Slides available at http://bit.ly/ianh_skao23

Radio Weak Lensing

Ian Harrison

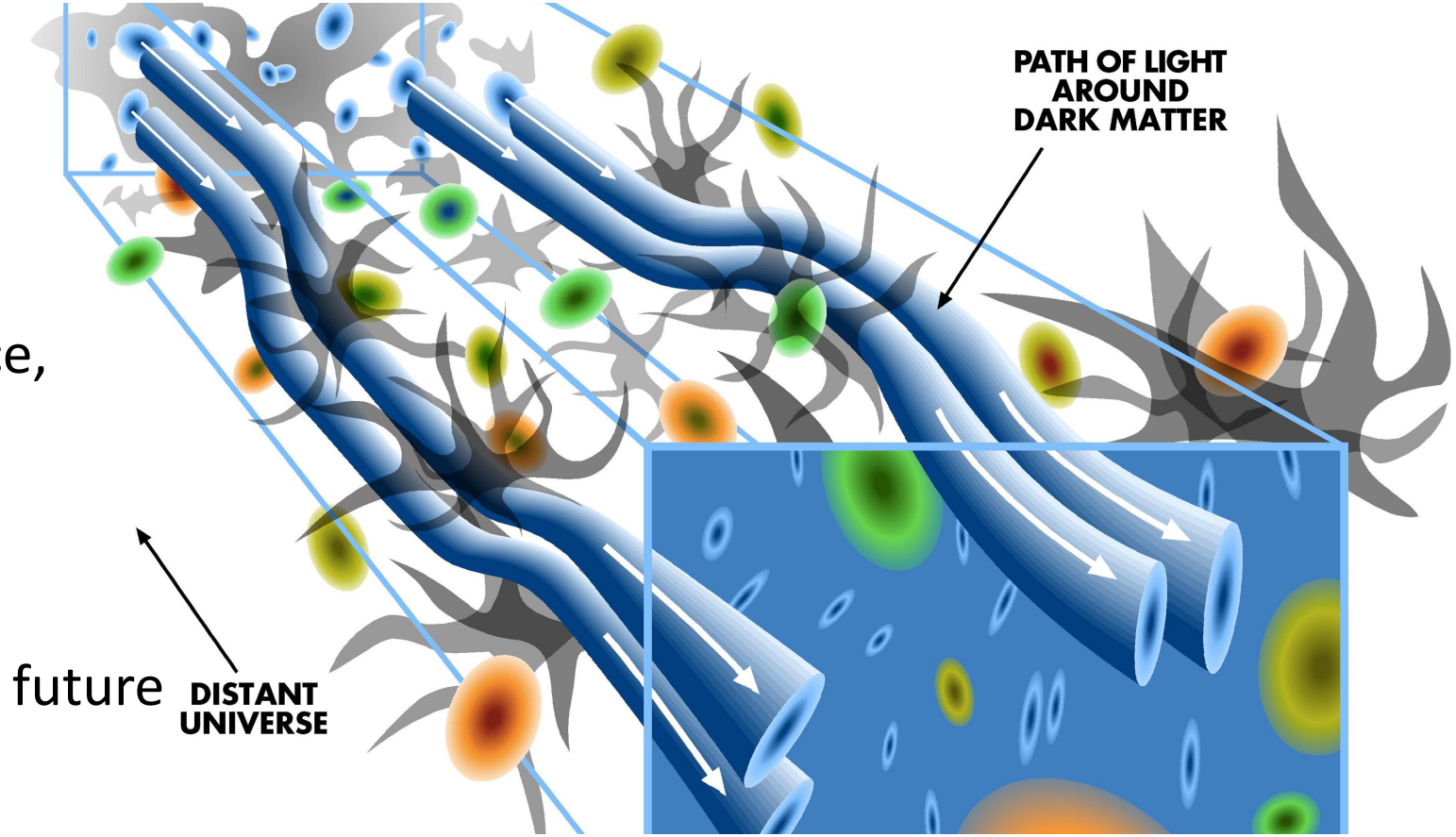
SKAO Cosmology SWG Meeting

17 January 2023

Slides at:
bit.ly/ianh_skao23

Radio Weak Lensing
Weak Lensing Cosmology

- Requires shape measurement of ~billions of high redshift (z~1) galaxies
- Excellent probe of abundance, growth of cosmic structures
  - Dark matter
  - Dark energy
- Motivates many current and future large optical/near-IR surveys

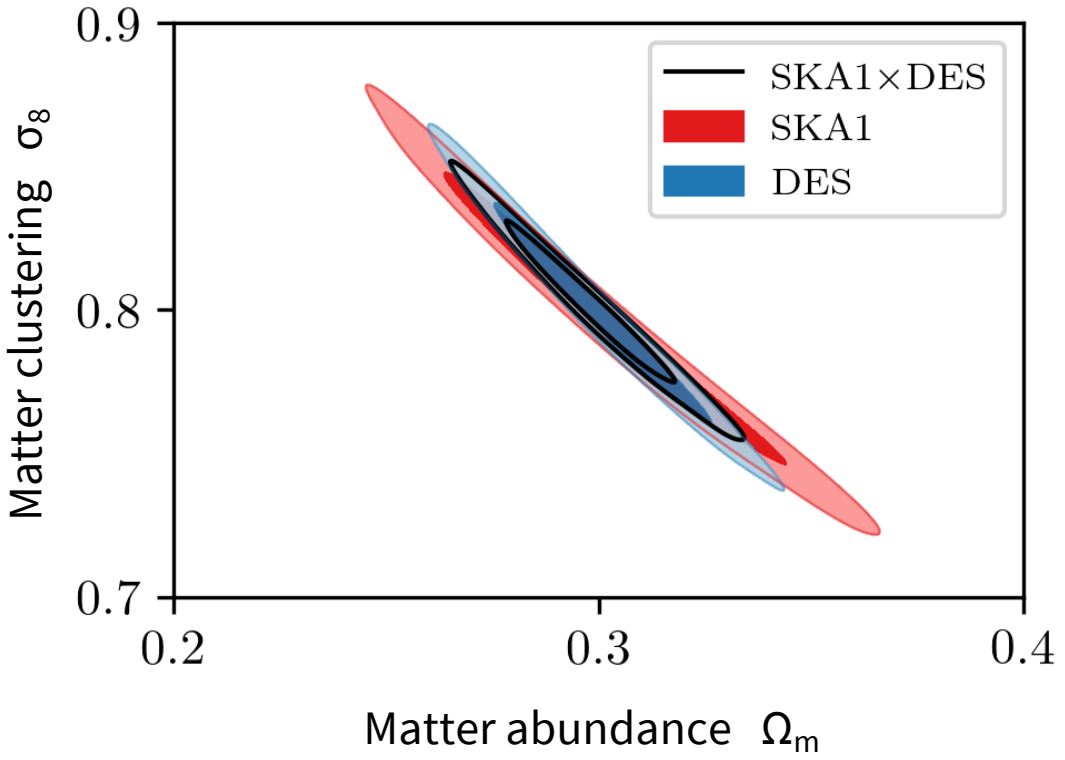


Wittman et al (2000)

Radio Weak Lensing
Weak Lensing Cosmology with SKAO

- Forecasts from 2016 still mostly valid
- Notional 5,000 deg^2 survey with SKAO-MID Band 2 at 1 arcsec PSF ('Medium-deep')
  - ~2 resolved star-forming galaxies arcmin^{-2}
- SKAO alone competitive with completed Dark Energy Survey (DES)
- Cross-correlation (only using $C_l^{\text{Rad.-Opt.}}$) of SKAO x DES weak lensing has:

same statistical power
but
removes systematics

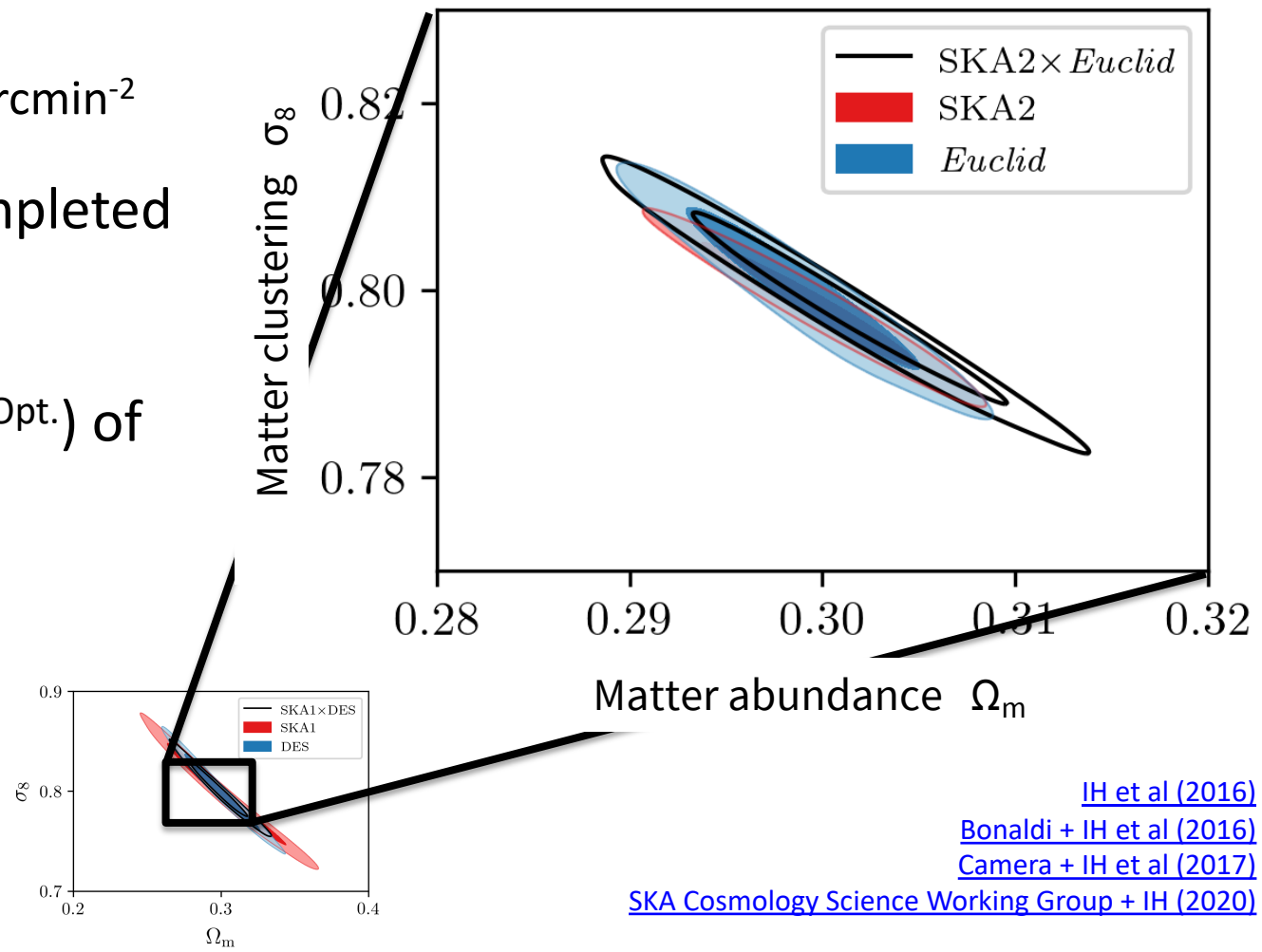


IH et al (2016)
Bonaldi + IH et al (2016)
Camera + IH et al (2017)
SKA Cosmology Science Working Group + IH (2020)

Radio Weak Lensing
Weak Lensing Cosmology with SKAO

- Notional 30,000 deg^2 survey with SKAO2-MID Band 2 at 1 arcsec PSF
  - ~10 resolved star-forming galaxies arcmin^{-2}
- SKAO2 alone competitive with completed *Euclid* or VRO's LSST
- Cross-correlation (only using $C_l^{\text{Rad.-Opt.}}$) of SKAO2 x *Euclid* weak lensing has:

same statistical power
but
removes systematics



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Radio Weak Lensing
Weak Lensing Cosmology with SKAO

