Images from Shimwell+ 2019

Continuum cosmology studies from LOFAR:

Results and lessons learned for the SKAO

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University of Oxford

On behalf of members in the LOFAR Surveys Cosmology Team

Overview

- Summary of LOFAR Surveys:
  - **Wide Area:** LOFAR Two-metre Sky Survey (LoTSS)
  - **Deep Fields:** LoTSS-Deep

- Summary of **Cosmology Studies** with LOFAR

- **Challenges** identified from LOFAR Cosmology studies + **requirements** for cosmology with the **SKAO**:
  - Field variations
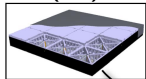 - Counterpart requirements
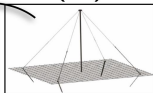 - Shape Information

The Low Frequency Array (LOFAR)

LOFAR is a telescope consisting of an array of **low frequency detectors** in **two observing bands:**

- **low** band (**10-90 MHz**)
- **high** band (**110 – 240MHz**)

Detectors consist of a **dense core** of stations in the **Netherlands** (the **Superterp**) alongside further stations spread across the **Netherlands** and more widely across **Europe**.
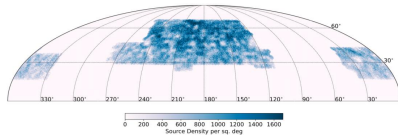
Credit: LOFAR/ASTRON

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LOFAR Surveys

Large Area Surveys

see Shimwell + 2017, 2019, 2022

8 hour pointings across the northern hemisphere
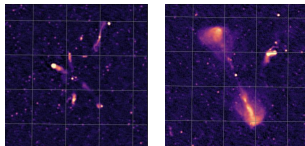
rms ~80-100 uJy/beam at 144 MHz

Credit: Hale+2023

Deep Field Surveys

see Tasse+ 2021, Sabater+ 2021, Bondi+ 2024, Shimwell+ in prep

70+ hour observations across four fields

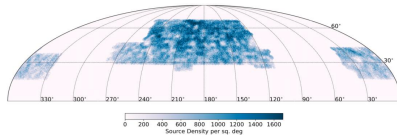rms ~30-60 uJy/beam at 144 MHz

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LOFAR Surveys

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Current data release is **data release 2** (DR2) from Shimwell+ 2022 covering **~ 5600 sq deg** across **two large contiguous fields**.
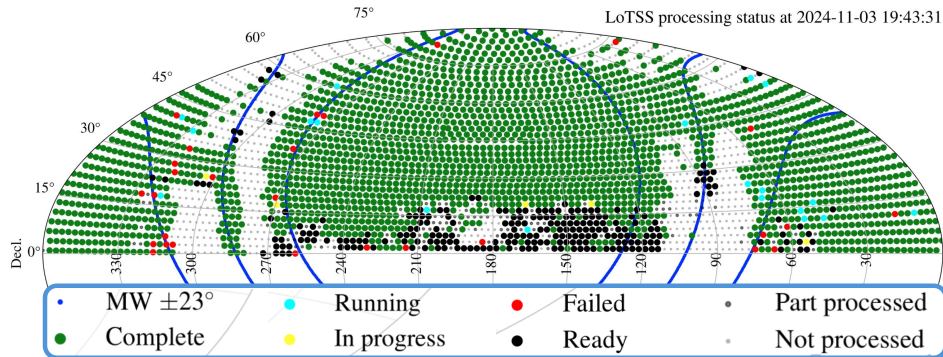
Contains **~4 million sources** across the sky

Coverage varies across the sky with **sensitivity variations** due to combination of: **elevation** effects, **bright** sources, **data reduction** effects

Will eventually cover majority of the northern sky – majority of observations now taken and processed.

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LOFAR Surveys

LoTSS processing status at 2024-11-03 19:43:31

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LOFAR Surveys

Field	Obs. Time (hr)	Area^{full} (deg^2)	N_S^{raw}	σ_{med}^{full} (μJy beam^{-1})
LH	112	25.0	50112	42
Boo	80	26.5	36767	60
EN1	164	24.3	69954	33
				Mandal+ 2021
NEP	72	~20	~23000	30-40
				Bondi+ 2024

+ **Cross-matching** to **host galaxies** through likelihood ratios and Galaxy Zoo
(Kondapally+ 2021)

+ **Redshifts** from photometric template fitting and machine learning (Duncan+ 2021)

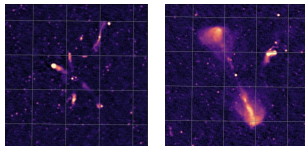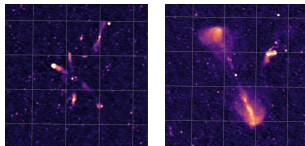+ **Source Classification** into source types (Best+ 2023)

