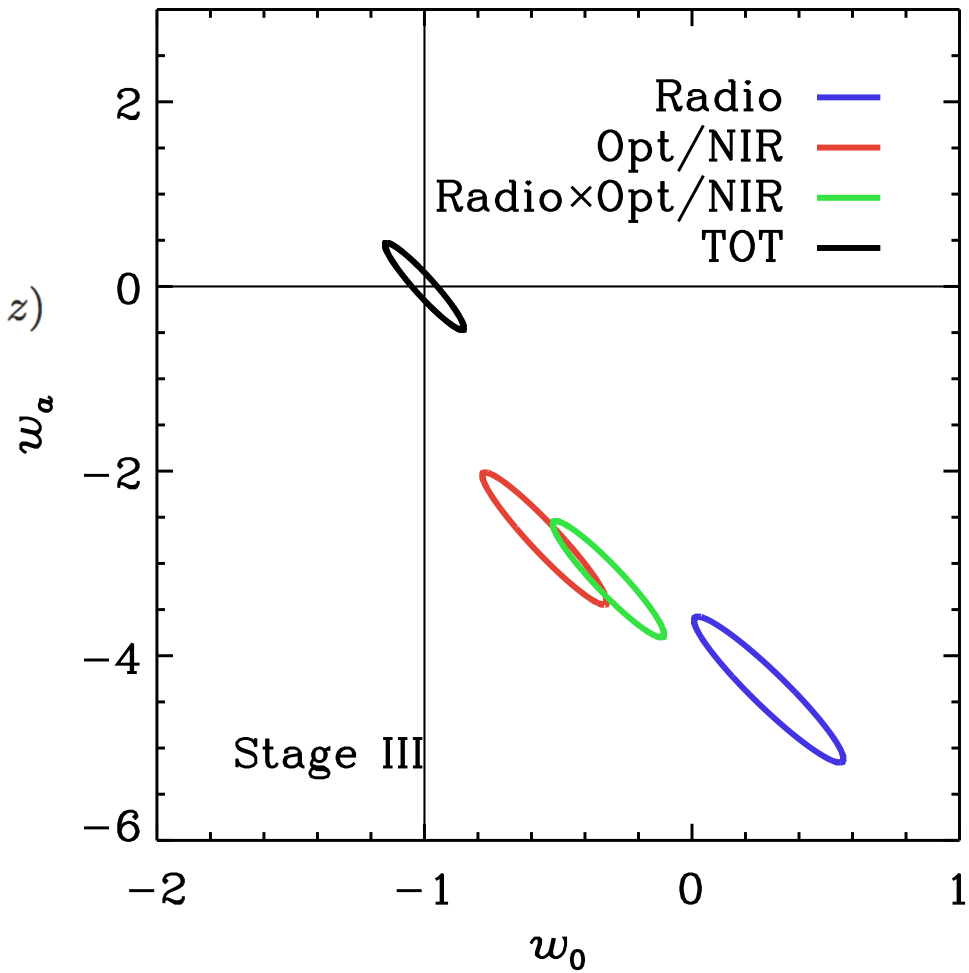
(Camera, IH et al 2016)

The Future
Cross-Correlations to Mitigate Systematics

- Can also consider multiplicative systematics:

$$\gamma^{\rm sys}(\theta, z) = \gamma^{\rm mul}(z)\gamma(\theta, z) + \gamma^{\rm add}(\theta, z)$$

- These will be important at Stage III
- OxR, RxR and OxO together in self-calibration can remove them



(Camera, IH et al 2016)