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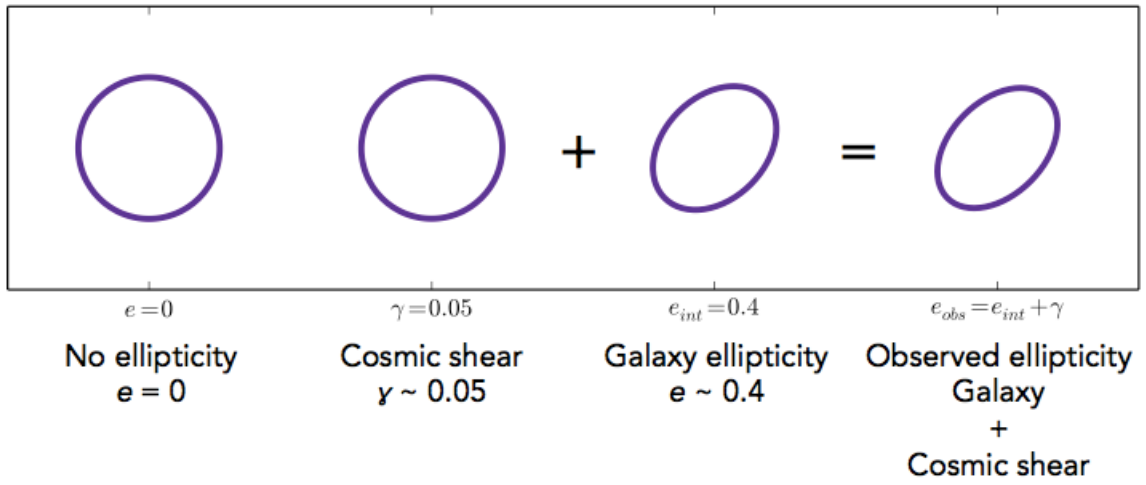
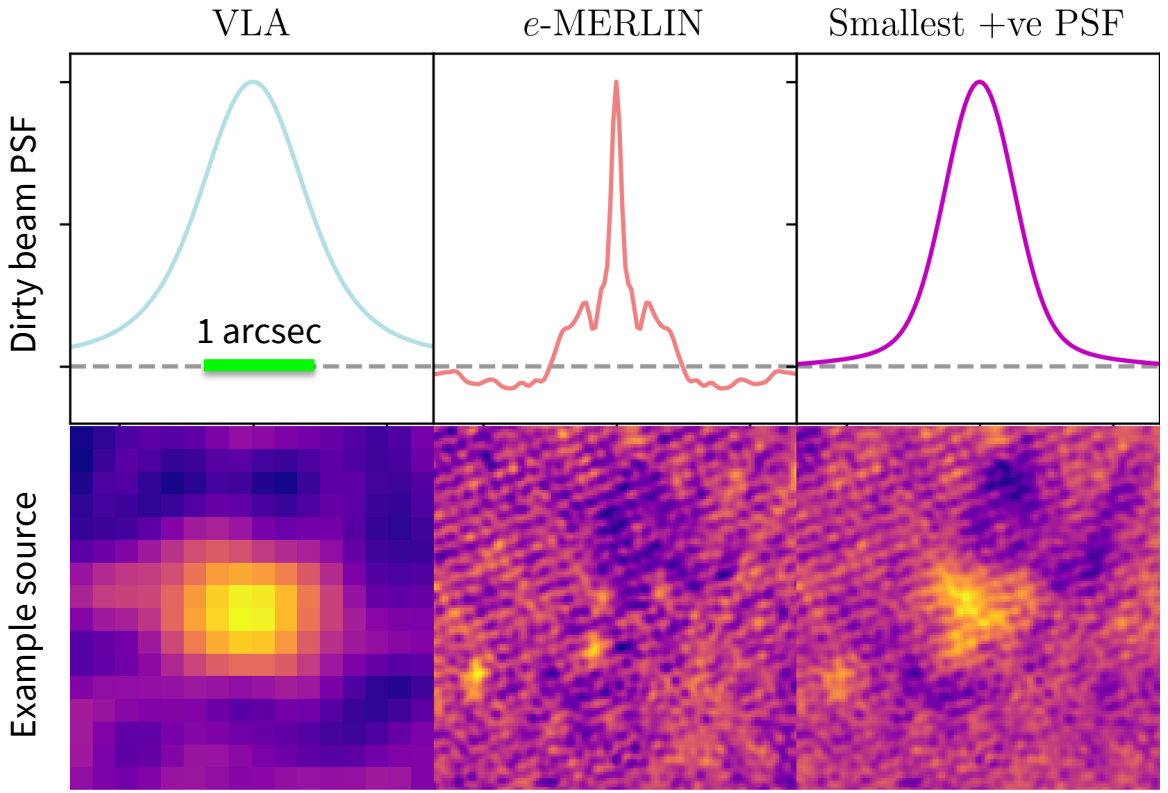
- Weak lensing has high requirements on precision of morphological measurement
  - Many astrophysical and instrumental effects can mimic the signal
  - Cross-correlations can remove telescope/wavelength-dependent systematics





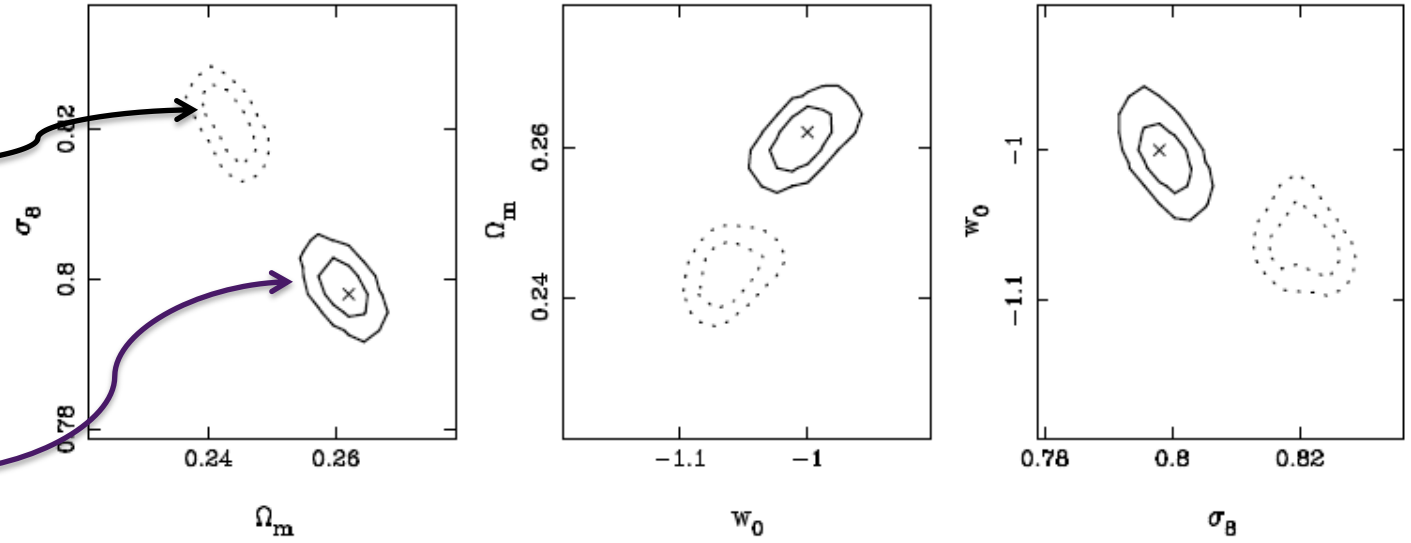
IH et al (2020)

Radio Weak Lensing
Weak Lensing Cosmology with SKAO

- Extra information from radio provides information on astrophysical systematics
  - Polarisation e.g. Brown & Battye (2011)
  - Rotation velocities e.g. Huff et al (2015)

Standard analysis biased by intrinsic alignment contamination

Contamination removed using new technique with no degradation in constraining power

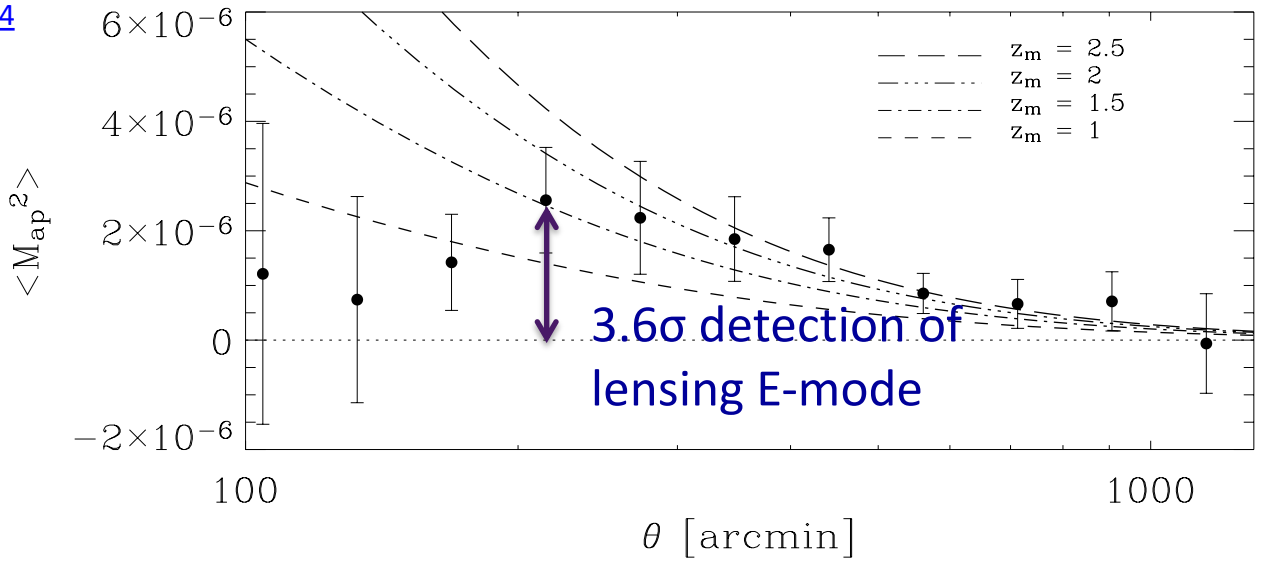


Brown & Battye (2011)

Radio Weak Lensing Work to Date

Slides available at http://bit.ly/ianh_skao23

- **Tentative (3.6σ detection) in archival VLA FIRST**
  - Very non-WL survey! Chang Refregier & Helfand 2004
- Unsuccessful measurements in too-noisy data
  - MERLIN+VLA Patel et al 2010
  - SuperCLASS DR1 IH et al (2020)
- Successful detections of radio-optical correlations using JVLA data
  - COSMOS shape correlation Hillier et al 2019
  - FIRST galaxy-galaxy lensing Demetroullas et al 2018



Chang Refregier & Helfand 2004

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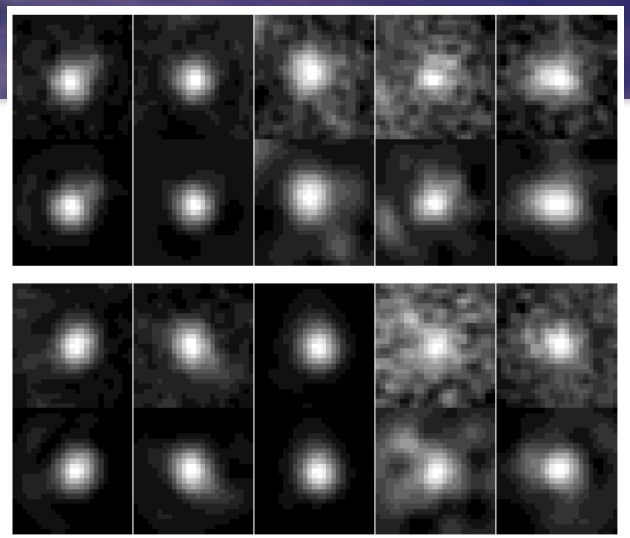
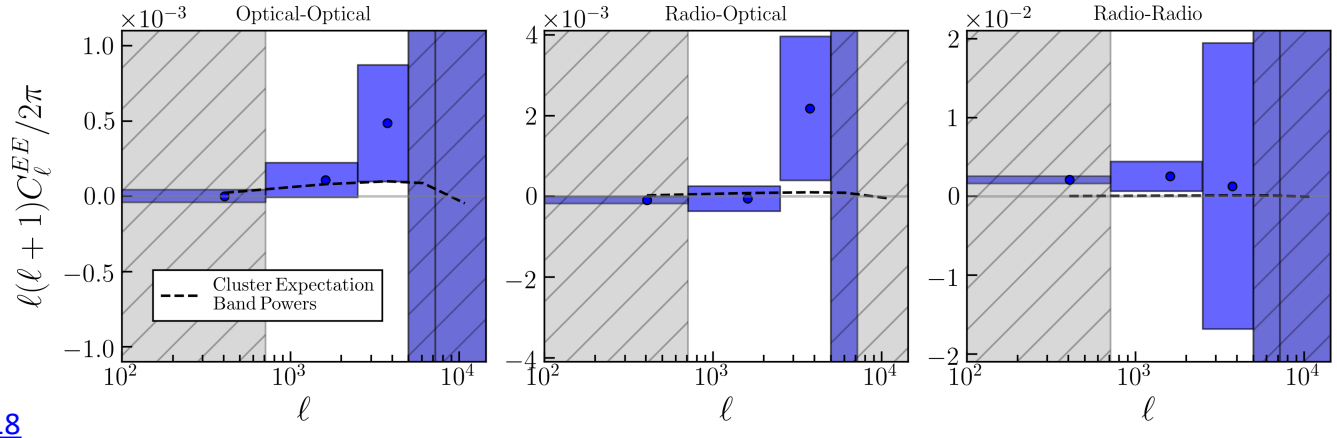


