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Data and Analysis Requirements for Precision Cosmology with Radio Weak Lensing

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SKA Delivering the Science
Cambridge

12 April 2016

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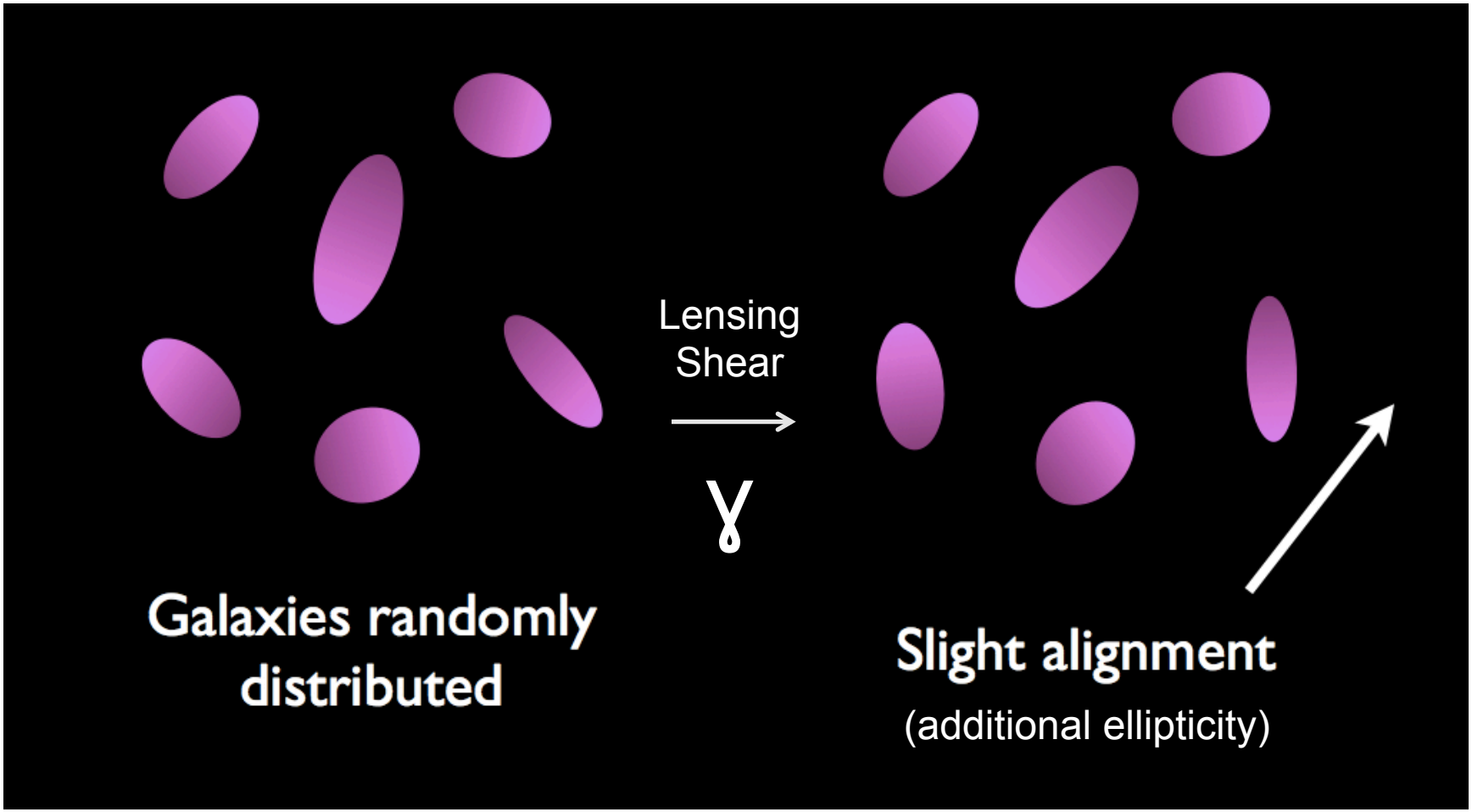
Weak Lensing Cosmology
Observables



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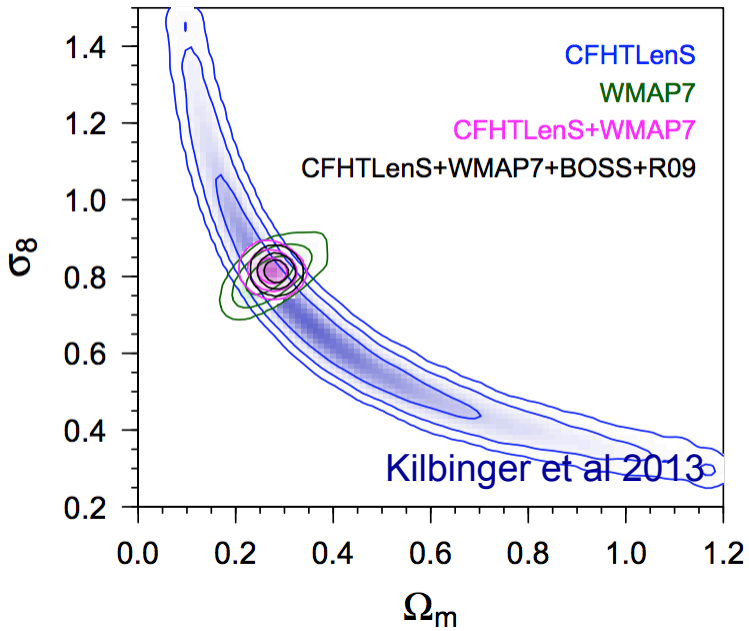
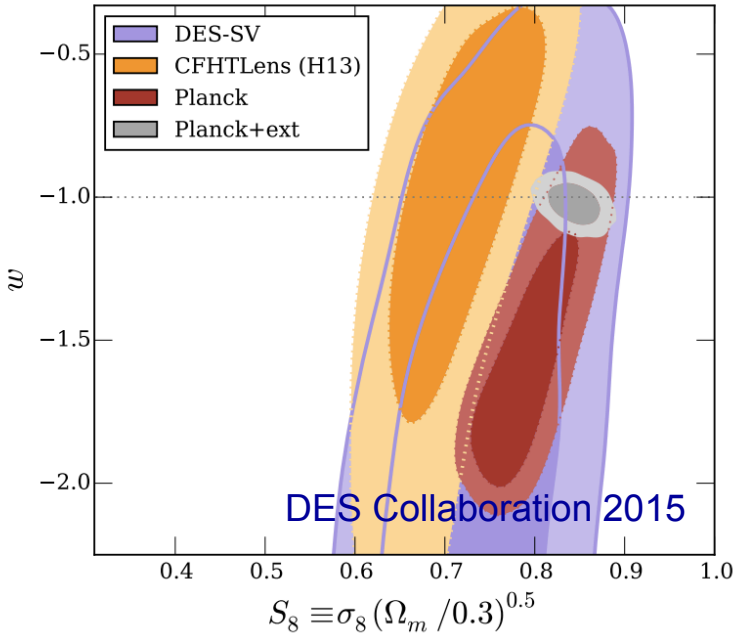
Weak Lensing Cosmology
Cosmology from Shear

- WL observables probe gravitational potential
  - Very good at measuring matter abundance
- Also track how structures grow over cosmic time
  - Split sources into tomographic redshift bins
  - Dark energy equation of state, modified gravity parameters





