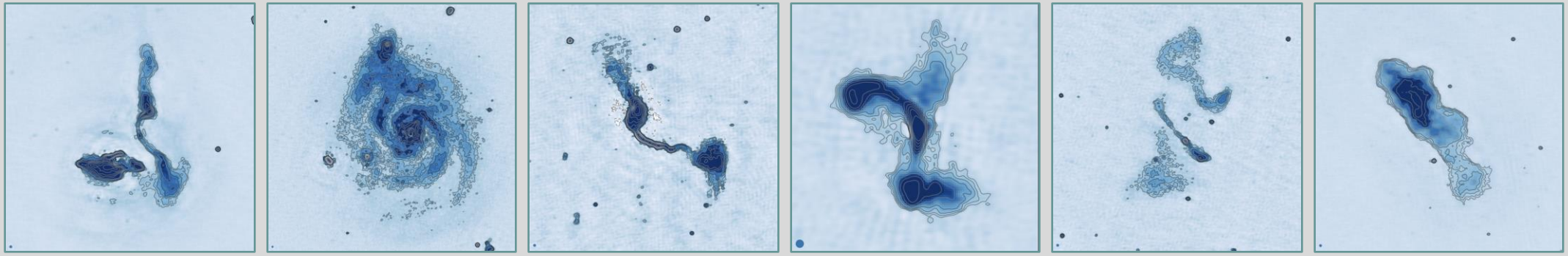
UNIVERSITÄT BIELEFELD
Faculty of Physics

On behalf of the LOFAR Surveys Cosmology Team
Notably: C. Hale, S. Nakoneczny, J. Zheng, M. Pashapour-Ahmadabadi

LOFAR ERIC

Cosmology with LOFAR Sky Surveys

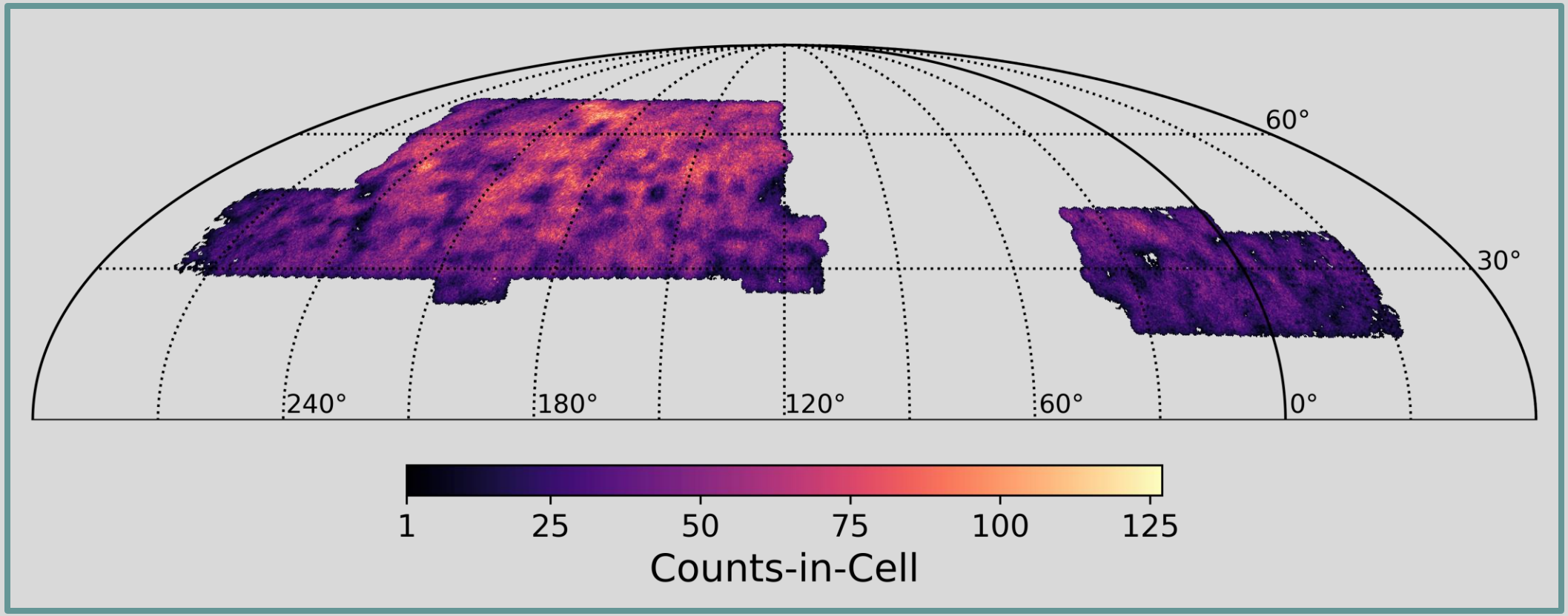


Images from Shimwell+ 2019

Lukas Böhme

LoTSS Data Release 2 (Shimwell+ 2022):

- 5600 sq. degrees
- ~4 million sources
- ~70-100 μJy/beam rms
- 144 MHz observations
- 6” resolution
- ~8-hour pointings



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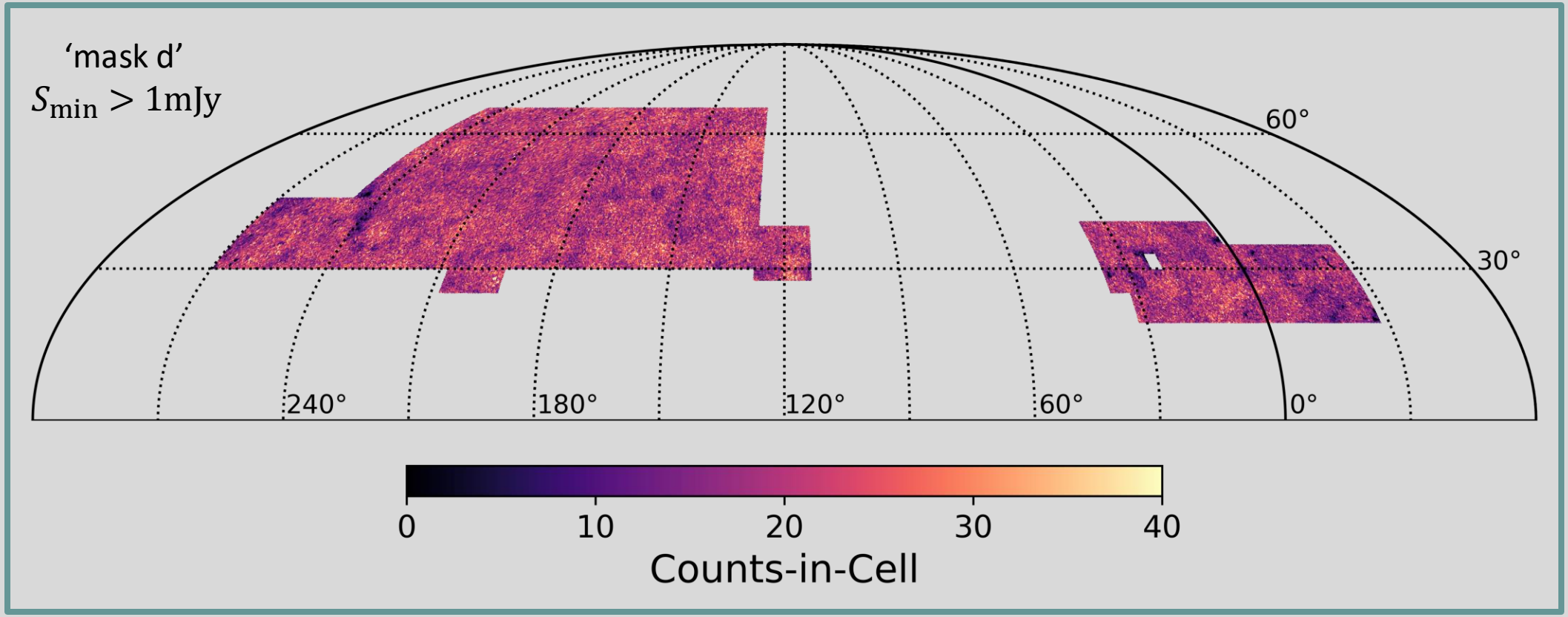
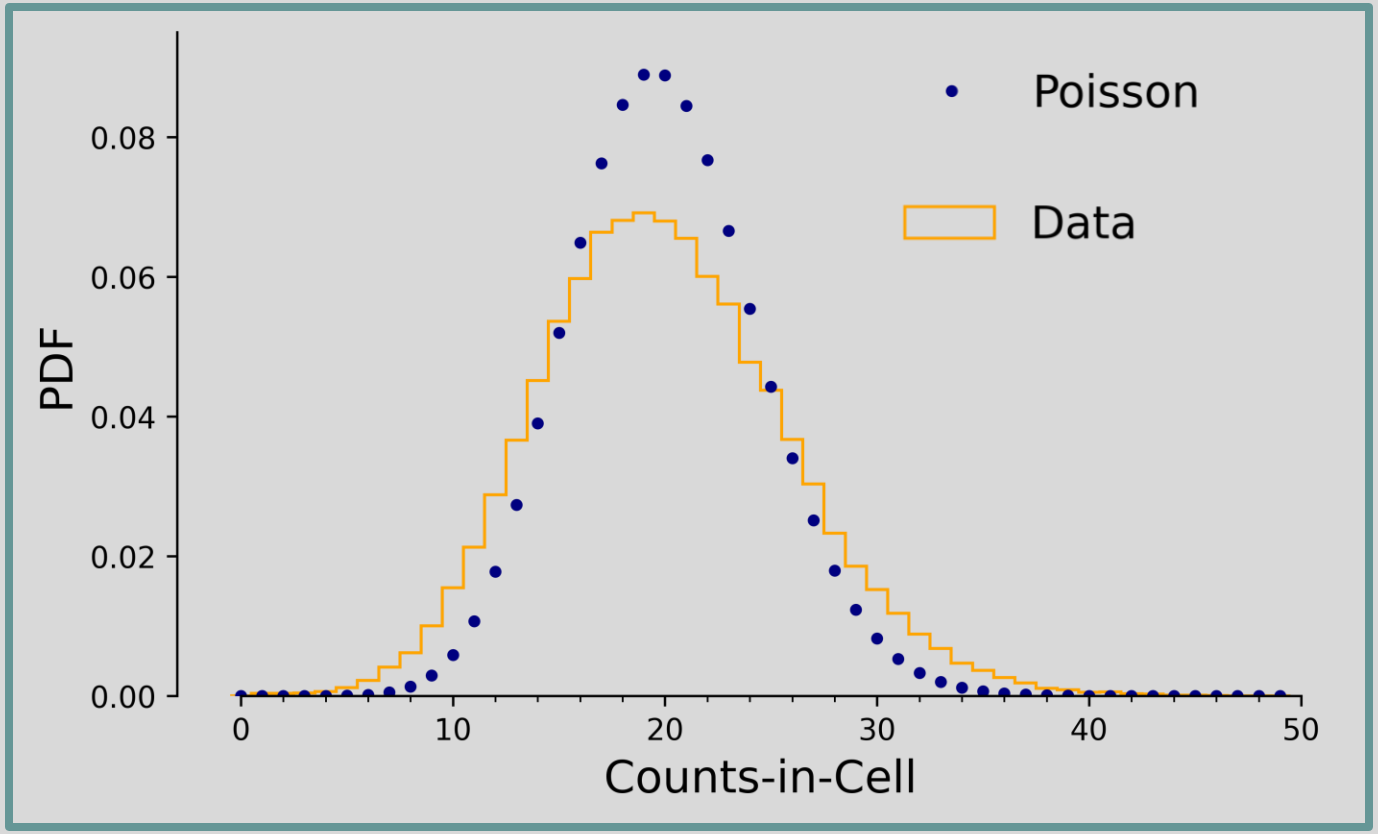