Patel et al 2010



IH et al (2020)

Radio Weak Lensing Work to Date

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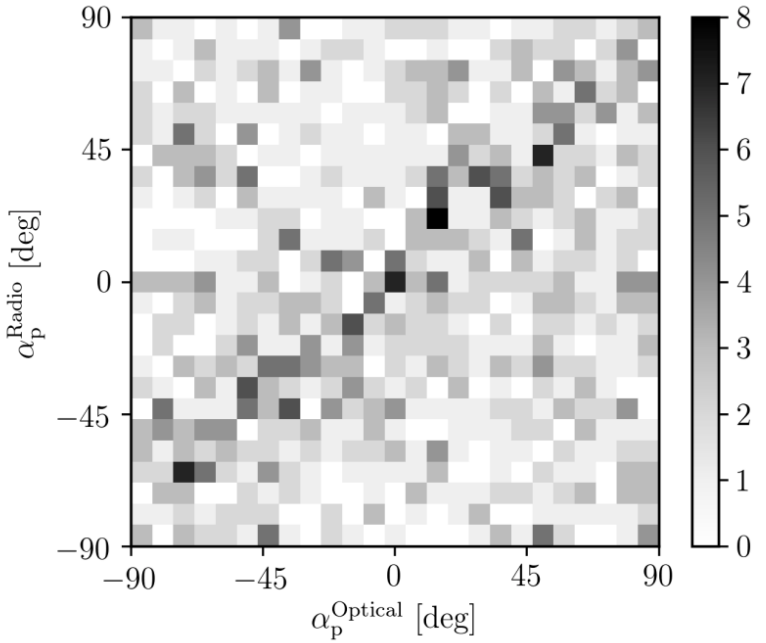
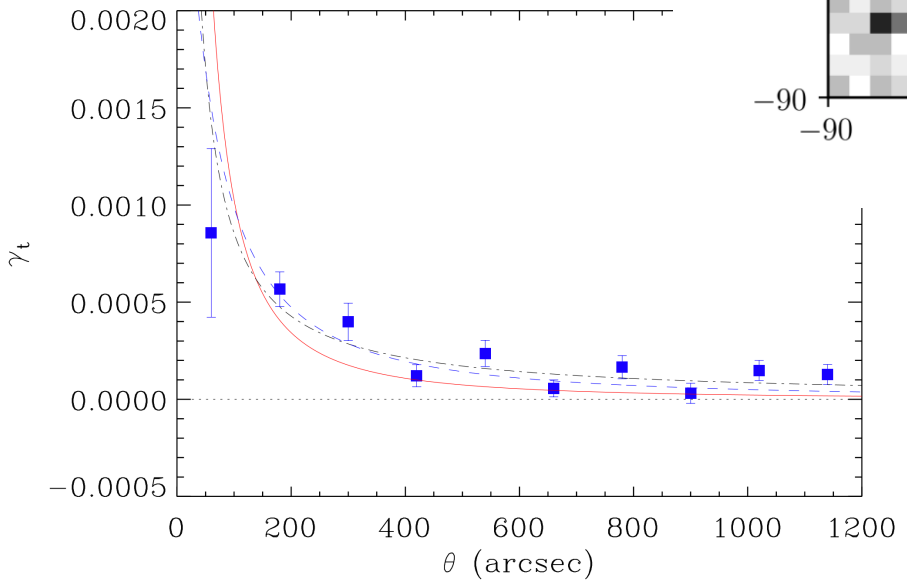


Hillier et al 2019



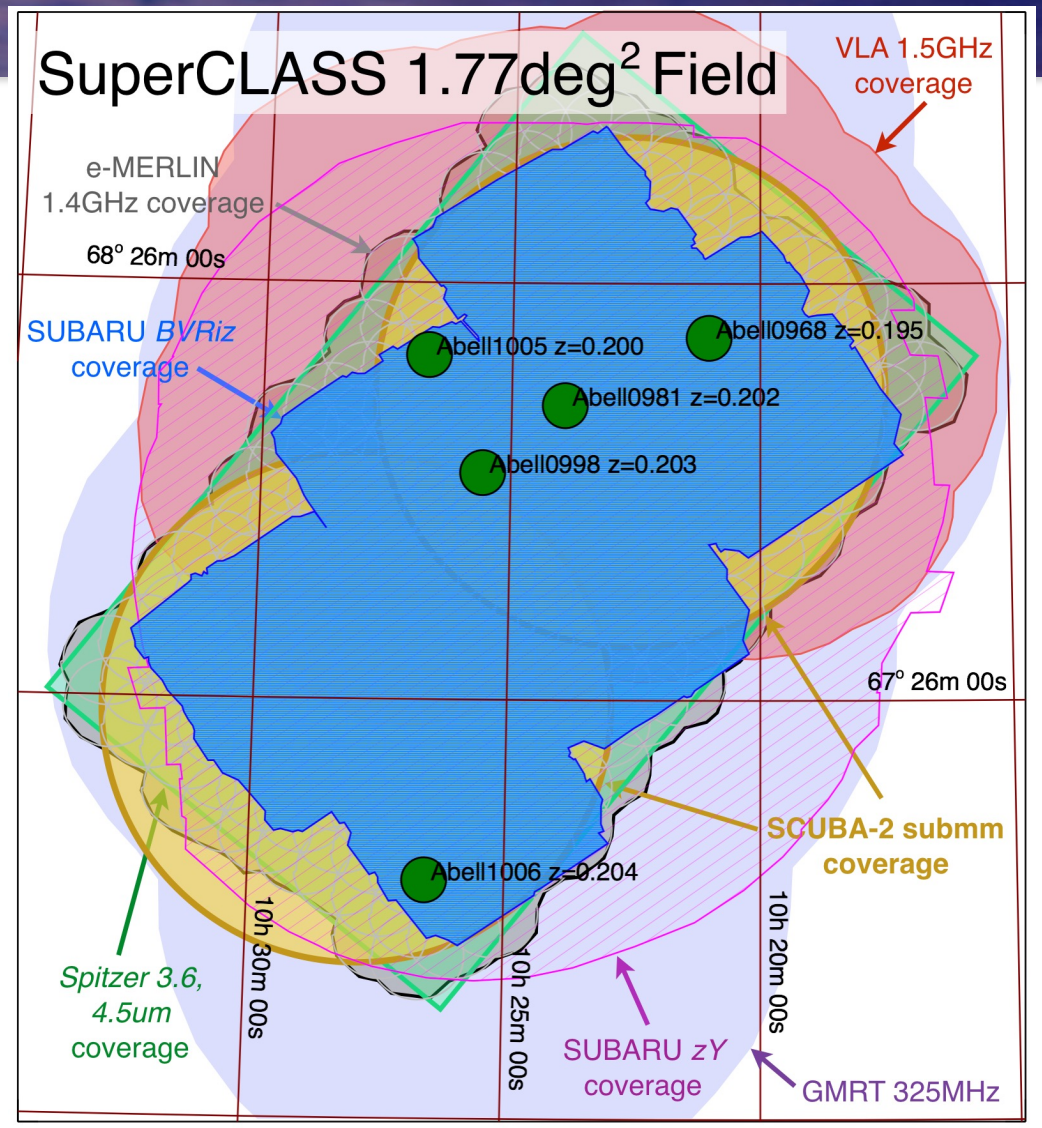
Demetroullas et al 2018

The SuperCLASS Survey

Introduction

Slides available at http://bit.ly/ianh_skao23

- "SuperCLuster Assisted Shear Survey"
- Multi-wavelength survey
  - Radio data for weak lensing shear:
    - e-MERLIN (1.4 GHz)
    - JVLA (1.5 GHz)
  - Optical shear, photo-*z*s:
    - Subaru (BVRIz)
    - CFHT (near-IR)
  - Source classification,
    RM-synthesis (polarisation calibration):
    - GMRT (325 MHz)
    - LOFAR (150 MHz)
  - Source classification:
    - Spitzer (3.6, 4.5 um)
    - SCUBA-2 (submm)
  - AMI (15 GHz)

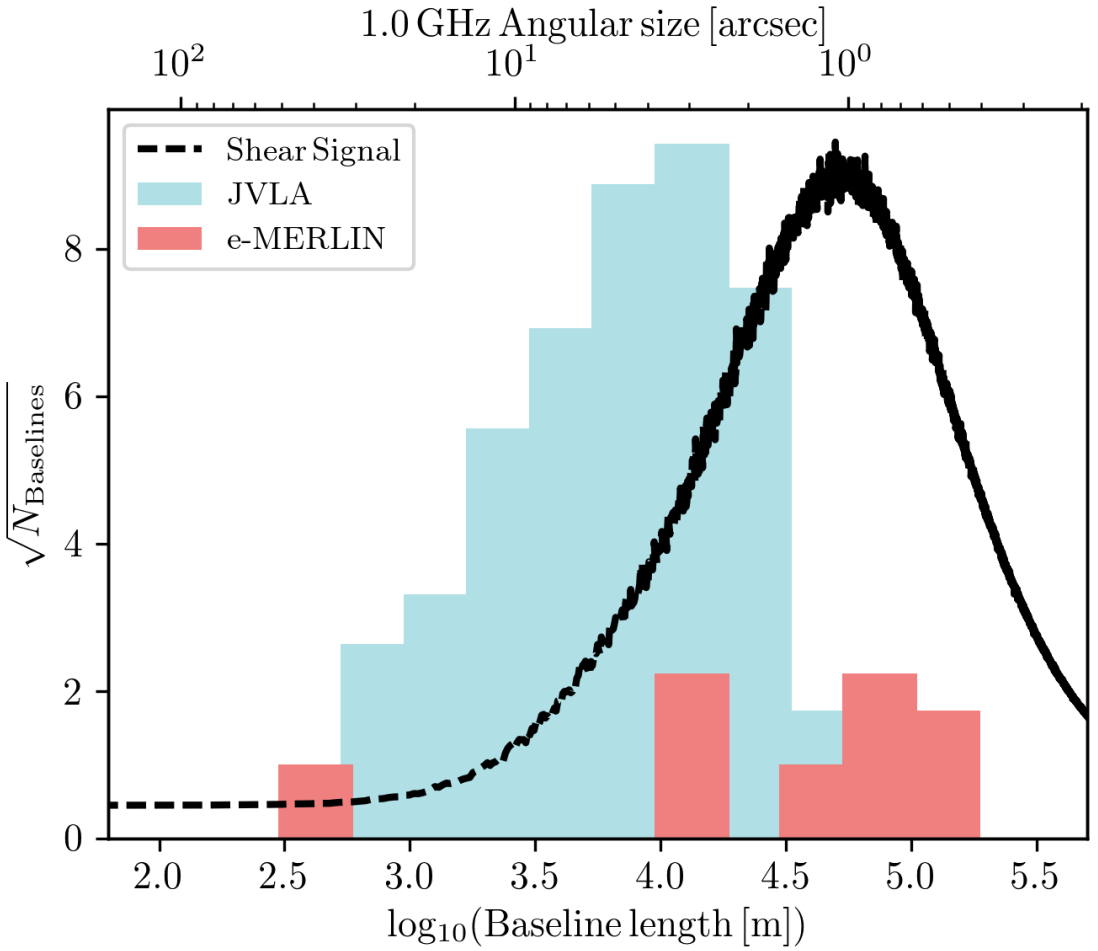


Caitlin Casey

The SuperCLASS Survey

Introduction

- *e*-MERLIN Legacy survey
  - Only interferometer pre-SKAO with ~100km baselines at ~1GHz frequencies
- Observe field at same frequencies with JVLA
  - Complementary baseline lengths
  - Cover relevant parts of the Fourier plane for weak lensing shear signal
- Ideally, would combine visibilities and then analyse and/or image



