Weak lensing with e-MERLIN and the JBNA

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(with Richard Battye, Anna Bonaldi, Stefano Camera, Constantinos Demetroullas, Ian Harrison, Neal Jackson, Aaron Peters, Ben Tunbridge, Bob Watson, Lee Whittaker, Joe Zuntz and SuperCLASS collaboration)

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Talk outline

PART 1: The Science Case

- Weak gravitational lensing as a precision cosmology experiment.
- Promise of radio surveys for weak lensing.
- Cross-correlations for robust dark energy science with SKA, Euclid & LSST.

PART 2: Implementation

- The SuperCLASS e-MERLIN legacy survey.
- Path to the SKA: Combine power of JBNA and JVLA to fill gap between current efforts and SKA coming online in next decade.

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PART 1: The Science Case

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PART 1: The Science Case

SKA Weak Lensing I: Cosmological forecasts and the power of radio-optical correlations (Harrison et al., 2016, arXiv:1601.03947)

SKA Weak Lensing II: Simulated performance and survey design considerations (Bonaldi et al., 2016, arXiv:1601.03948)

SKA Weak Lensing III: Added value of multi-wavelength synergies for the mitigation of systematics (Camera et al., 2016, arXiv:1606.03451)

Gravitational lensing

Abell 2218: A Galaxy Cluster Lens
A Fruchter (STScI) et al., WFPC2, HST, NASA

- Distortions in images of background galaxies due to light deflections in an inhomogeneous universe.

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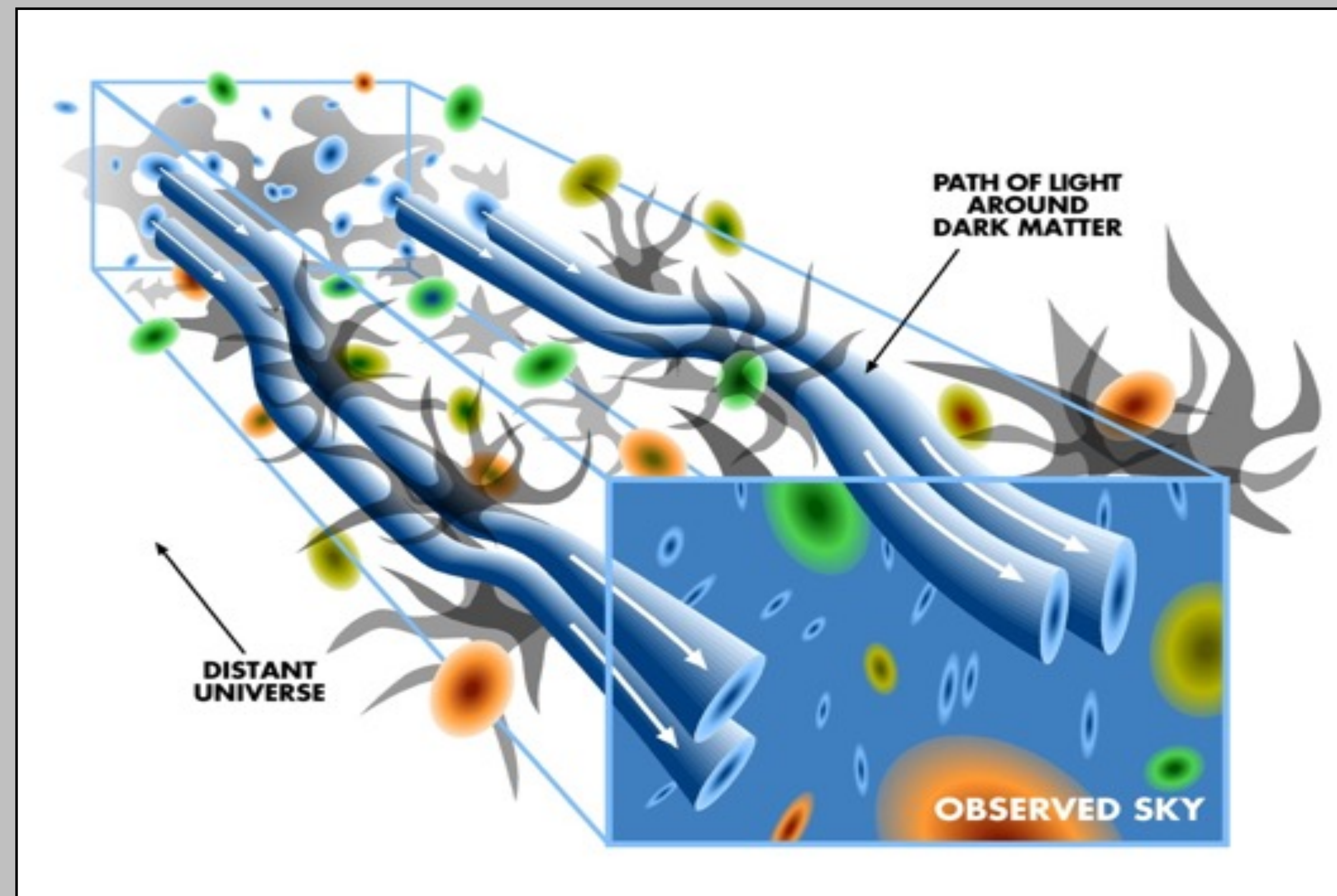
Weak gravitational lensing

Lensing on cosmological scales ("cosmic shear") provides information on growth of structure and the expansion history of the Universe.



Lensing convergence (surface mass density)

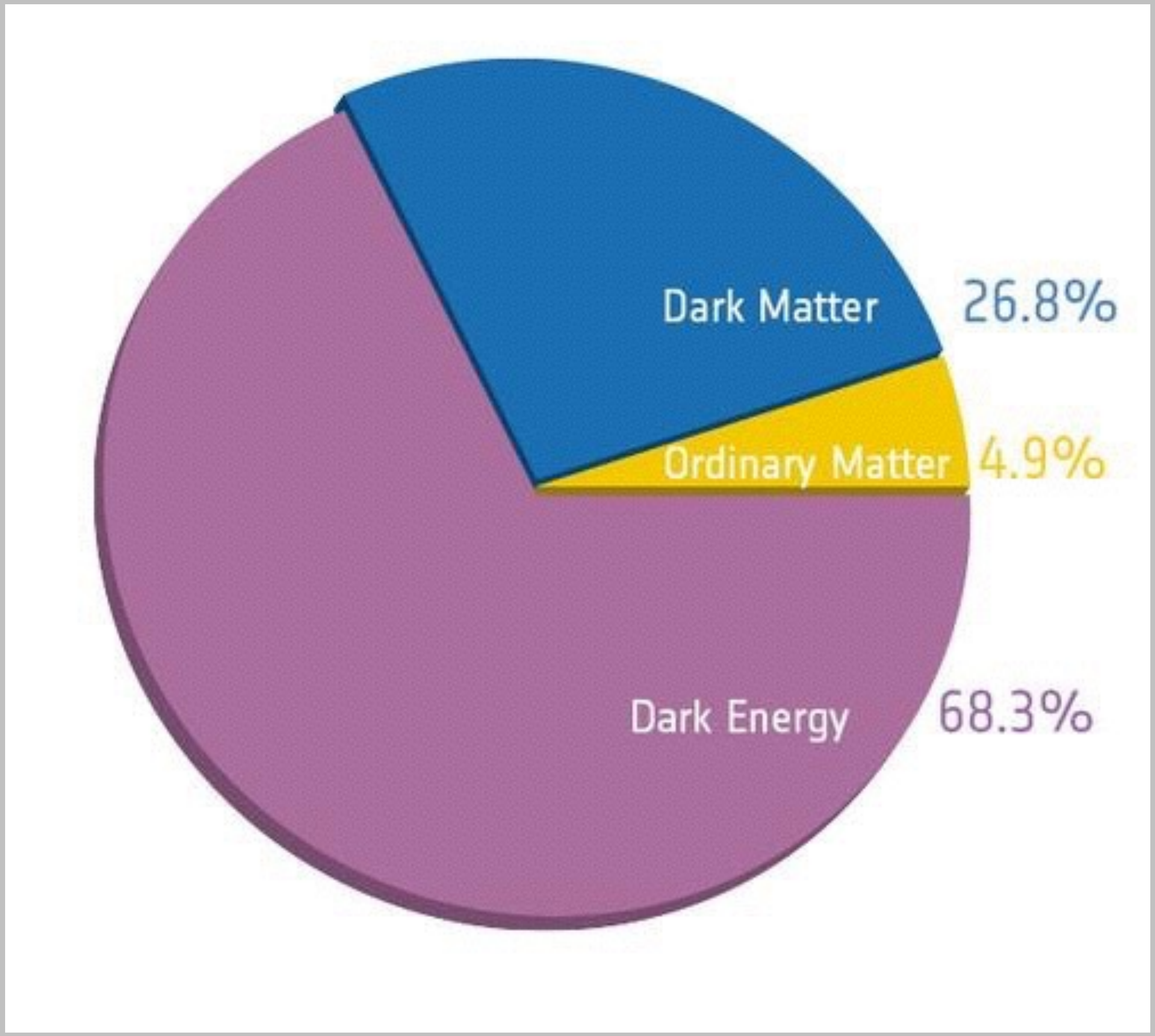
Distances

Power spectrum, growth rate of structure

$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^\omega \frac{f_K(\omega-\omega')\, f_K(\omega')}{f_K(\omega)} \frac{\delta\left[f_K(\omega')\,\boldsymbol{\theta};\omega'\right]}{a(\omega')}\, d\omega'$$

Both depend on the dark matter and dark energy content in the Universe

Energy content of the Universe



Planck collaboration (2013)