Pashapour-Ahmadabadi, Böhme+ in prep

Work in progress

- Poisson distr. Point sources

Counts-in-Cell histogram

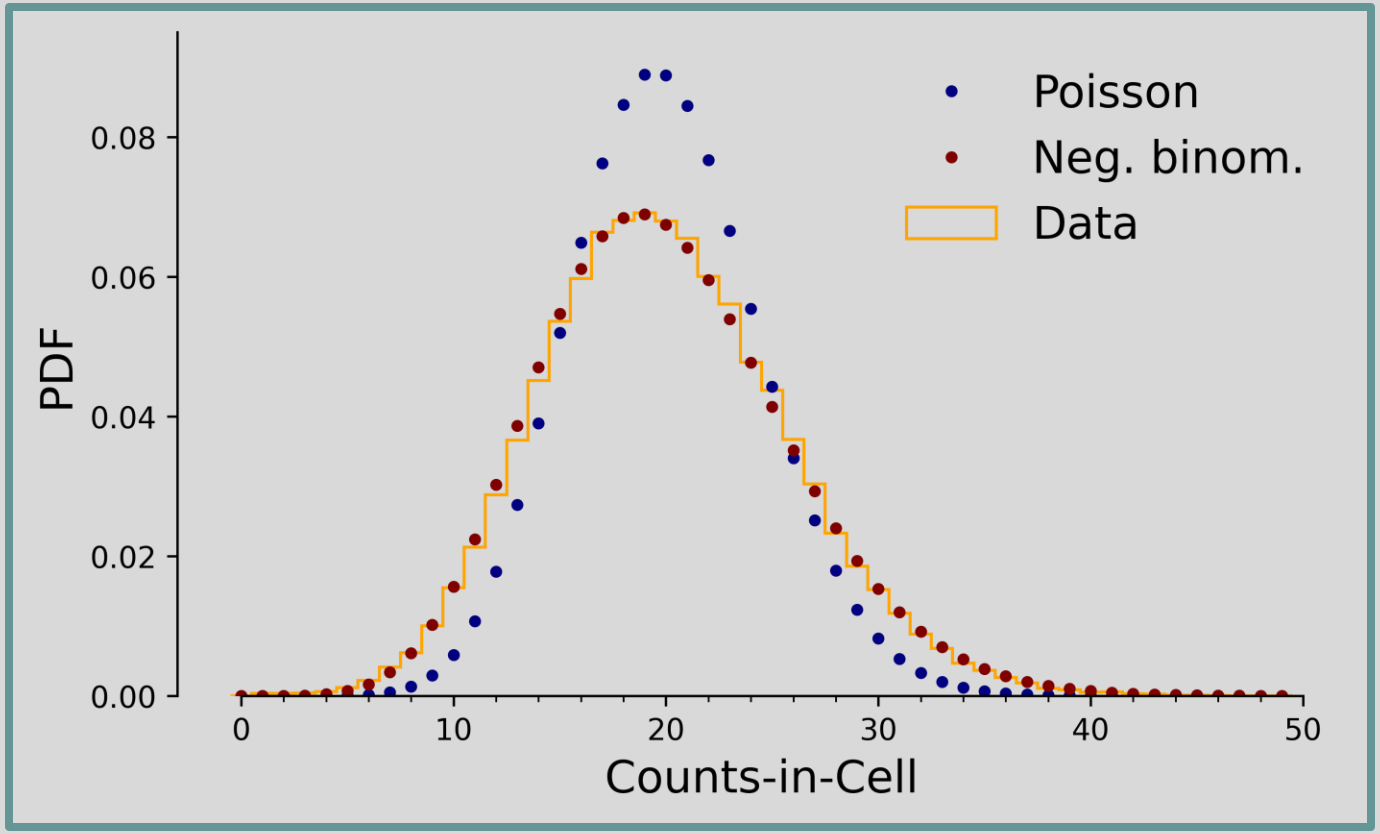


Pashapour-Ahmadabadi, Böhme+ in prep

Work in progress

✔ Negative binomial distribution

Counts-in-Cell histogram



Poisson: $\chi^2_{\rm r} = 692.23$

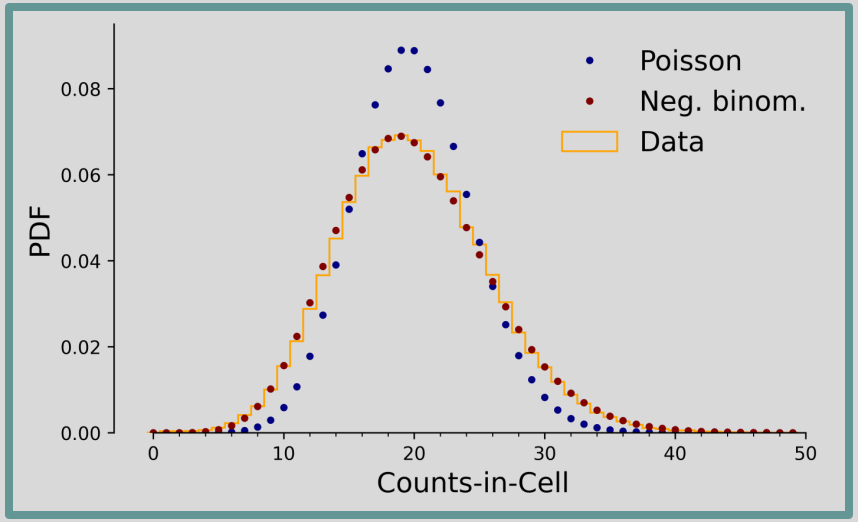
Neg. binom.: $\chi^2_{\rm r} = 3.74$

Pashapour-Ahmadabadi, Böhme+ in prep

Work in progress

Model: $$N = \sum_{j=1}^{O} C_j$$

Count of radio sources in cell



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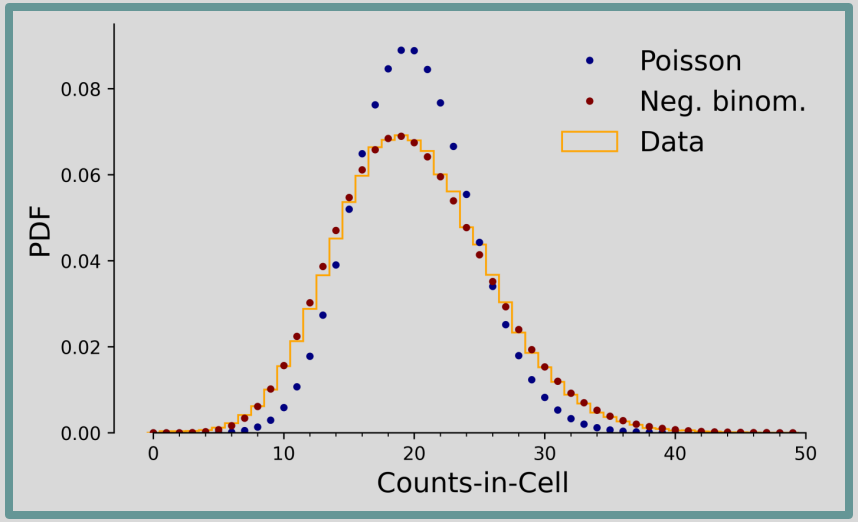
Work in progress