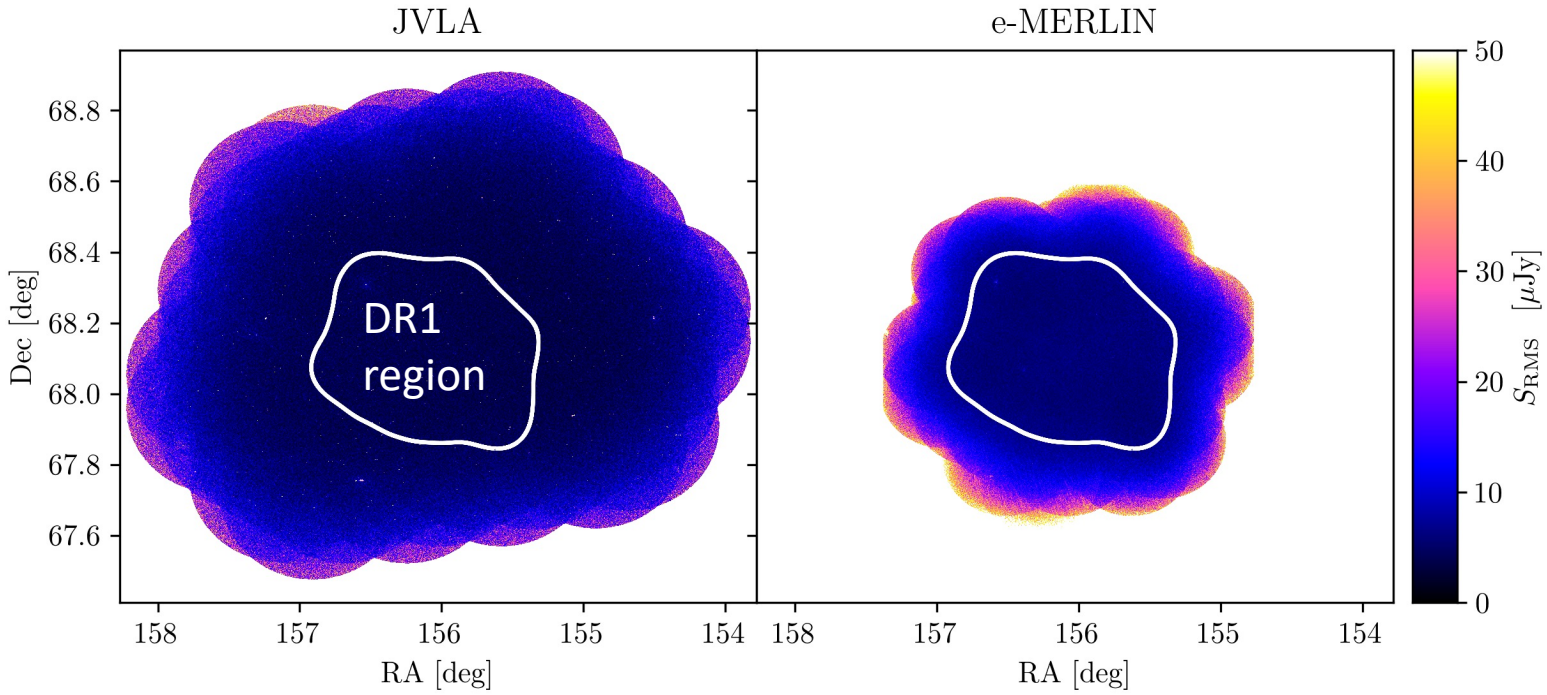
Battye + IH et al (2020)

The SuperCLASS Survey

DR1 Results

Slides available at http://bit.ly/ianh_skao23

- Data taken in 2014-2017 results in 2020 DR1 of 0.26 deg^2
- ~12 uJy/beam depth in both *e*-MERLIN (~400 hours), JVLA (~24 hours) separate images



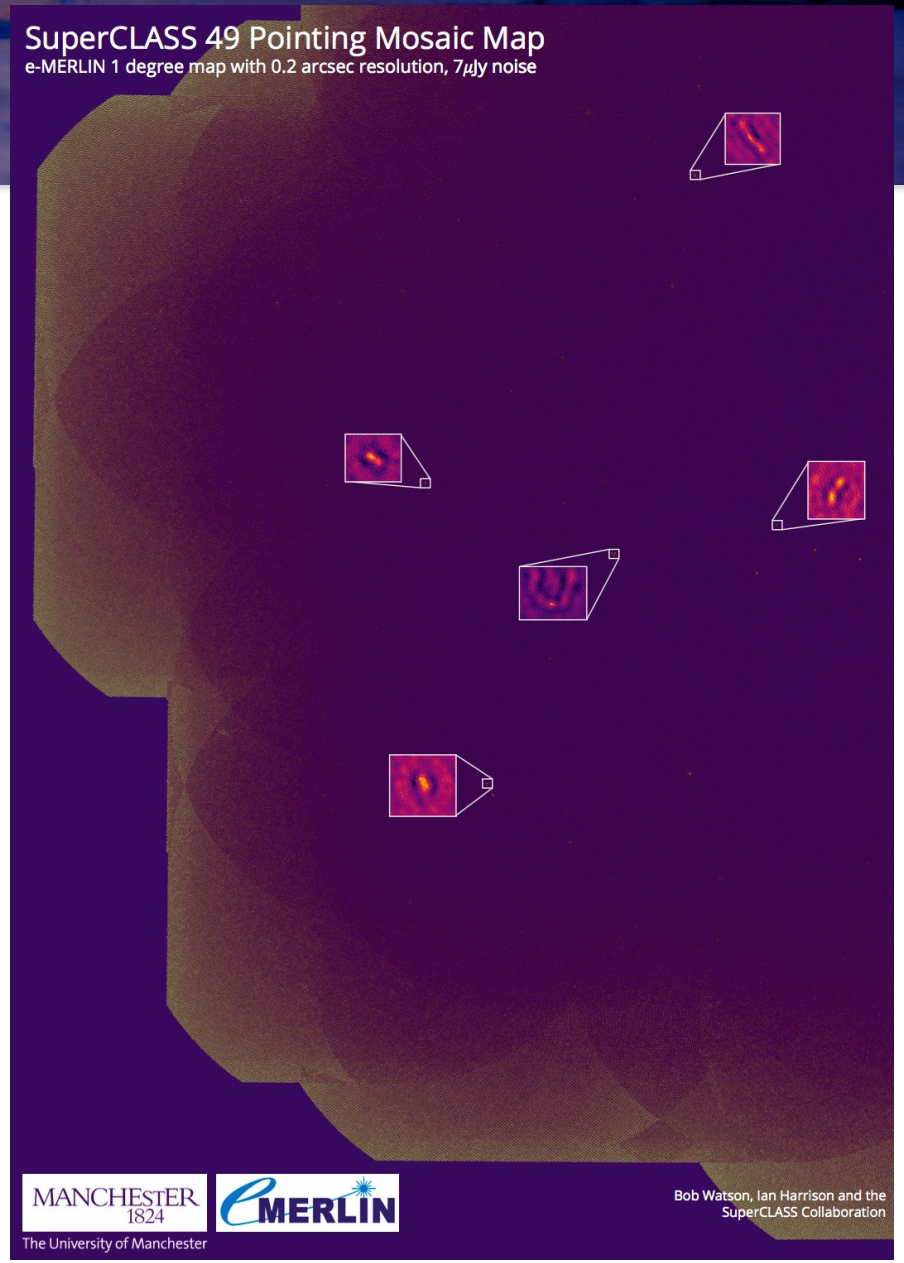
Battye + IH et al (2020)

The SuperCLASS Survey

DR1 Results

Slides available at http://bit.ly/ianh_skao23

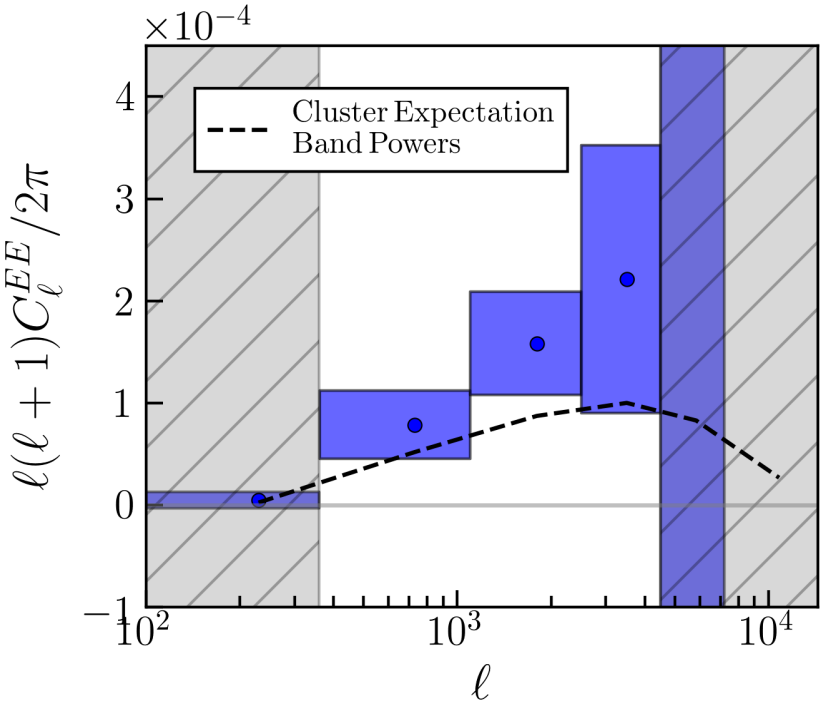
- Over the past decade created our own:
  - Source population model (Bonaldi, IH)
  - RFI mitigation (RA Watson)
  - *e*-MERLIN pipeline (RA Watson, *e*-MERLIN support staff)
  - JVLA imaging (Hales, RA Watson, AP Thomson)
  - Joint imaging (AP Thomson, RA Watson, IH)
  - End-to-end simulation pipeline (IH)
  - Supercluster N-body sims (Peters, Kay)
  - Shape measurement algorithm (IH)
  - Visibility-plane data analysis (Tunbridge, DB Thomas, IH)
  - Source classification tool (IH)
  - +more

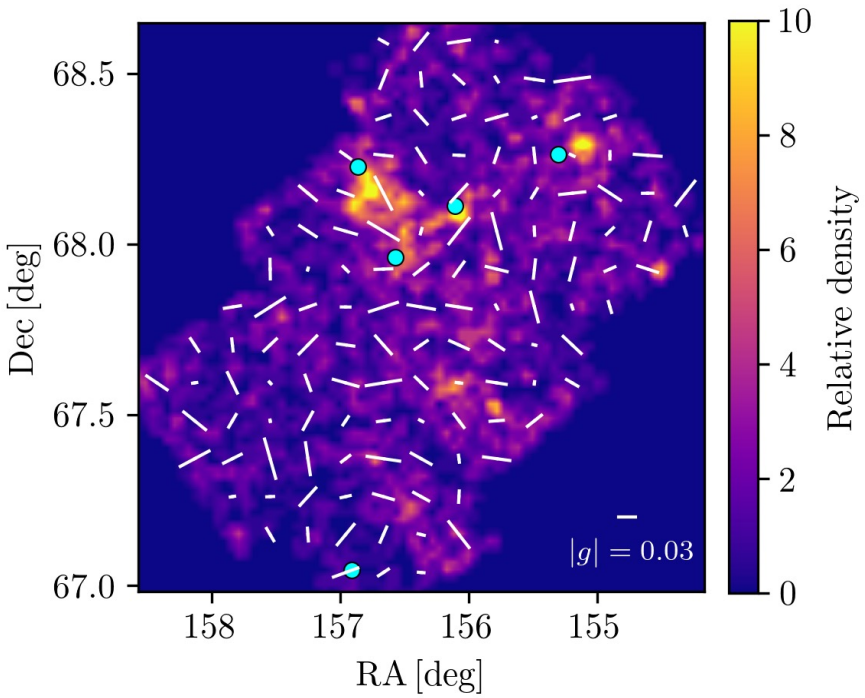


The SuperCLASS Survey

DR1 Results

- Optical data allows detection of clusters and weak lensing signal





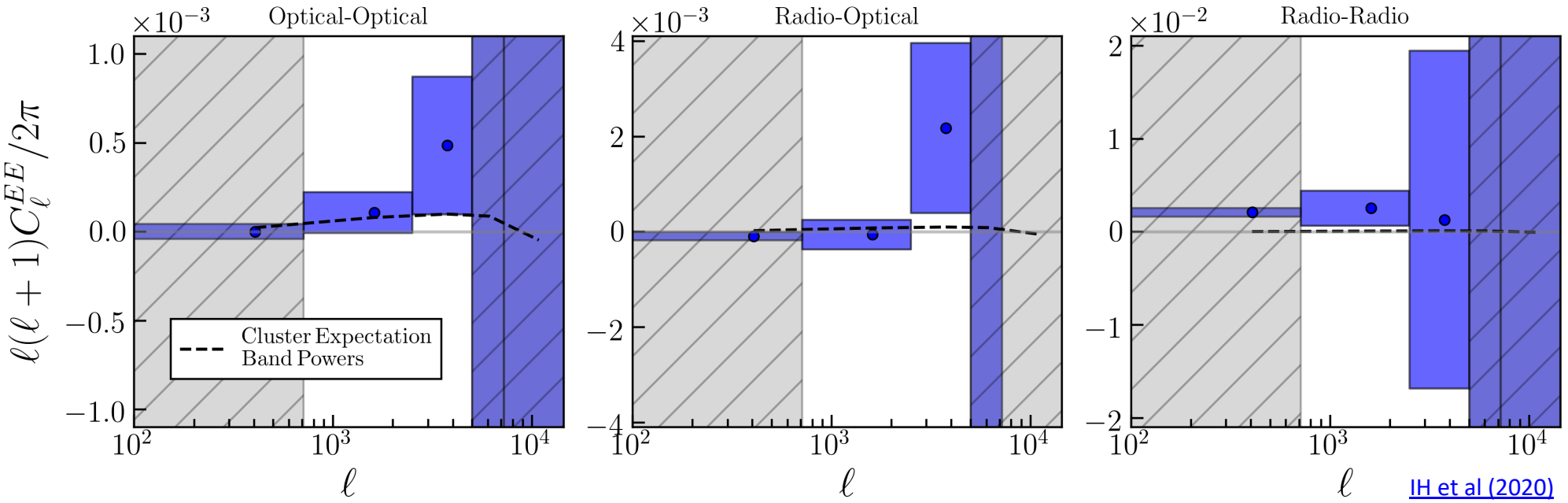
IH et al (2020)