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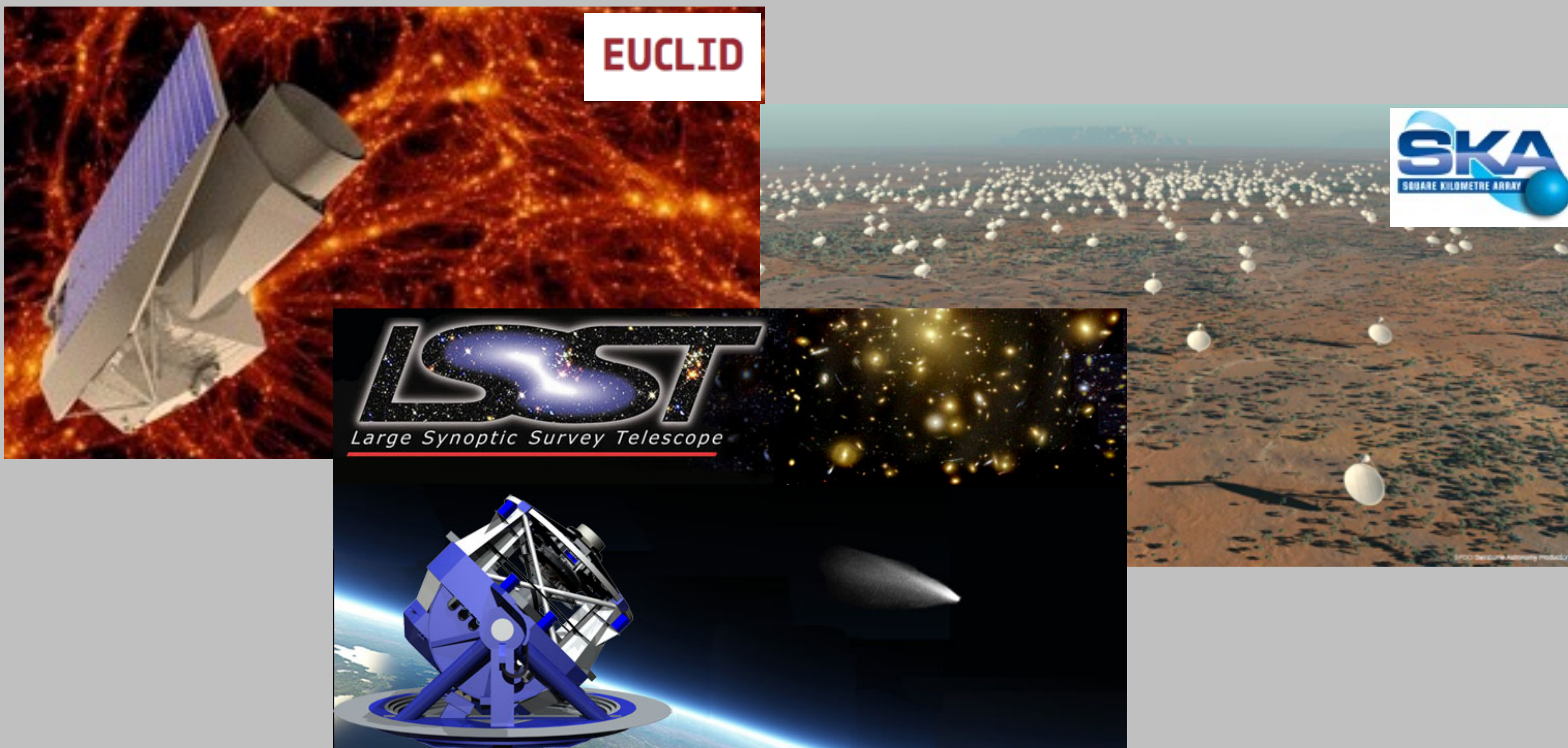
Precision weak lensing to probe accelerated expansion is key science driver for future experiments.



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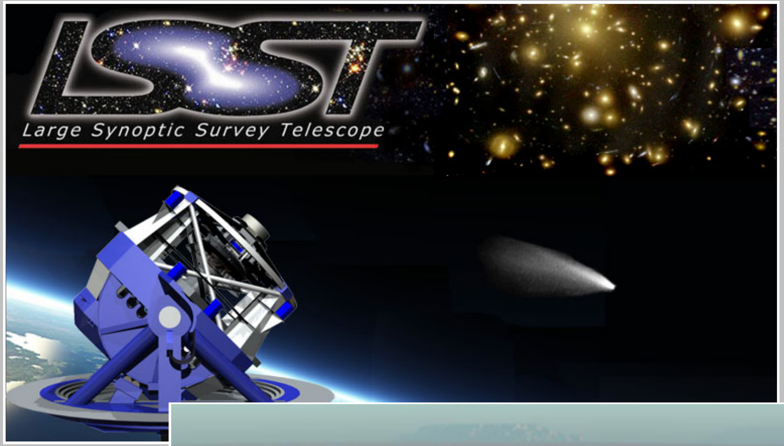
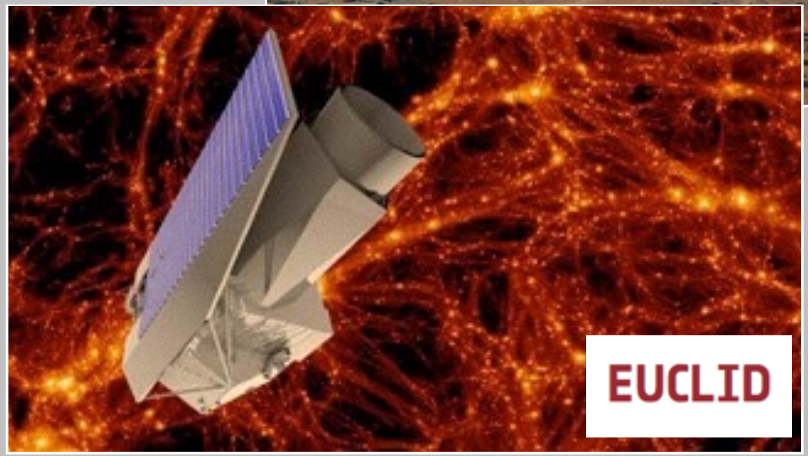
Precision weak lensing to probe accelerated expansion is key science driver for future experiments.

- Require exquisite control of systematics.
- Major systematics for weak lensing:
  - ⋆ Photometric redshift errors.
  - ⋆ Instrumental systematics (e.g. PSF anisotropies).
  - ⋆ Colour-gradient systematics.
  - ⋆ Intrinsic galaxy alignments.

Radio band offers solutions to potentially all of these problems!

- ⋆ Stable and deterministic beam with radio interferometer ⇒ instrumental systematics potentially less of a problem. In any case, optical-radio x-corr. v. robust to systematics.



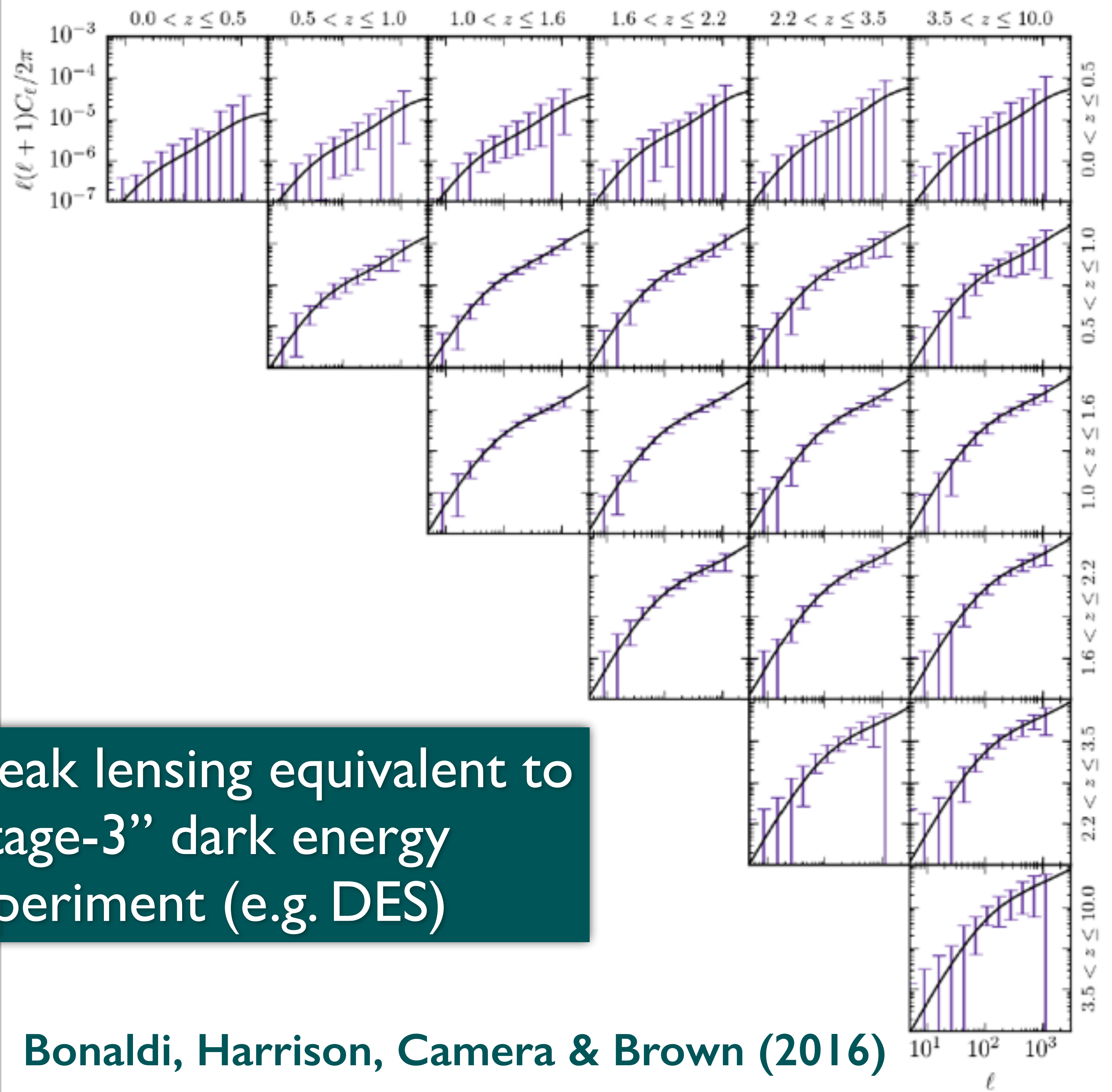


- ⋆ Measure frequency dependent beam directly to remove colour gradient bias .

- ⋆ Precise redshift information from detection of 21cm HI lines (probably an SKA-2 application).

- ⋆ Use polarization and/or HI rotation velocities to reduce noise and control contamination from intrinsic alignments.