Poisson distributed physical objects

Model: $N = \sum_{j=1}^{O} C_j$ ← Number components of object j, distributed logarithmic with p

Count of radio sources in cell



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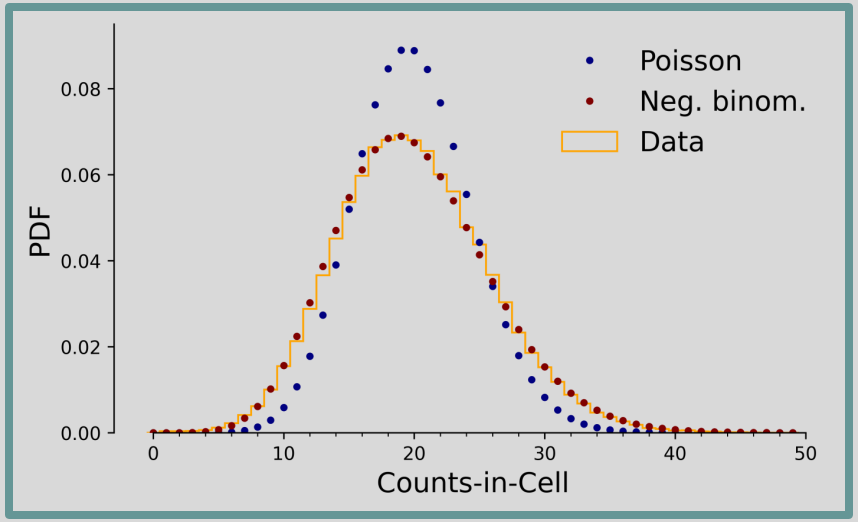


$$P_{\mathrm{NB}}(N) = \binom{N+r-1}{N}(1-p)^N p^r \qquad p = \frac{\lambda}{\sigma^2}, \quad r = \frac{p\lambda}{1-p} \qquad \lambda = \mathbb{E}[\mathrm{Data}] \\ \sigma^2 = \mathbb{V}ar[\mathrm{Data}]$$

$p \to 1$
$r \to \infty$ Poissonian limit, $p < 1$: Clustering

Böhme+ in prep

Work in progress

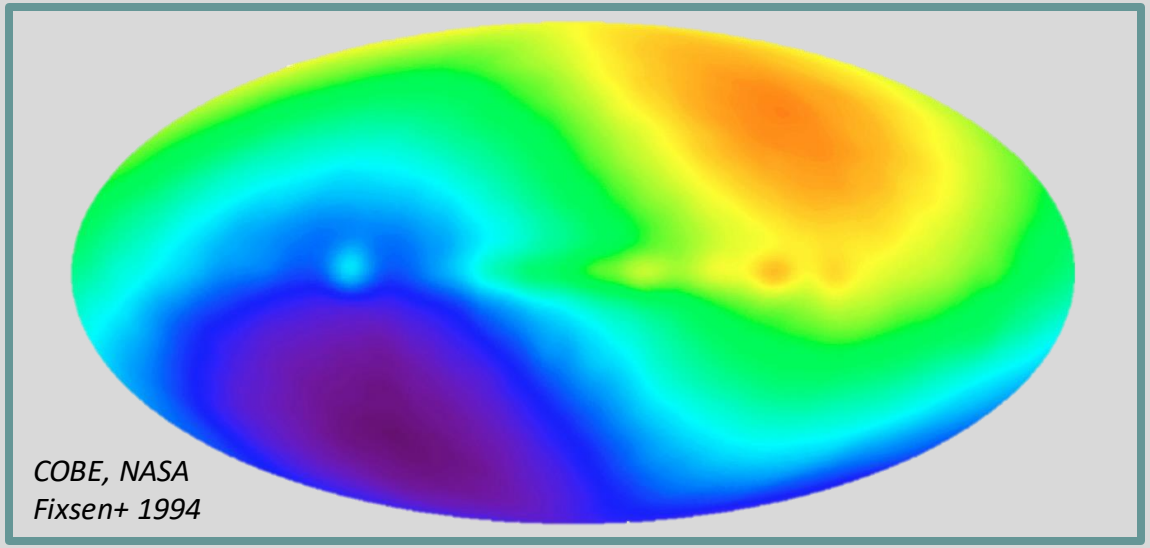
Counts-in-Cell

$$\left.\frac{dN}{d\Omega}\right|_{\rm obs} = \left.\frac{dN}{d\Omega}\right|_{\rm rest} (1 + d\cos\theta)$$

(Ellis and Baldwin, 1984)

$\theta = \angle$ (Pixel, direction of motion)

$$v_{\rm CMB} = 369.82\,{\rm km\,s^{-1}}$$



COBE, NASA
Fixsen+ 1994

Böhme+ in prep

Work in progress

Counts-in-Cell

$$\left.\frac{dN}{d\Omega}\right|_{\rm obs} = \left.\frac{dN}{d\Omega}\right|_{\rm rest} (1 + d\cos\theta)$$

(Ellis and Baldwin, 1984)

$$d_{exp} = (2 + x(1+\alpha))\frac{v_{\rm CMB}}{c} \approx 0.5 \times 10^{-2}$$

Radio survey dependent

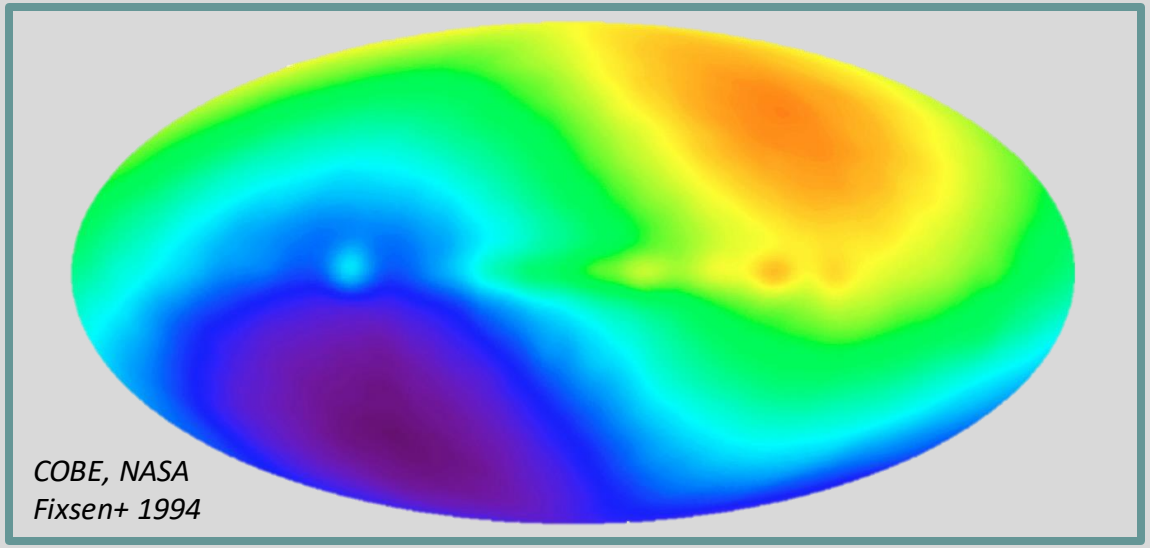
⇒ 0.5% effect at max and min

$\theta = \angle$ (Pixel, direction of motion)