The SuperCLASS Survey

DR1 Results

Slides available at http://bit.ly/ianh_skao23

- Radio shapes for 440 sources from JVLA data in the DR1 region (~0.47 arcmin^{-2})
  - Calibrated ‘SuperCALS’ image plane shape measurements
- …too much shape noise for detection of radio or radio-optical shear power spectrum

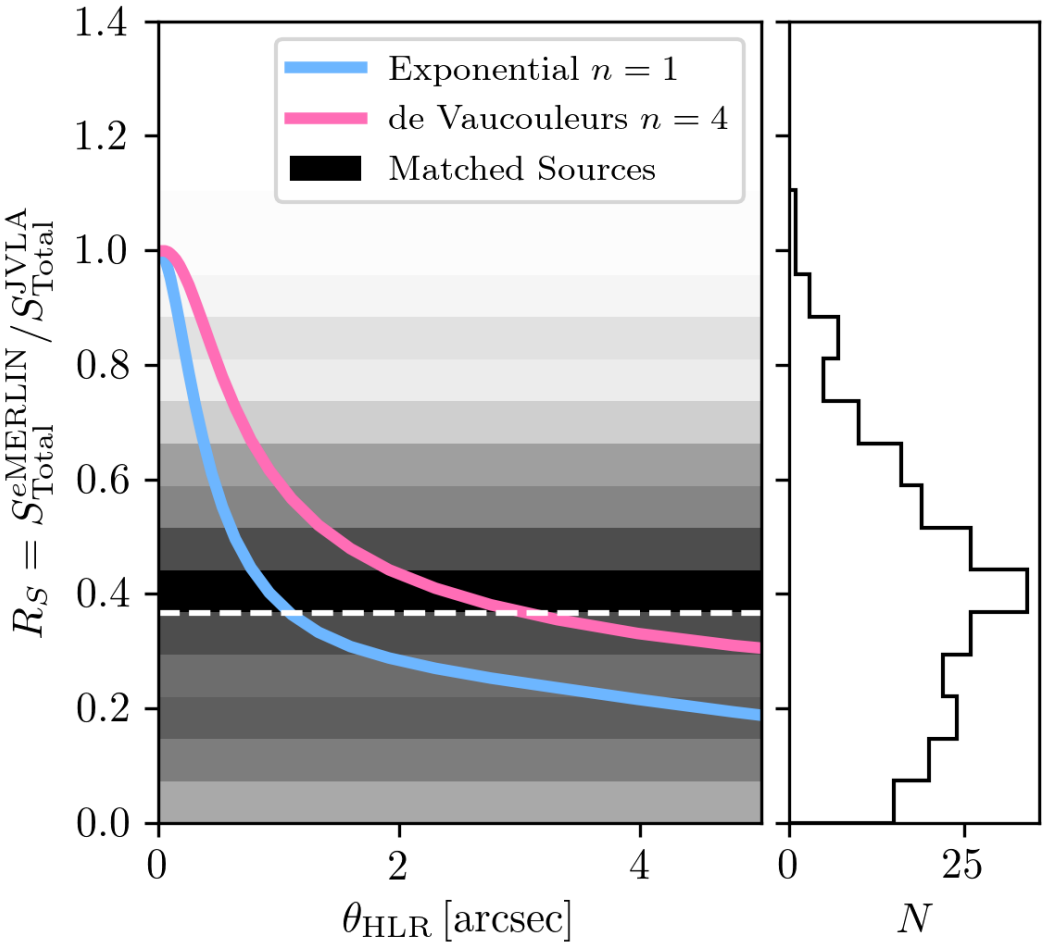


IH et al (2020)

The SuperCLASS Survey

DR1 Results

- Only used JVLA data for shape measurement
- Methods for combination with *e*-MERLIN not satisfactory
- *e*-MERLIN Sersic profile sensitivity relatively poor even when point source sensitivity good
- Degeneracy between source radius and Sersic index
  - Not enough information for good fitting of elliptical profiles



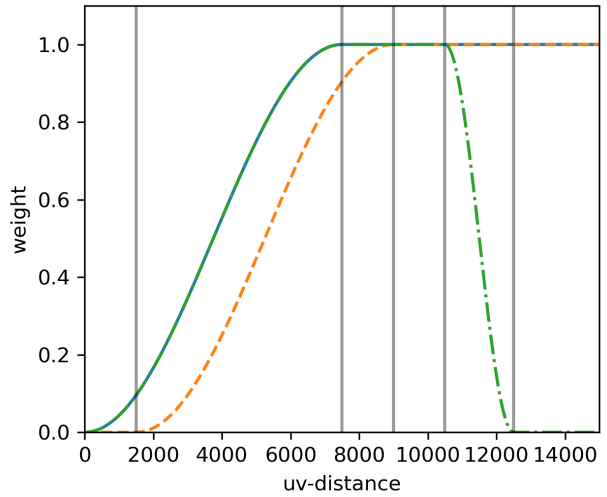
Battye + IH et al (2020)

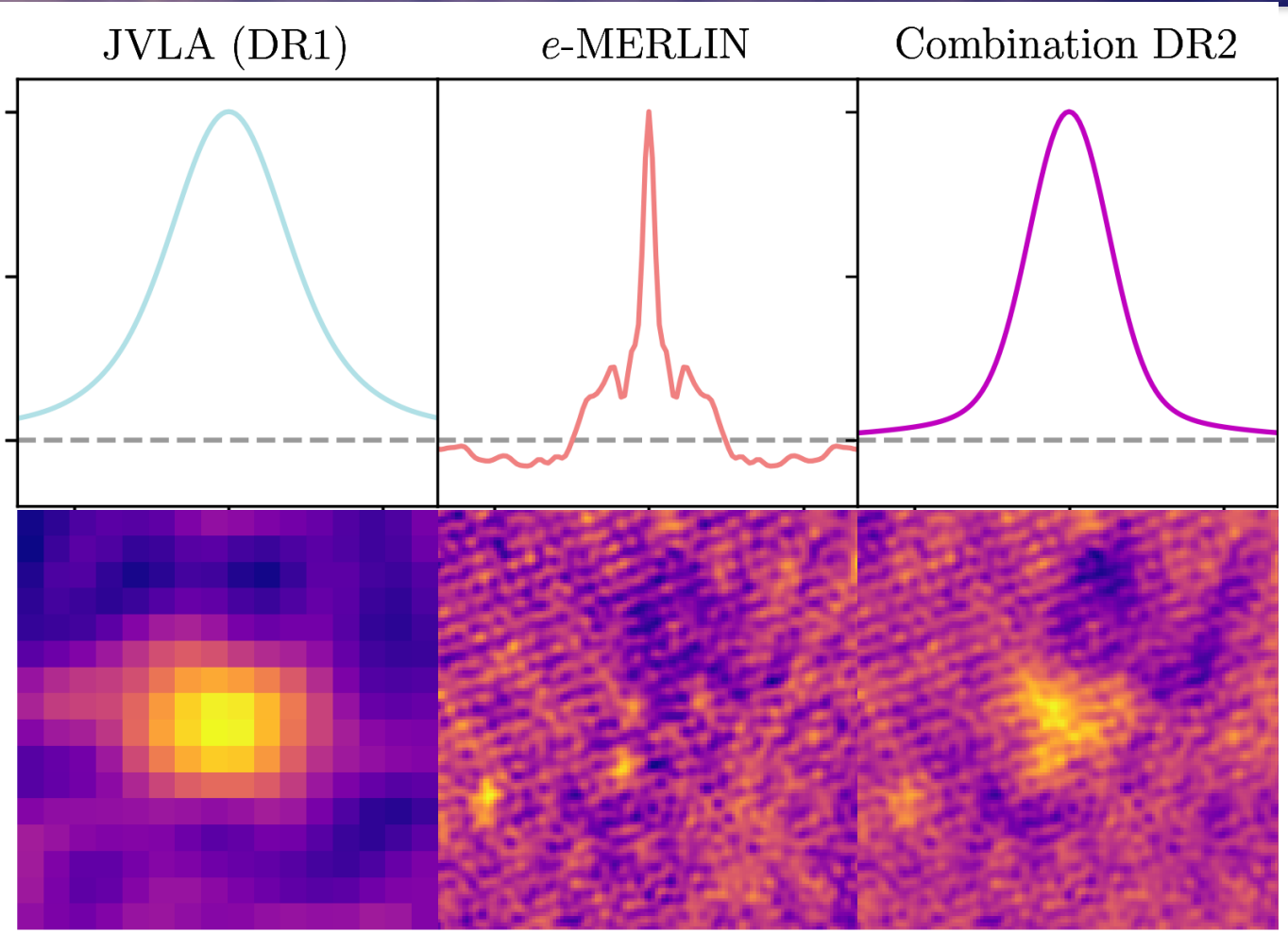
The SuperCLASS Survey

Progress on DR2

Slides available at http://bit.ly/ianh_skao23

- Will address this with DR2 (well underway)
- At end of DR1 papers explored optimal Tukey weighting between JVLA and e-MERLIN
- Minimise PSF size whilst staying strictly +ve
- Create images combining multiple .ms with Tukey weighting using wsclean



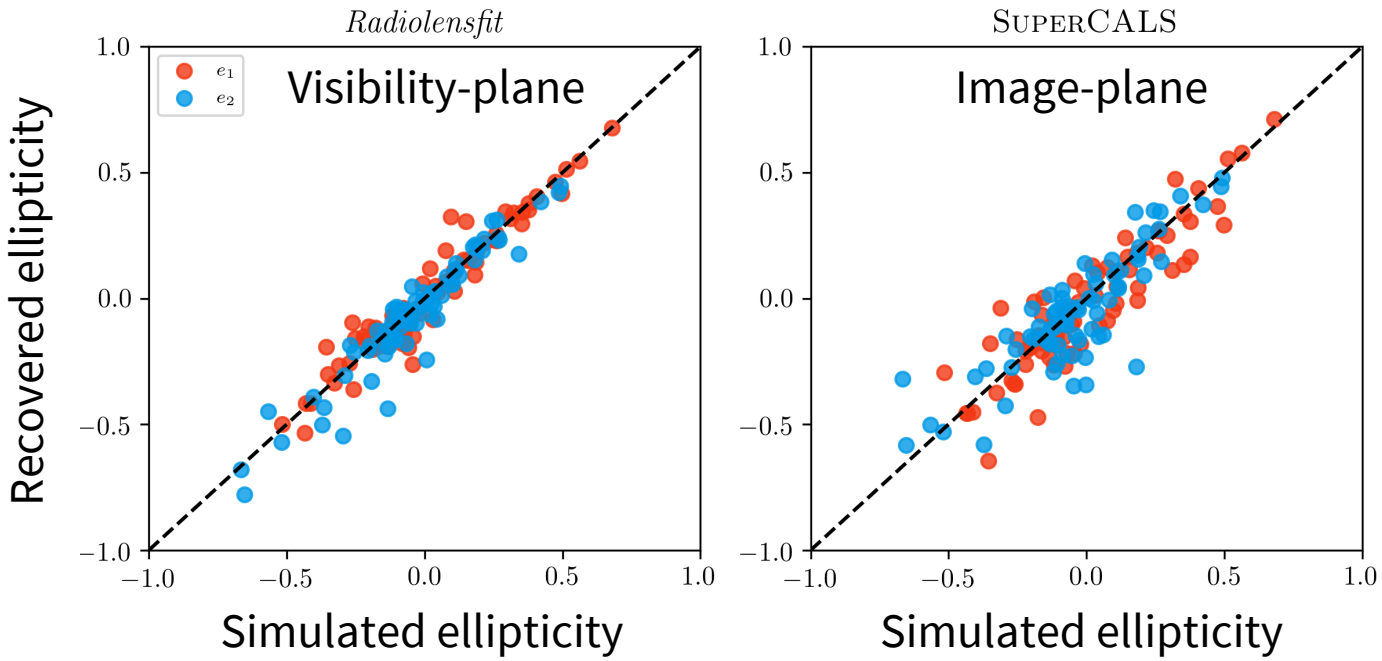


IH et al (2020)