Simulated weak lensing performance of SKA-1:



SKA1 weak lensing equivalent to "Stage-3" dark energy experiment (e.g. DES)

Bonaldi, Harrison, Camera & Brown (2016)

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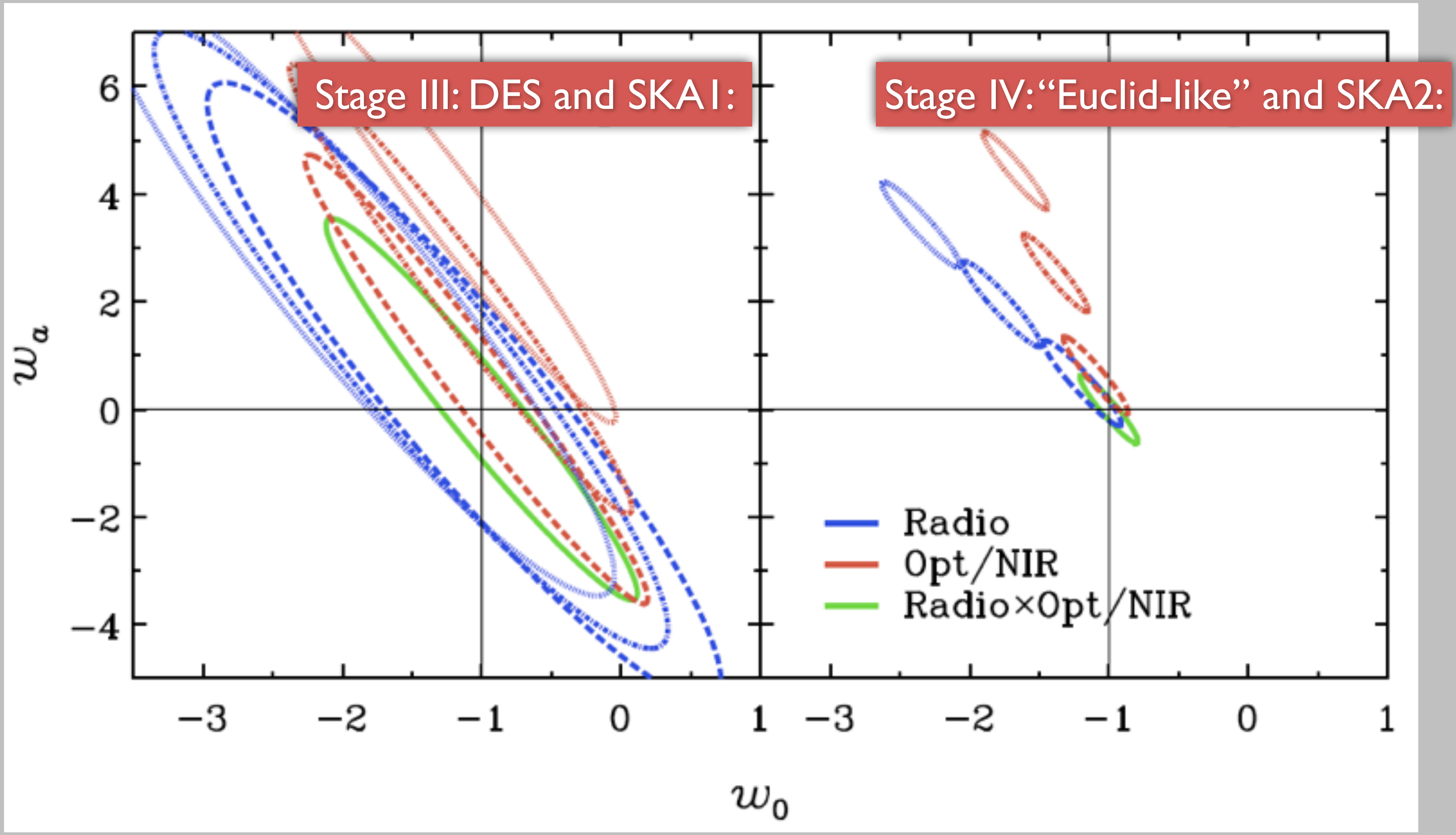
Cosmology with radio-optical shear cross-correlations:

Mitigating instrumental systematic effects:



Camera, Harrison, Bonaldi & Brown (2016)

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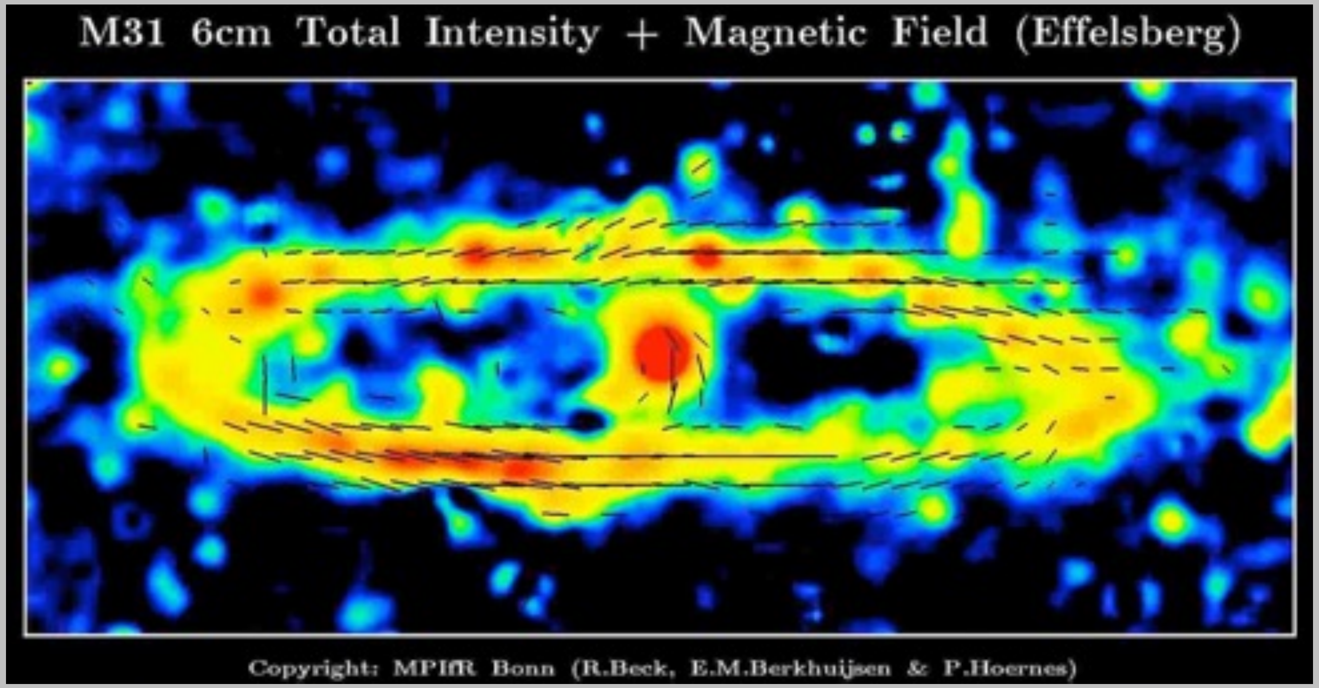
Radio polarization as a proxy for intrinsic galaxy orientation

Brown & Battye (2011a, 2011b)
Whittaker, Brown & Battye (2015)

- Orientation of integrated polarized emission from a background galaxy is unaffected by gravitational lensing.

- Radio polarization traces intrinsic orientation of galaxy.

- Subtract this from galaxy shear estimate to **remove intrinsic alignment bias**.



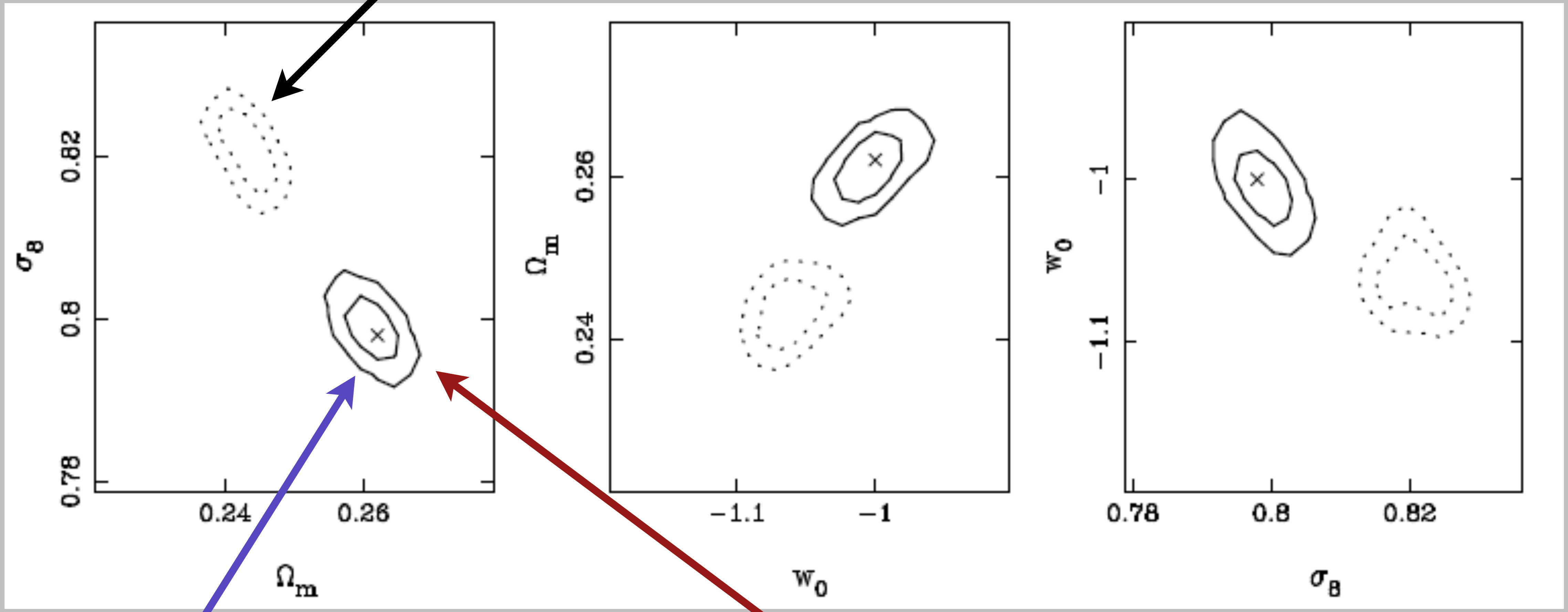
Berkhuijsen, Beck & Hoernes (2003)

- Can also use **21cm-derived rotational velocities** in a similar way.

Blain (2002), Morales (2006), Huff et al. (2013)

Radio polarization as a proxy for intrinsic galaxy orientation

Standard analysis biased by intrinsic alignment contamination



Bias removed using polarization technique with no degradation in constraining power

x = input model

Brown & Battye (2011)

PART 2: Implementation

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SuperCLuster Assisted Shear Survey (SuperCLASS):

- An 800 hr e-MERLIN legacy survey to demonstrate radio weak lensing techniques and act as pathfinder for weak lensing studies with SKA.
- Aim to achieve a flux rms of 4 μJy/beam over ~1 deg^2 at L-band (1.4 GHz).
- Resolution ~ 0.2”, source density ~ 1-2 $arcmin^{-2}$.
- Observe a supercluster region to increase signal-to-noise.
- Complement with JVLA data to fill in short baselines.
- Lower freqs from GMRT and LOFAR.
- Optical data (B, V, R, i, z) obtained with Suprime-cam / Subaru. CFHT / WIRCam (K-band) imaging forthcoming.

