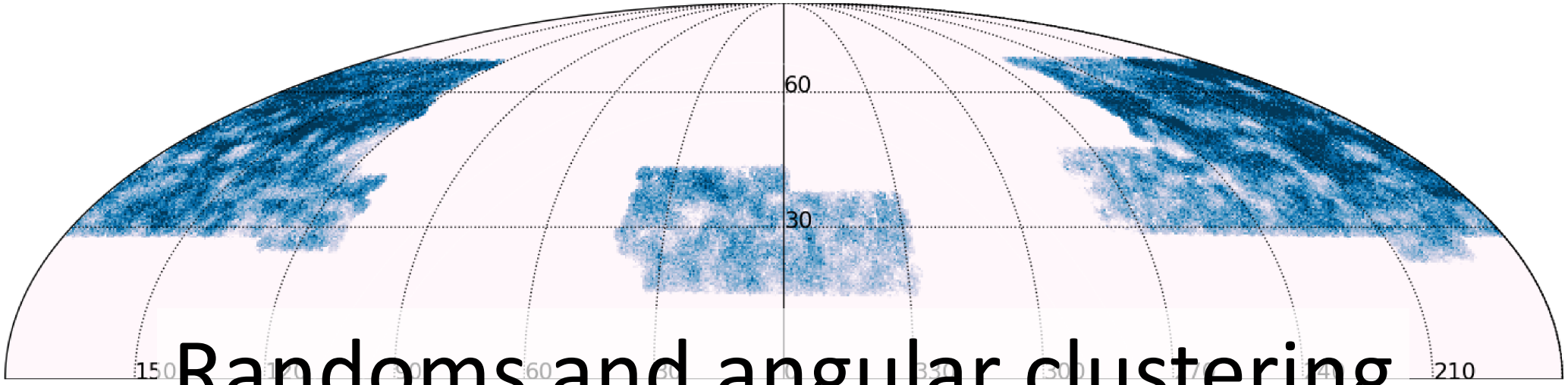

Randoms and angular clustering studies with the Low Frequency Array (LOFAR)

THE UNIVERSITY of EDINBURGH

LEVERHULME TRUST

Dr Catherine Hale

University of Edinburgh

Work in progress!

Low Frequency Array (LOFAR)

- Radio telescope
- Core based in Netherlands
- Observes at Low frequencies:
  - LBA: 10-80 MHz
  - HBA: 120-240 MHz

See van Haarlem+ 2013

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  - 6” with NL stations
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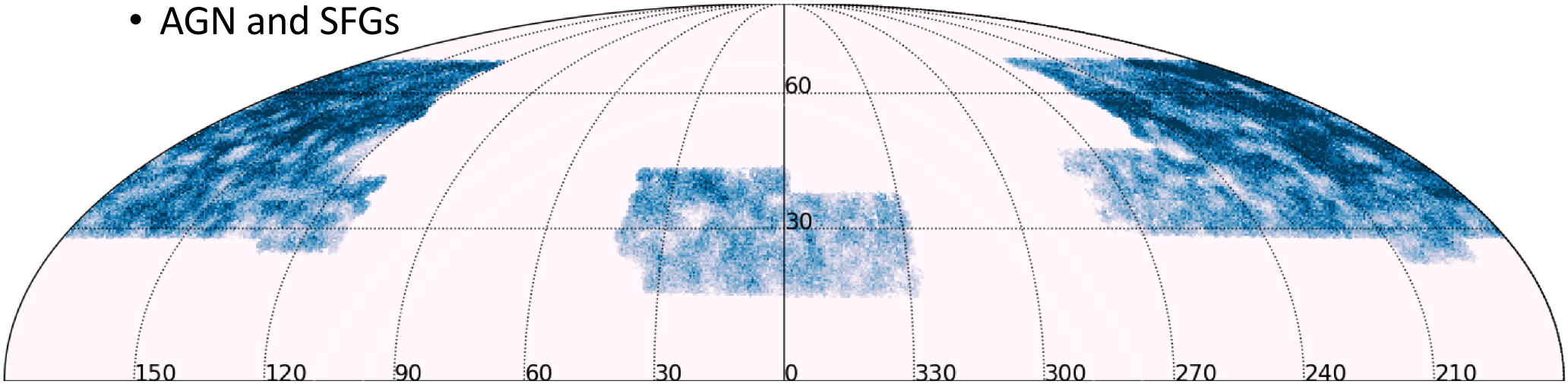
LOFAR Two-Metre Sky Survey (LoTSS-DR2)

Shimwell+ 2022

- Observations covering ~5,600 sq deg to ~0.1 mJy/beam RMS
- ~4 million sources observed
  - AGN and SFGs

Very non-uniform detection over the sky, not just with declination sensitivity!



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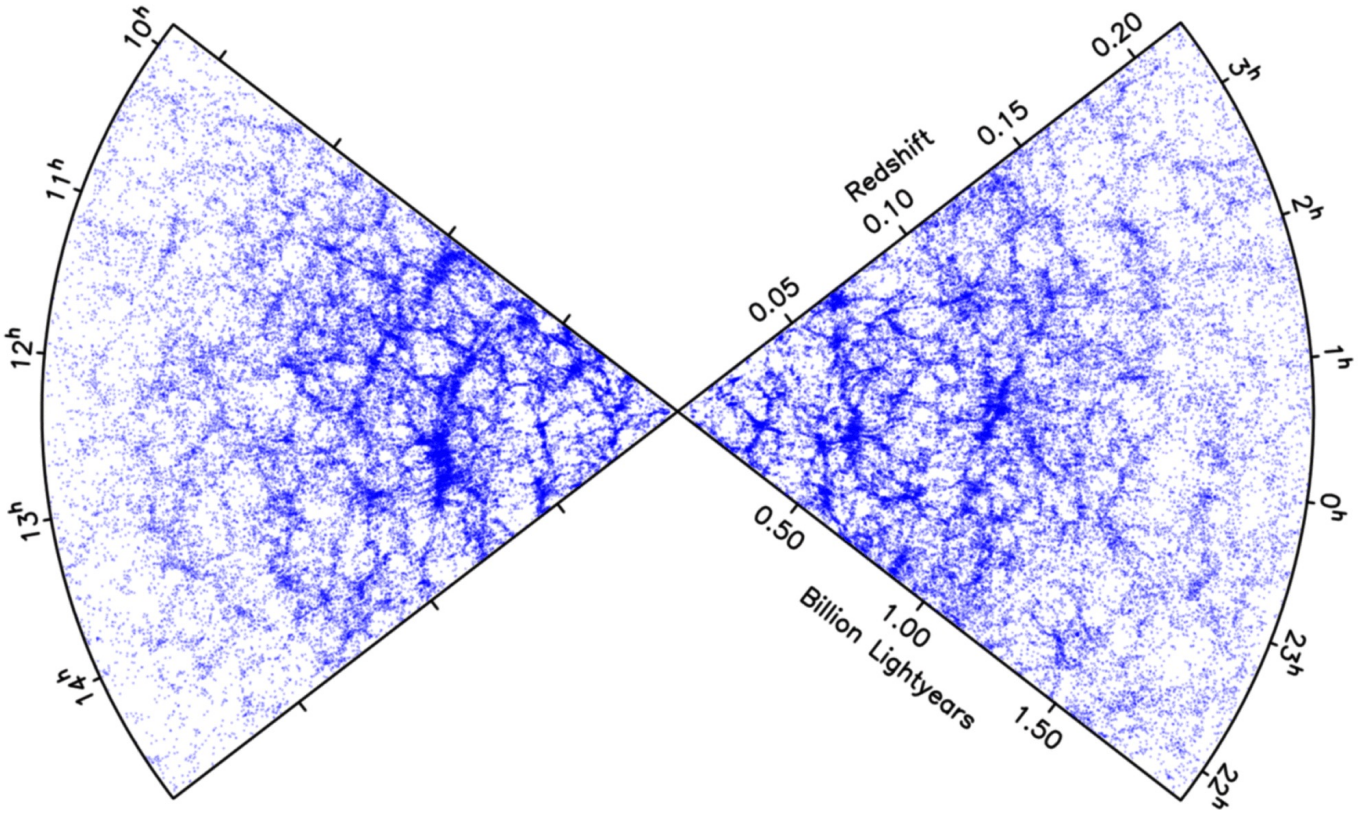
Cosmology Studies: Large-Scale Structure