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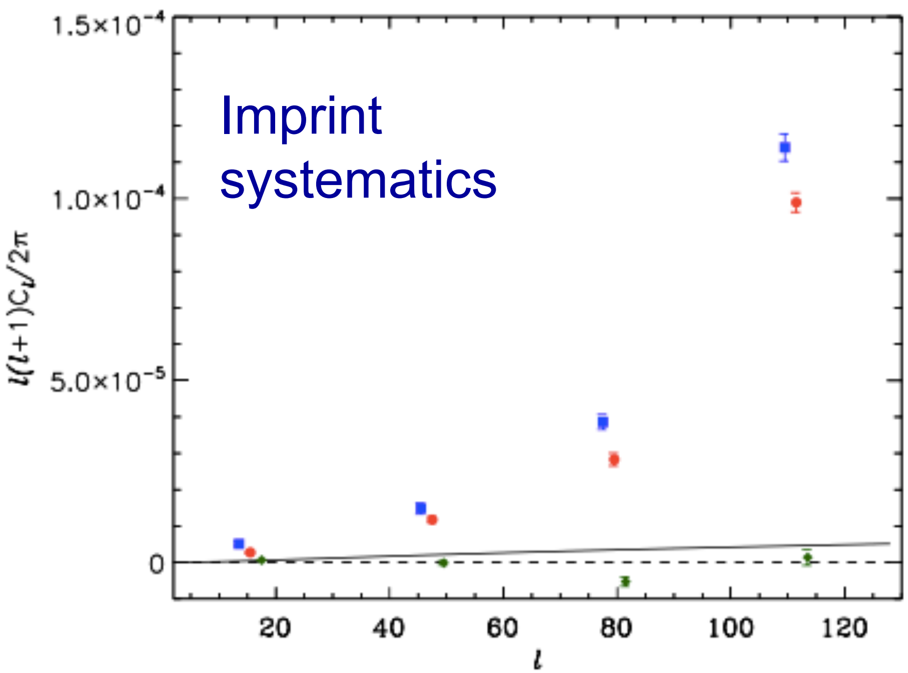
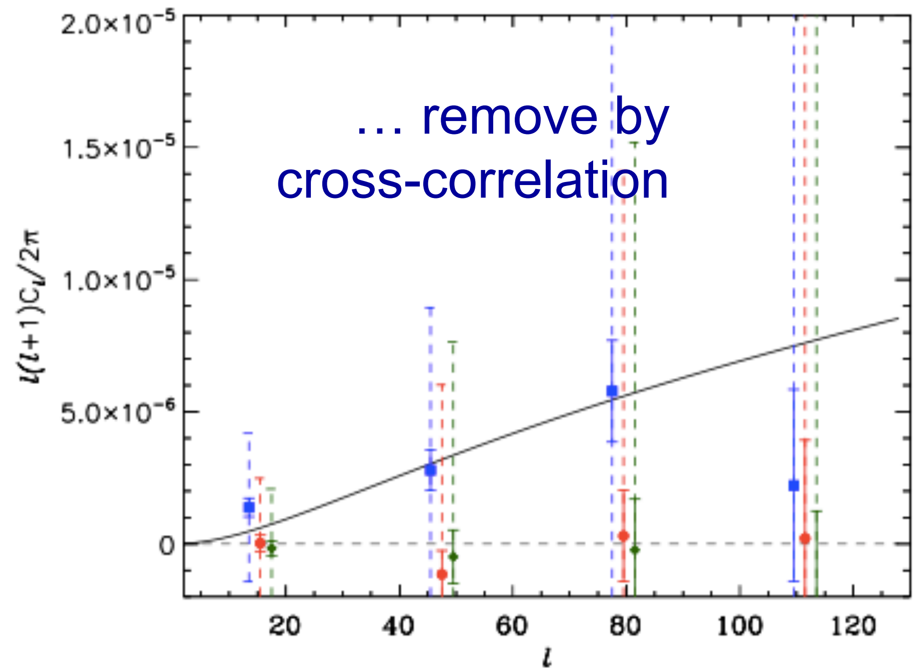
The Present
Demonstration in SDSSxFIRST