The SuperCLASS Survey

Progress on DR2

- As well as improved data, improved methods
- Will also add visibility-plane measured shapes from *Radiolensfit*
  - Faceting to reduce necessary number of simultaneous source fits
    Rivi & Miller (2018)
  - *lensfit*-style marginalisation over nuisance parameters
- Have verified gives consistent results in simulations to calibrated image-plane method used in DR1

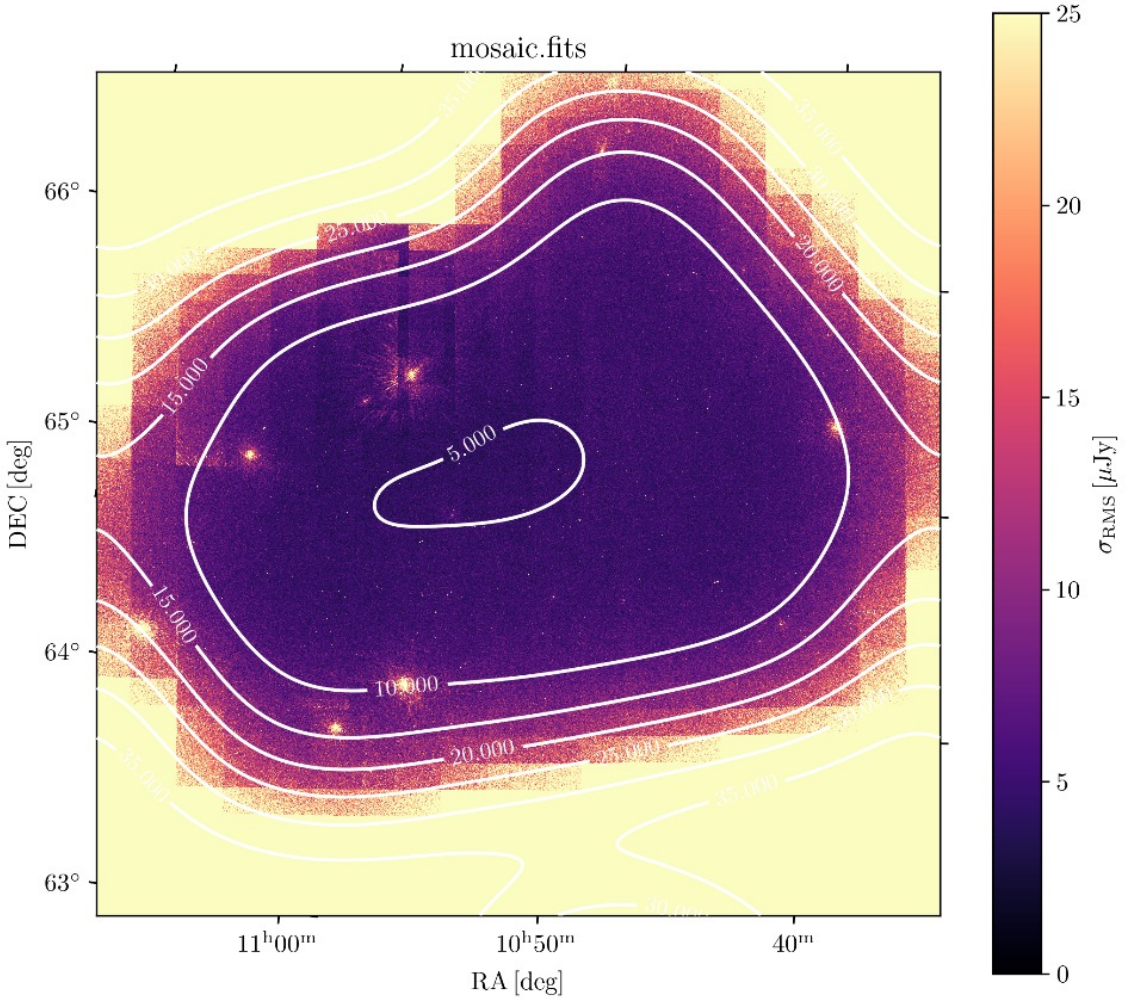


The SuperCLASS Survey

Progress on DR2

Slides available at http://bit.ly/ianh_skao23

- Combined imaging ~~complete~~ almost complete
  - Further peeling required on each individual ms before combination
- Running further simulations to compare visibility and image-plane shape measurement with final PSF



thanks to Bob Watson!

The SuperCLASS Survey

Progress on DR2

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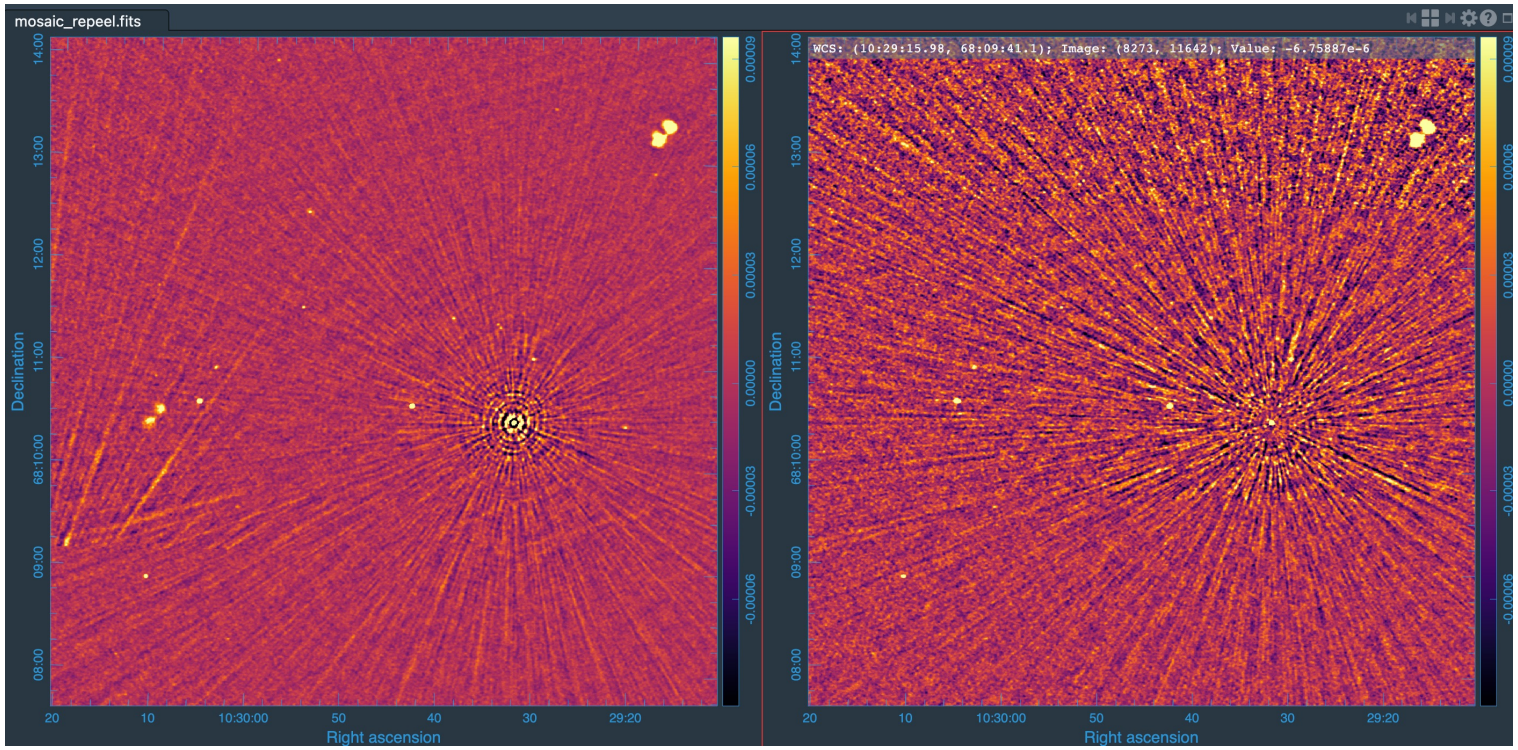
With extra peeling

First image



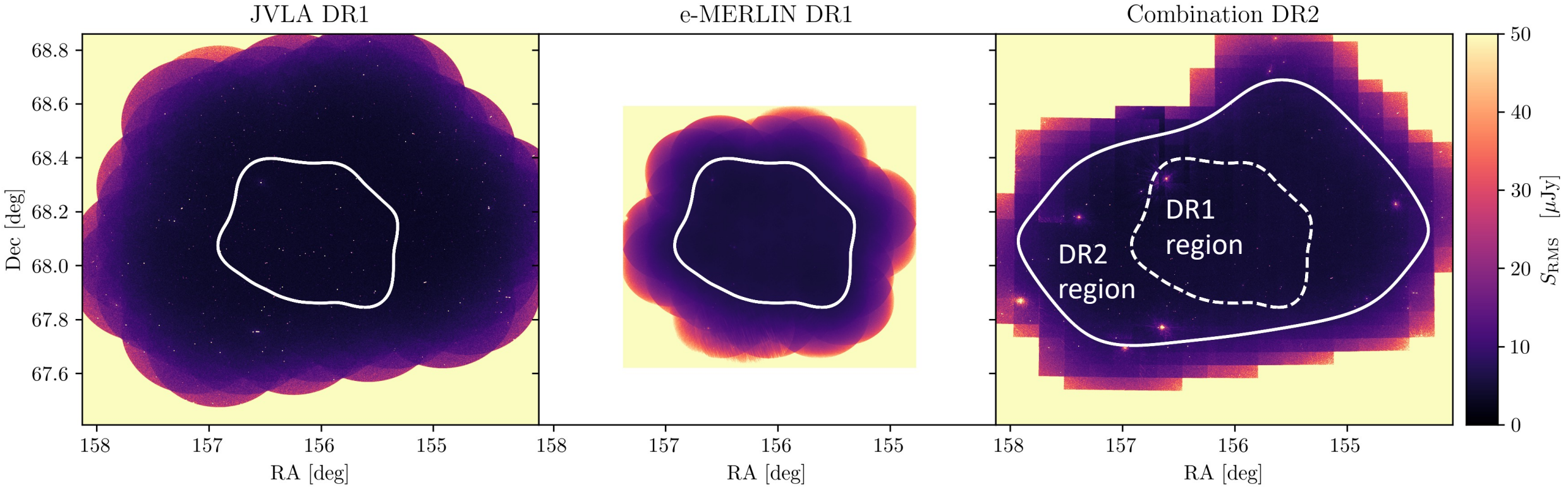
thanks to Bob Watson!