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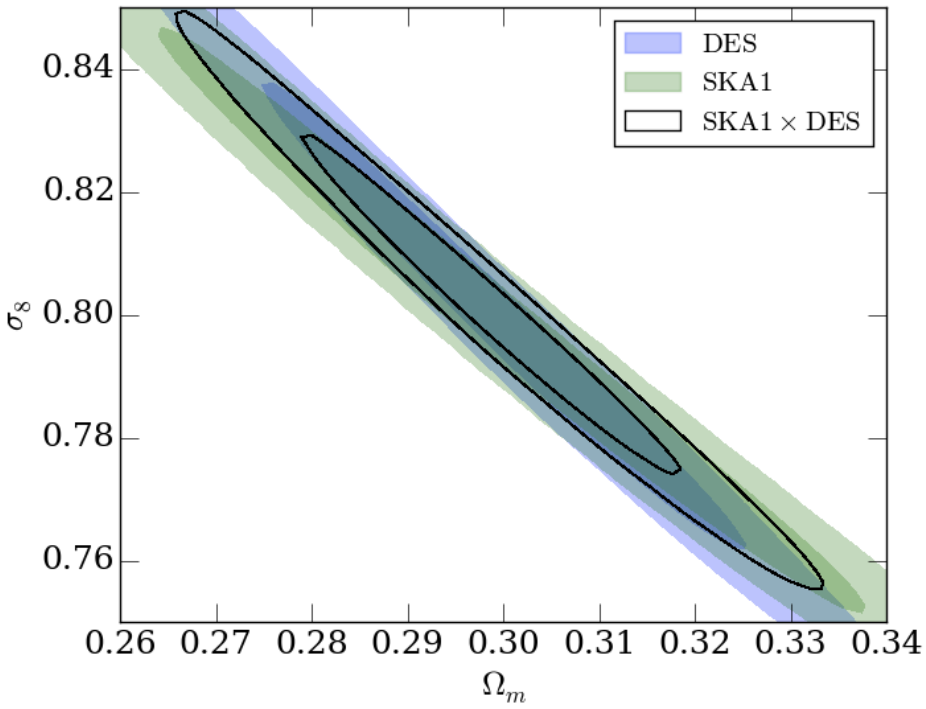
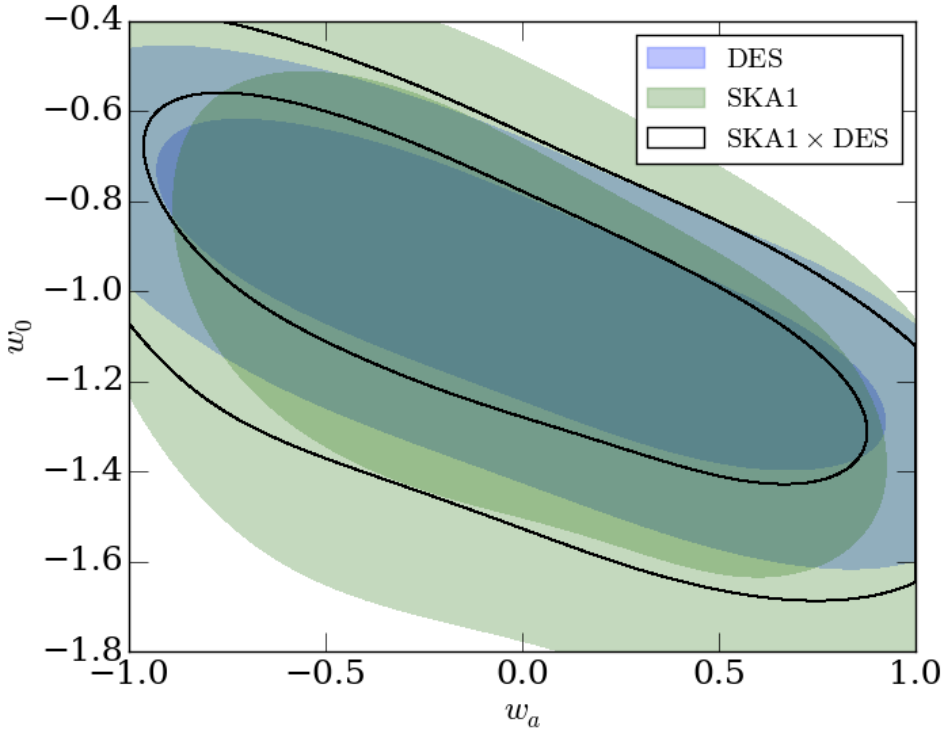
Weak Lensing Cosmology
SKA Forecasts

- SKA1 comparable to Dark Energy Survey (DES)





(IH et al arXiv:1601.03947)

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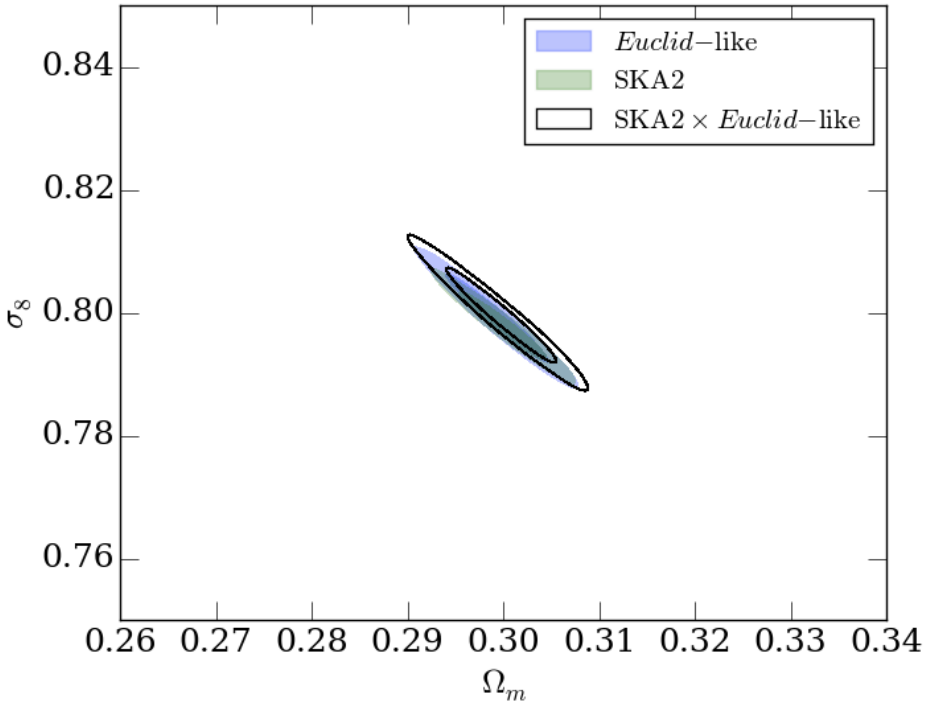
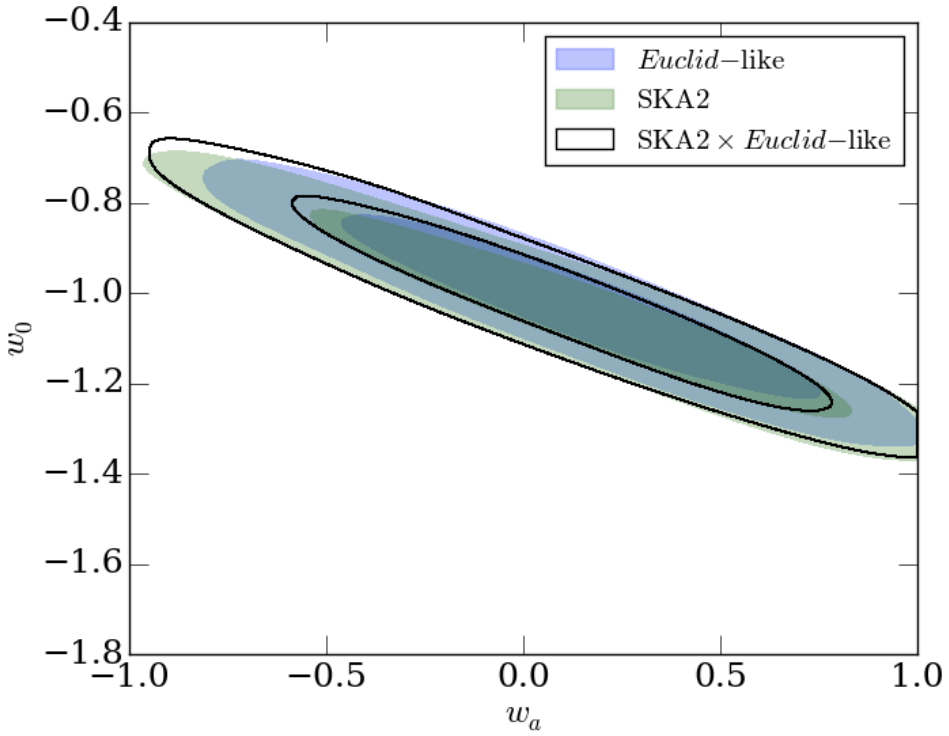
Weak Lensing Cosmology
SKA Forecasts

- SKA2 can beat a *Euclid*-like weak lensing experiment!