$dN/d\Omega(>S) \propto S^{-x}$ Slope in source counts

$S \propto \nu^{\alpha}$ Spectral index

$$v_{\rm CMB} = 369.82\,{\rm km\,s^{-1}}$$



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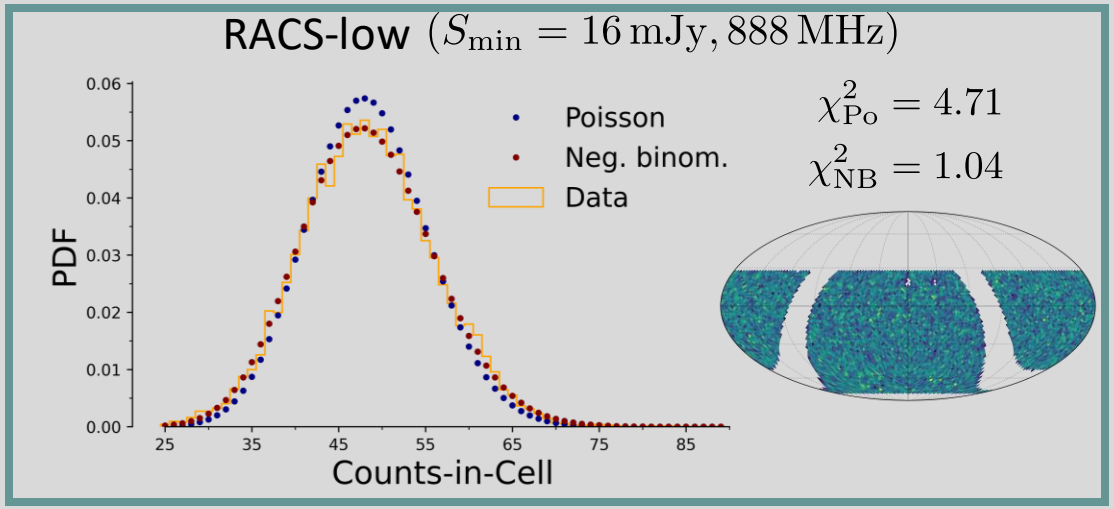
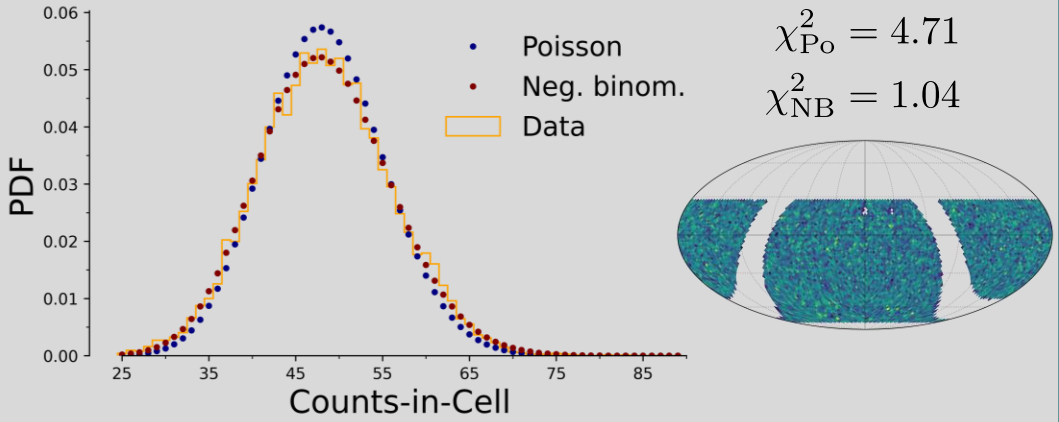


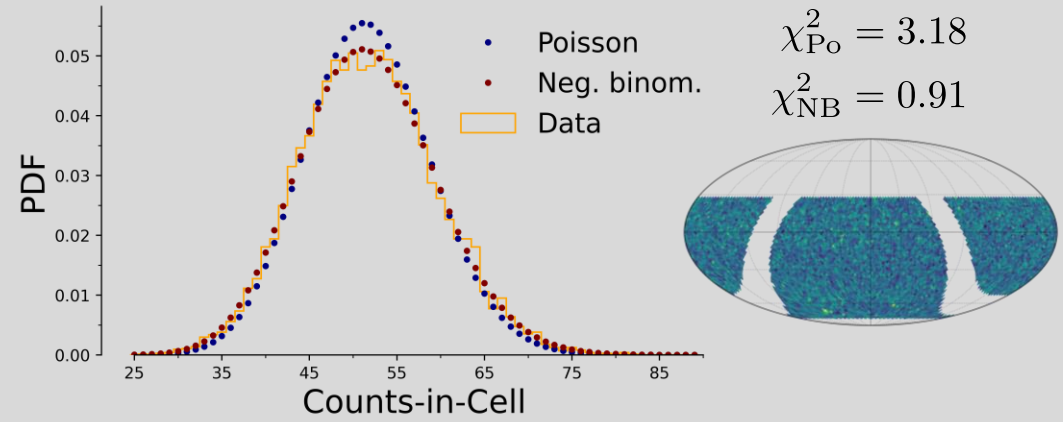
Böhme+ in prep

Work in progress

RACS-low ($S_{\rm min} = 16\,{\rm mJy}, 888\,{\rm MHz}$)



RACS-mid ($S_{\rm min} = 11.5\,{\rm mJy}, 1368\,{\rm MHz}$)



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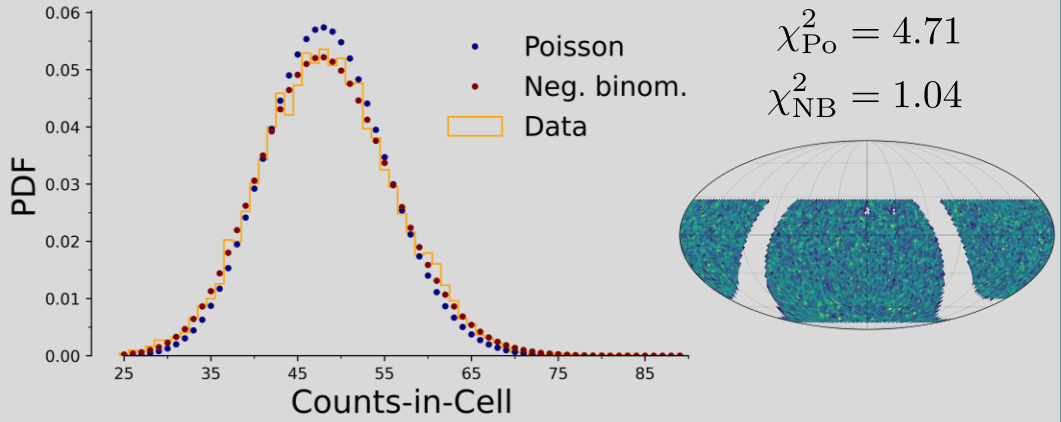

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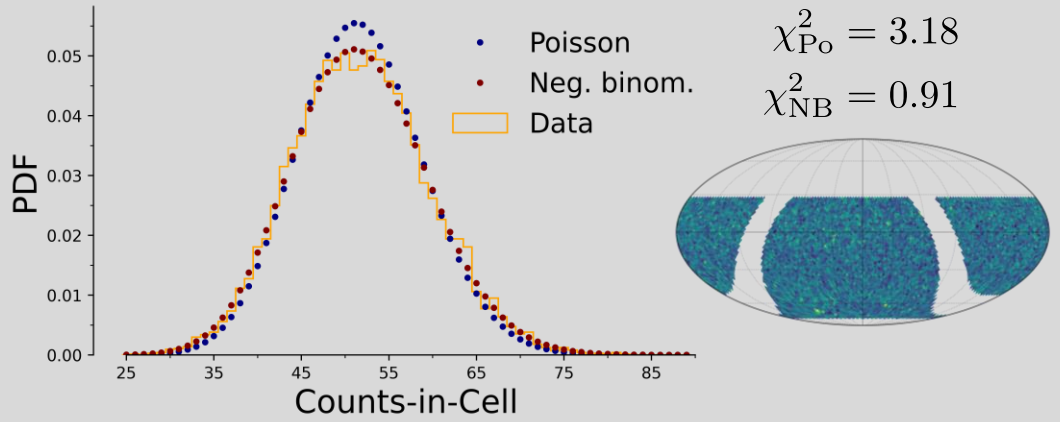
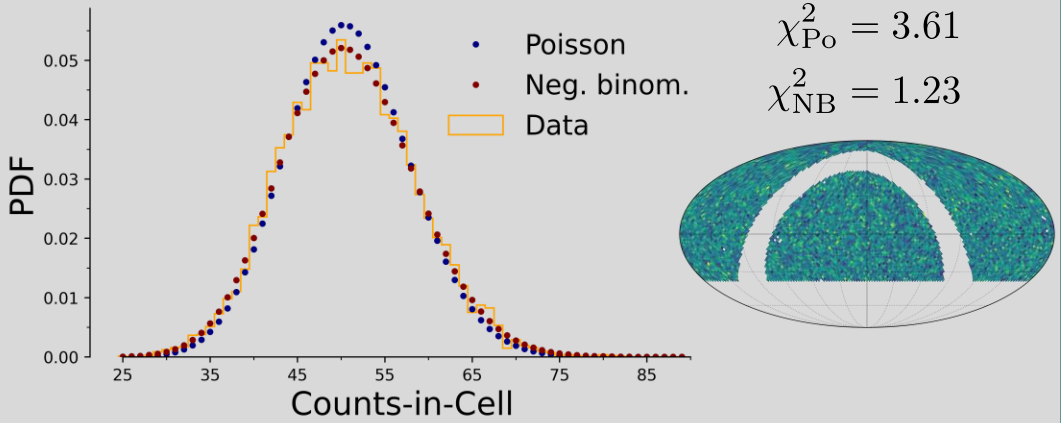


NVSS ($S_{\rm min} = 11.5\,{\rm mJy}, 1400\,{\rm MHz}$)