The SuperCLASS Survey

Progress on DR2

Slides available at http://bit.ly/ianh_skao23

- DR2 area will extend to (at least) 0.62 deg^2
- Number density (probably at least) 0.85 gal/arcmin^2
  - Prospects for >1 gal/arcmin^2



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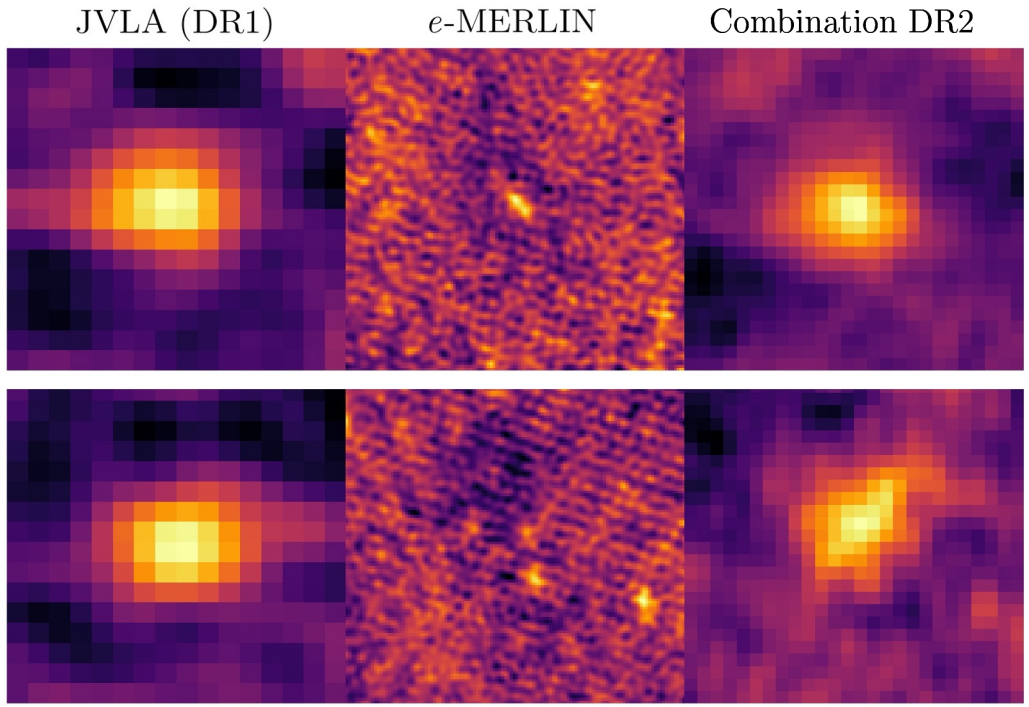
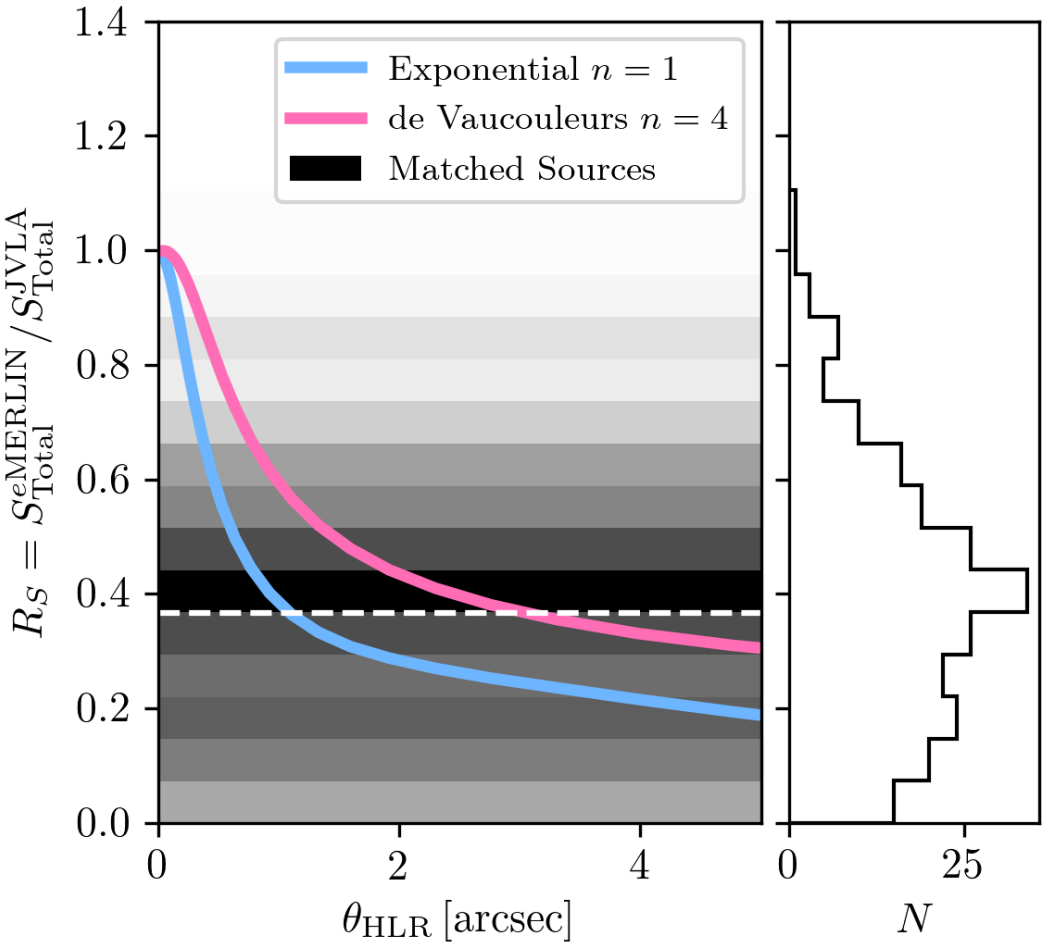


Radio Weak Lensing

Ongoing projects

- SuperCLASS DR1 showed importance of a good model prior for brightness profiles of star-forming galaxies
  - Sizes
  - Sersic indices
- Construct deep training sample with as much *uv* coverage as possible
- Cardiff MPhys project student working on which combinations work best
  - Simulate sources in uv plane
  - Run MCMCs with different combinations of uv coverage

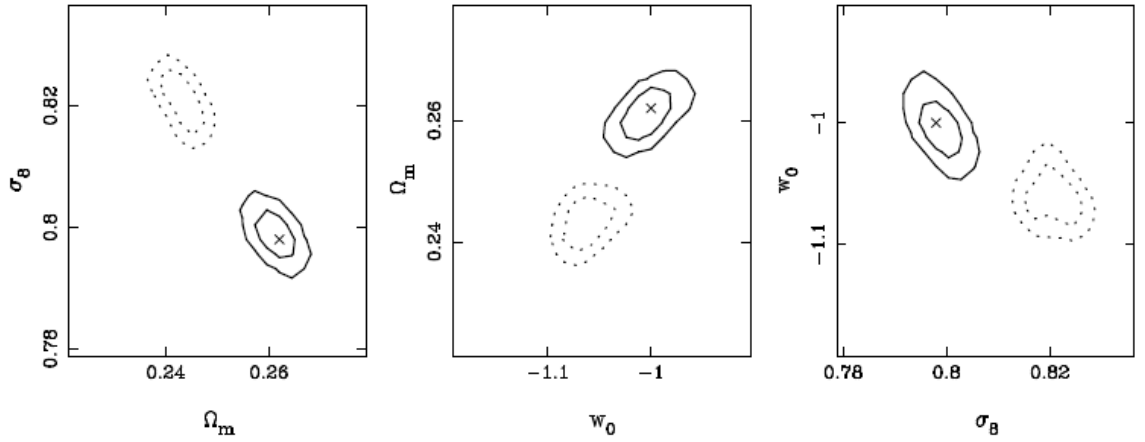


Radio Weak Lensing

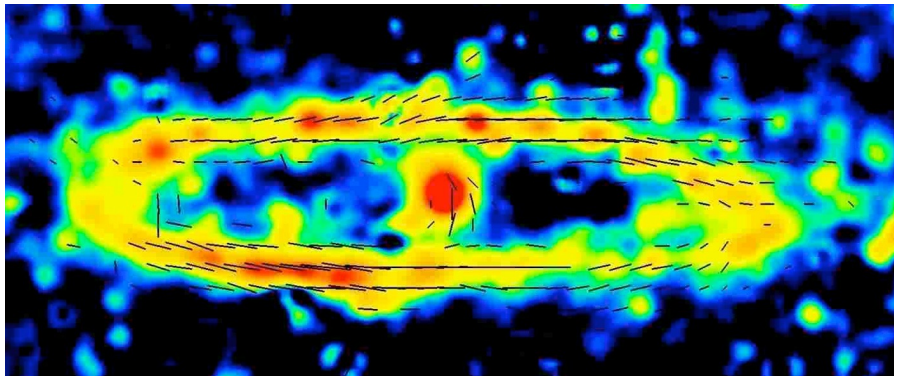
Ongoing projects

- SuperCLASS also always intended to look at polarisation as a tracer of source alignments
  - Galaxy Intrinsic Alignments
  - Cosmic shear signal

e.g. Brown & Battye (2011), Whittaker et al (2015)



- Cardiff MSc project student will work on this starting soon (thanks to Illaria Ruffa for assistance)
  - JVLA polarisation image
  - Stretch goal: also look at LOFAR International Baseline data



Berkhuijsen, Beck, Hoernes (2003)

Radio Weak Lensing

Ongoing projects

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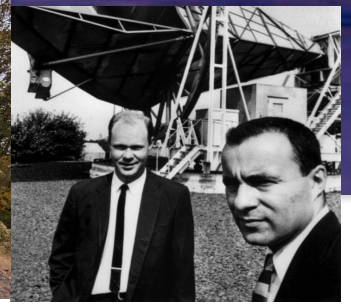
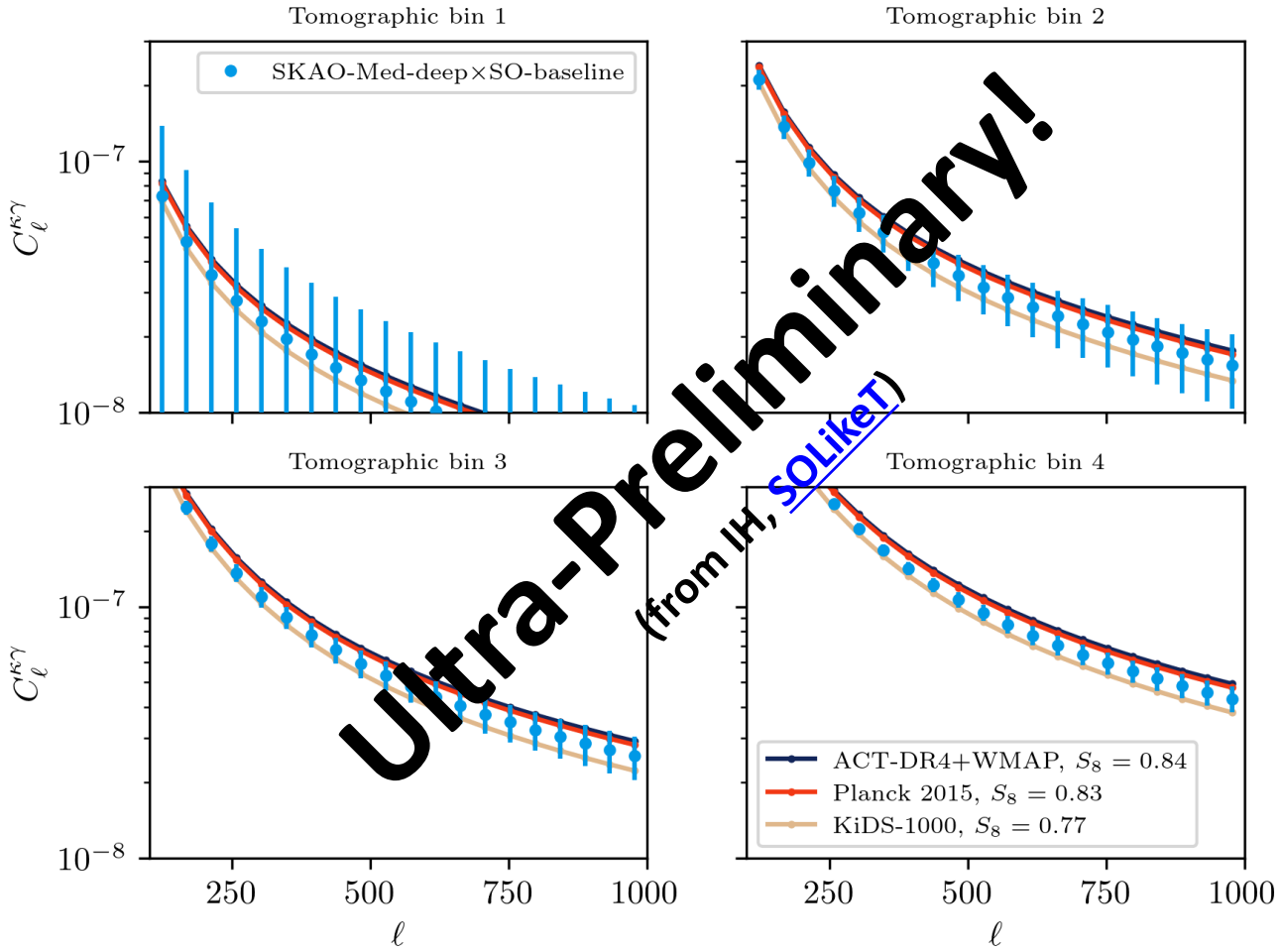


Save Holmdel Horn Antenna!