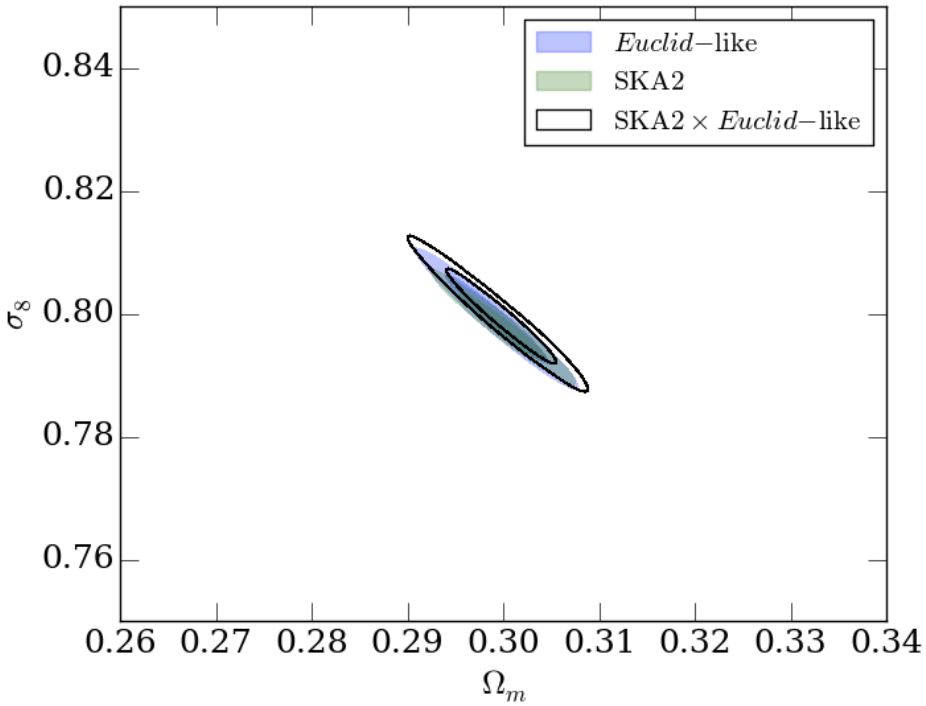


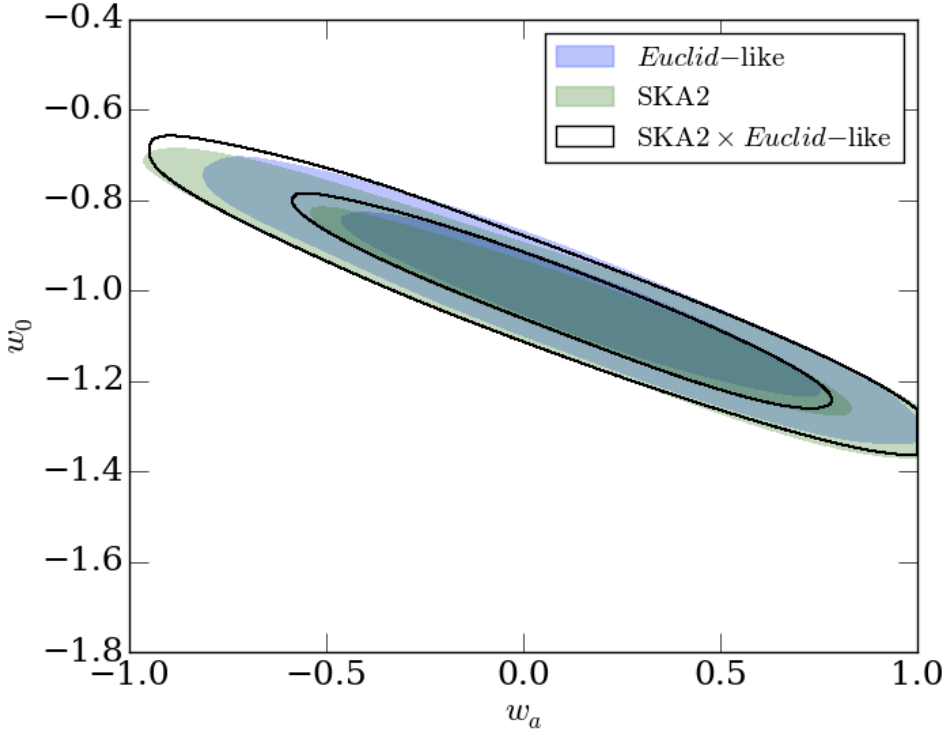


(IH et al arXiv:1601.03947)

Weak Lensing Cosmology
SKA Forecasts

- …and *cross-correlations* do not significantly degrade statistical precision, but greatly improve robustness to systematics





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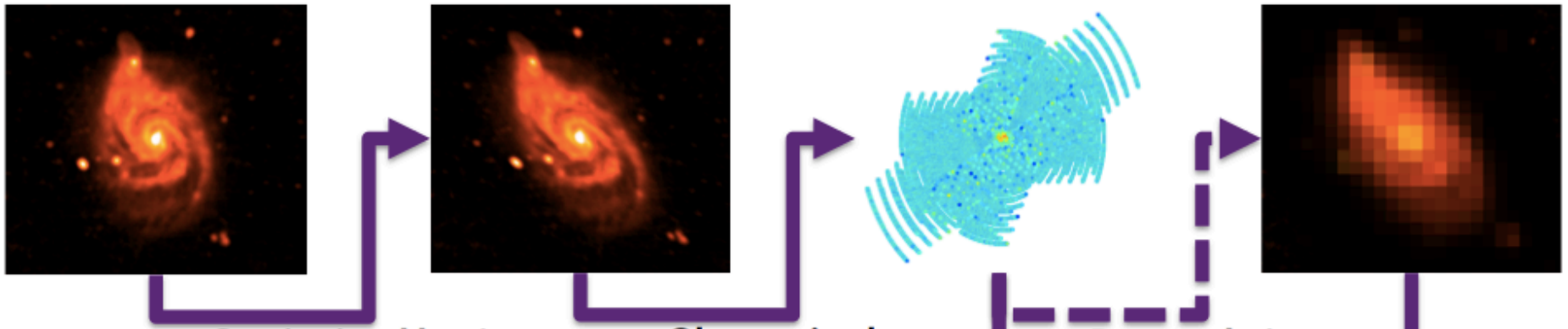
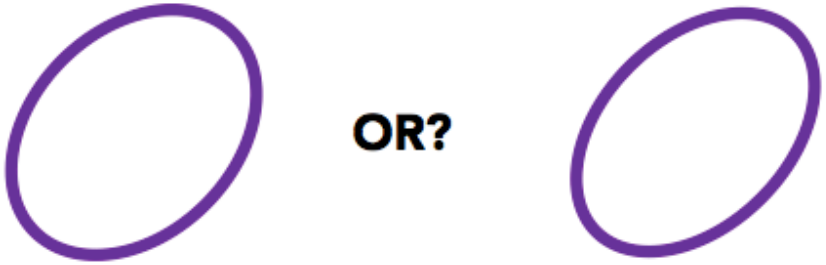
Weak Lensing Cosmology
Shape Measurement





Cosmological Shear Measurement

σ_{sys} **<1% for detection**

σ_{sys} **<0.01% for useful cosmology**

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Weak Lensing Cosmology
Shape Measurement

Want to measure shear γ to one part in 10^4

- Measure in Images
  (all optical WL analyses ever)
- Preserve 2nd order moments of source shapes
- Infer ~6 parameters simultaneously

- Measure in Visibilites
  (Tarr later, Rivi+ 2016, Chang+ 2004)
- Preserve 2nd order moments of FT of source shapes

  $\gamma_{Fourier} = -\gamma_{Image}$
- Infer ~60,000 parameters simultaneously

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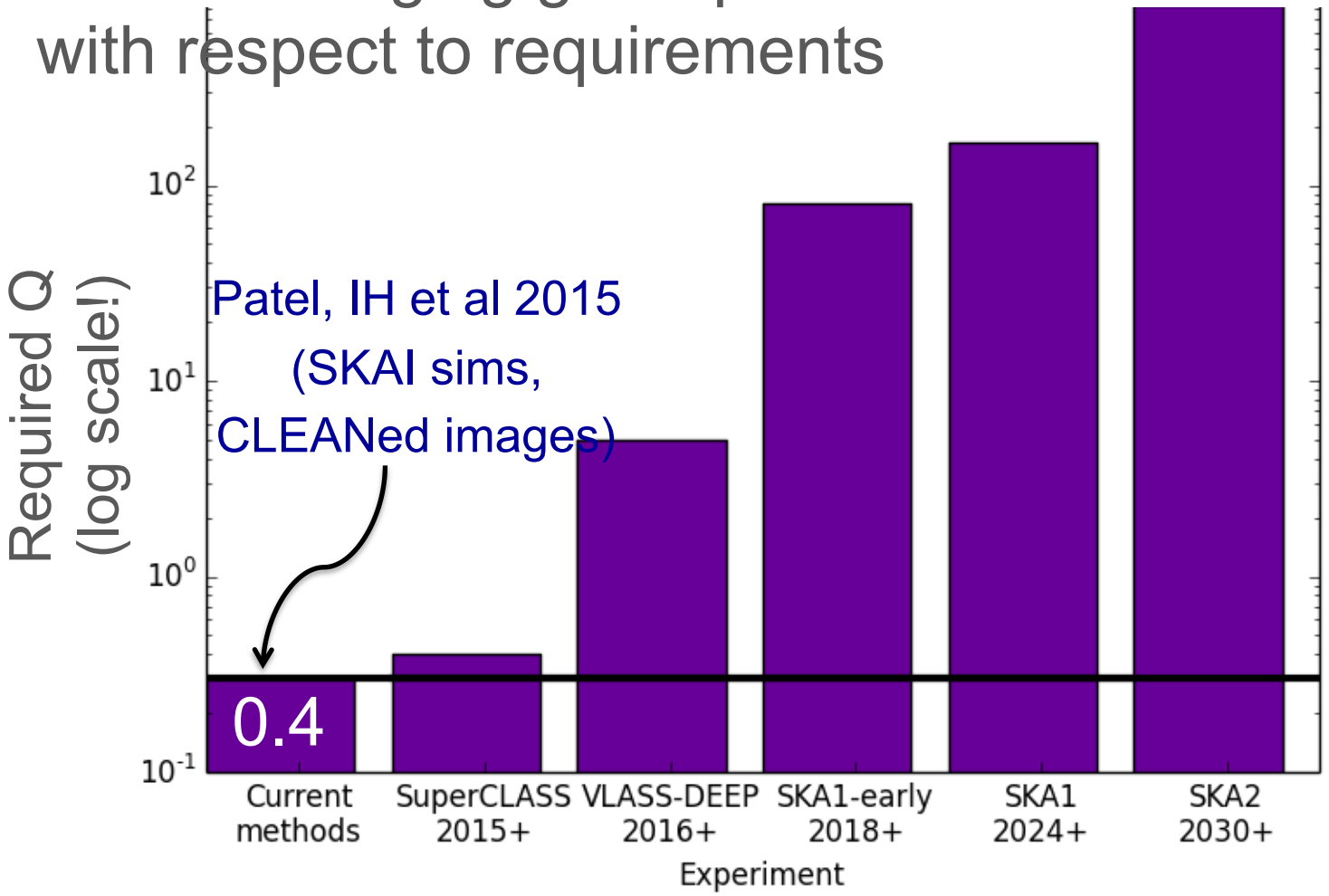
Weak Lensing Shape Measurement
'Traditional' Performance