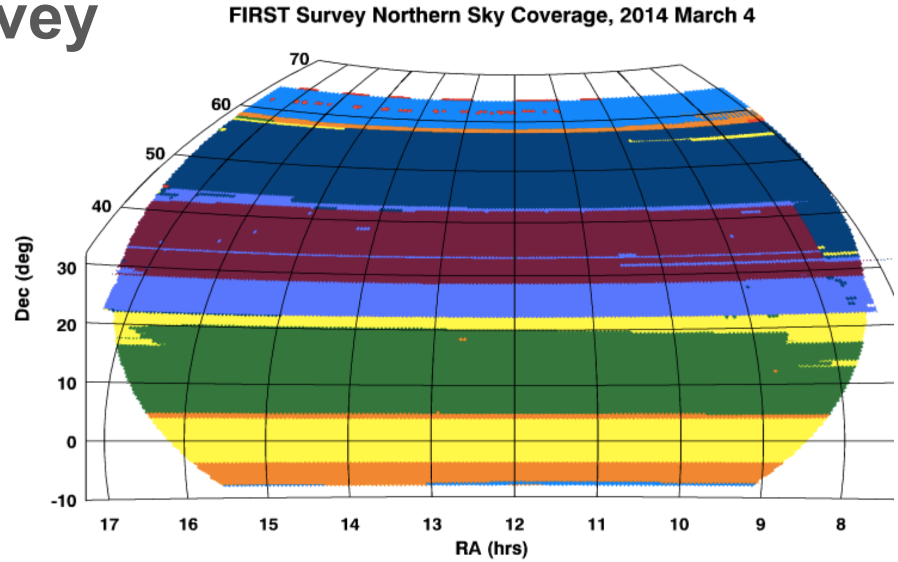
- Recently demonstrated in FIRST radio and SDSS optical lensing:





(Demetroullas & Brown 2015)

The Past
The FIRST Survey



- Faint Images of the Radio Sky at Twenty-Centimetres
  - 5 arcsec resolution
  - 1 mJy depth
  - ~20,000 sources
  - 10^4 deg^2
  - Only 0.0056 sources $arcmin^{-2}$

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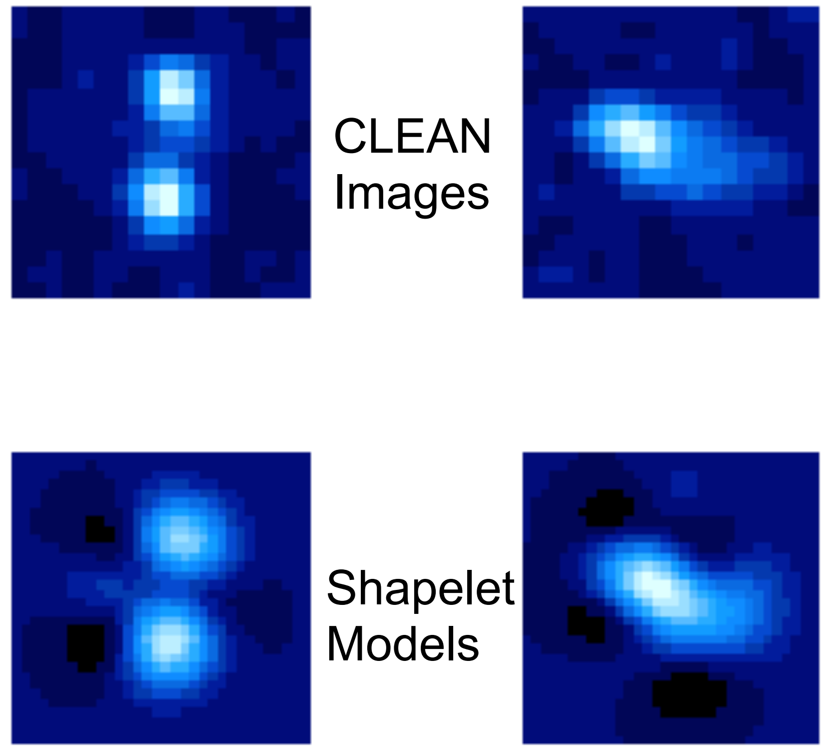
The Past
The FIRST Survey