SuperCLASS collaboration

University of Manchester

Richard Battye (PI)
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University of Bristol

Mark Birkinshaw

University of Hawaii

Chao Ling Hung

MPA, Garching

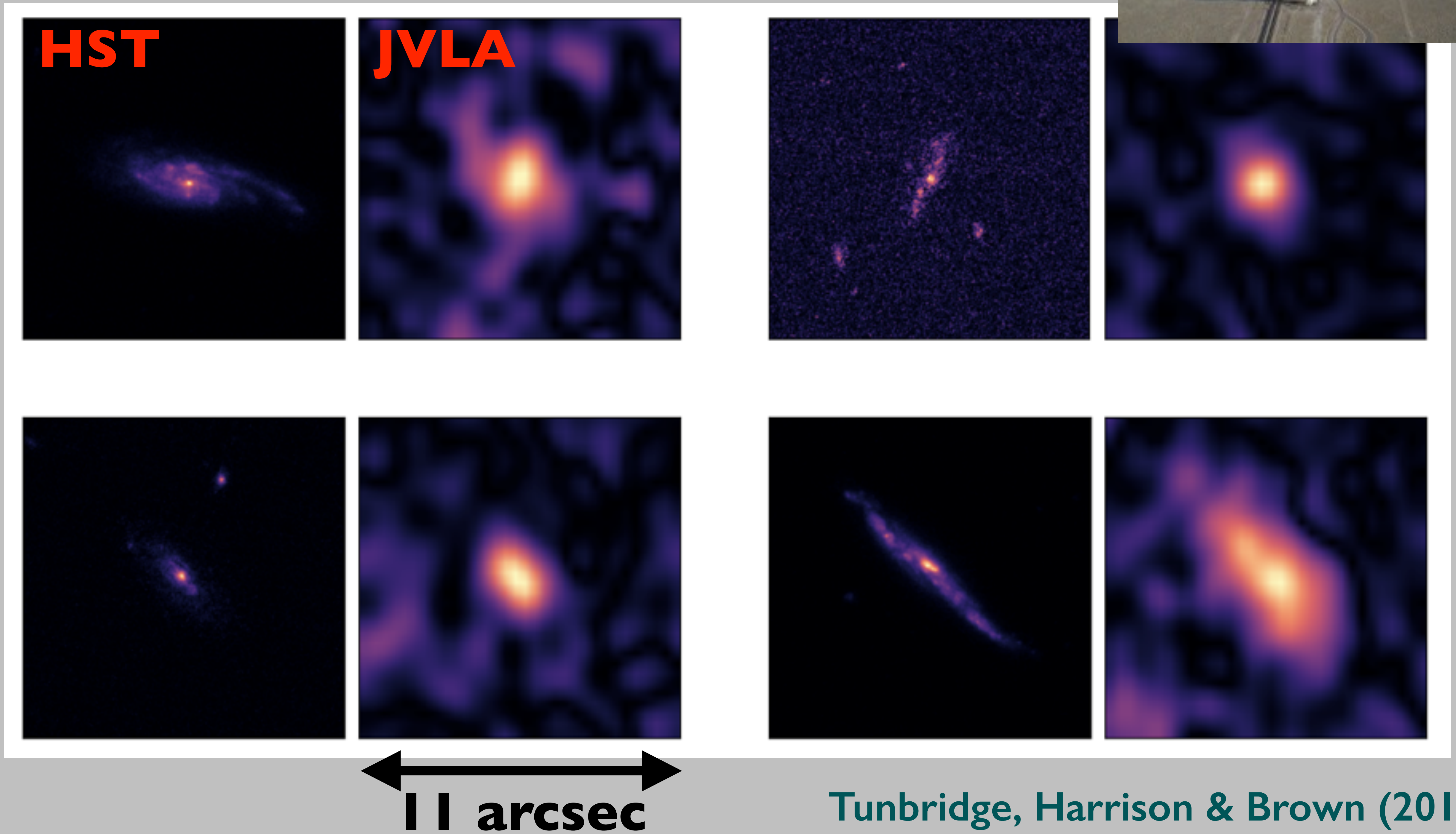
Torsten Ensslin

Dalhouise University

Scott Chapman

Why e-MERLIN / JBNA?

- **COSMOS** field has exquisite HST optical imaging and deep VLA (1.4 GHz) and JVLA (3 GHz) radio observations.



Tunbridge, Harrison & Brown (2016)

SuperCLASS observations

- e-MERLIN data in this area already in the can to full SuperCLASS depth.

- As of last week, low-level processing and calibration of these data is complete!

Bob Watson, Neal Jackson

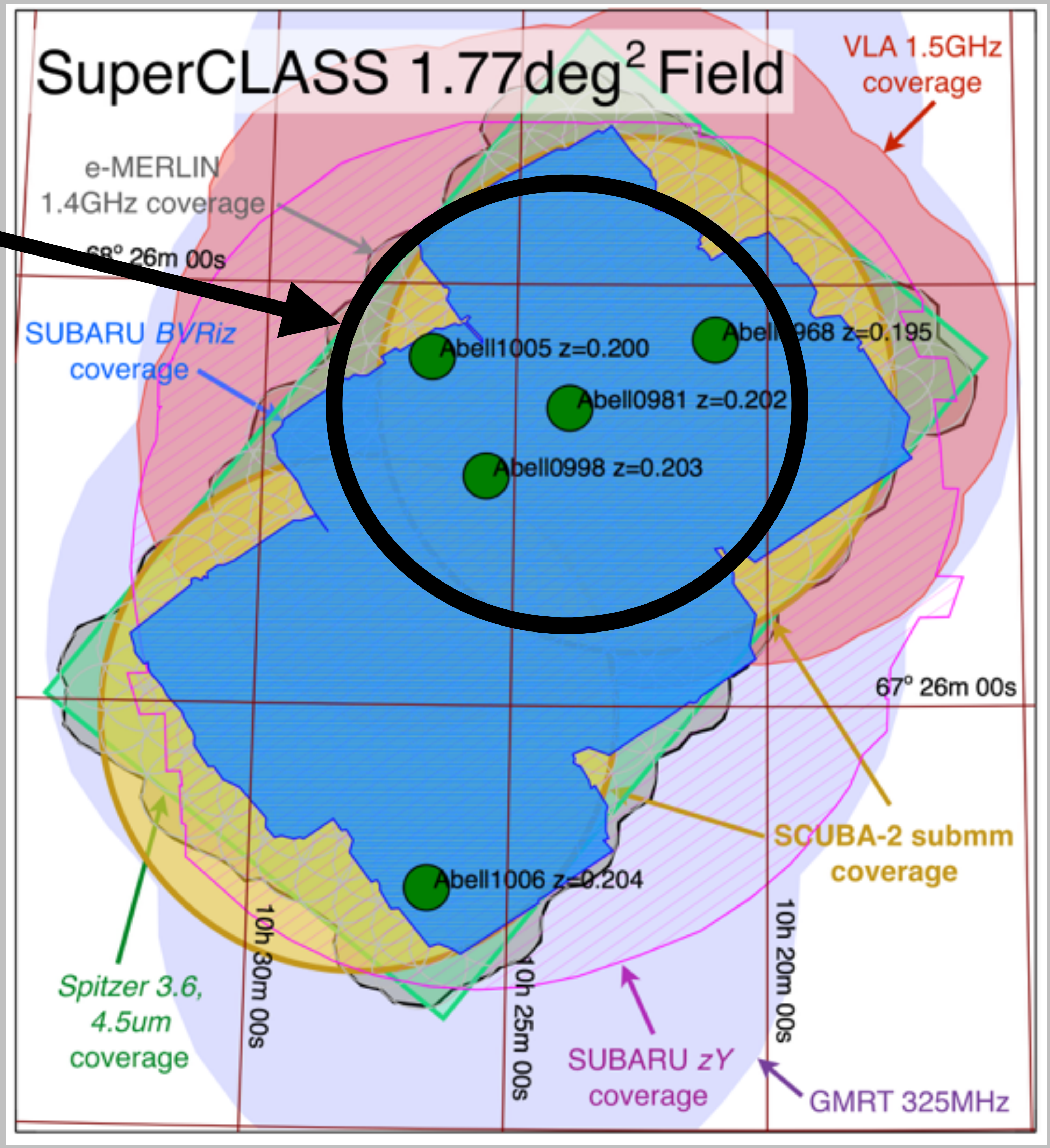


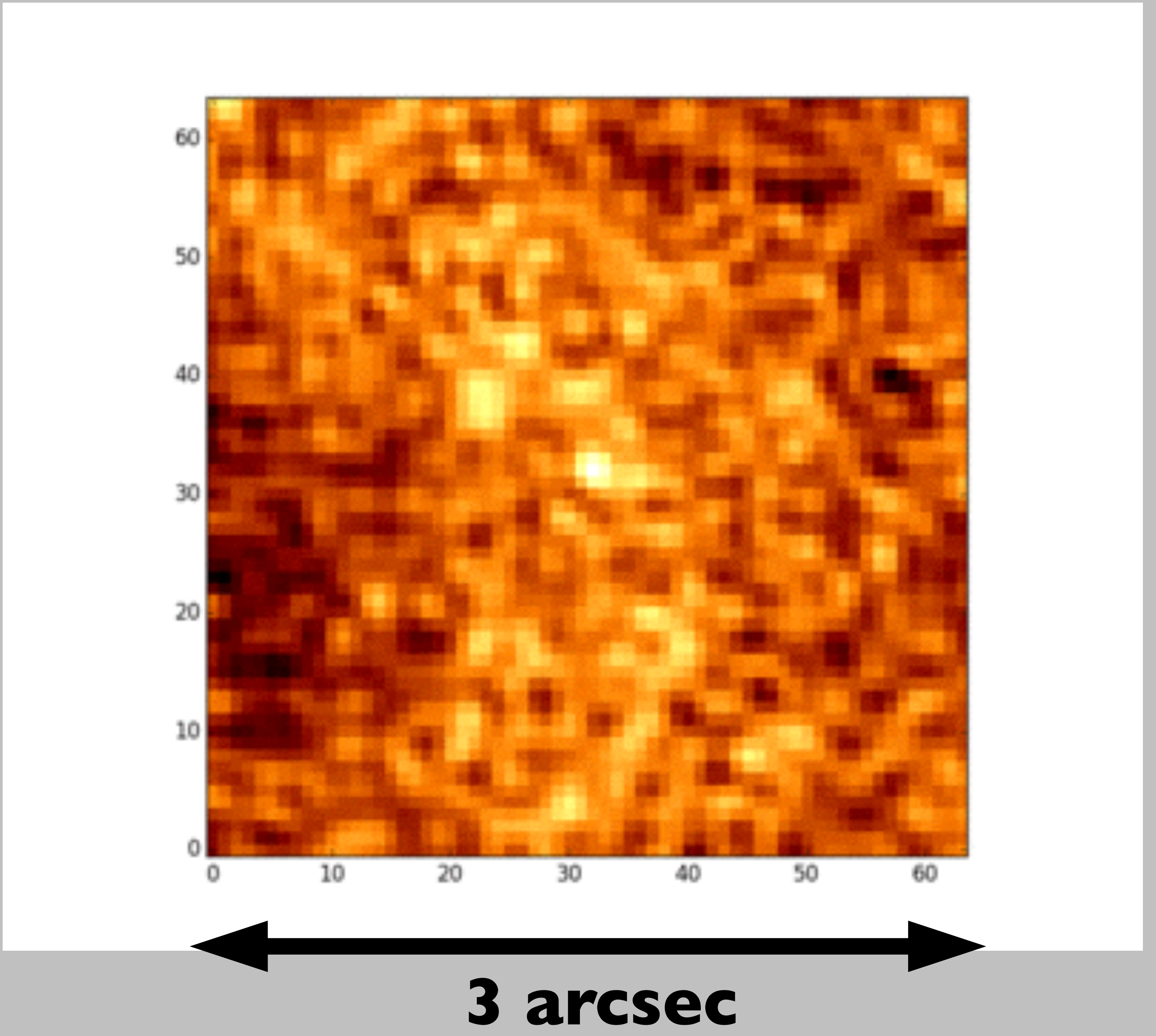
Figure credit: Caitlin Casey

SuperCLASS observations

- Sources detected in central 2 fields of e-MERLIN data only.