All fields except for NEP

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see Tasse+ 2021, Sabater+ 2021, Bondi+ 2024, Shimwell+ in prep

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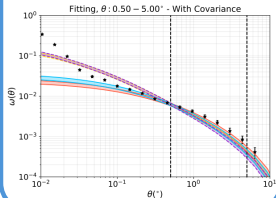**+ Plans to go deeper – 500h observations coming soon!**

Cosmology Studies with LoTSS

Cosmology Studies with LoTSS Wide

Auto-correlation
Hale+ 2023

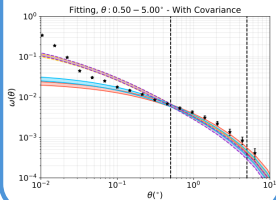Angular clustering + bias evolution

Cosmology Studies with LoTSS Wide
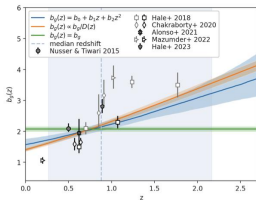

Auto-correlation
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Angular clustering + bias evolution

Cross-correlation
Nakoneczny + 2023

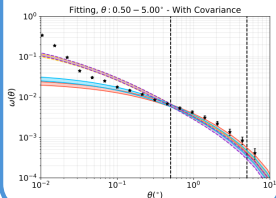Cross-correlation with CMB lensing + bias evolution

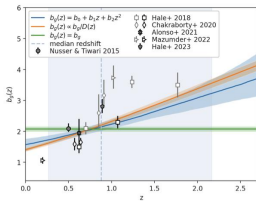# Cosmology Studies with LoTSS Wide

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Hale+ 2023

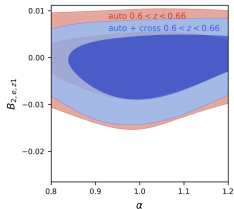Angular clustering + bias evolution

Cross-correlation
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Cross-correlation with CMB lensing + bias evolution

Cross-correlation
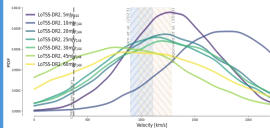Zheng + subm

Cross-correlation with eBOSS LRGs + bias evolution

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Cosmology Studies with LoTSS Wide

Dipole Studies
Böhme+ in prep

Dipole measurement + comparisons to other surveys and the CMB

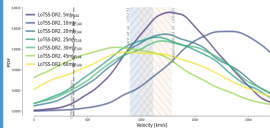catherine.hale@physics.ox.ac.uk

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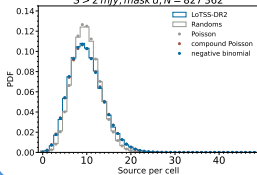Dipole measurement + comparisons to other surveys and the CMB

One-Point Statistics
Pashapour-Ahmadabadi + subm

One-Point statistics to consider the process to generate sources
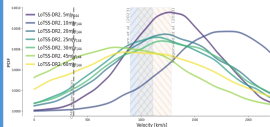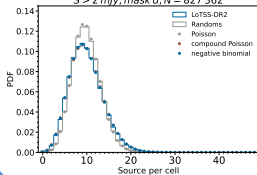
$S > 2\ mJy$, mask d, $N = 827\ 362$

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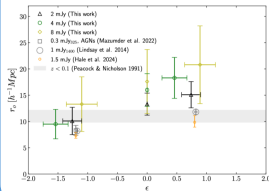One-Point statistics to consider the process to generate sources

$S > 2 \, mJy, \, mask \, d, \, N = 827 \, 362$

Flux-Dependent Clustering
Bhardwaj + 2024

Clustering length dependency on flux density cuts
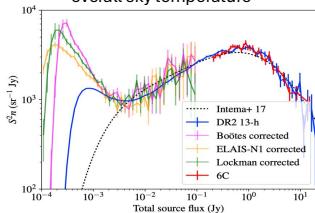
catherine.hale@physics.ox.ac.uk

Cosmology Studies with LoTSS Deep

Sky Temperature Background
Hardcastle+ 2023

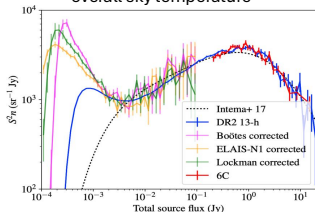Contribution of radio detected sources to the overall sky temperature