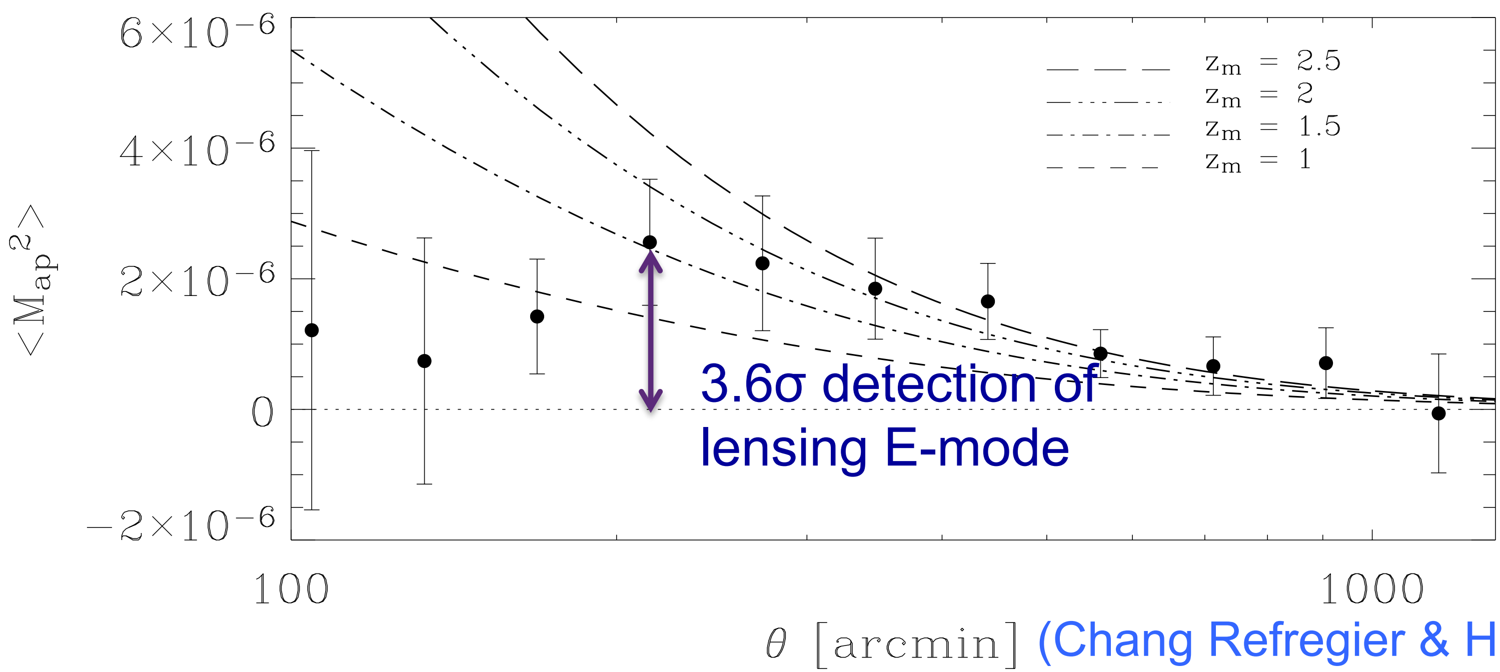
- Take source positions from images
- Model visibilities using Fourier-plane shapelet basis functions
- Estimate shear from combination of shapelet coefficients
- Model systematics with simulations



(Chang Refregier & Helfand 2004)

The Past
The FIRST Survey

- Make a 3.6σ detection of an aperture mass variance across survey
- Detection significance increases when low-redshift sources removed