- Currently achieving ~7 μJy/beam. Should get to target sensitivity (4 μJy/beam) on addition of JVLA data

- Numbers suggest we should achieve ~1 galaxies per sq. arcmin in combined e-MERLIN and JVLA data.



Data analysis: Bob Watson
Figure credit: Ian Harrison

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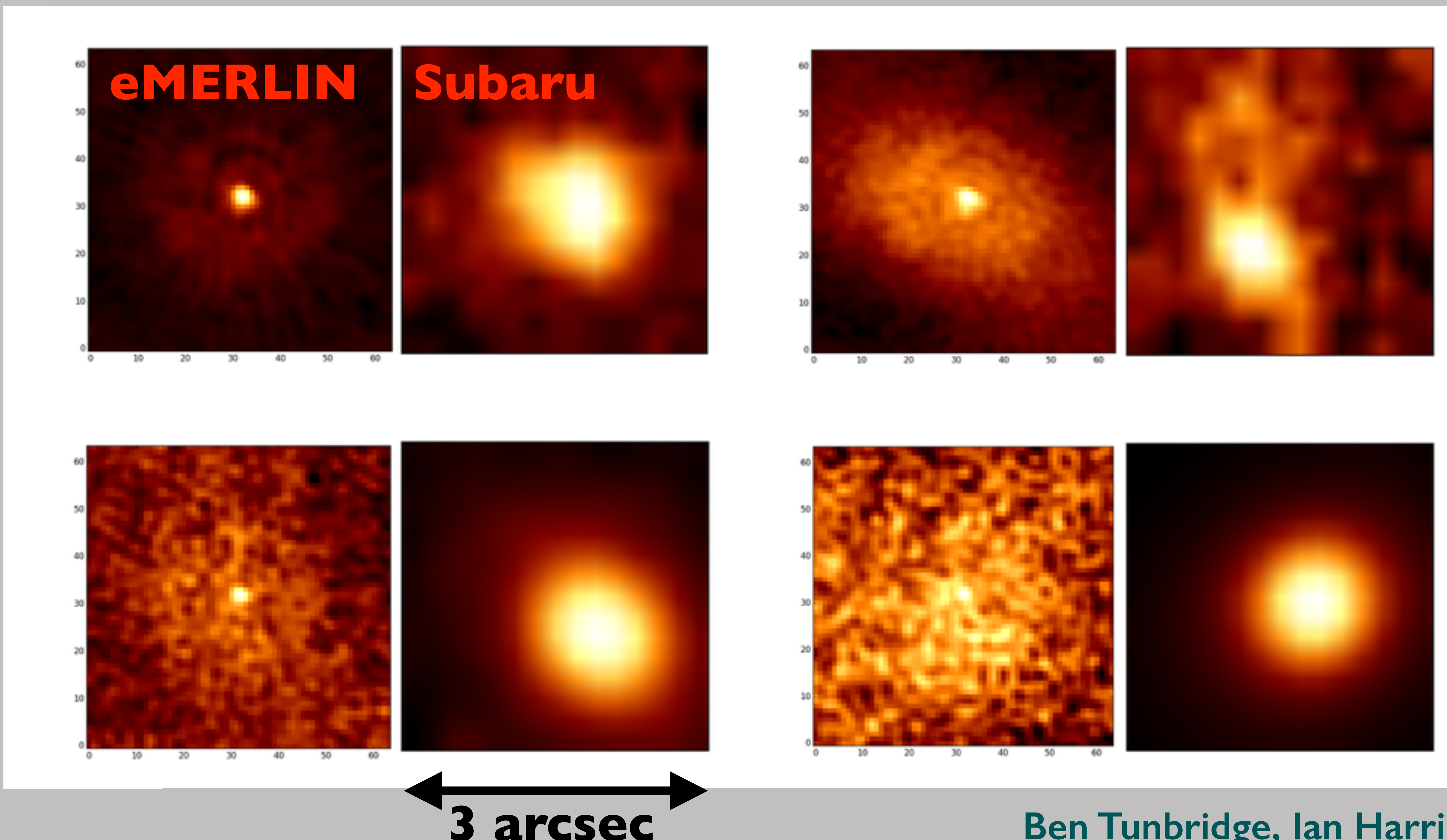
SuperCLASS observations