- CLEAN imaging gives poor results with respect to requirements



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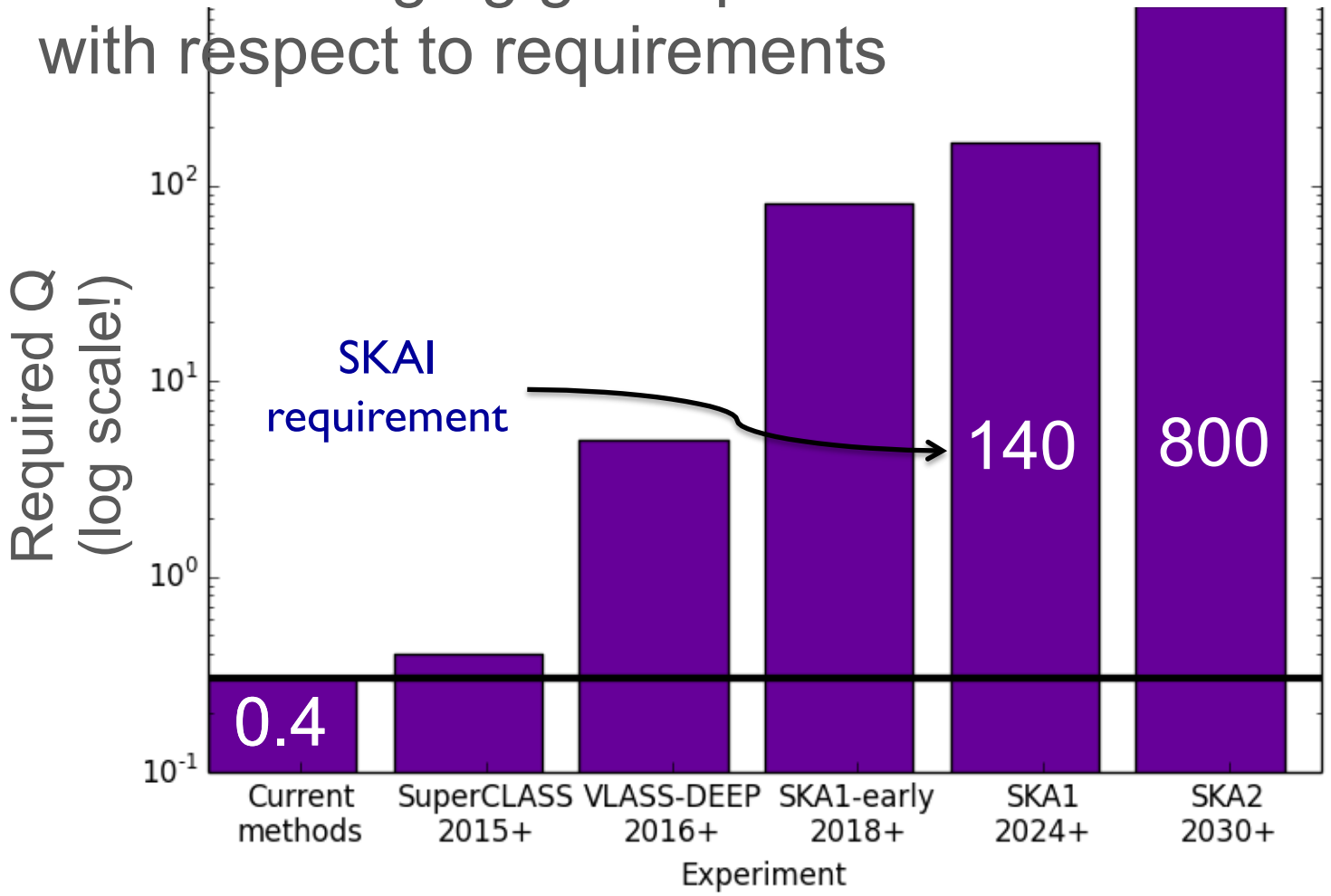

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Weak Lensing Shear Measurement Solution – radioGREAT

- 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 visibility data supplied
- Like inference challenges?
  Image analysis?
  SKA data simulation?
  - http://radiogreat.jb.man.ac.uk

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Weak Lensing Shear Measurement Problems Avoided So Far

- Gridded visibilities will be a data product! 🎉
  - as a ‘custom experiment’
- Time, bandwidth smearing should not be a problem (IH, Brown, arXiv:1507.06639)
  - With < 50 kHz channels, < 1 s time sampling
- Shear achromatic so channel averaging okay
  - Even if source shapes frequency dependant (Rivi *et al* in prep)

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Weak Lensing Shear Measurement Requirements from SKA

- Anything which can affect source shapes needs to be controlled, quantified!
  - Primary beam corrections
  - Antenna pointing accuracy
  - Ionospheric calibration
  - Bright source subtraction
  - RFI etc
- Options
  - These are small enough not to matter
  - These are well understood enough to be simulated, calibrated

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Weak Lensing Shear Measurement Requirements from SKA

- An SKA1-MID survey useable for Weak Lensing would look something like:
  - Band 2
  - 10,000 hours
  - ~1,000 deg^2 (overlapping with DES)
  - to ~few μJy
- With output data products:
  - Continuum images (source finding, shape priors)
  - ~0.1 arcsec pixels in dirty image / gridded visibilities with ~1 deg^2 FoV
  - ~1 output visibility grid per pointing (channels averaged together)

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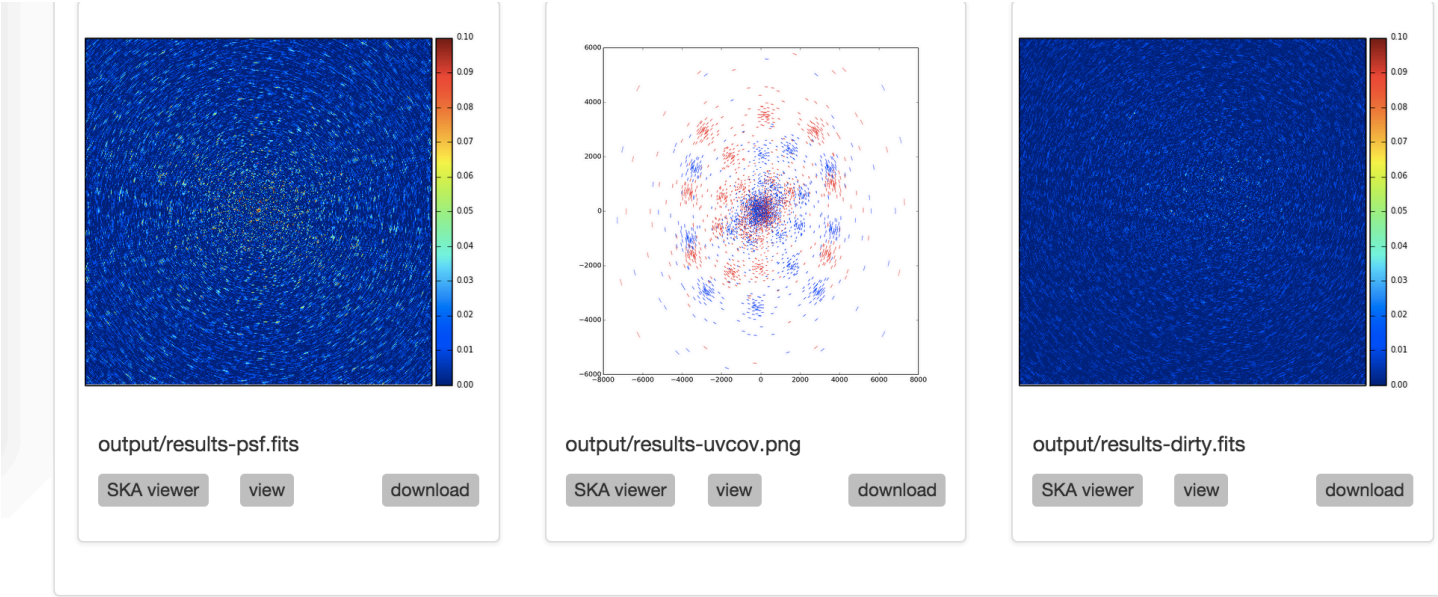
Weak Lensing Shear Measurement Requirements from SKA

- High quality, high volume, coherent end-to-end simulations will be crucial
  - Realistic weak-lensing relevant sky models
  - Forward model of telescope
  - Noise sources (RFI, calibration errors)



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Radio Weak Lensing
Summary

- SKA can do WL cosmology competitive with premier optical surveys… but not just ‘me too’
  - Radio can be panacea for many WL systematics
- Weak lensing has a very specific quality metric
  - Preservation of sky brightness second order moments
  - …in image plane *or* visibility plane
- Ongoing efforts with simulations, pathfinder experiments and algorithm challenges
  - SuperCLASS, e-MERGE, CHILES-con-pol, VLASS
  - radioGREAT