2dF Galaxy Survey
Colless+ 2001

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Cosmology Studies: Angular Two-Point Correlation Function

- To look at large-scale structure can investigate the angular two-point correlation function (TPCF)
- TPCF investigates excess clustering of galaxies to if uniformly distributed in the Universe

See e.g. Peebles 1980

Cosmology Studies: Angular Two-Point Correlation Function

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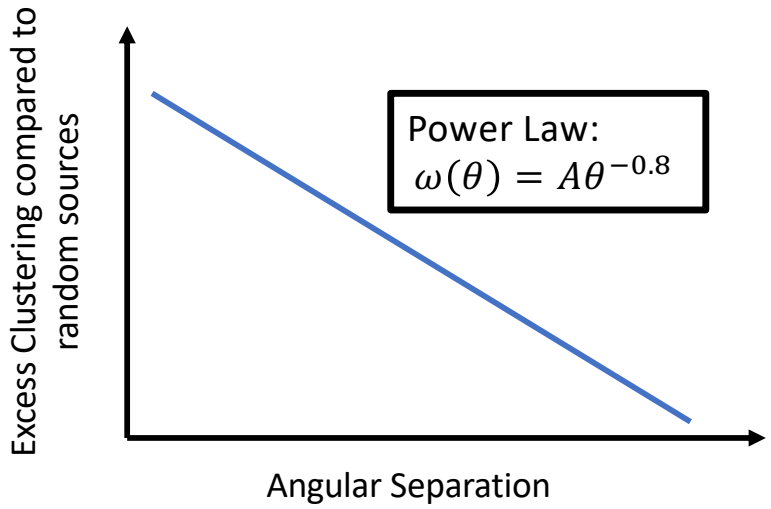
Whilst there is redshift information for some sources, these are typically photometric and only for a fraction of LoTSS sources

See e.g. Peebles 1980

Cosmology Studies: Angular Two-Point Correlation Function

- To look at large-scale structure can investigate the angular two-point correlation function (TPCF)
- TPCF investigates excess clustering of galaxies to if uniformly distributed in the Universe
- We use: $\omega(\theta) = \frac{DD(\theta) + RR(\theta) - 2DR(\theta)}{RR(\theta)}$ from Landy & Szalay 1993

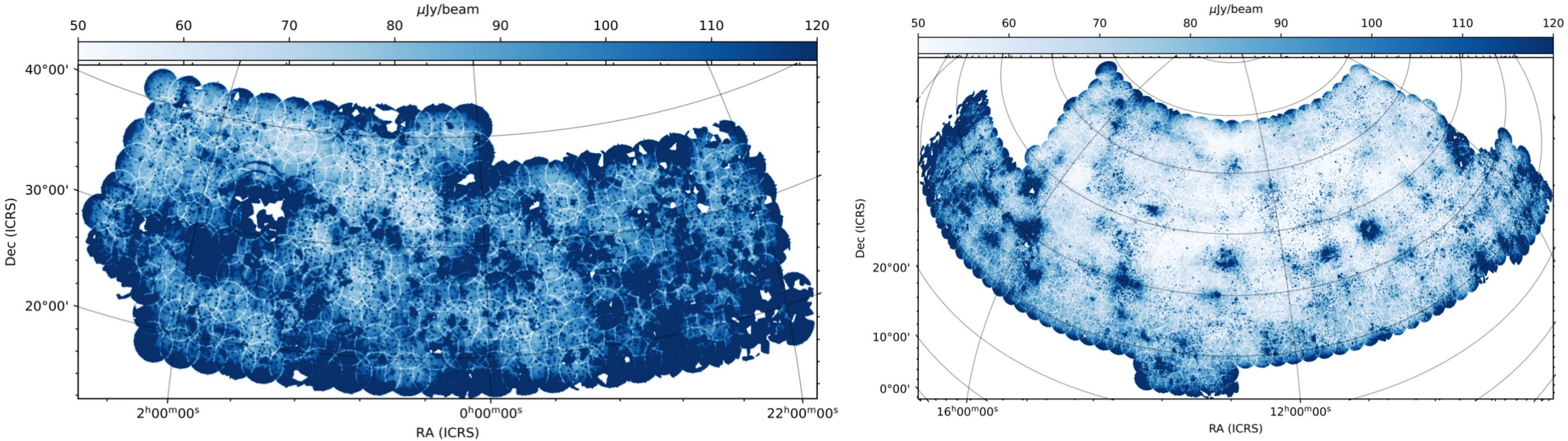


Using normalised number of galaxy pairs in data (randoms or data-to-randoms) in an angular separation

See e.g. Peebles 1980

Simulated Random Catalogues

Sensitivity variations



Shimwell+ 2022

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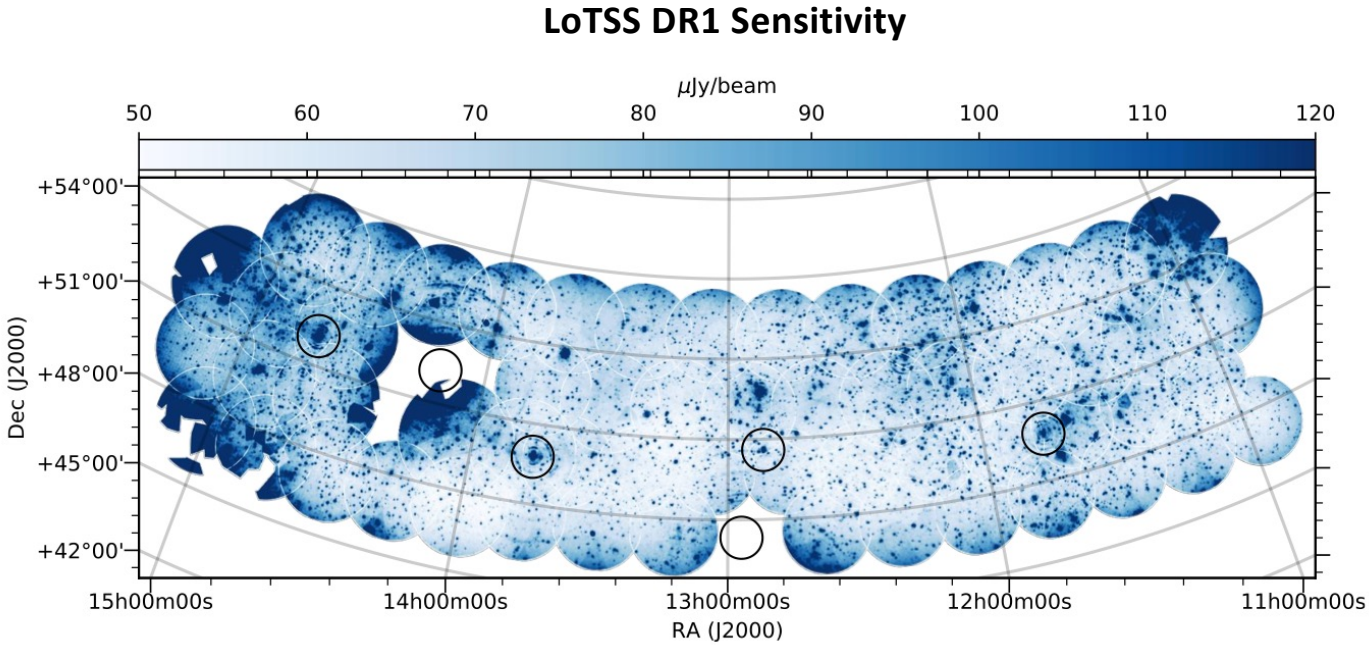
Simulated Random Catalogue – DR1 Prescription



Method used:

1) Generate randoms sources across the field of view
2) Find RMS at given source location
3) Assign a random flux density from simulated catalogues
4) From RMS generate a random noise value
5) If Noise + Flux >= 5 x RMS keep the random source