Böhme+ in prep

Work in progress

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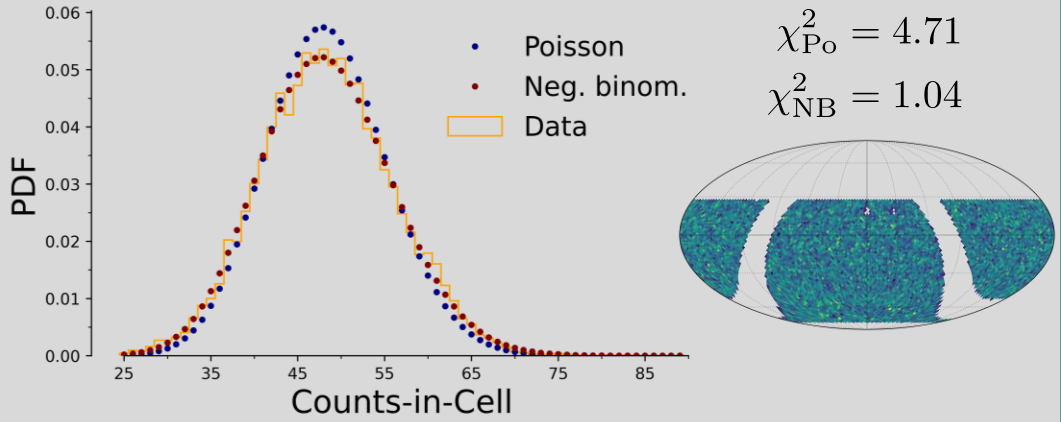

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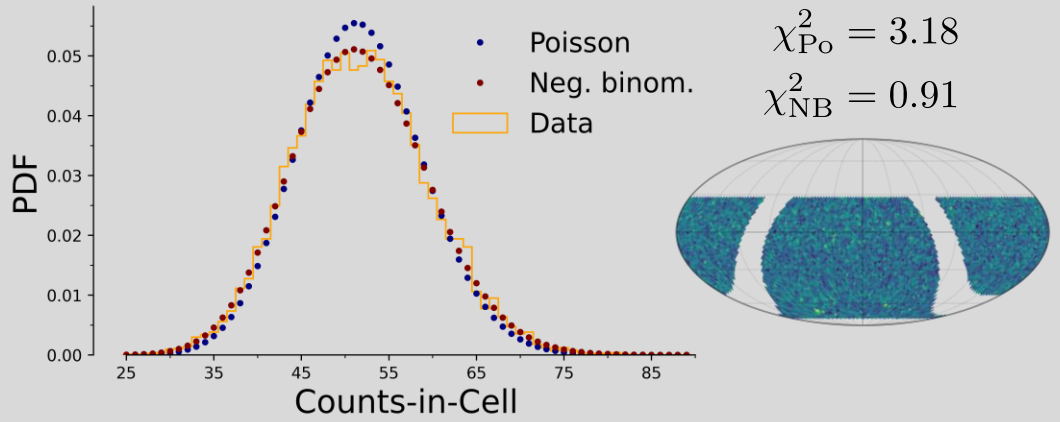

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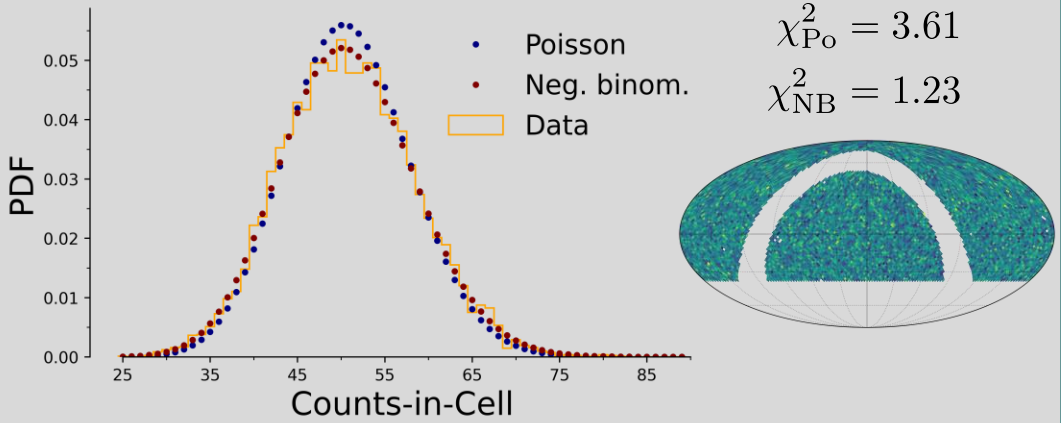
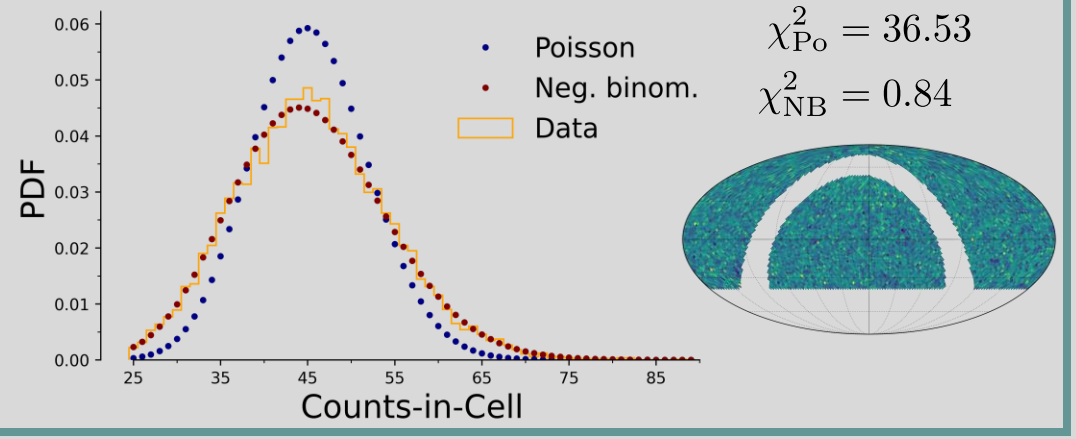


VLASS ($S_{\rm min} = 6.5\,{\rm mJy}, 3000\,{\rm MHz}$)

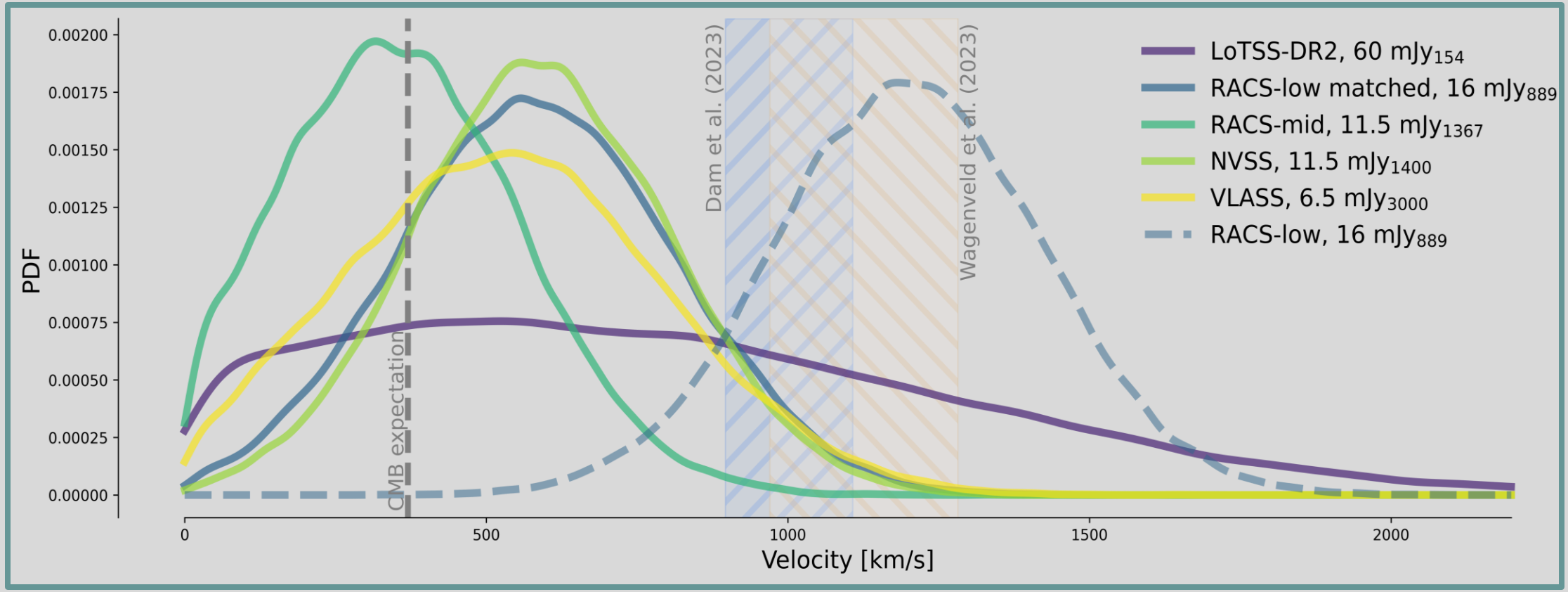


Böhme+ in prep

Work in progress

- Same source density
- Fix direction towards CMB dipole
- Cross-match RACS-low with RACS-mid

- Consistent with CMB dipole
- Excess dipole still possible



Hale+ 2024

Excess probability to observe galaxies at a given angular scale compared to if no large-scale structure