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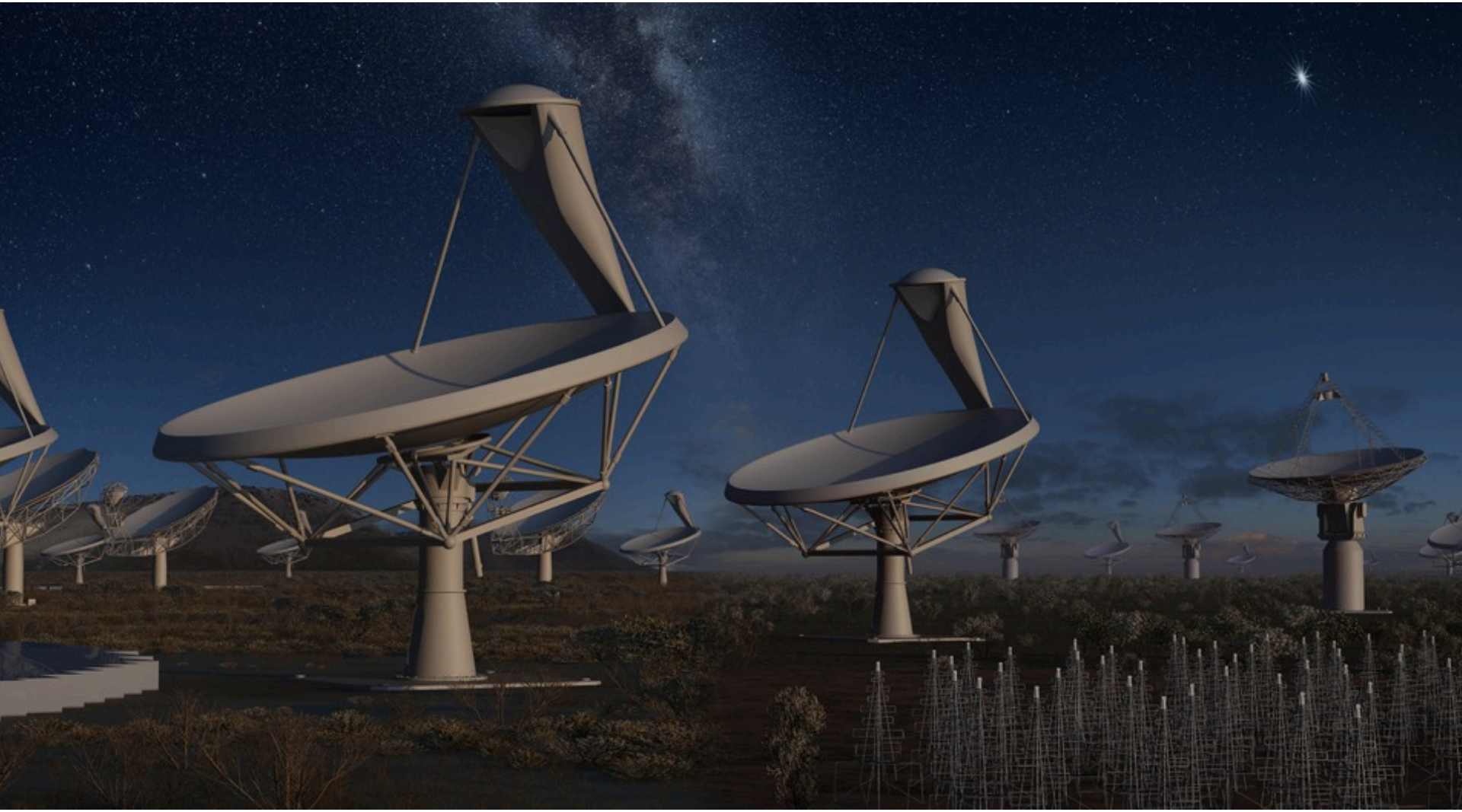
Bonus Slides



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Radio x Optical Weak Lensing Rationale

- For optical and radio shear estimates with wavelength-dependent systematics:

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

- These should disappear in the cross-correlation:

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

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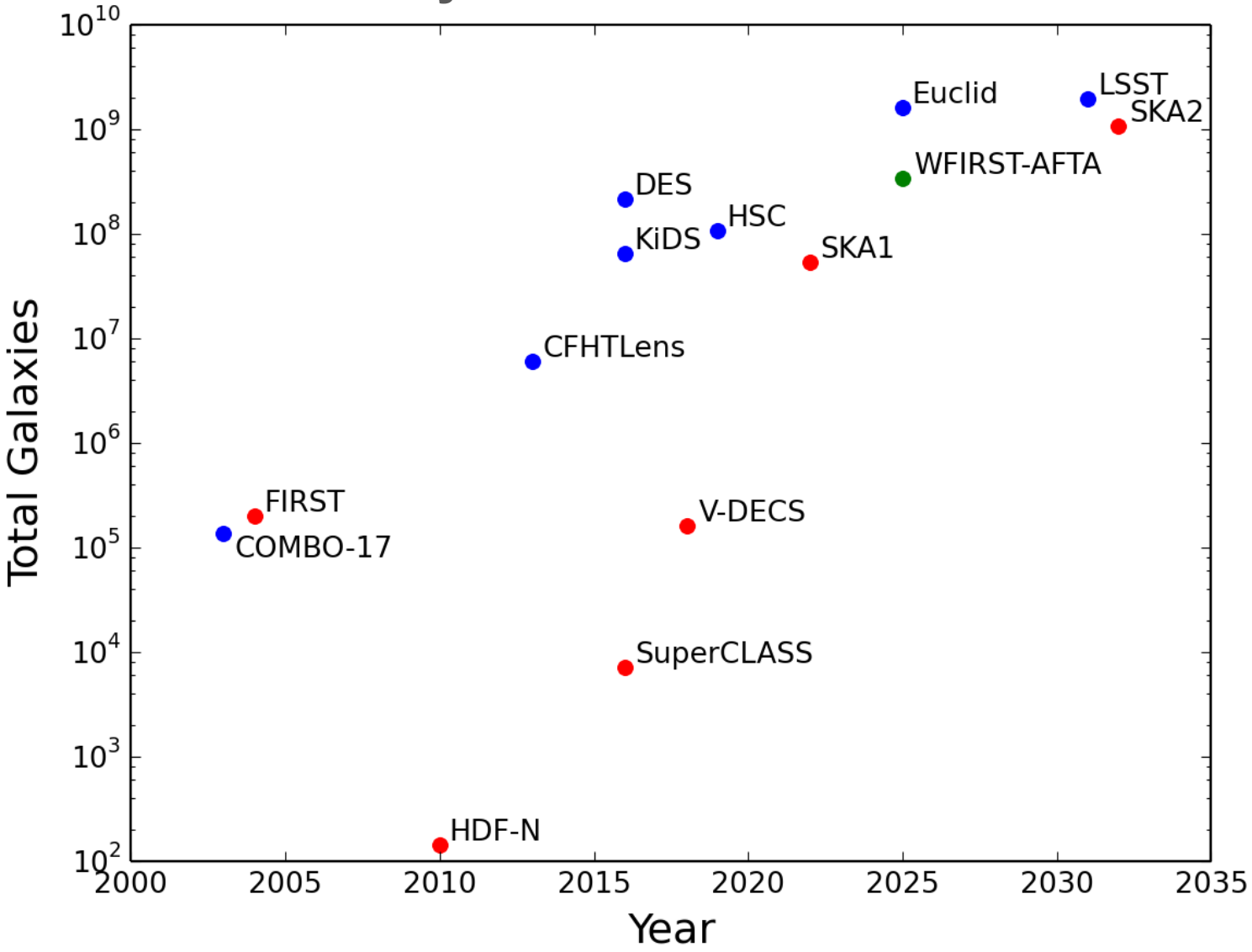
Radio Weak Lensing Survey Timeline



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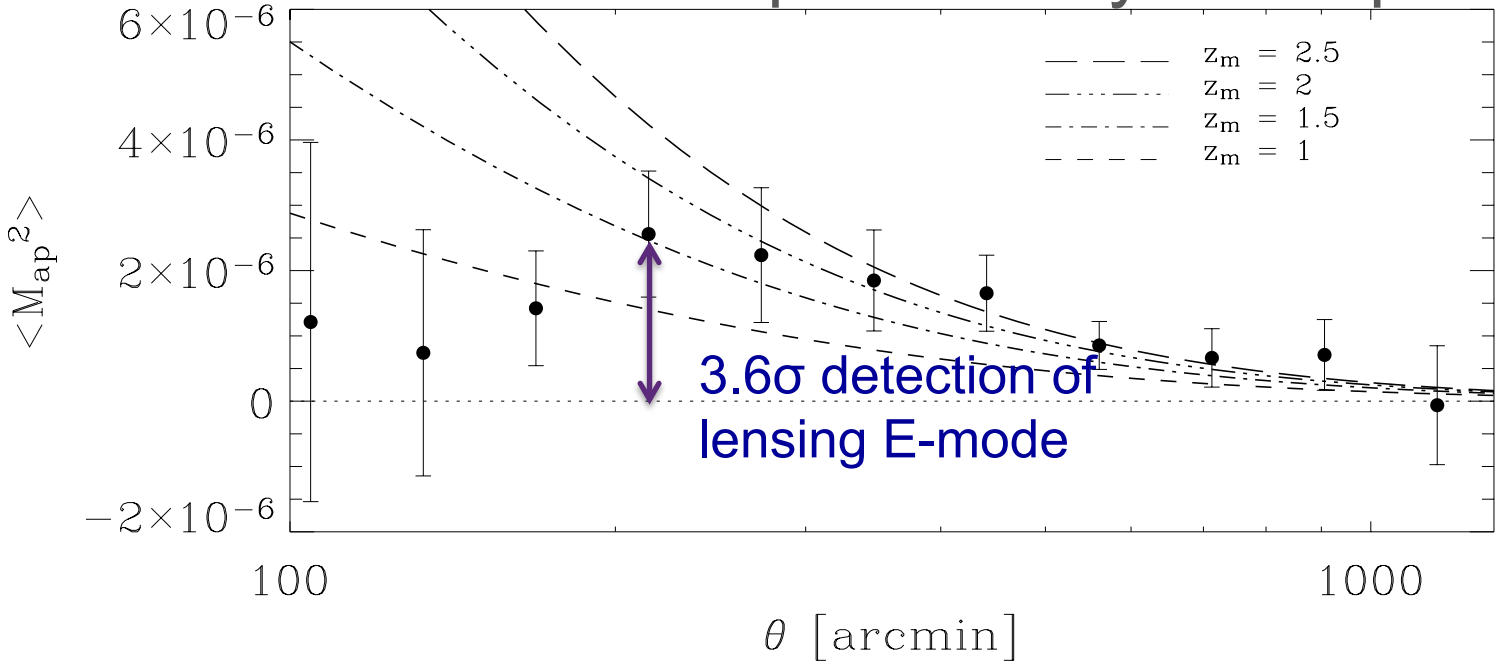
Surveys to Date
VLA FIRST