Shimwell+ 2019

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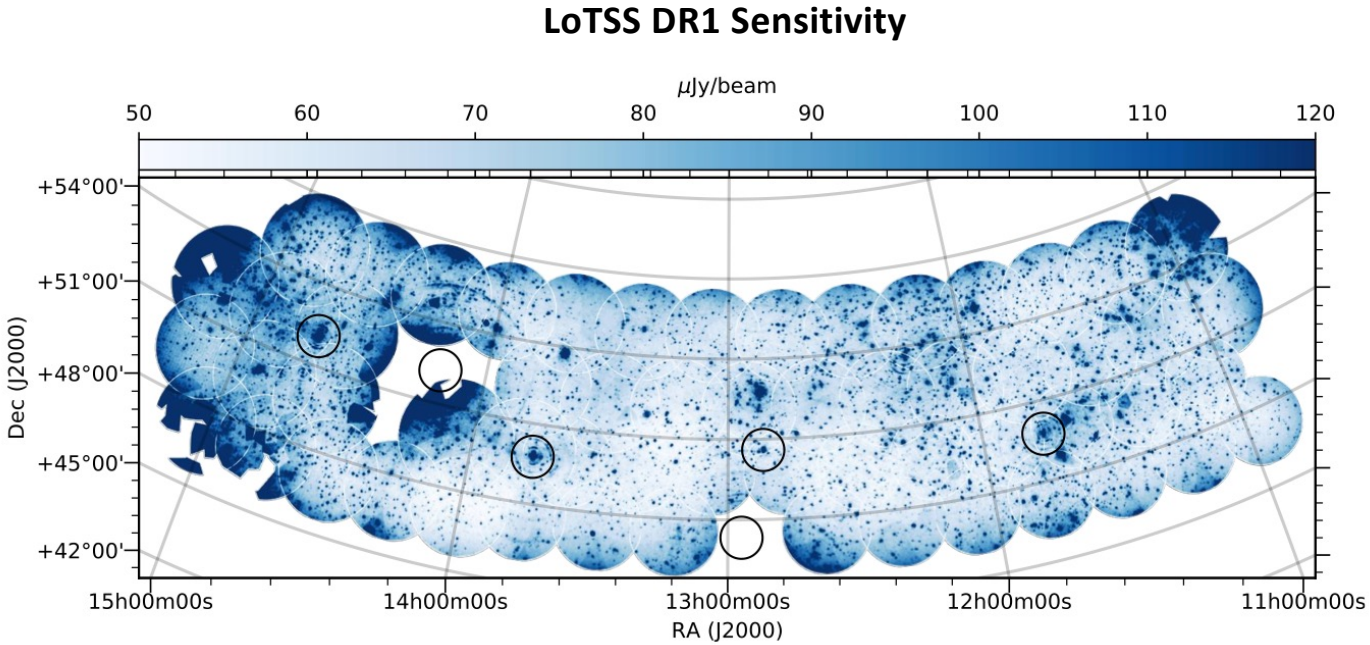

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Limitations:

- Not 100% complete at 5σ
- Sources are resolved (not point like)
- PyBDSF has measurement errors
- Smearing occurs across the field of view

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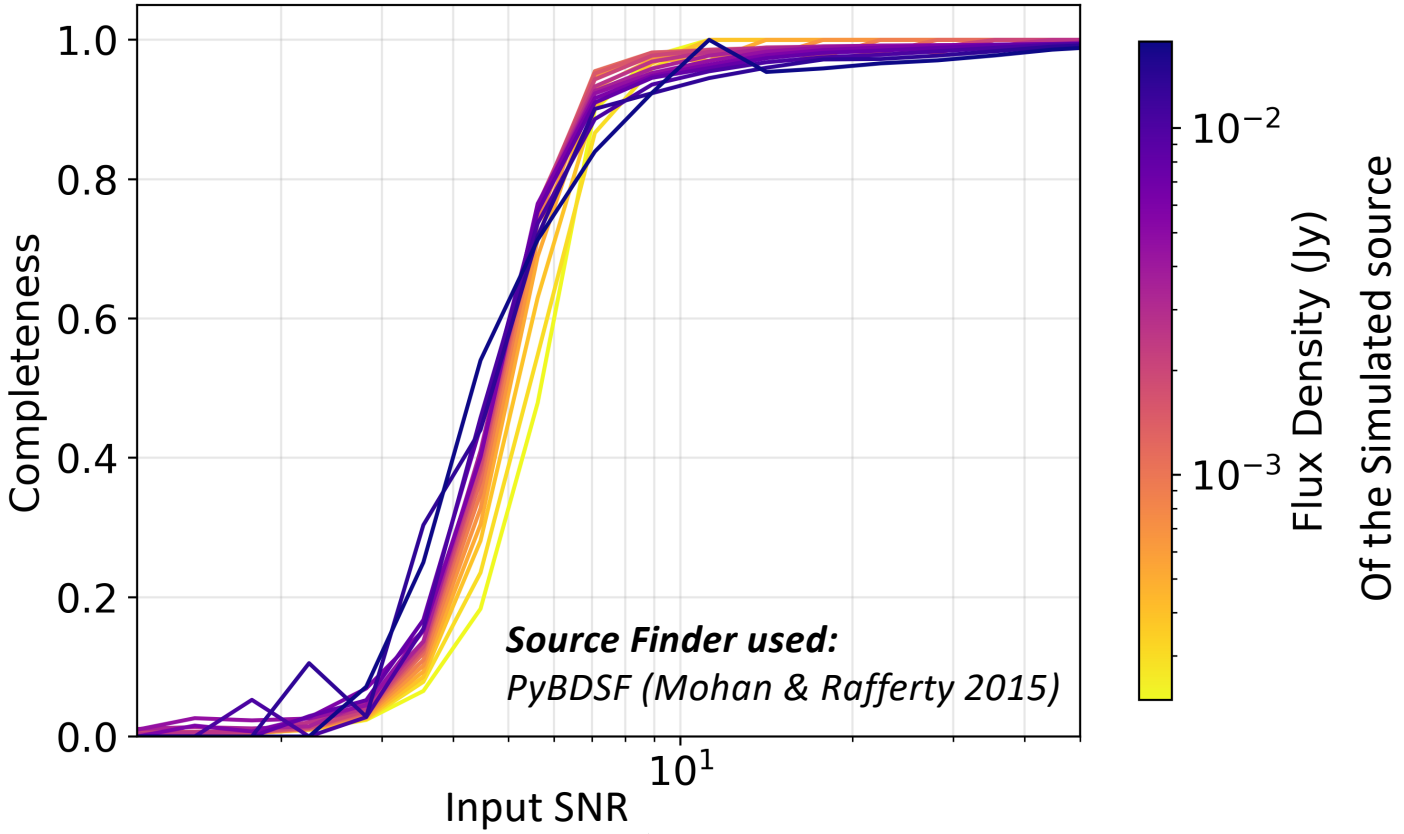
Simulations from Shimwell+ 2022

- Shimwell+ 2022 run a number of simulations where **sources** were **injected** into the image
- These have source **sizes** based on the **clean component models** from the LoTSS catalogues and fluxes based off source counts from **deeper LOFAR data** (Mandal+ 2022)
- But:
  - Number in each field **not distributed uniformly** across the sky (i.e. not constant in cos(dec)
  - **Source sizes** affected by **incompleteness**
  - **Smearing** effects not propagated across image