- Comparing optical (Subaru) and radio (eMERLIN) SuperCLASS sources…

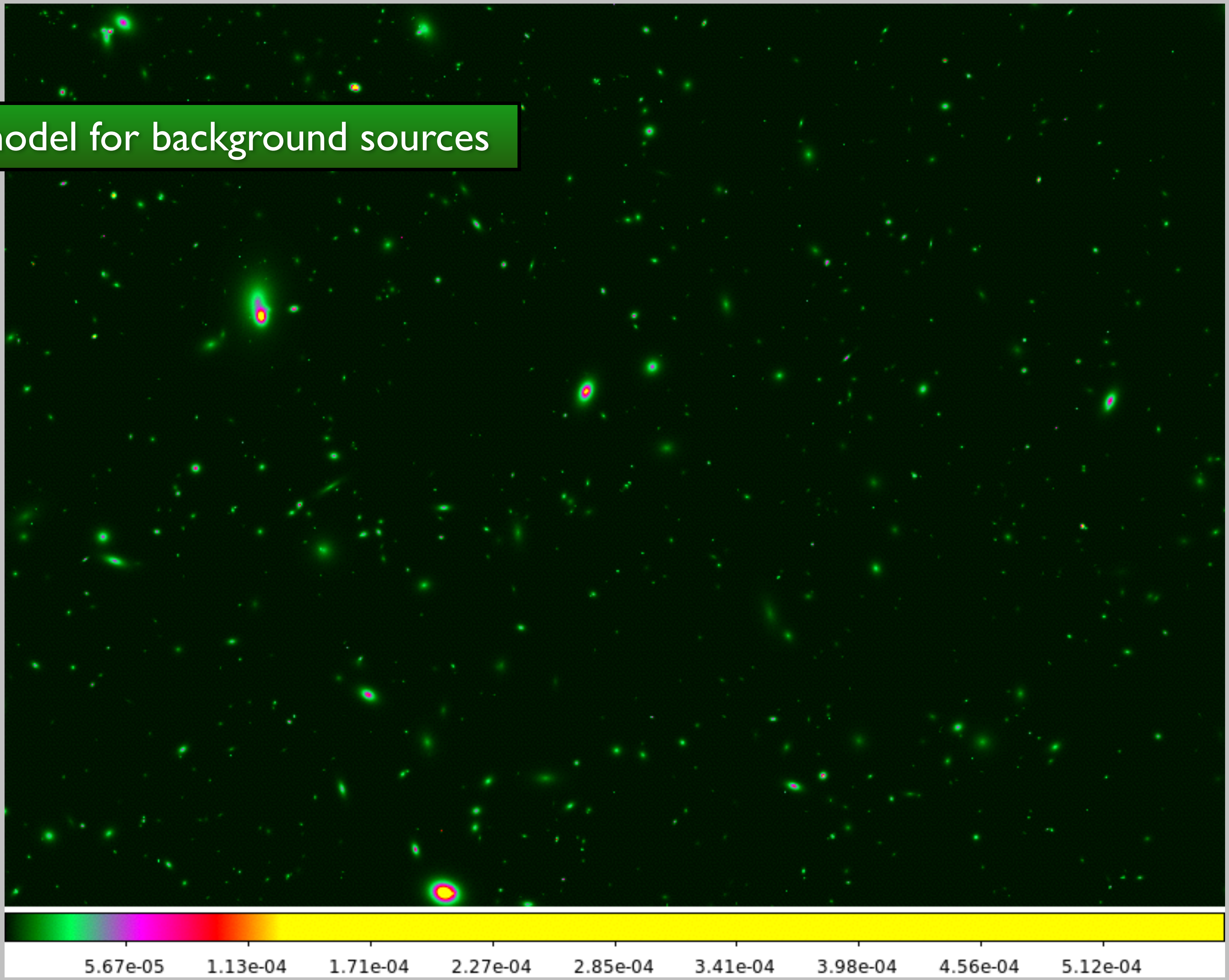


Ben Tunbridge, Ian Harrison

SuperCLASS analysis

- **Precision cosmology measurements require end-to-end simulation capability:**

Begin with realistic sky model for background sources

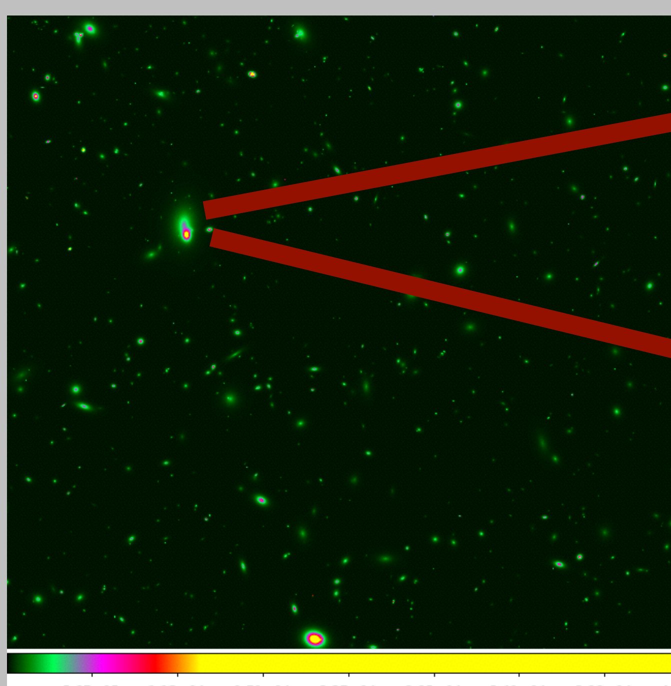


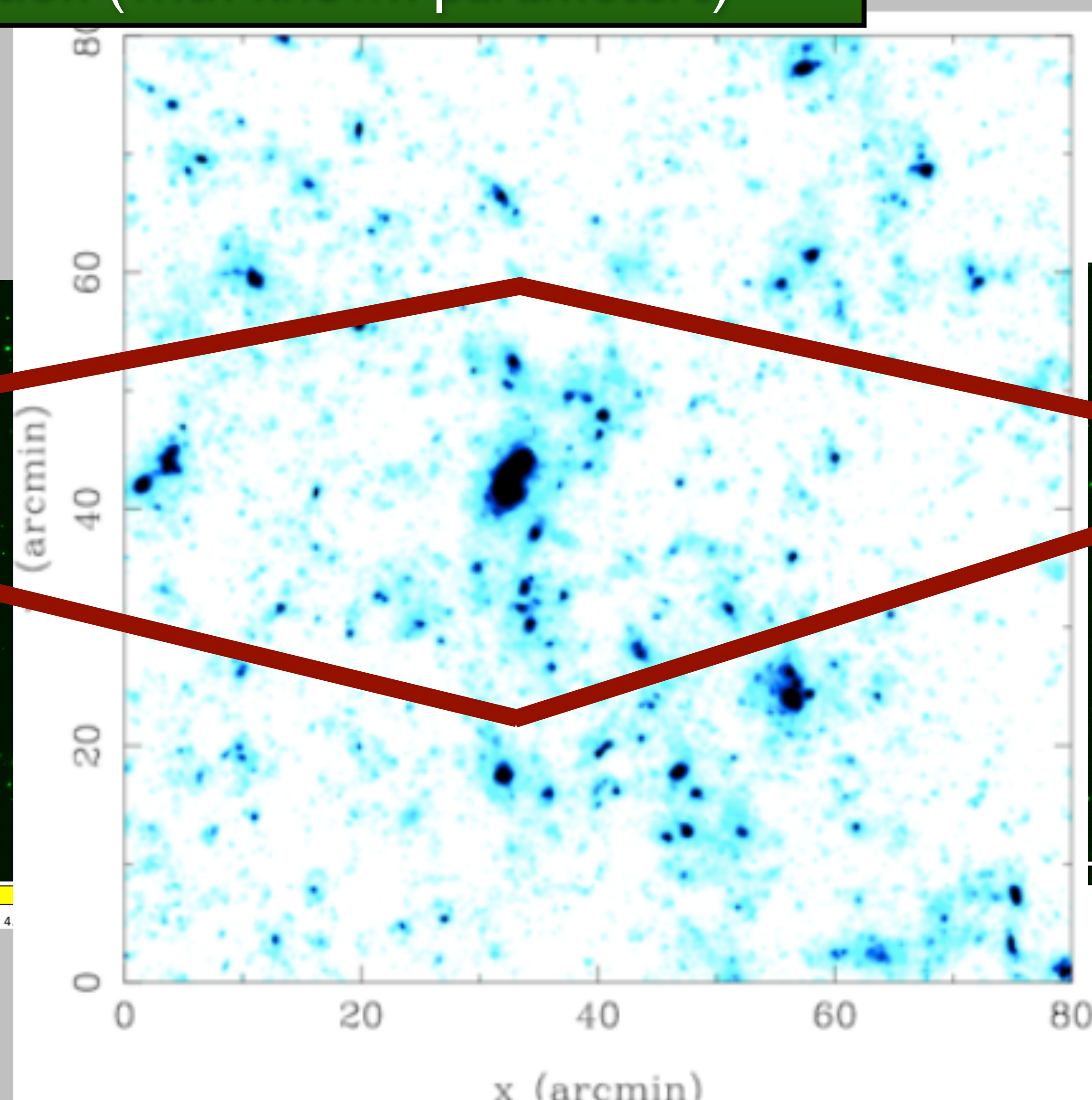
T-RECS simulations
(Anna Bonaldi)

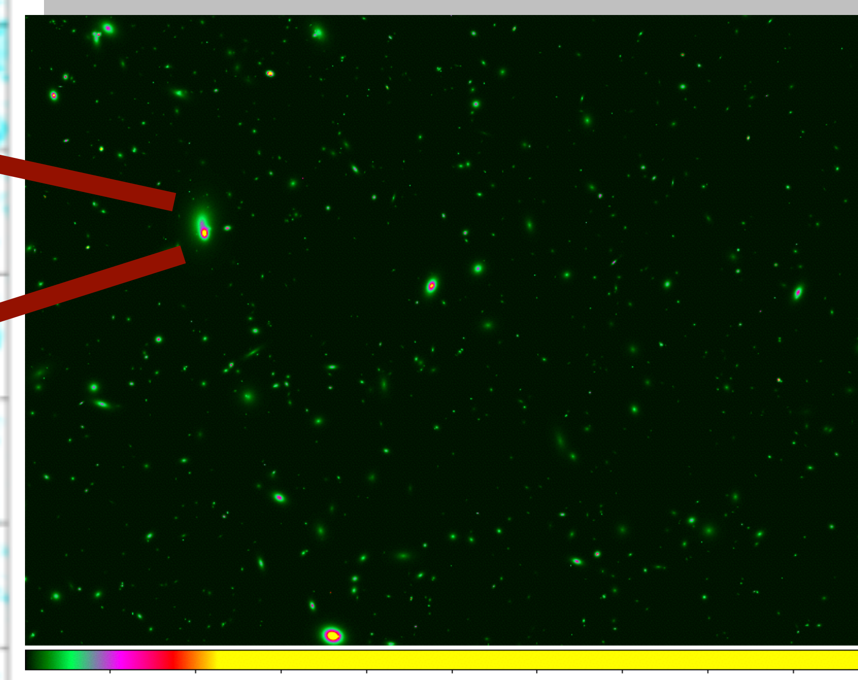
SuperCLASS analysis

- **Precision cosmology measurements require end-to-end simulation capability:**

Lens these sources according to simulated foreground dark matter distribution (with known parameters)







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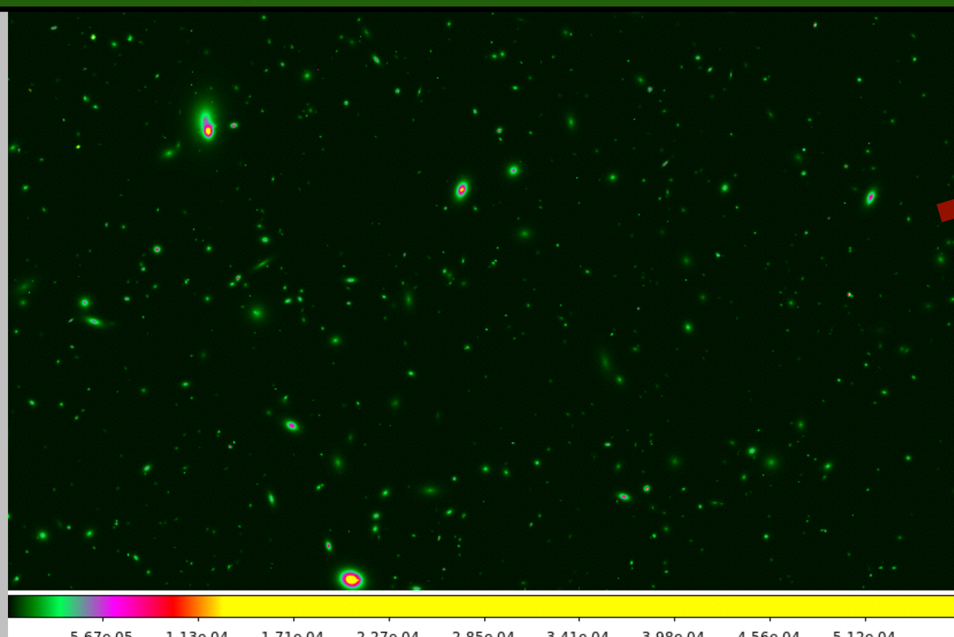
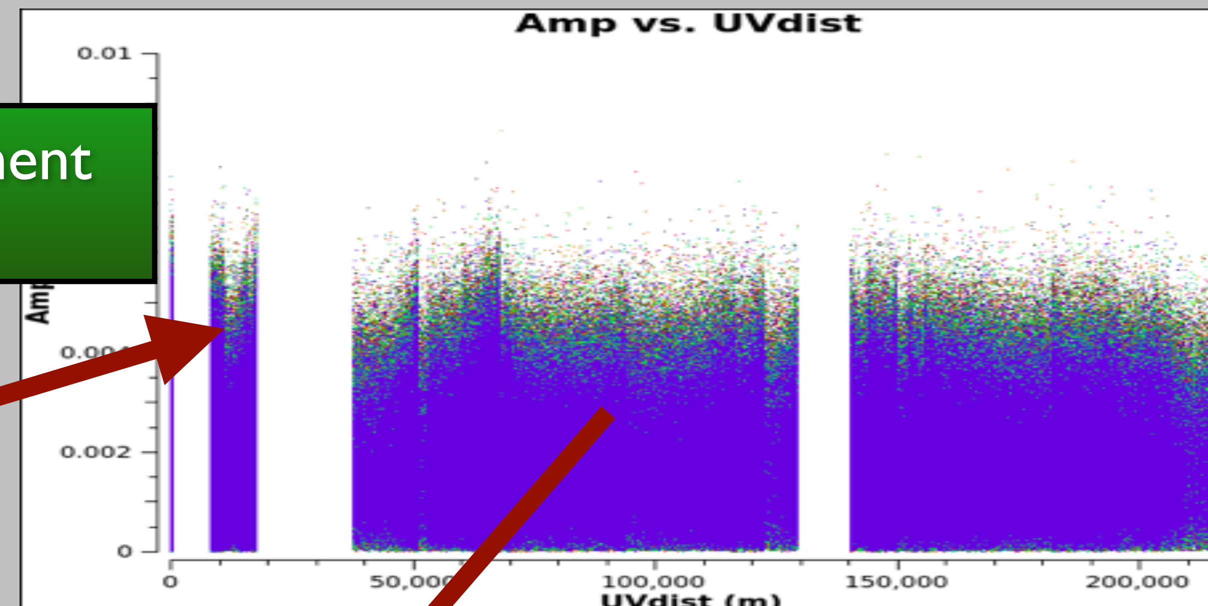
SuperCLASS analysis