- Detection of weak lensing in VLA FIRST survey
  (Chang, Refregier & Helfand 2004)
- Wide but (very) shallow survey
  - 8,000 deg^2, ~20 sources deg^{-2}
- Measured source shapes directly in UV plane



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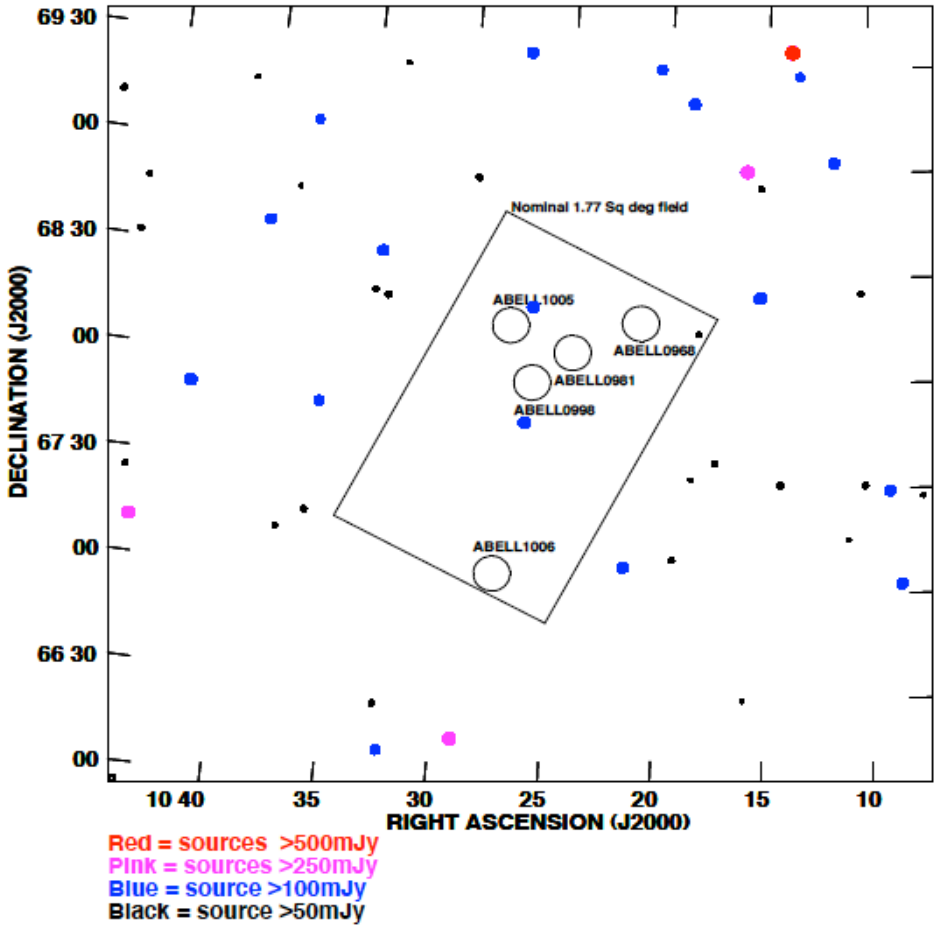
Current Surveys
SuperCLASS

- Dedicated radio WL survey
  - 1 deg^2
  - 0.2 arcsecond resolution
  - 2-3 galaxies arcmin^{-2} in radio
  - Dense supercluster target field
  - ~300 of 800 hours observed so far
- Multiwavelength coverage
  - e-MERLIN and JVLA at 1.4GHz
  - Subaru in optical
  - LOFAR and GMRT at low radio
  - SCUBA-2 in sub-mm
  - Spitzer in NIR



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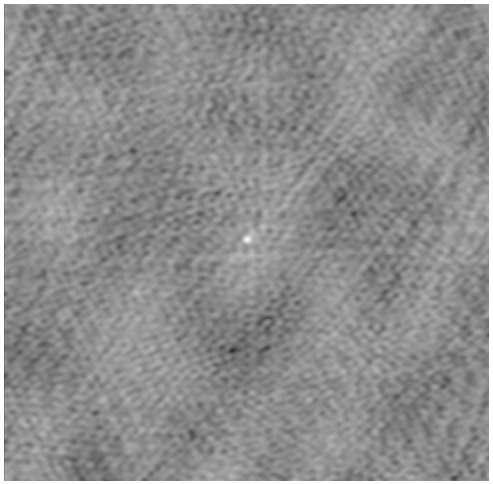
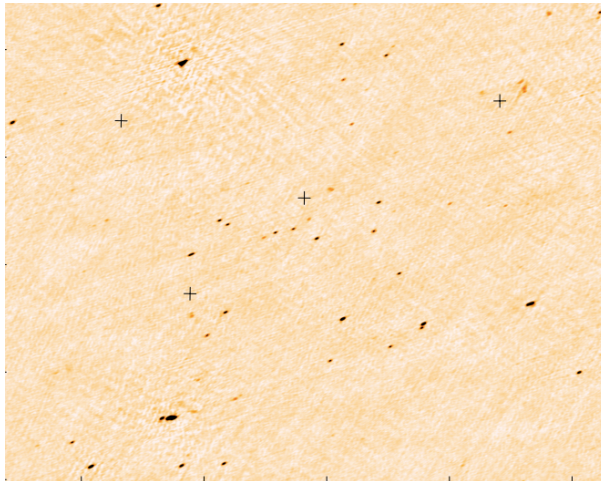
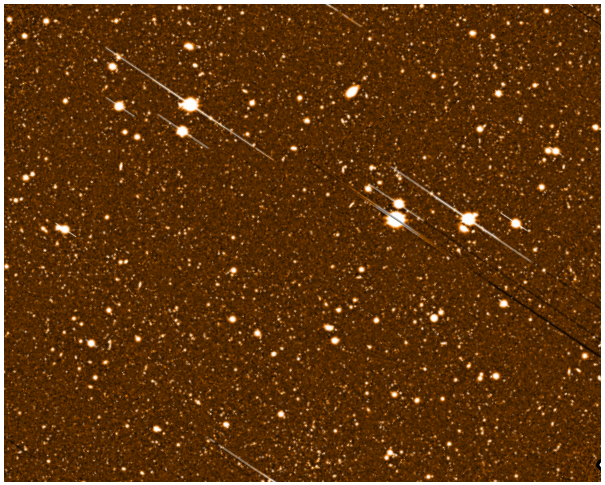
Current Surveys
SuperCLASS







- e-Merlin 1.4GHz
- Achieving ~17muJy noise
  - expected from data so far

- GMRT 330MHz (Riseley et al)
- 34μJy/beam rms noise

- SuprimeCam BVRiZ (Caitlin Casey)
- Completed to 25mag

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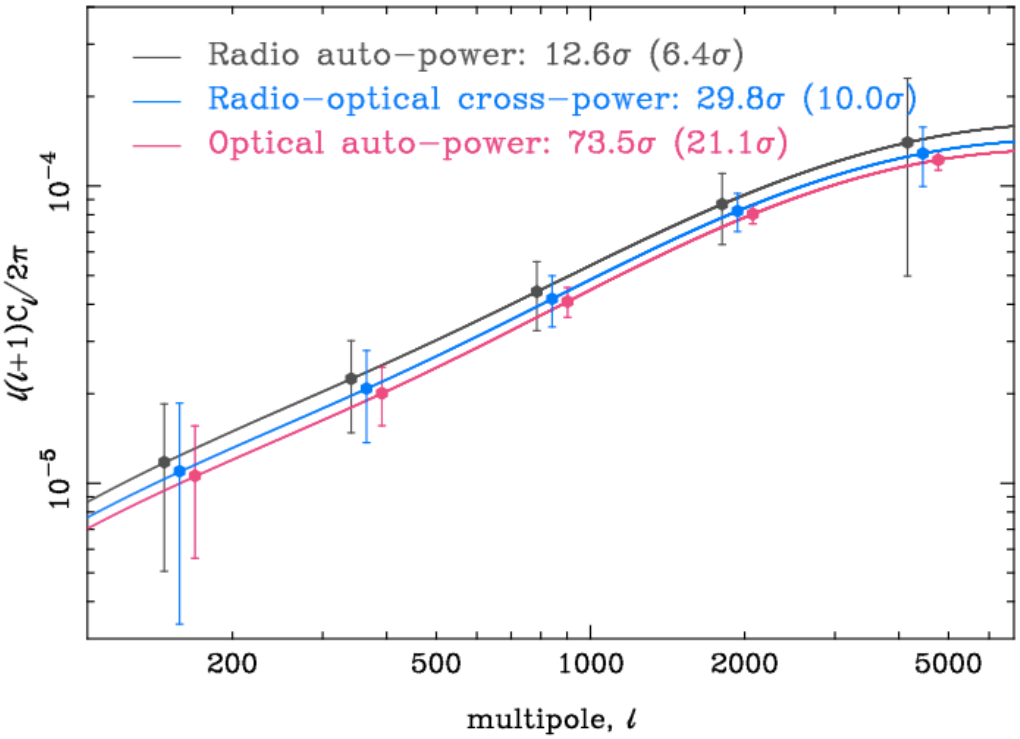
Future Surveys
V-DECS