Landy & Szalay 1993

$$\omega(\theta) = \frac{DD(\theta) + RR(\theta) - 2DR(\theta)}{RR(\theta)}$$

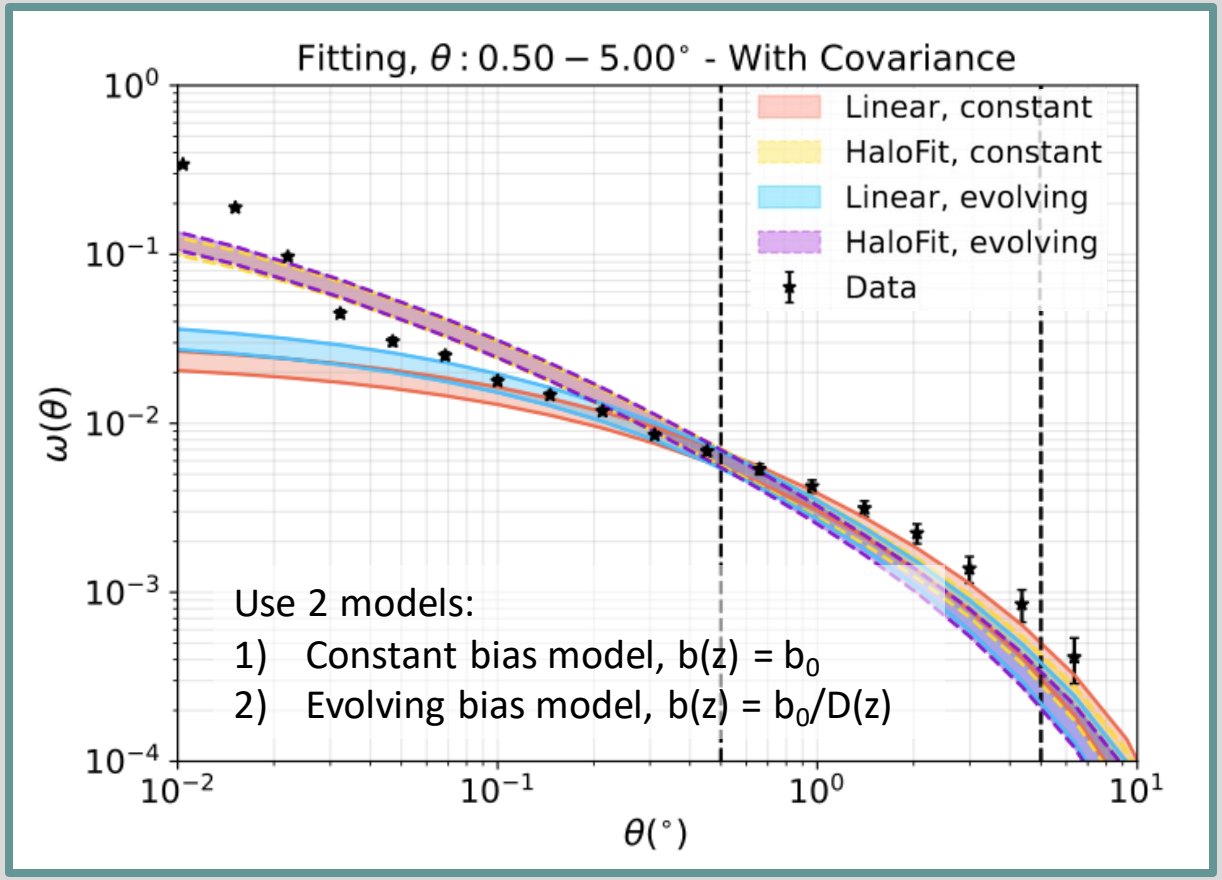
Normalised pairs of galaxies in the data (randoms or data-to-randoms) at an angular separation θ

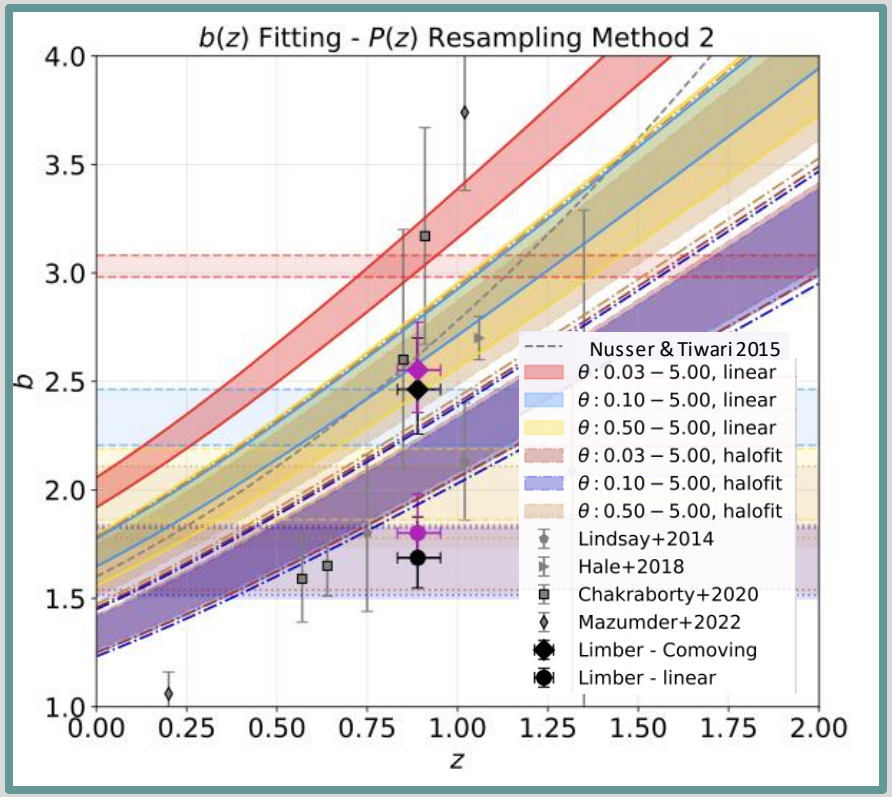
Creating survey-specific random catalogues is crucial!