- Will Coulton, Alba Kalaja have project looking at CMB lensing X radio weak lensing
- Similar detections in CMB X optical e.g. Robertson et al 2021
- CMB lensing is an extra high-z lensing bin
- Measure S_8 with a broad redshift kernel
- Information on weak lensing nuisance parameters (shear calibration, redshift calibration, IA amplitude)

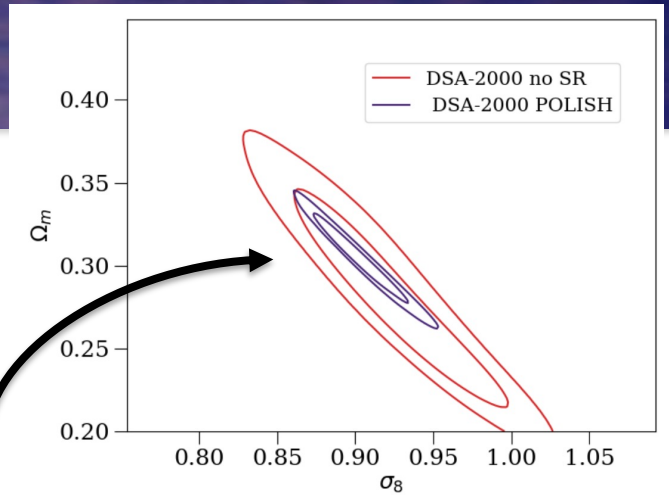


Radio Weak Lensing

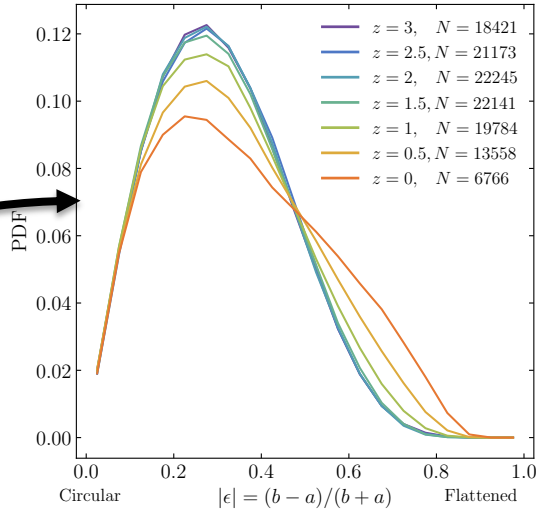
More potential projects

Slides available at http://bit.ly/ianh_skao23

- New things to pick up?
  - Obtain good training samples of star-forming galaxy morphology for shear measurement algorithms
    - Based on conclusions of Cardiff MPhys project
  - Super-resolution imaging a real possibility?
  - Synergies with other SKAO science cases
  - Source tomography (and data challenge)
  - Now know more about radio IAs and shape noise as a function of redshift from N-body+ simulations
    - Update 2016 forecasts in light of this (and other) new information



Connor et al 2021



Hill, private communication

Hill et al 2021

Radio Weak Lensing

Summary

- The **SKAO-Medium-deep** survey will be capable of weak lensing cosmology **comparable to Stage III surveys** like (completed DES, KiDS)
  - Unique value from different systematics, cross-correlations, information on IAs from polarization
- **SuperCLASS pathfinder** project has made methodological strides, **DR2 incoming with a possibility of a detection**
- **Knowledge of radio star forming galaxies at z~1 very important**
- Other pieces of work continue on a best-efforts basis
  - But nobody specifically funded for radio weak lensing work currently

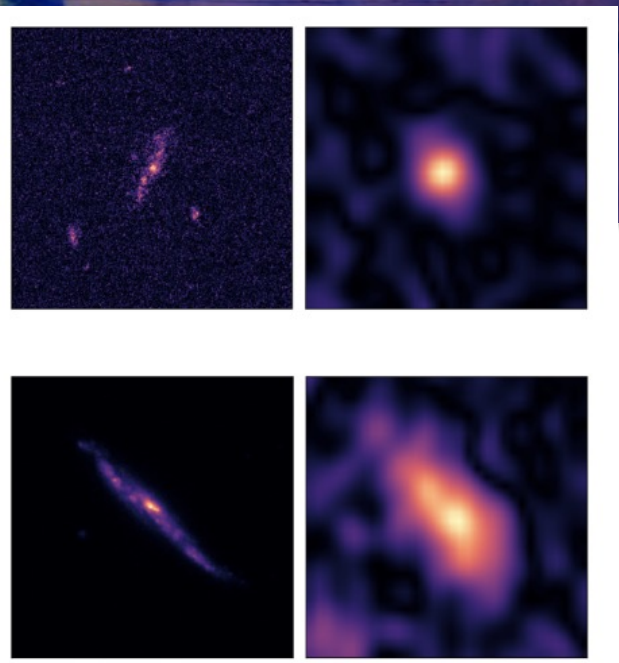
Radio Weak Lensing

Reserve Slides

Slides available at http://bit.ly/ianh_skao23

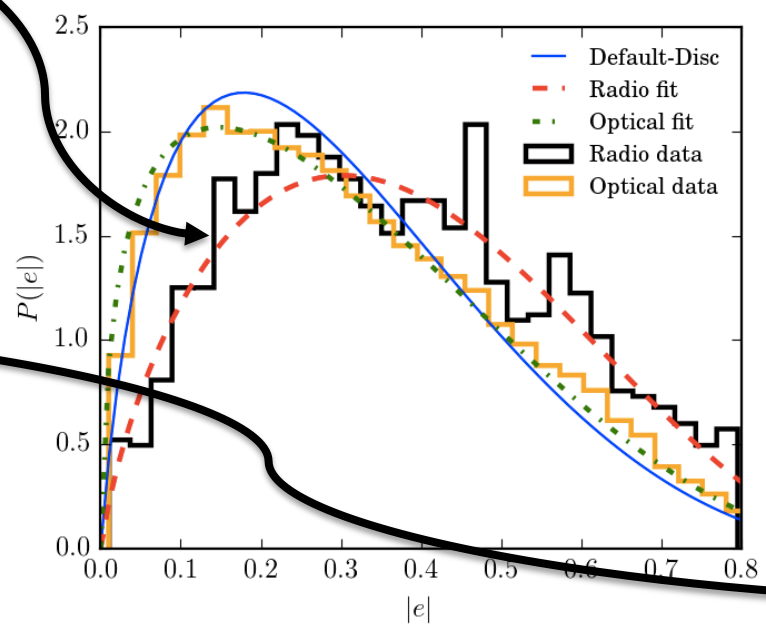
Radio Weak Lensing
A Brief History

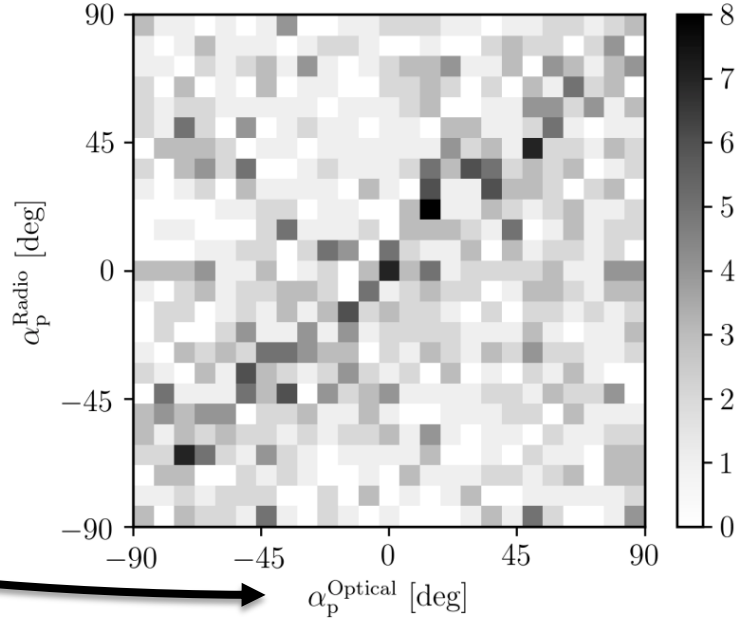
Slides available at http://bit.ly/ianh_skao23



- Work on archival JVLA data in COSMOS field
  - 1.4 Ghz (Tunbridge + IH et al 2016)
  - 3 Ghz (Hillier + IH et al 2019)
- Radio ‘shape noise’ comparable to optical
- Measure Pearson correlation $R = 0.14 \pm 0.03$ between radio, optical position angles α
- Shape noise covariance of 0.016

$$\mathcal{N}^{\mathrm{RO}}(\ell) = \frac{1}{n^{\mathrm{R}}_{\mathrm{gal}} n^{\mathrm{O}}_{\mathrm{gal}}} \left\langle \sum_{\alpha \in \mathrm{R}} \epsilon_\alpha \sum_{\beta \in \mathrm{O}} \epsilon_\beta \right\rangle = \frac{n^{\mathrm{RO}}_{\mathrm{gal}}}{n^{\mathrm{R}}_{\mathrm{gal}} n^{\mathrm{O}}_{\mathrm{gal}}} \mathrm{cov}(\epsilon_{\mathrm{R}}, \epsilon_{\mathrm{O}}).$$

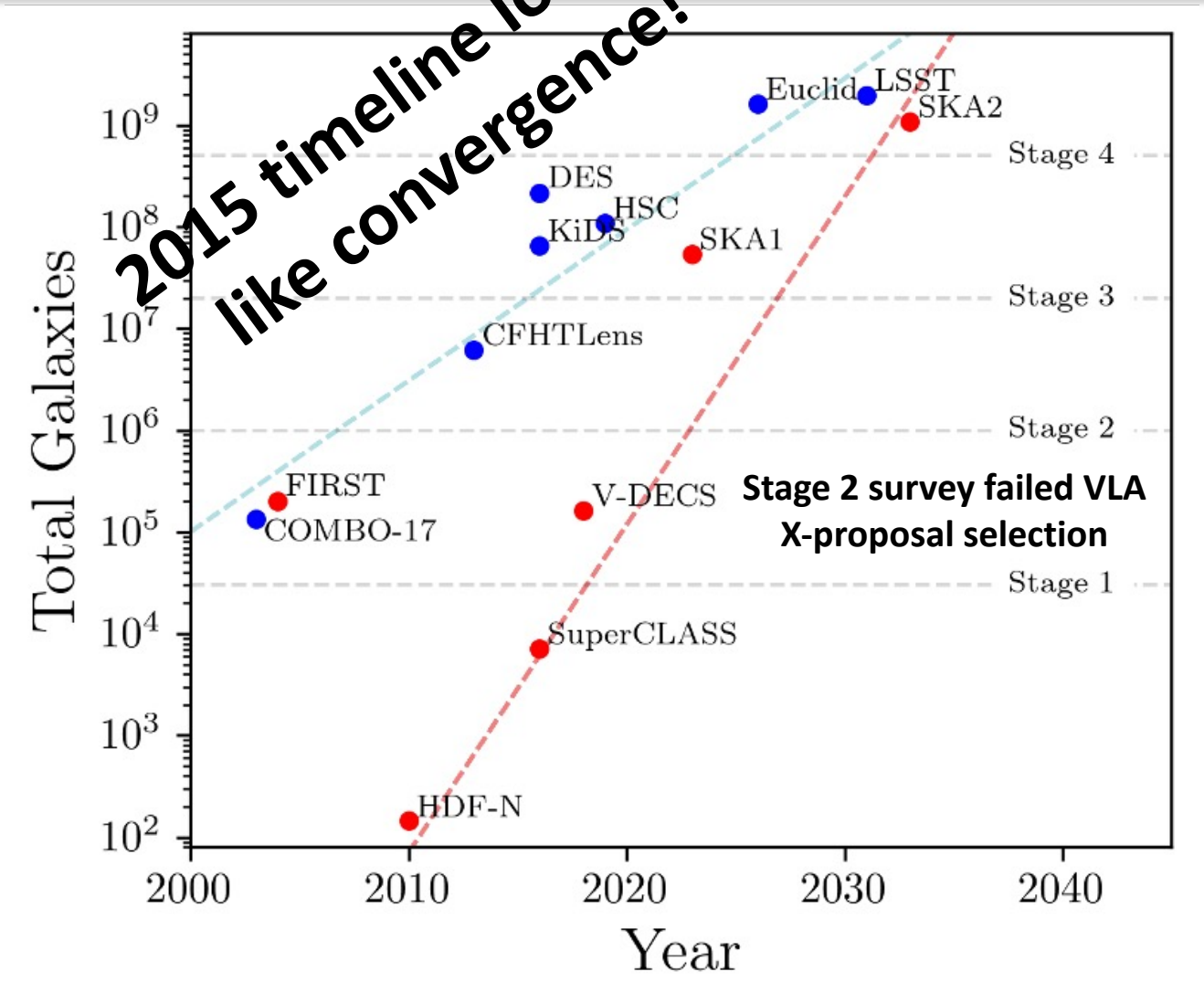




Radio Weak Lensing

A Brief History

- Radio weak lensing surveys lag behind optical in constraining power
- Big leap from no detection to Stage 4 ‘precision cosmology’ surveys
- Pre 2010, design a Stage 1 ‘discovery’ survey: SuperCLASS



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