- VLA-Deep Extragalactic Cosmology Survey
- Proposed JVLA survey
  - recasting of DEEP component of VLASS
- WL key science driver
  - 10 deg^2
  - 0.75 arcsecond resolution
  - 3-4 galaxies arcmin^{-2}
  - COSMOS, ELIAS-N1 fields
- High significance detection of shear power spectrum



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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)

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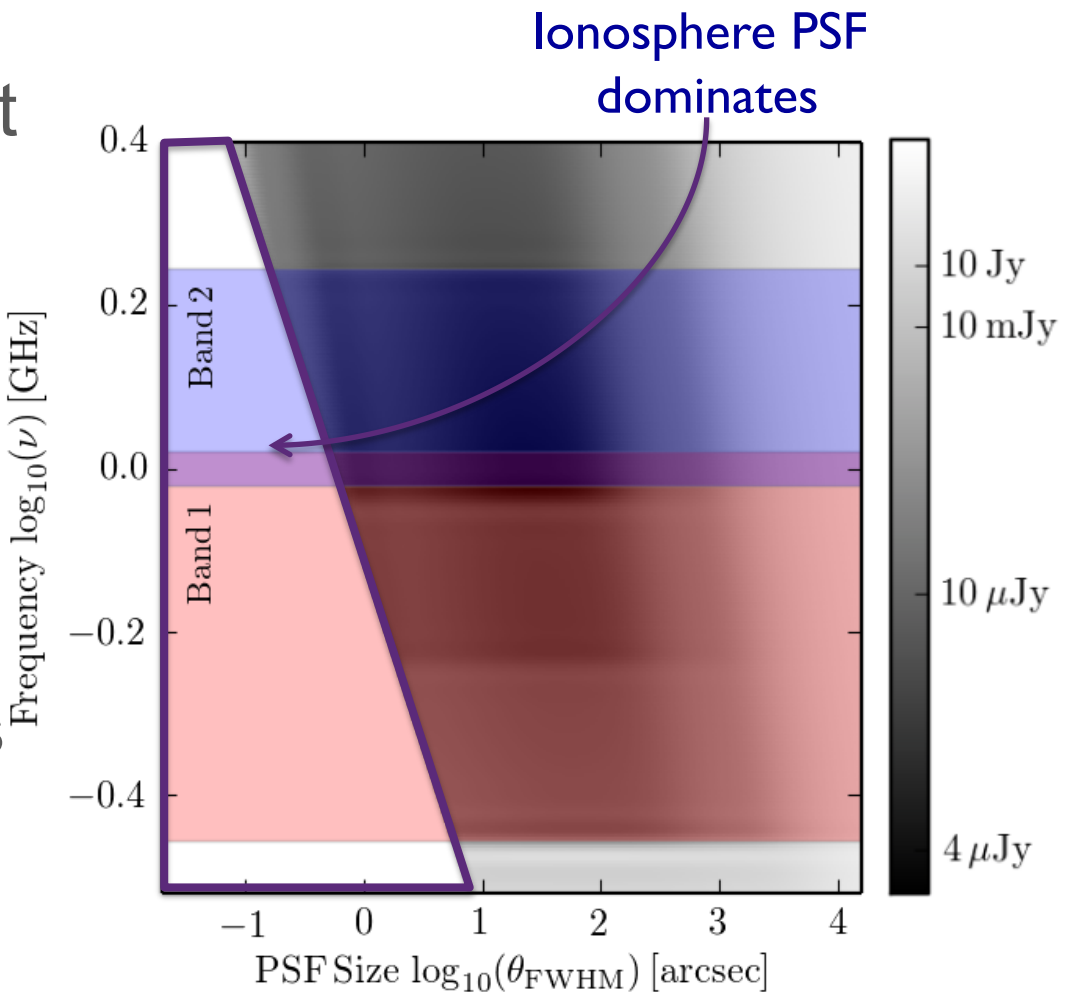
SKA Weak Lensing
Survey Optimisation with skalens

- Choose experiment configuration from SKA1-MID Sensitivity curve (Robert Braun)
- Source catalogues from star-forming galaxy distributions in semi-empirical SKADS sims (Wilman et al 2008)



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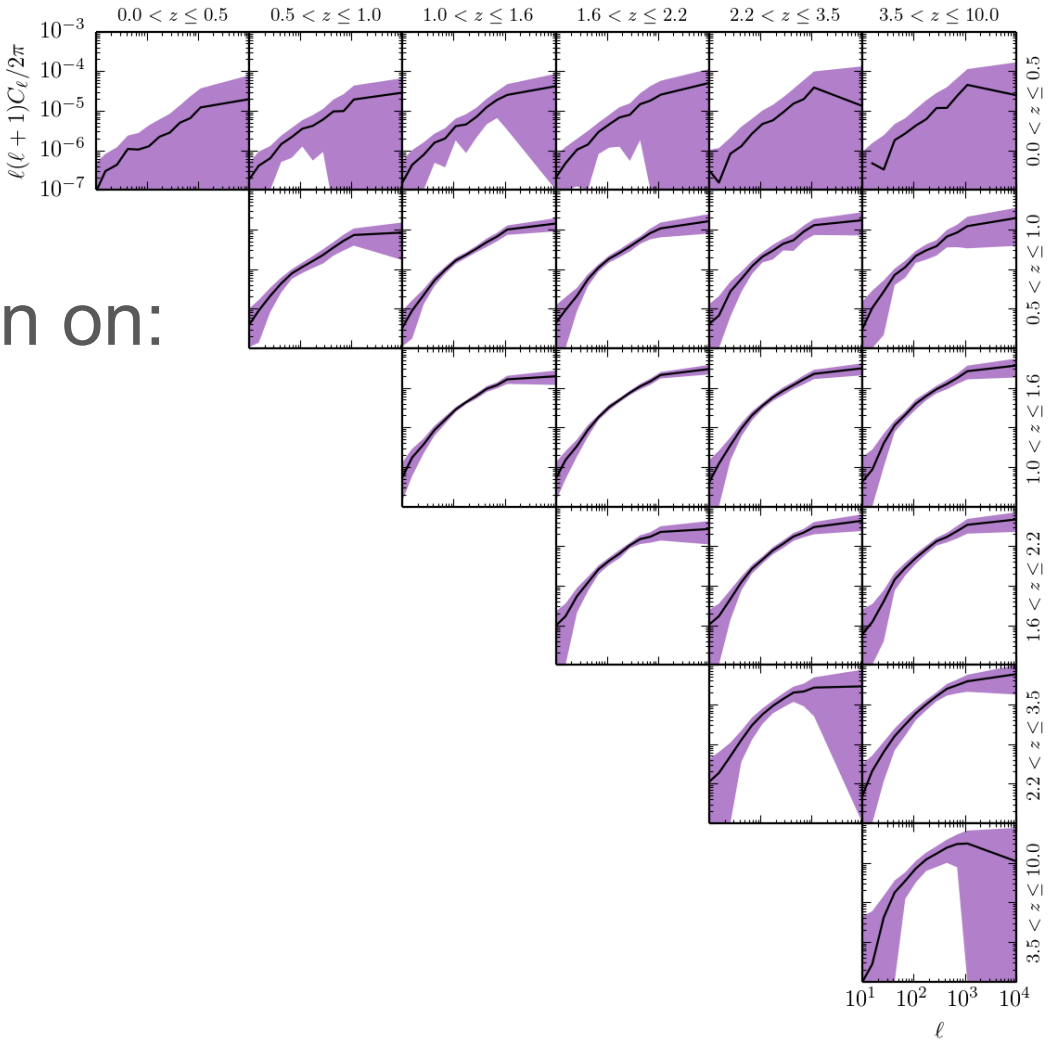
SKA Weak Lensing
Survey Optimisation with skalens

- Recover observed shear power spectra in 6 redshift bins
- Optimise configuration on:
  - Total shear SNR
  - DETF Figure of Merit (constraint on w_0-w_a)
- 'Sweet spot'
  - ~1.00 GHz central ν
  - 0.5 arcsec FWHM
  - 1,000 – 5,000 deg^2