Simulated Random Catalogues



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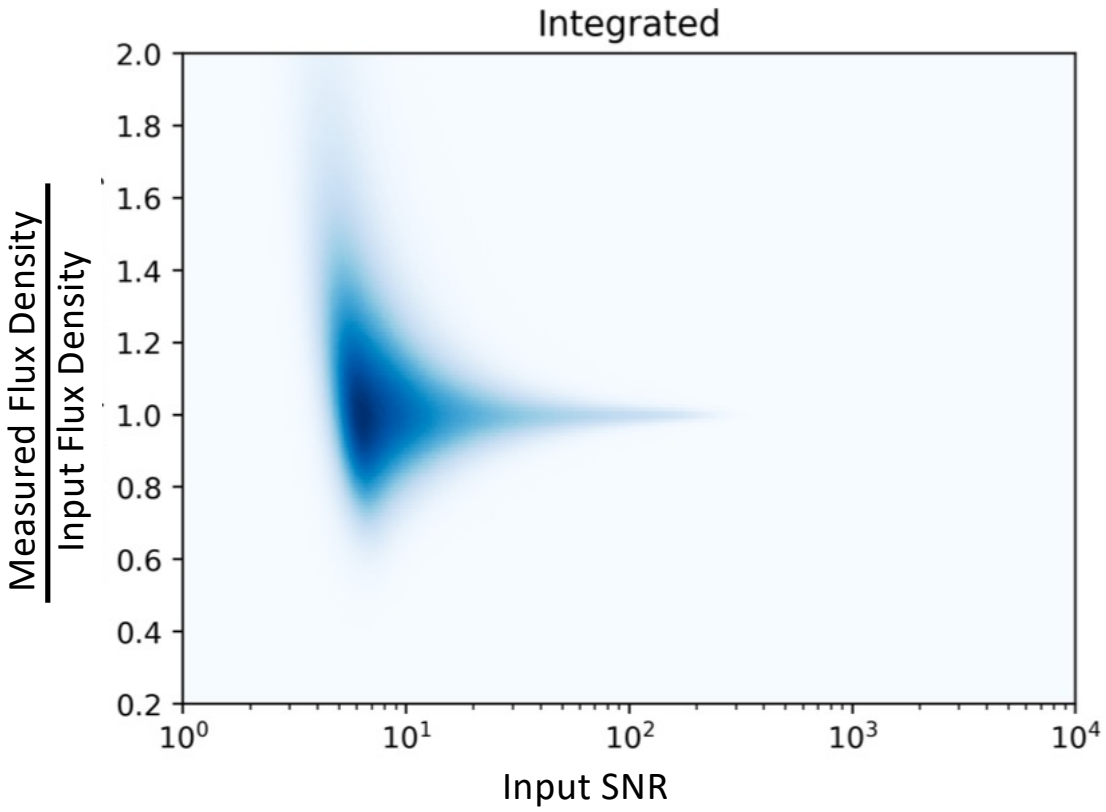
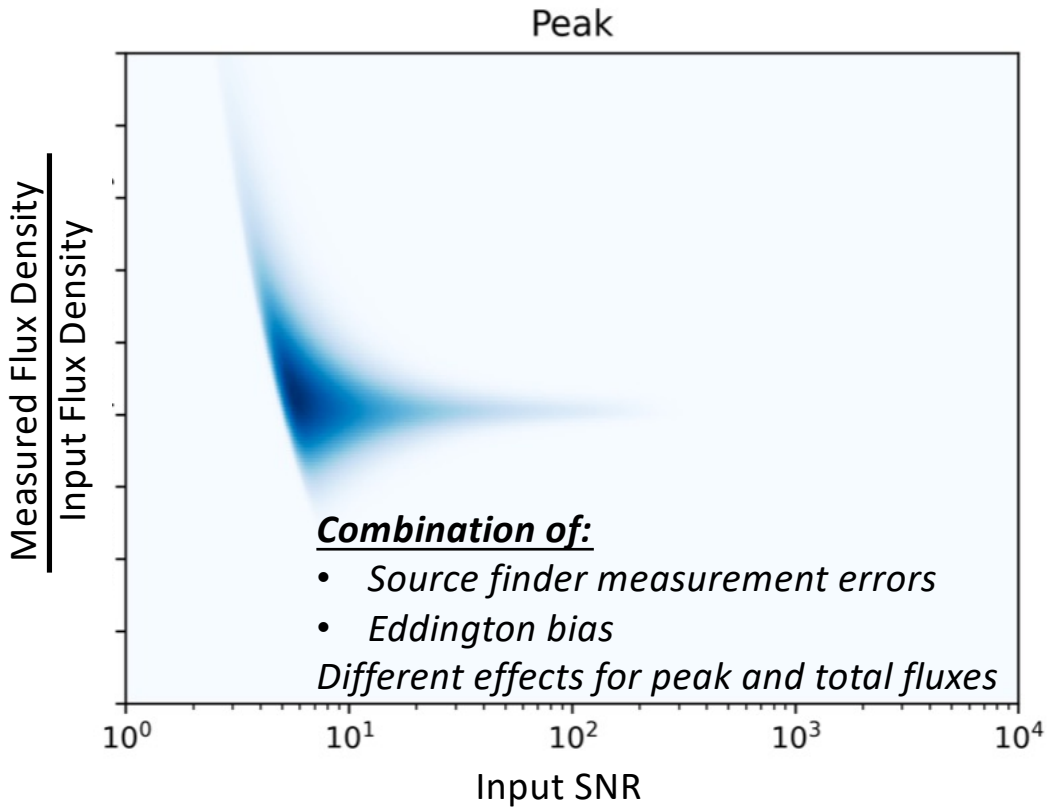
Simulated Random Catalogues





Combination of:

- *Source finder measurement errors*
- *Eddington bias*

Different effects for peak and total fluxes

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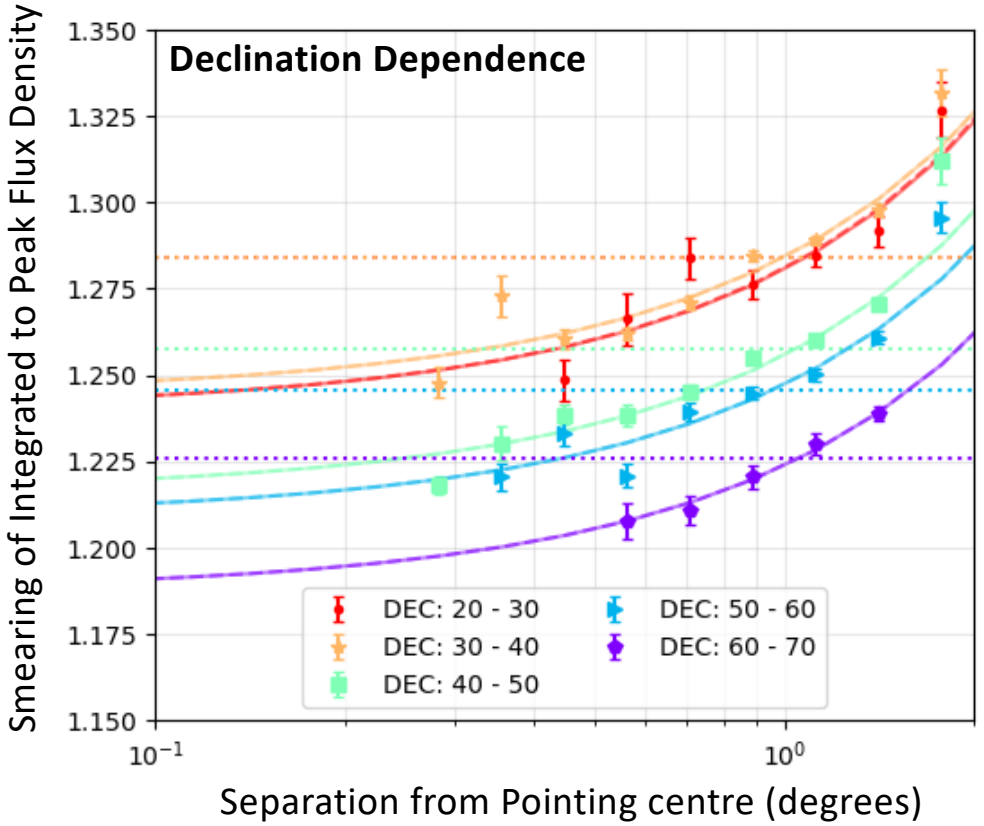
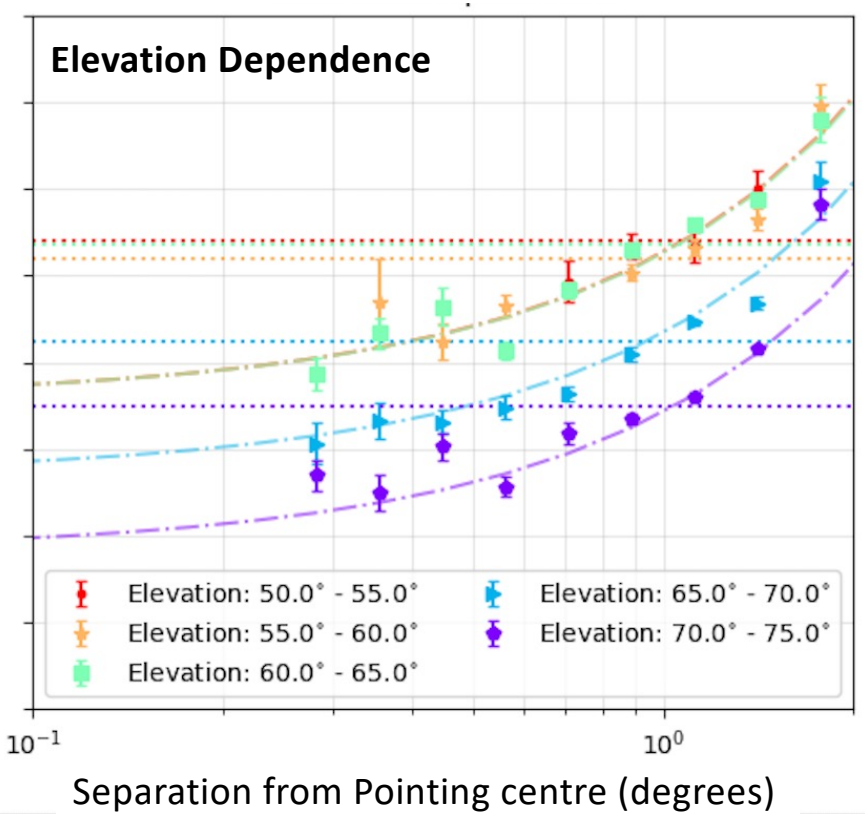
Simulated Random Catalogues