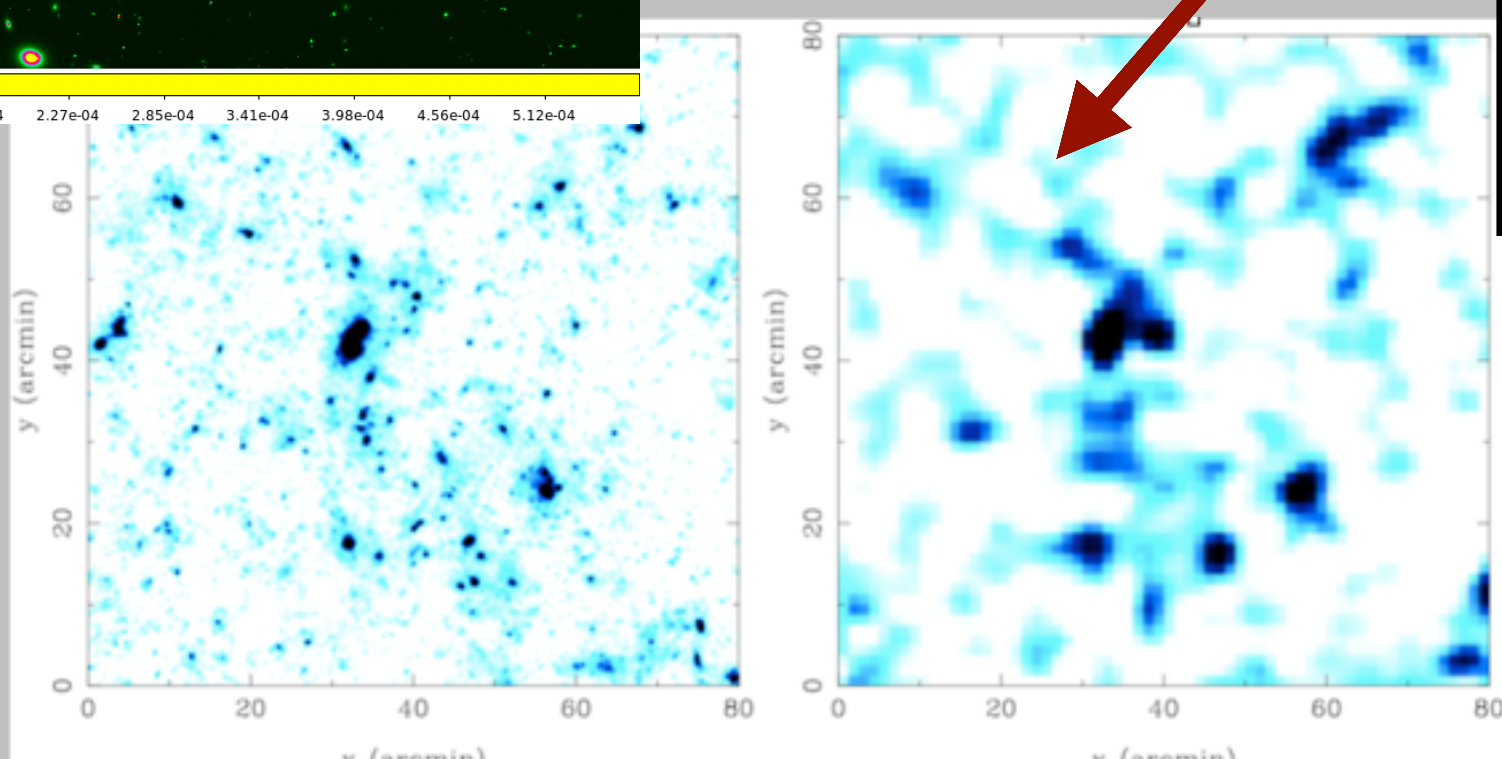
- **Precision cosmology measurements require end-to-end simulation capability:**

“Observe” this sky with eMERLIN, adding instrument noise and systematic effects:





Process the same way as the real data, measure galaxy shapes and test accuracy of reconstructed dark matter map.



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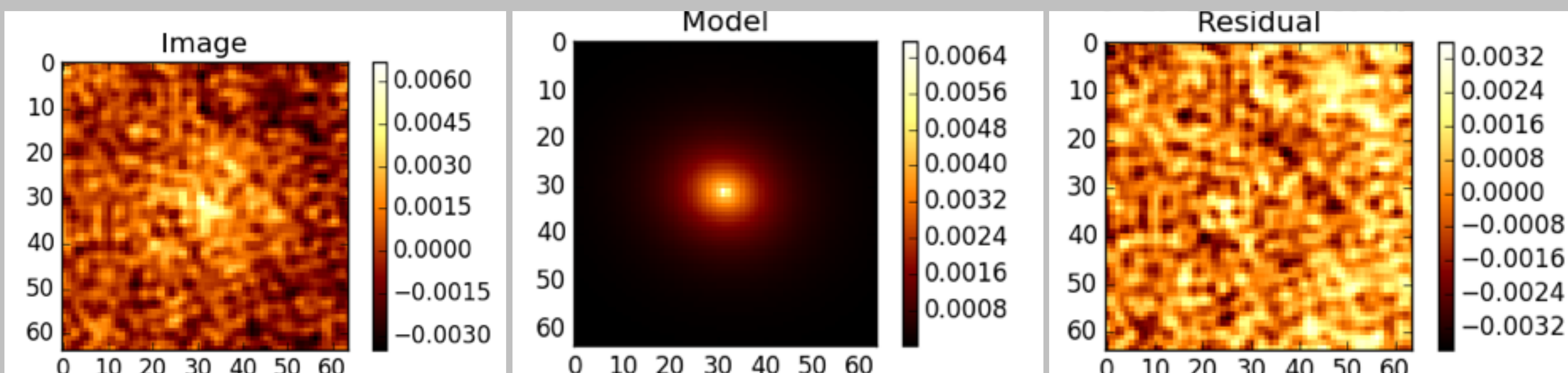
SuperCLASS analysis

- **We need new approaches for measuring galaxy shapes from radio data. Trialling three approaches for SuperCLASS:**
  - “Brute-force” multi-object fitting in UV space.
  - Imaging followed by “standard” shape measurement on images:



Ian Harrison

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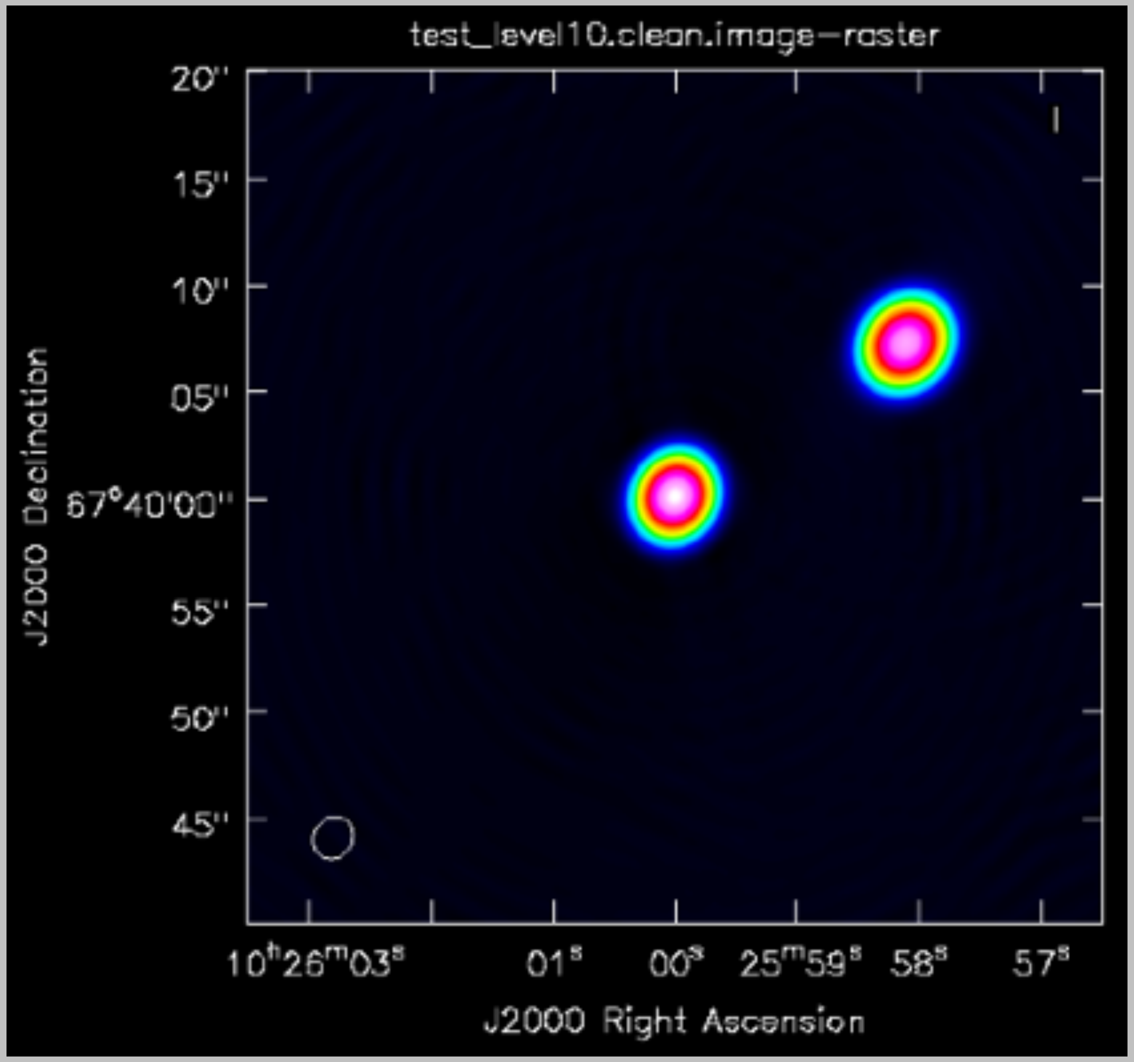
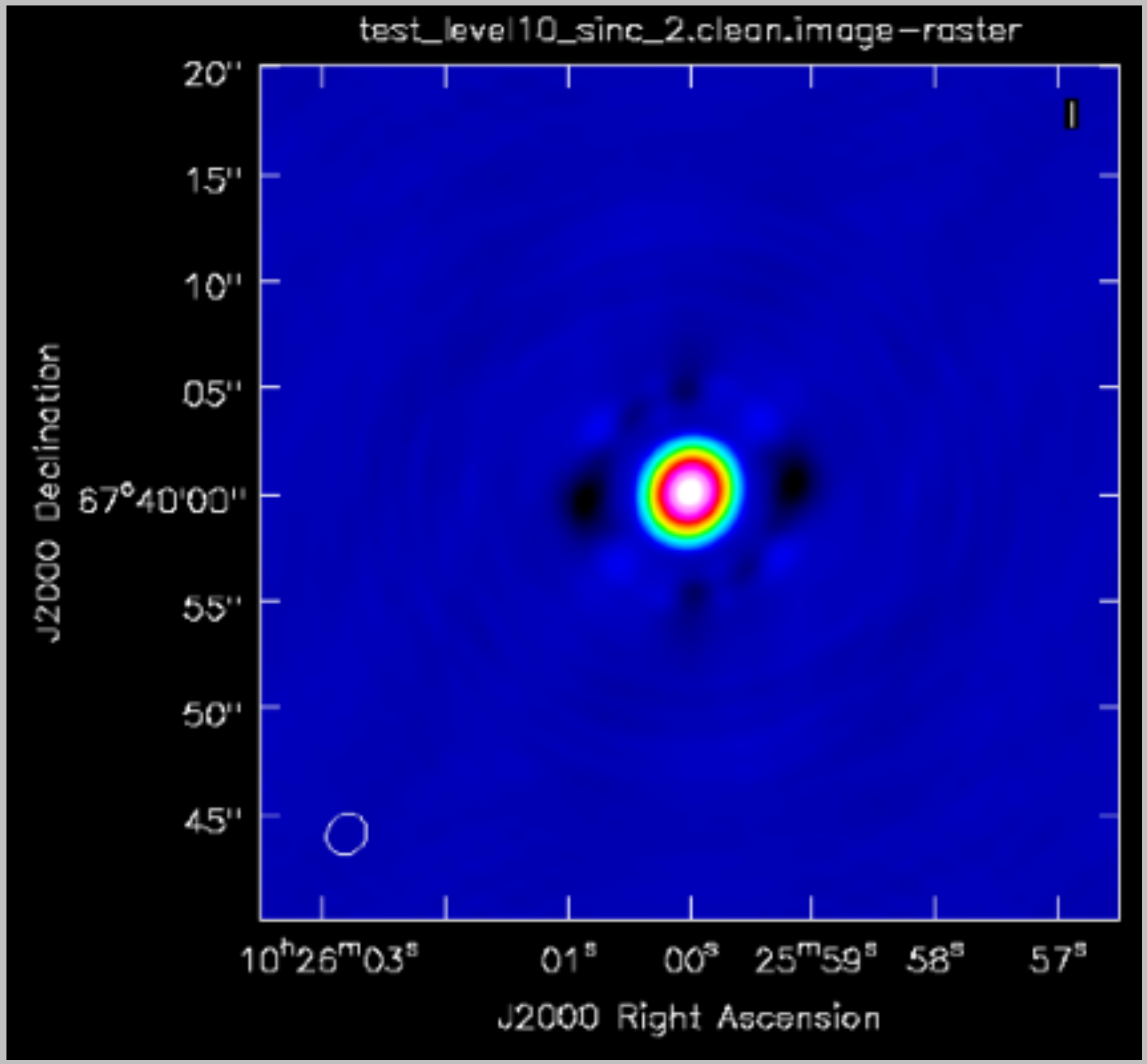
SuperCLASS analysis