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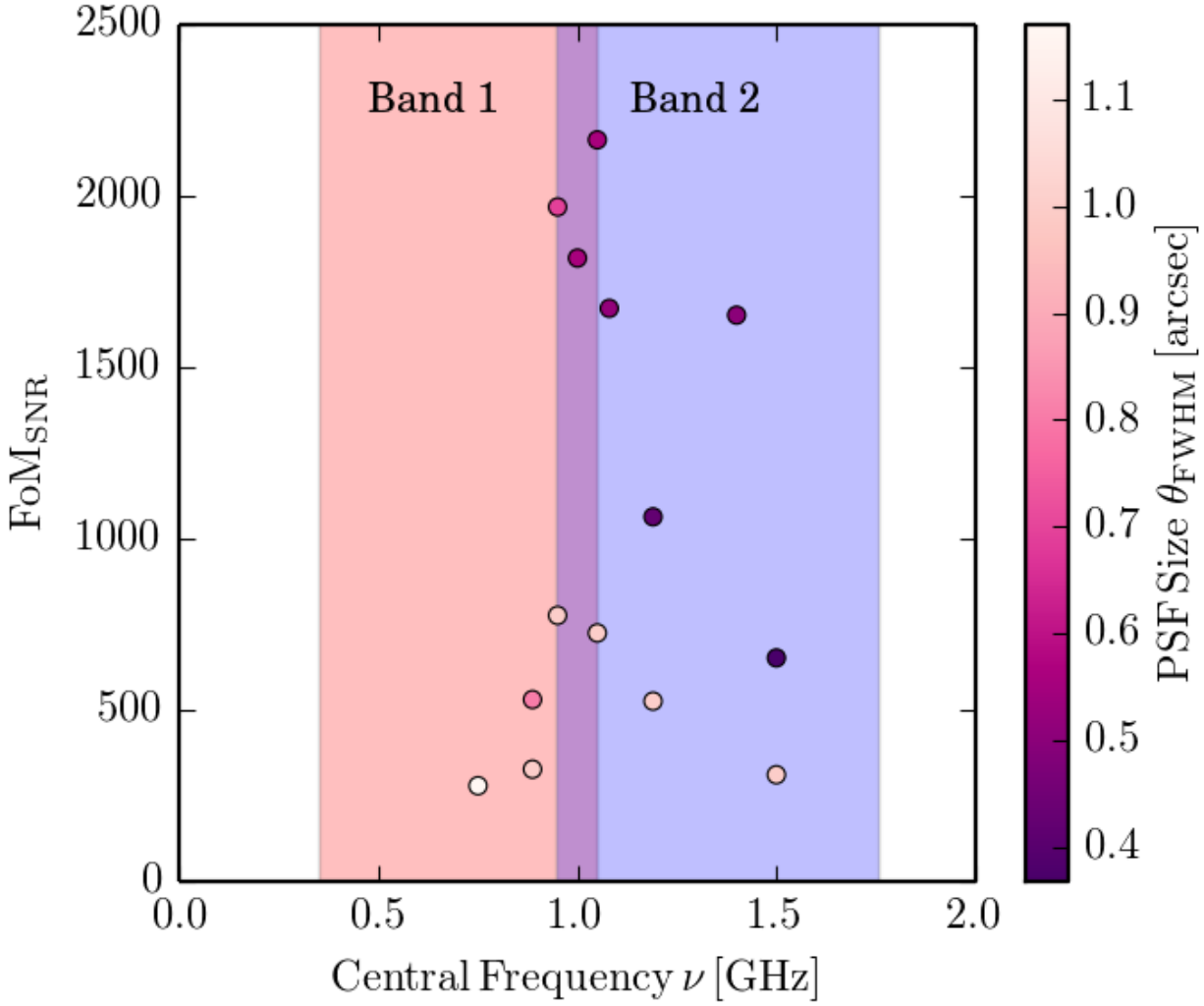

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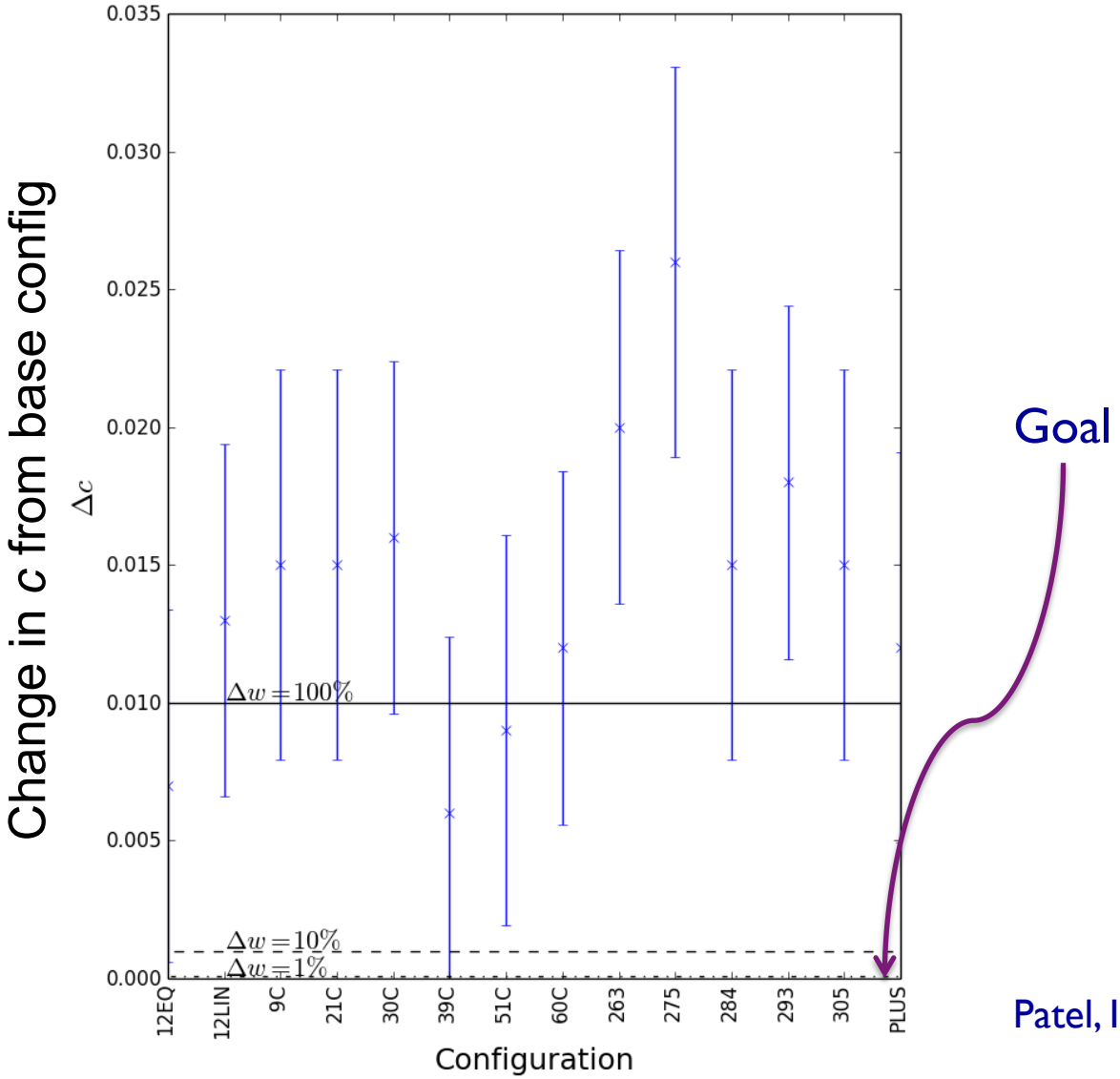
Radio Shape Measurement
Effect of Antenna Configuration



Patel, IH et al 2015

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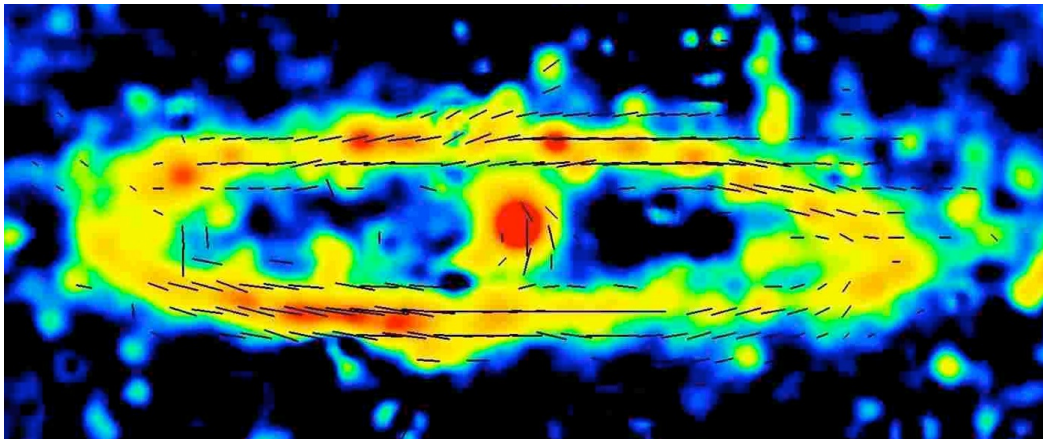
Extra WL Information from Radio Polarisation

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



(Berkhuijsen, Beck, Hoernes 2003)