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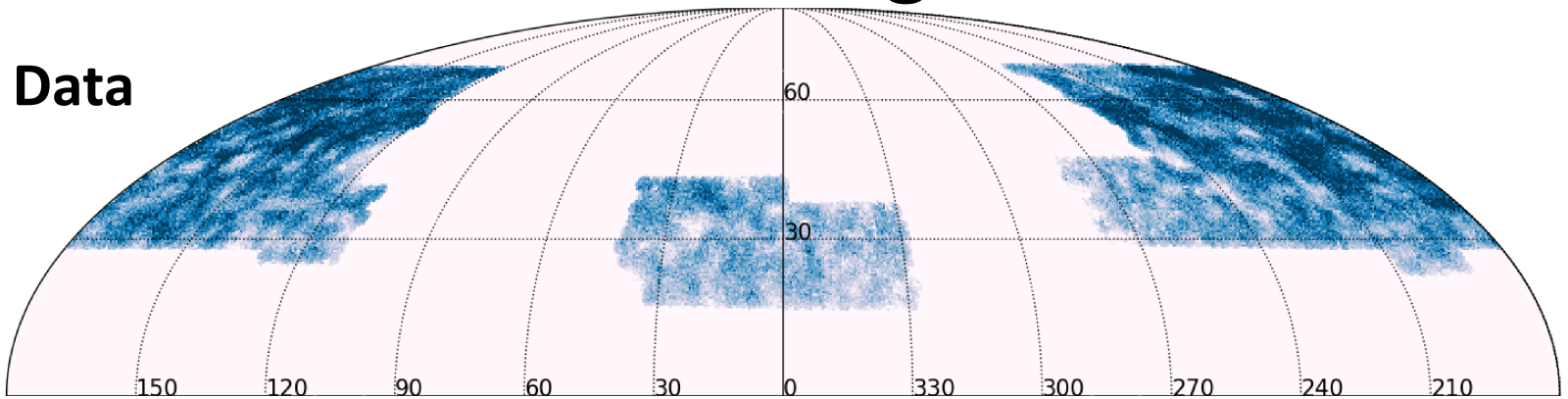
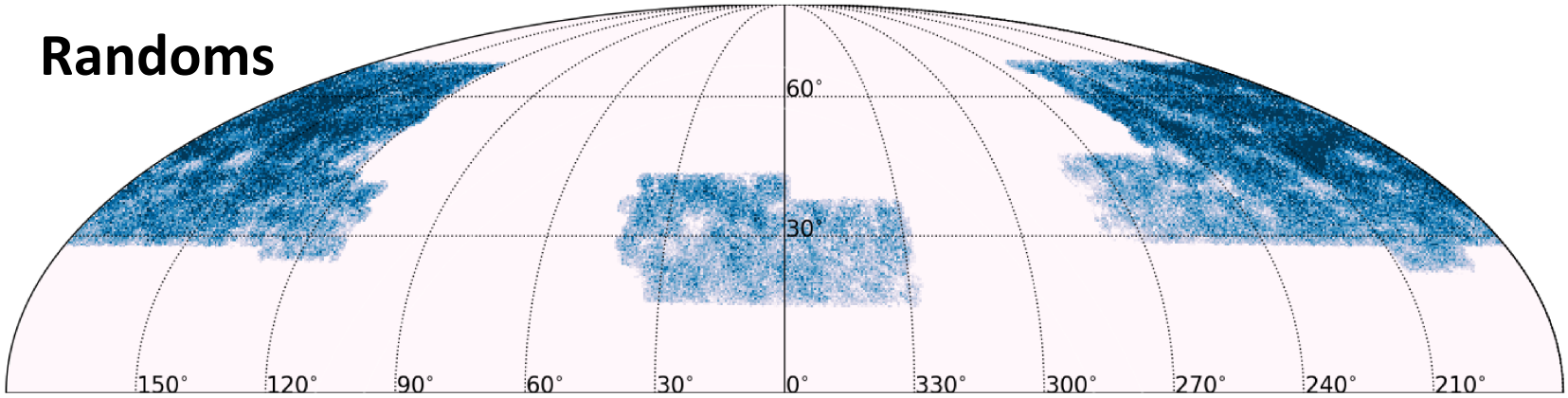
Simulated Random Catalogues

Data



Randoms



Work in progress

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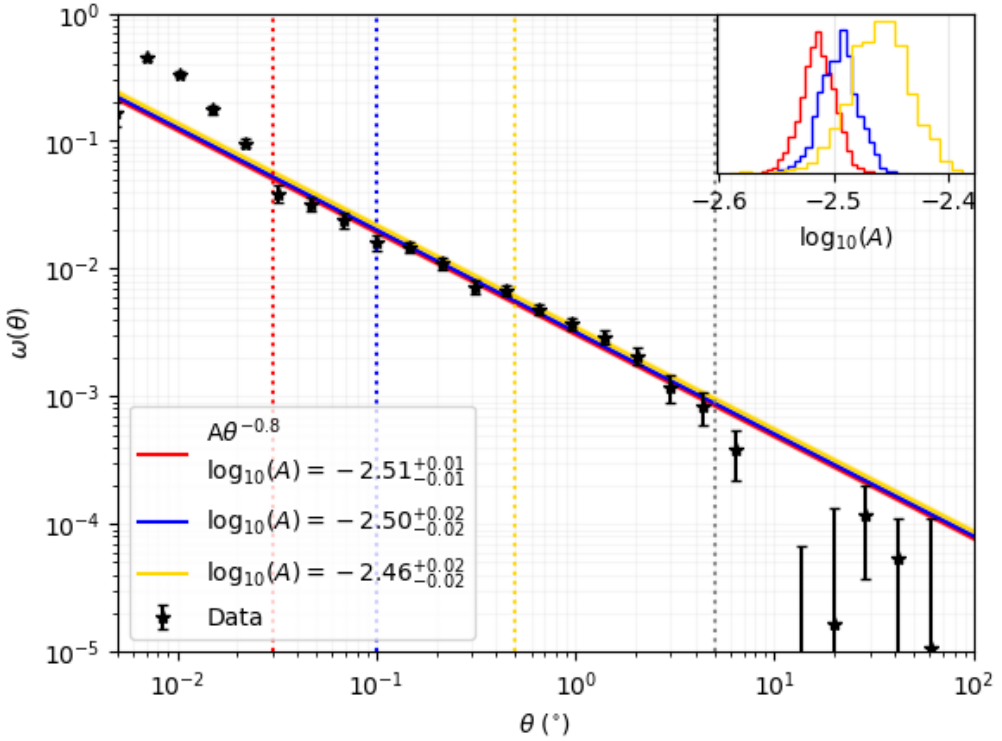
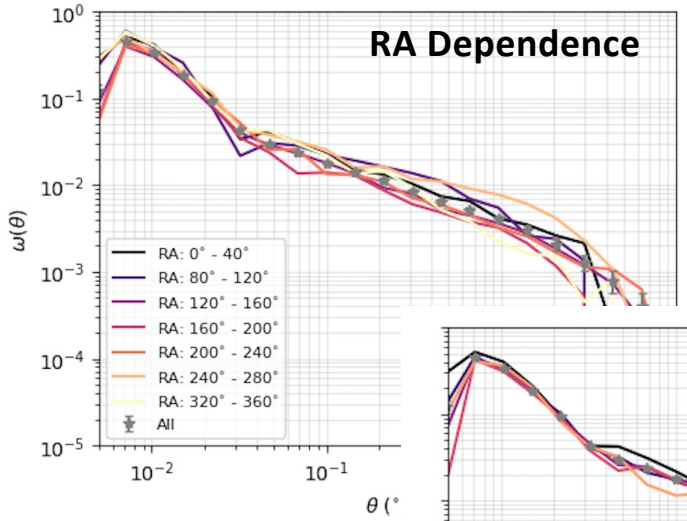
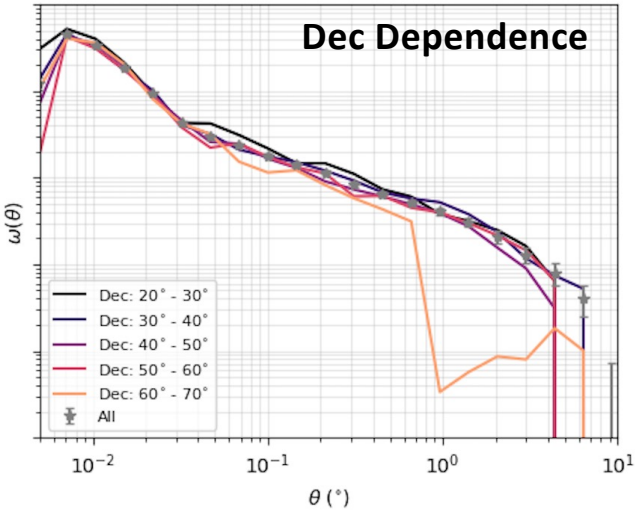
Angular Two-Point Correlation Function