Hale+ 2024

P(z) from deep fields $S_{\min} > 1.5$ mJy

⇒ **Evolving bias**

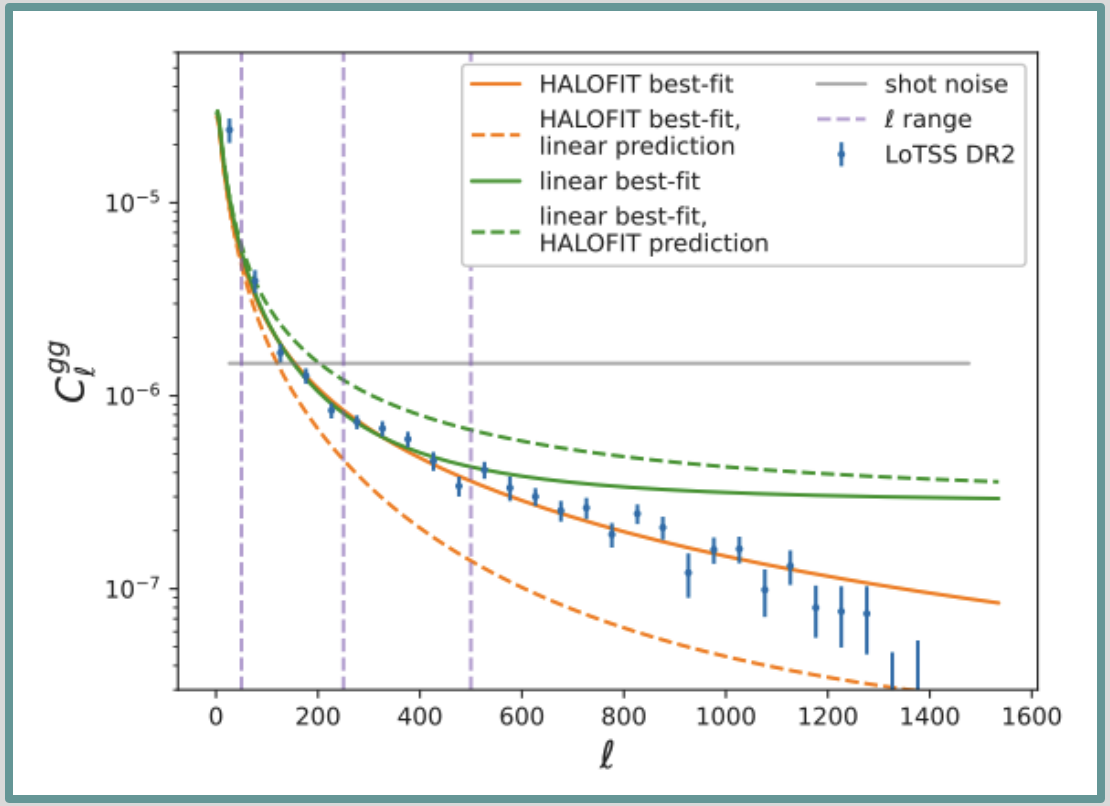




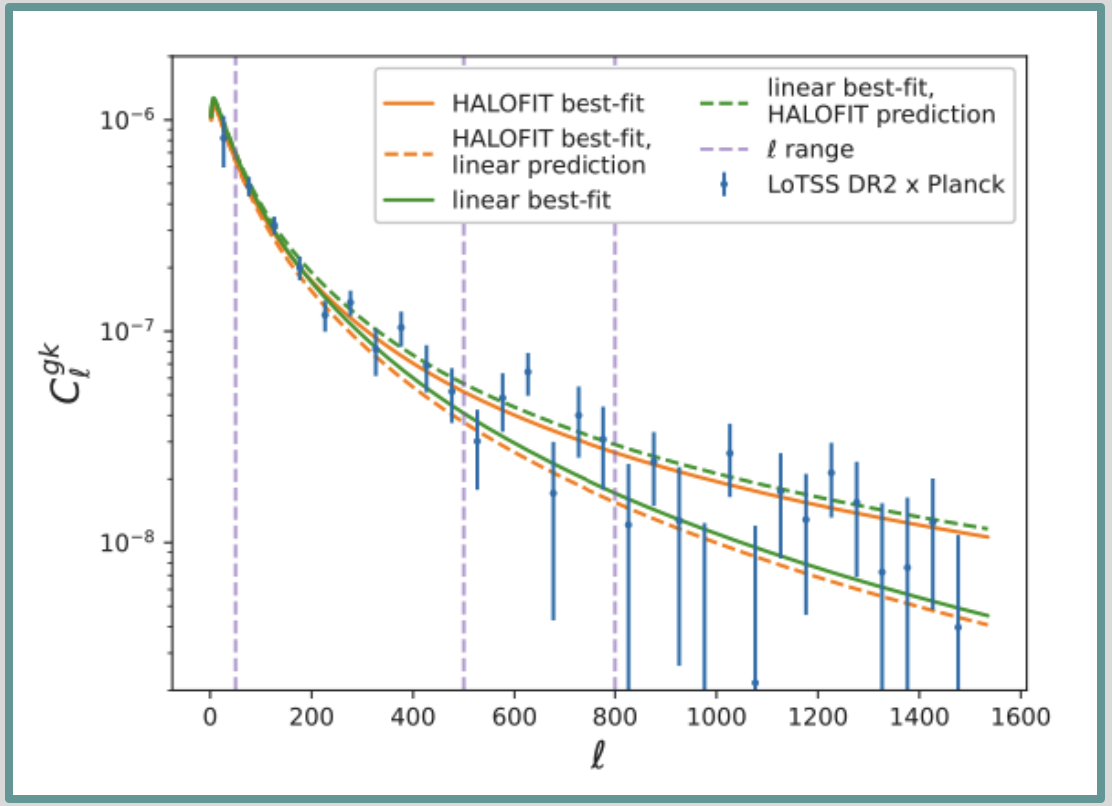
Nakoneczny+ 2024

- LoTSS-DR2 and **CMB lensing maps** (Planck Collaboration+ 2020) measure **angular power spectrum**
- **Detection of cross-correlation at S/N of 26.6 σ**

LoTSS x LoTSS

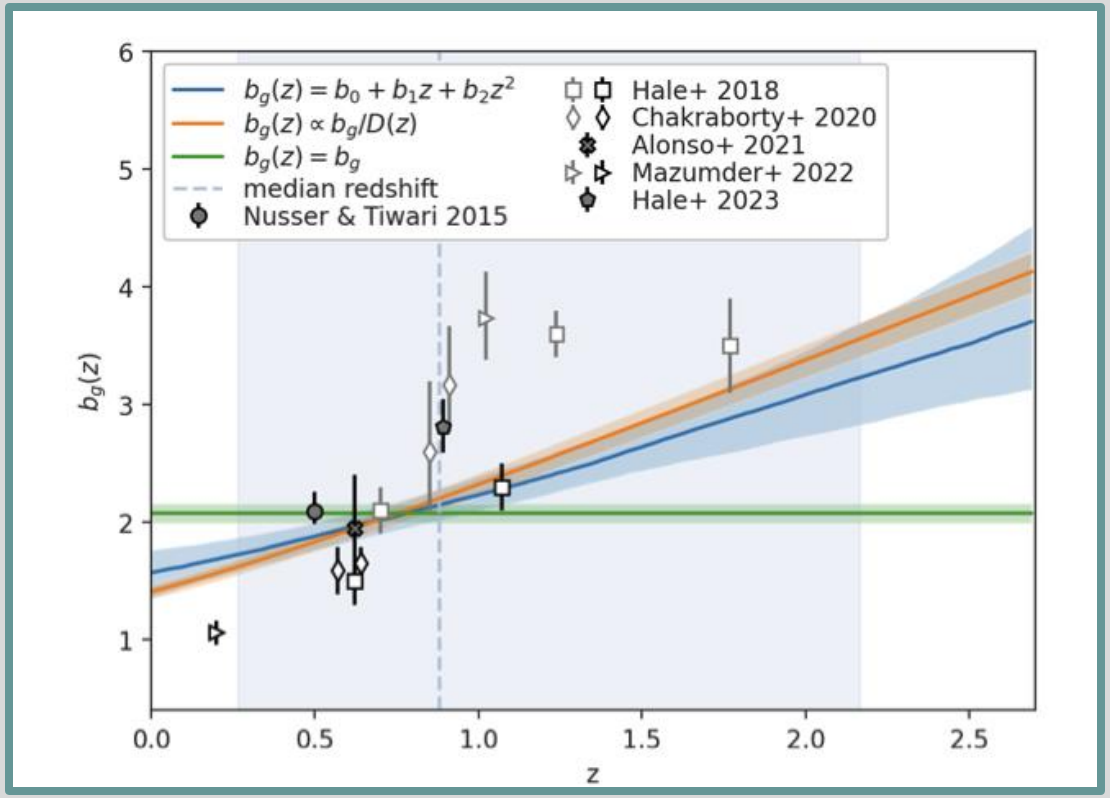


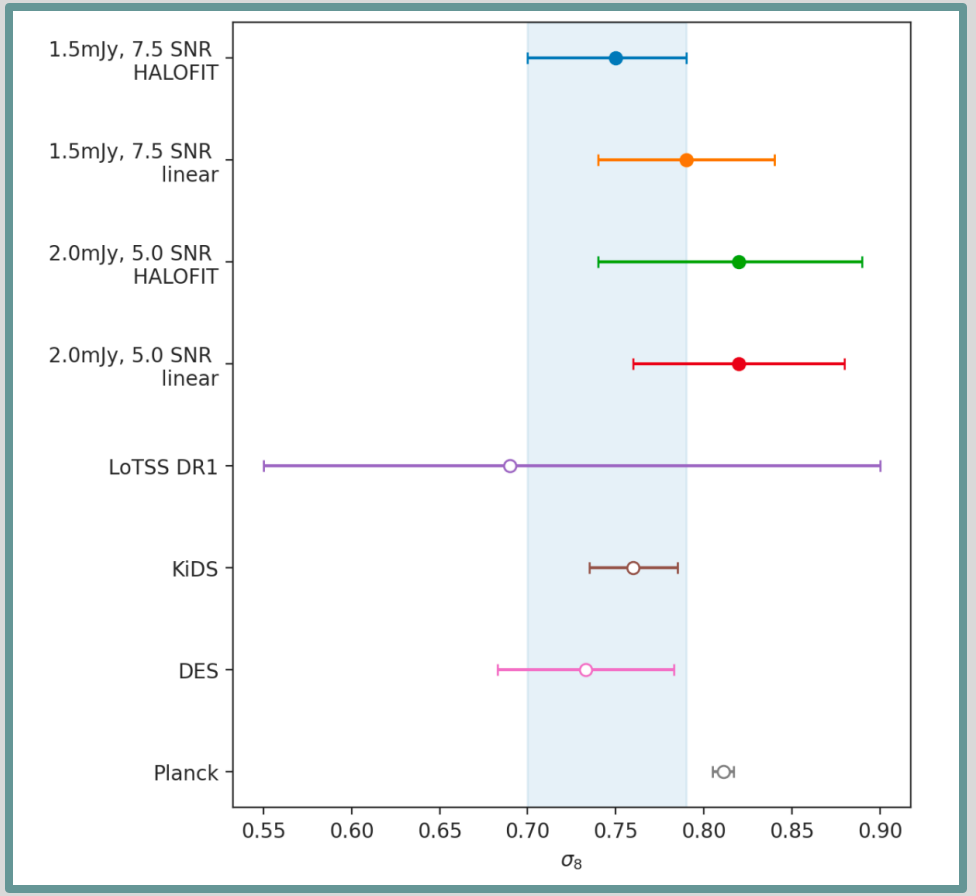
LoTSS x CMB



Nakoneczny+ 2024

- Constrain **bias evolution models ⇒ evolving bias**
- Fix certain parameters, able to constrain $\boldsymbol{\sigma_8}$