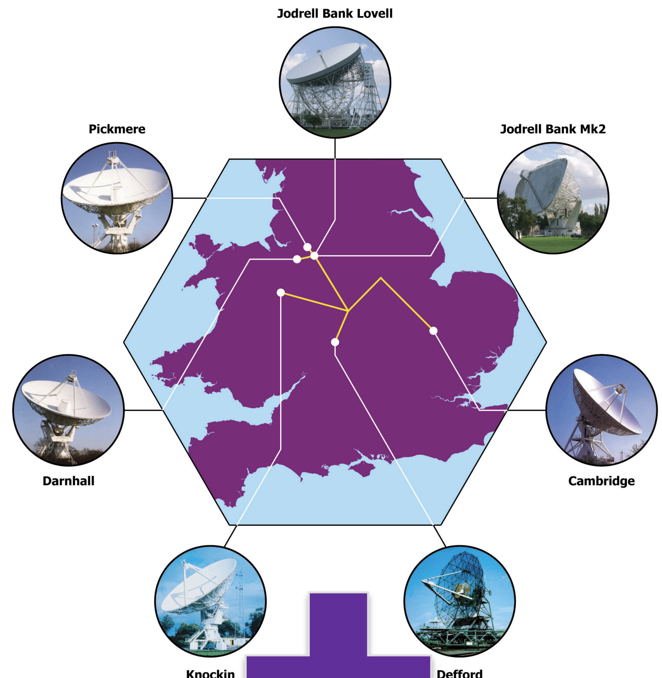


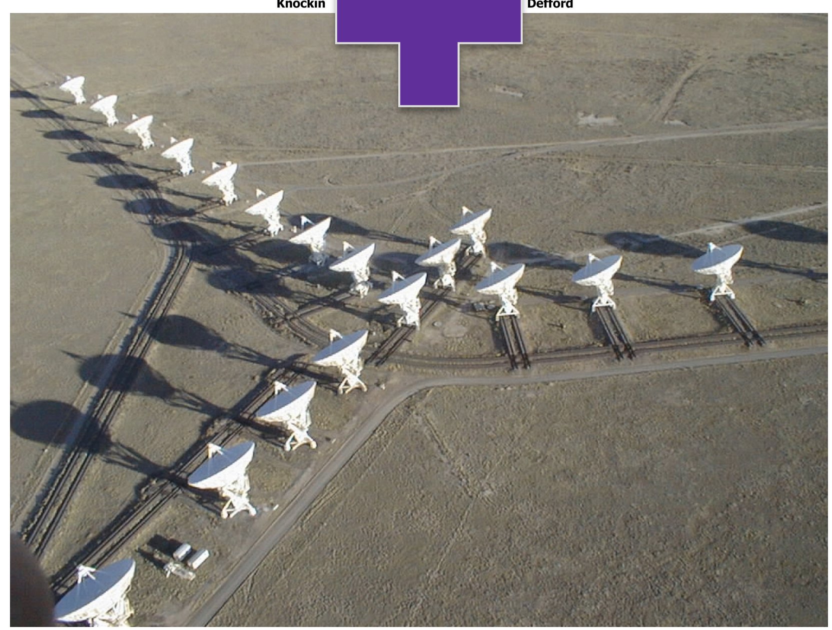
(Chang Refregier & Helfand 2004)

The Past
The HDF-N Survey

- Use combined data from Merlin and VLA
  - Longer baselines for higher resolution
- HDF-North field
  - 0.4 arcsec resolution
  - 50 μJy depth
  - ~1-4 sources arcmin^{-2}
  - Only 70 arcmin^{2}
  - ~50-300 sources

(Patel et al 2010)





The Past

The HDF-N Survey

(Patel et al 2010)

- Measure shapes in reconstructed images, with image-plane shapelets
- No detection of shear
- Also cross-correlate with shapes measured in optical images
  - …find no correlation, somewhat controversially