Sources: >1.5 mJy, >7.5 SNR; Inner region







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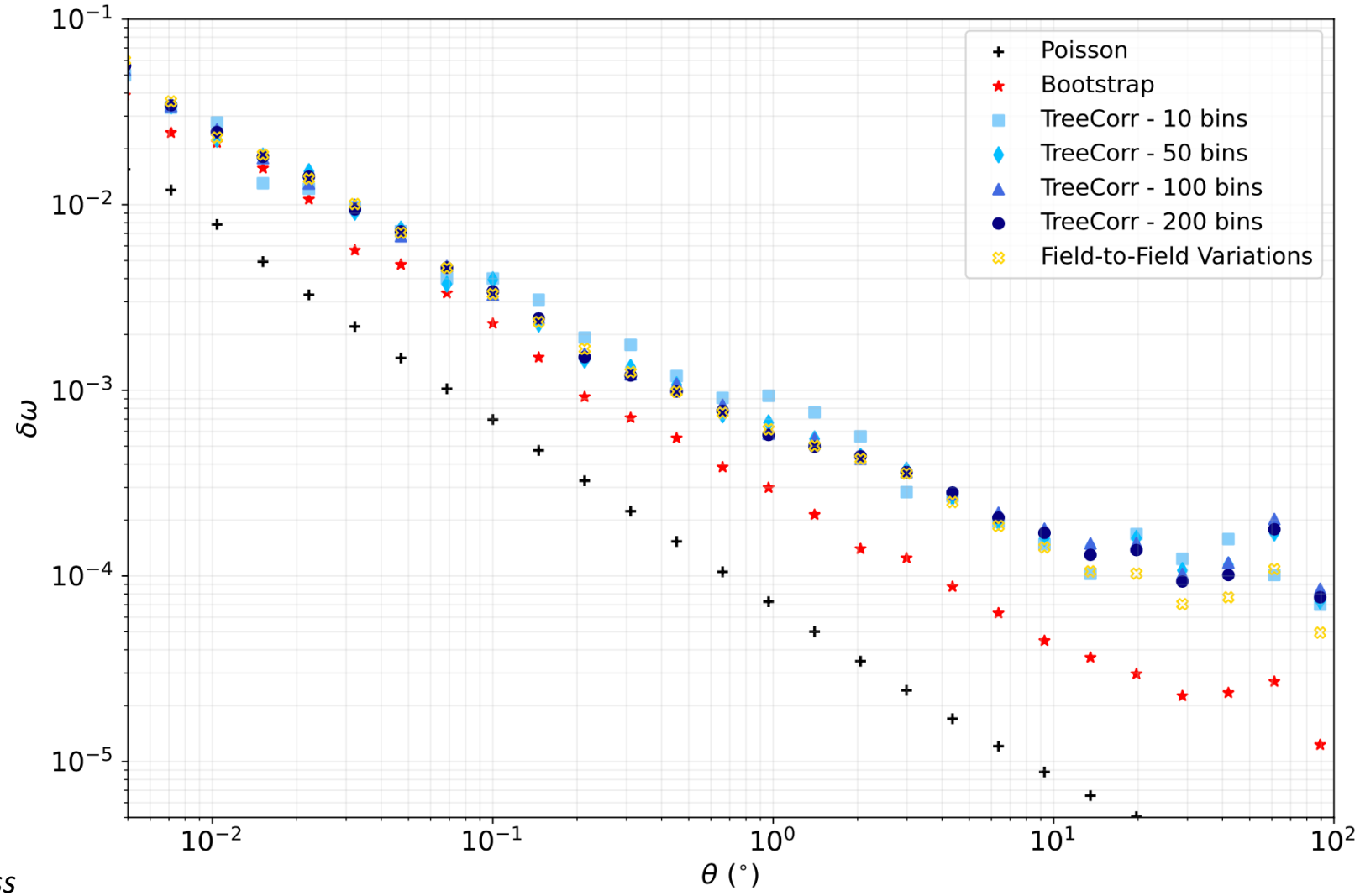

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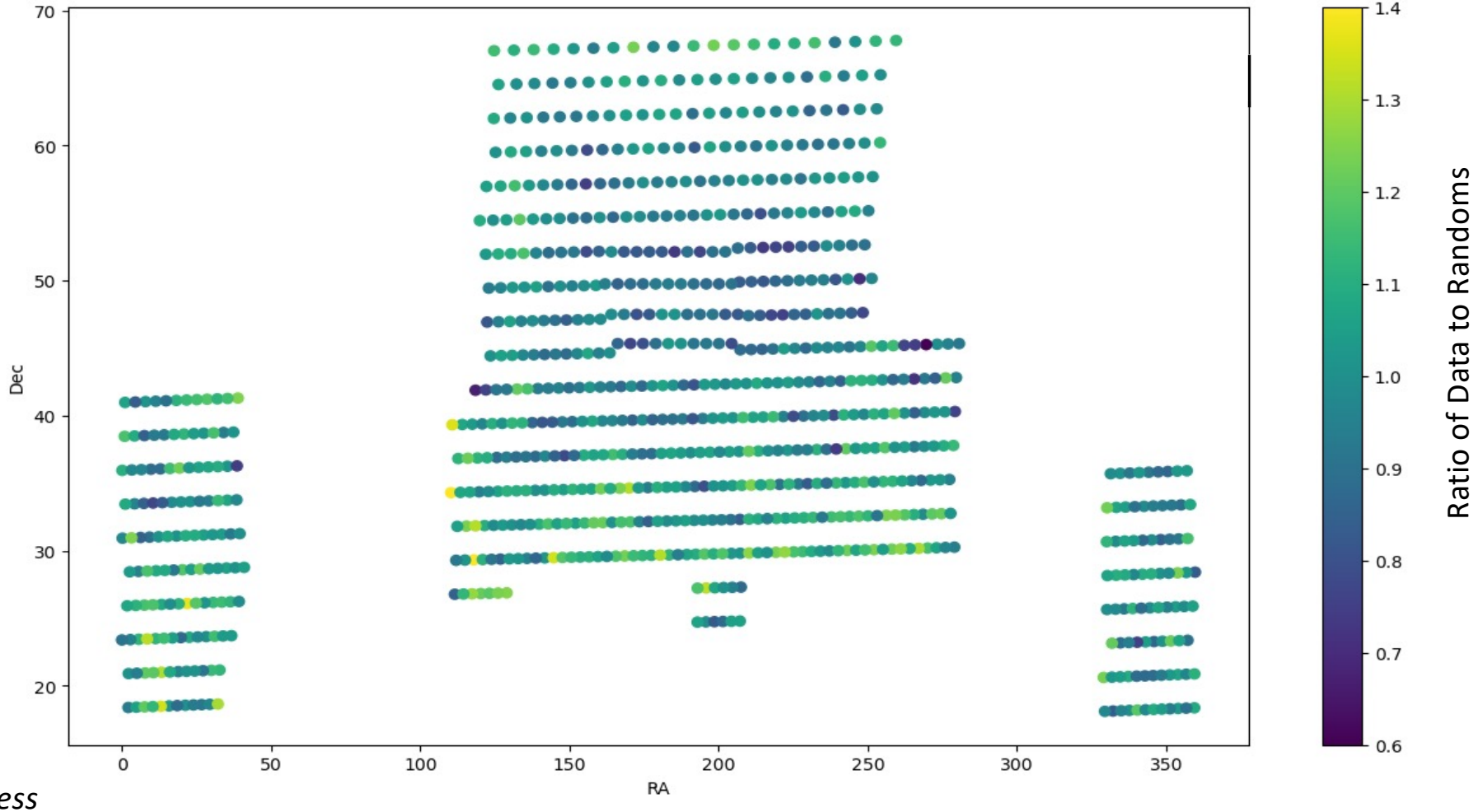