Cosmology Studies with LoTSS Deep

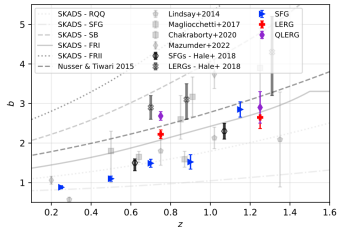## Sky Temperature Background

Hardcastle+ 2023

Contribution of radio detected sources to the overall sky temperature

Source Dependent Bias Evolution

Hale+ in prep
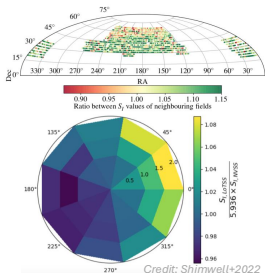
Bias evolution for SFGs and AGN seperately

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Challenges with LOFAR + lessons for SKAO

Completeness Effects

Field Variations across the Sky
Sensitivity variations + flux calibration offsets between fields

Credit: Shimwell+2022

Variations across pointings
Elevation dependent smearing
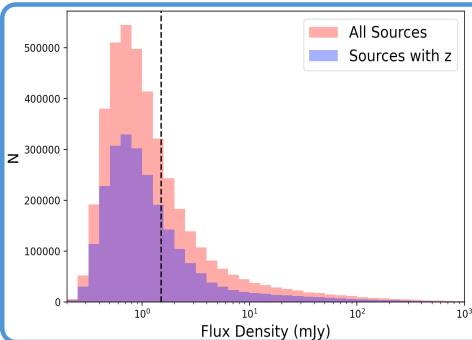
Source Finding Challenges
Incompleteness challenges + measurement errors + differences between source finders
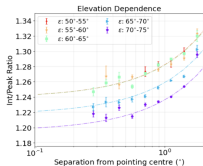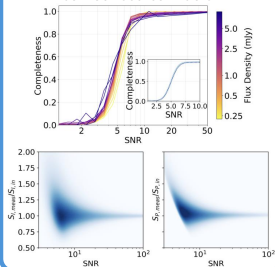
+ e.g. ionospheric effects for SKA-LOW

+ Biases from data reduction processes

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Multi-Wavelength Counterparts

For LoTSS-Wide, cross-matched catalogue from Hardcastle+ 2023 provides **hosts** and **redshifts** for **~50-60%** of sources.

Cannot split into **source populations** needed for **multi-tracer** techniques or into **redshift** ranges
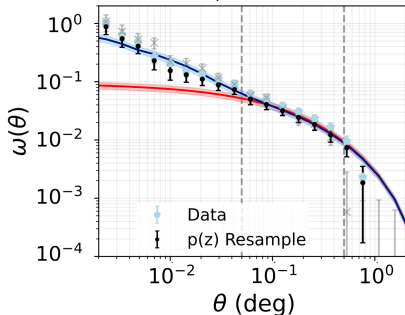
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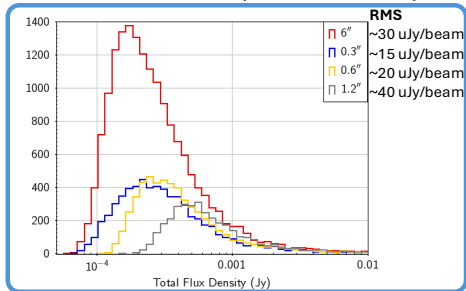
Also need to account for the **uncertainties** associated with **classifications** and **redshift** modelling to accurately **trace source populations**

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Source Shape Information

Morabito+ 2022
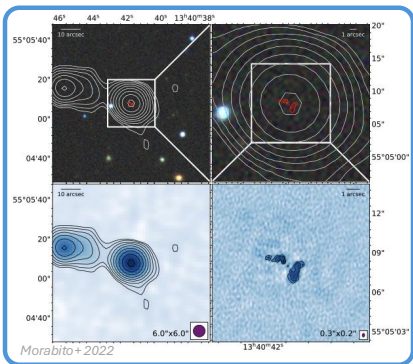
LoTSS High Res observes at resolutions the SKAO could reach.

Introduces **challenges** of **resolution bias** and **baseline effects** and so **accurate source shape/size** information is key.

RMS	
6″	~30 uJy/beam
0.3″	~15 uJy/beam
0.6″	~20 uJy/beam
1.2″	~40 uJy/beam

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Summary

- LOFAR has provided **excellent radio surveys** to test cosmology with radio surveys from both **small** and **wide areas**

- Allows good **indications** of **challenges** we can expect for **SKAO** (especially Low)

- LOFAR Surveys cosmology team have done a **number** of **cosmological studies** to probe e.g. bias evolution, cosmological parameters, the cosmic dipole

- However, LOFAR surveys have also identified a number of **challenges** which we need to know how to overcome for the **SKAO** to be able to use such surveys to their **maximal capacity**

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