- **We need new approaches for measuring galaxy shapes from radio data. Trialling three approaches for SuperCLASS:**
  - Phase rotation & averaging followed by single-object fitting in UV space.





Ben Tunbridge

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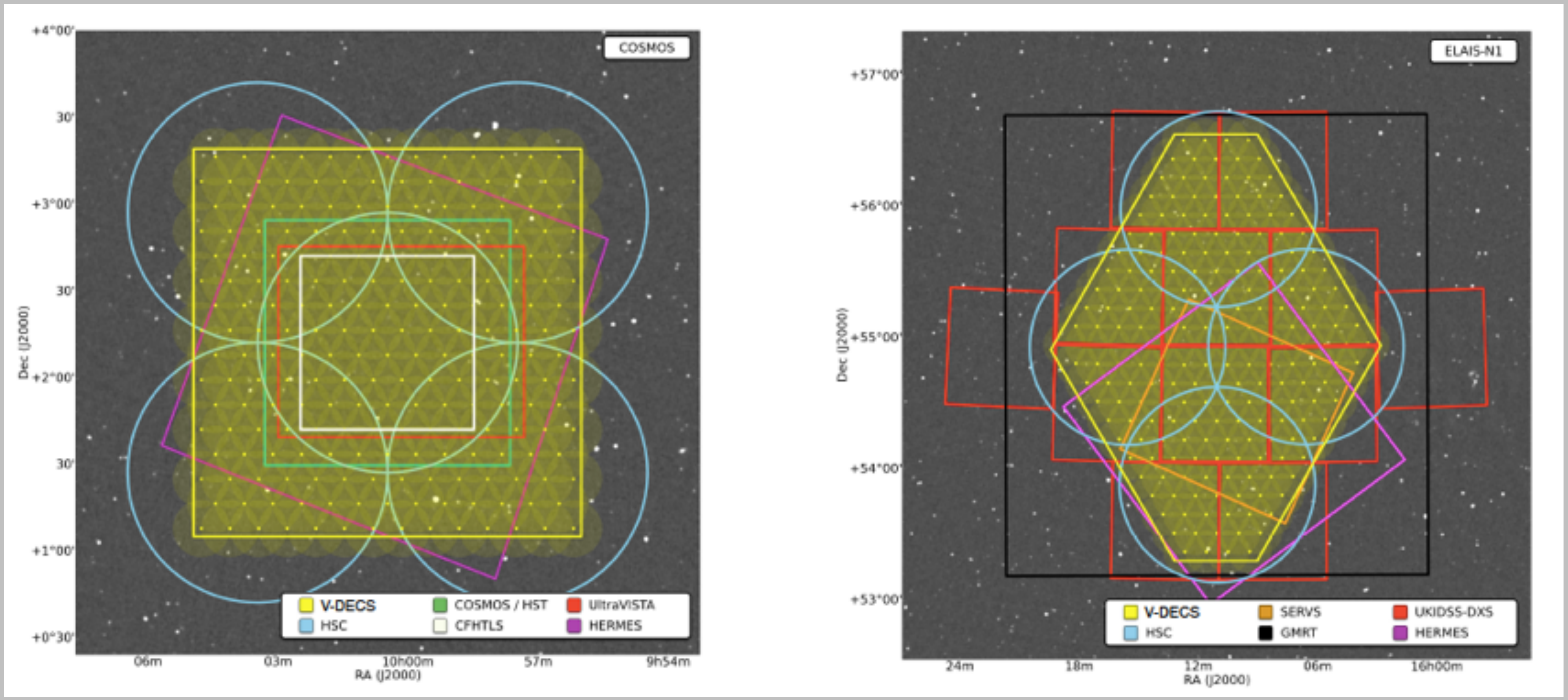
Radio Weak Lensing: Path to the SKA

- ⋆ Beyond SuperCLASS, next stage is to conduct a genuine cosmic shear measurement (covering ~10 sq. degs of "blank" sky).

- ⋆ Proposed VLASS deep fields / V-DECS survey on the JVLA but requires 3000 hrs of JVLA time!

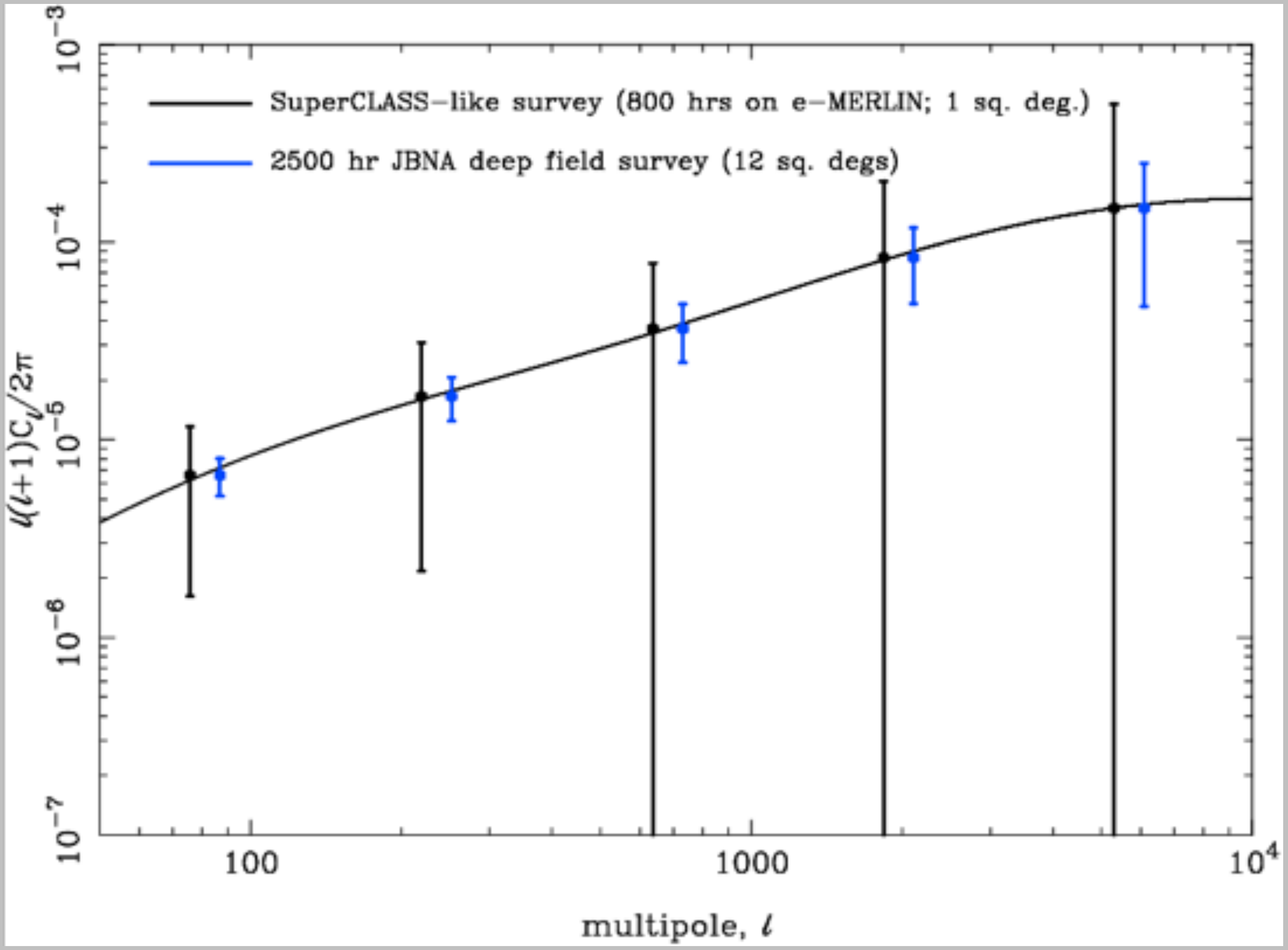


Radio Weak Lensing: Path to the SKA

⋆ **A large L-band JBNA extragalactic survey** could also achieve this science. (This example assumes a 2500 hr legacy survey.)

⋆ **Lovell PAF is crucial** to increase survey speed (x4).

⋆ Still require JVLA time but ~200 hrs rather than 3000 hours for V-DECS.



⋆ Will also facilitate **all other science goals in the V-DECS case** (Large-scale structure & radio galaxy bias, AGN & star-formation over cosmic time, the deep polarized sky & cosmic magnetism).

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Summary

• Radio surveys, and radio-optical synergies offer **unique advantages** for dealing with key issues in **precision weak lensing**:

⋆ Precisely known PSF of an interferometer offers prospect of very accurate galaxy shape measurements.

⋆ SKA lensing competitive with future optical surveys. Cross-correlation techniques will provide robust dark energy science.

⋆ Polarization information to reject intrinsic galaxy alignments.

• **SuperCLASS** is pathfinding this science now on e-MERLIN (survey data, but also simulations & analysis techniques suitable for cosmology).

• **Large multi-purpose extragalactic JBNA L-band survey** will bridge gap between current surveys and SKA in next decade.

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END