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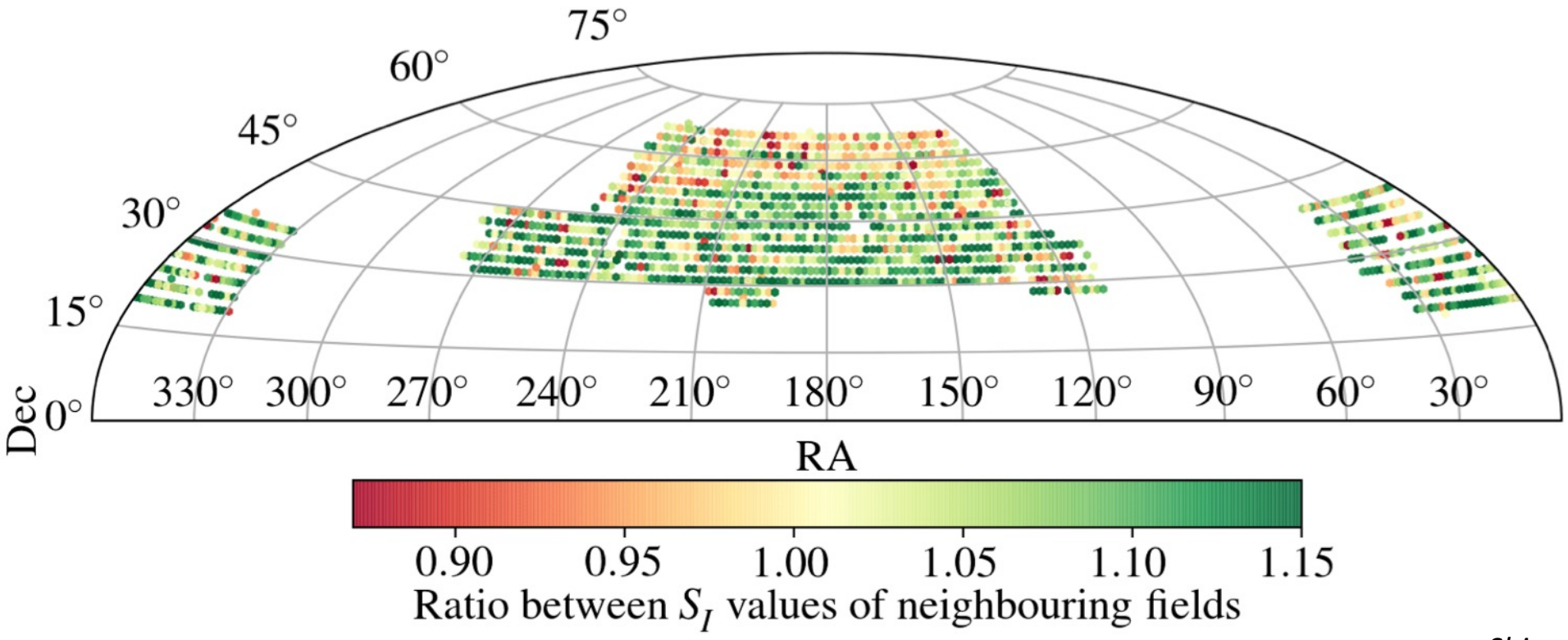
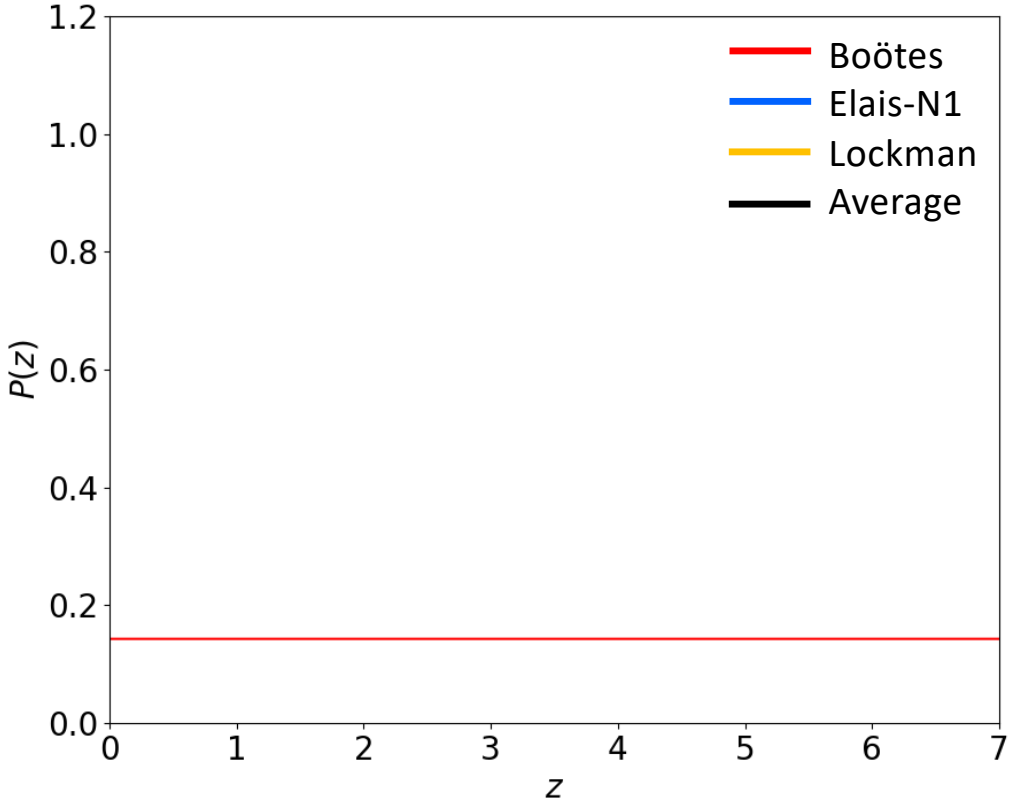
Field-to-Field Variations



Shimwell+ 2022

Redshift Distributions

- Need to use knowledge of the redshift distribution to relate the projected angular clustering to 3D distribution
- Make use of LOFAR Deep Fields:
  - 3 Well studied fields
  - RMS depth of ~30 uJy/beam
- Build up P(z) based on sources above flux cut
- Use weighted average across three fields



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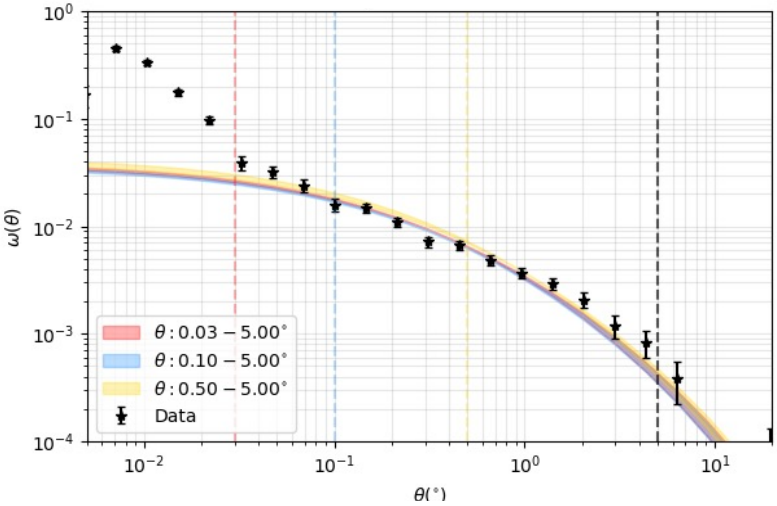
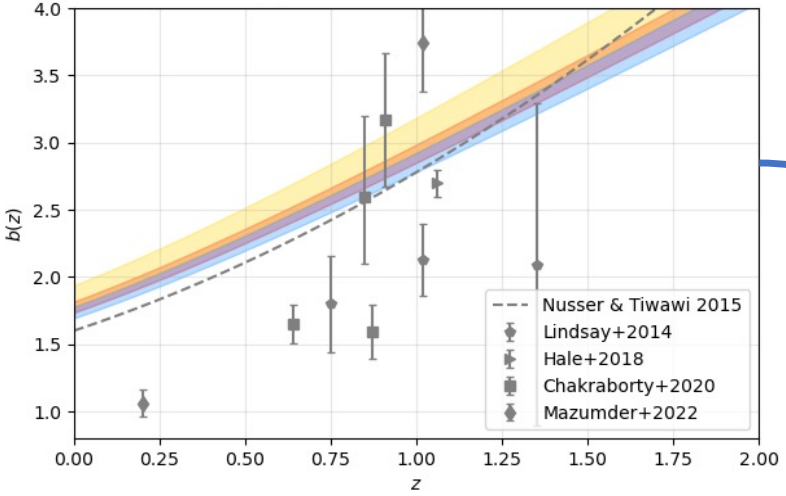
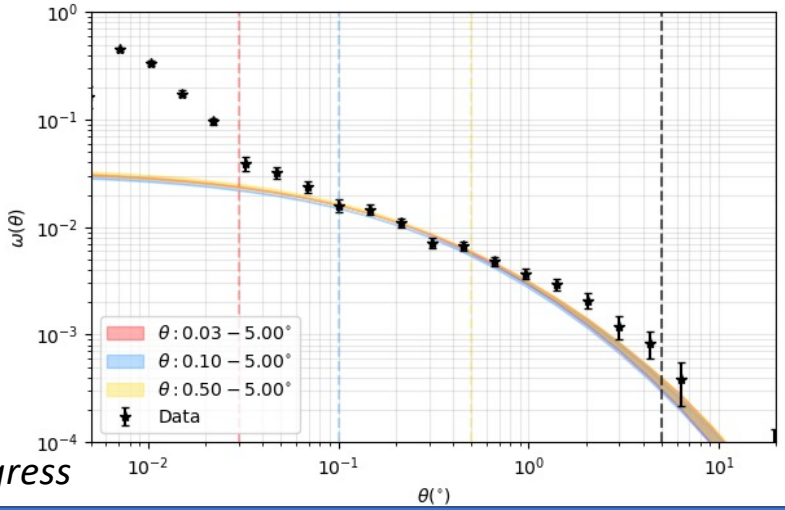
TPCF Fitting - Diagonal errors only



Bias Evolutionary Models



TPCF Fitting - Using Covariance array



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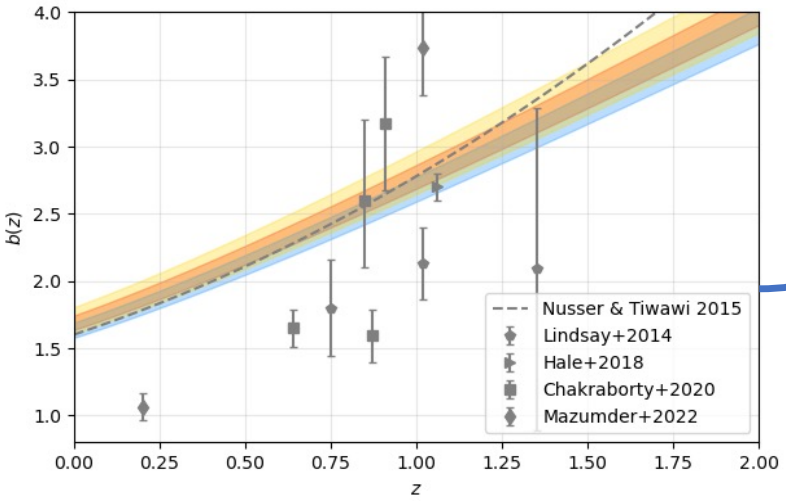

Can also be used to infer about the dark matter haloes hosting sources

Work in progress

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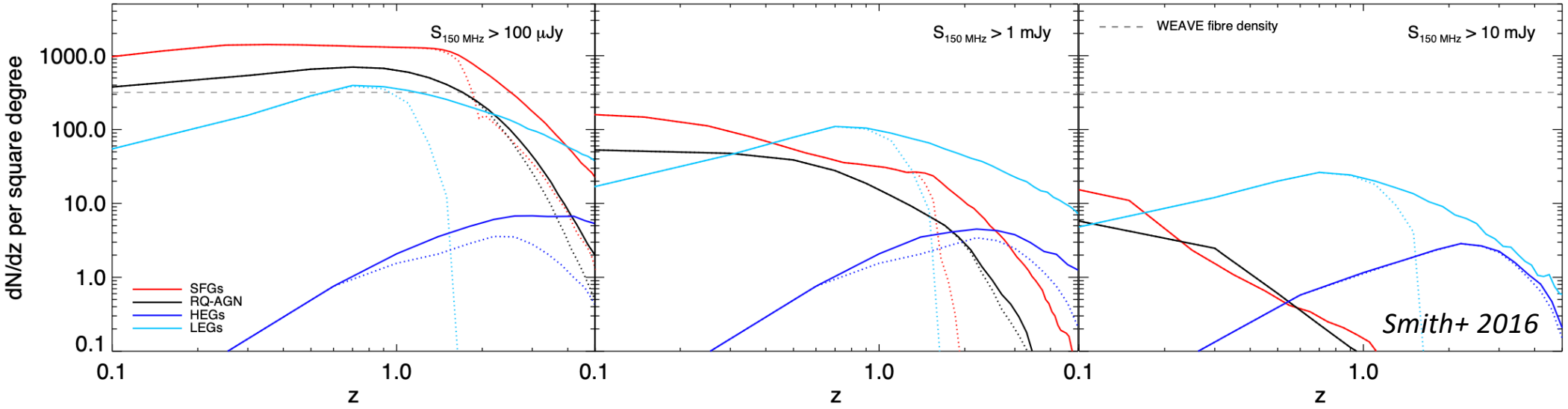
WEAVE-LOFAR

Solid lines = Predicted numbers
Dotted lines = Expected numbers



Should have large, complete spectroscopic samples to z~1

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Summary

- We have a number of large **radio** surveys, suitable for **cosmology** studies
- **LoTSS DR2** (Shimwell+ 2022) is a **large area, deep, low frequency survey** - useful for cosmology studies
- Covers ~5600 sq deg to an rms depth of ~ 80-100 uJy/beam
- **Angular clustering** allows us to look at projected LSS, but:
  - Lots of **observational systematics** in radio data which need accounting for:
    - **Source finder** measurement/detection errors
    - **Sensitivity** variations
    - Observational **smearing**
  - **Substantial** time spent improving this analysis from DR1
- We have measured the angular clustering of LoTSS DR2 sources and used this to establish bias models for radio sources
- Future LoTSS + WEAVE-LOFAR + Deep Fields will transform radio cosmology measurements