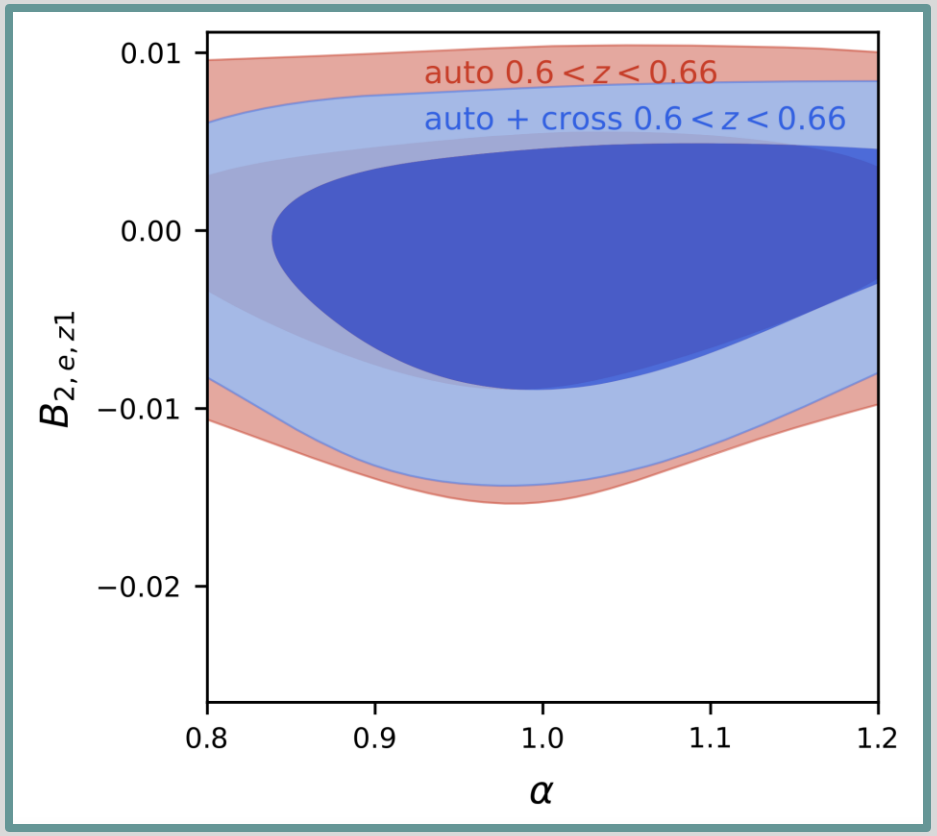




Zheng+ in prep

Work in progress

(a nuisance parameter to do with the shape of the power spectrum)

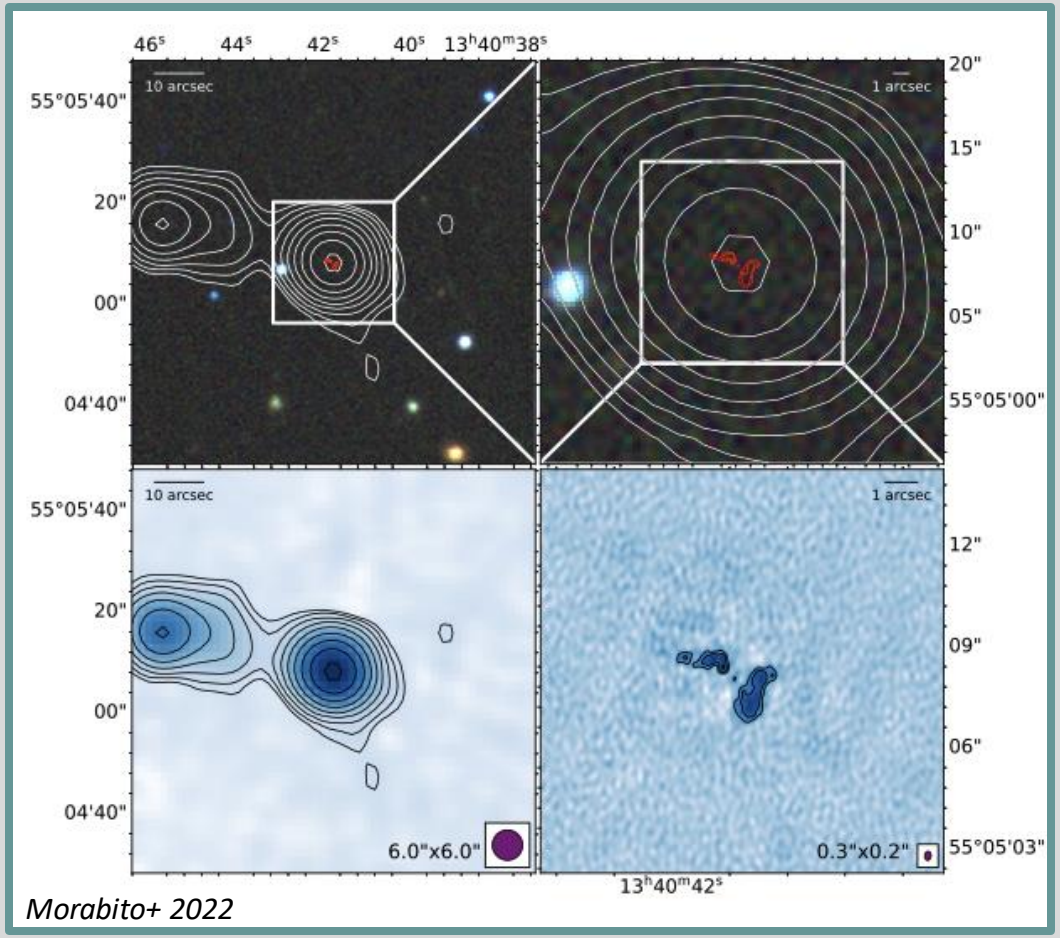


(Angular location of observed BAO relative to fiducial cosmology.
$\alpha \neq 1$ means deviation from fiducial cosmology)

- LoTSS-DR2 x eBoss (Ross+ 2020) **LRG**
- Constrain **angular BAO parameter α**
- Improve constraints on cosmological parameters

auto = eBoss x eBoss
auto + cross = LoTSS-DR2 x eBoss

LOFAR High Resolution (matches Euclid res.)



Morabito+ 2022

Combination of **High-resolution** imaging (better classification + host galaxy association → more reliable photo-z)

Future with LOFAR

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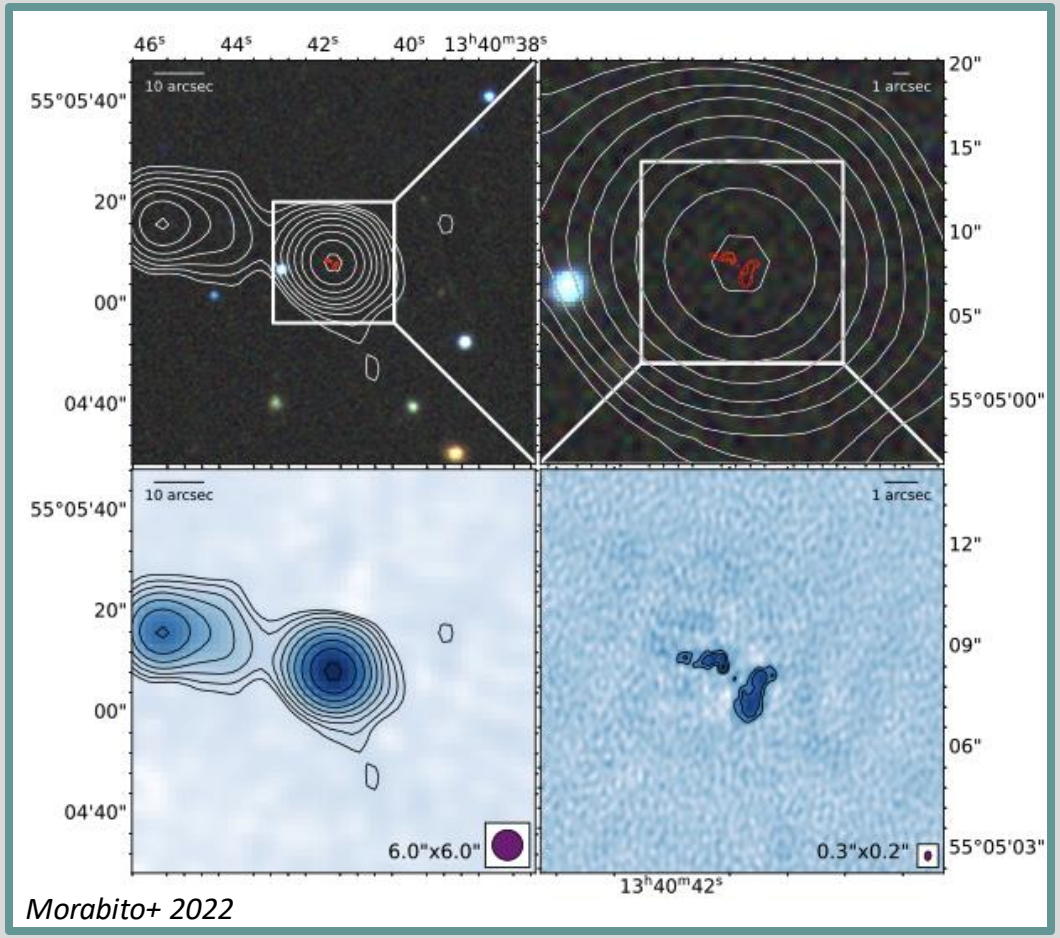
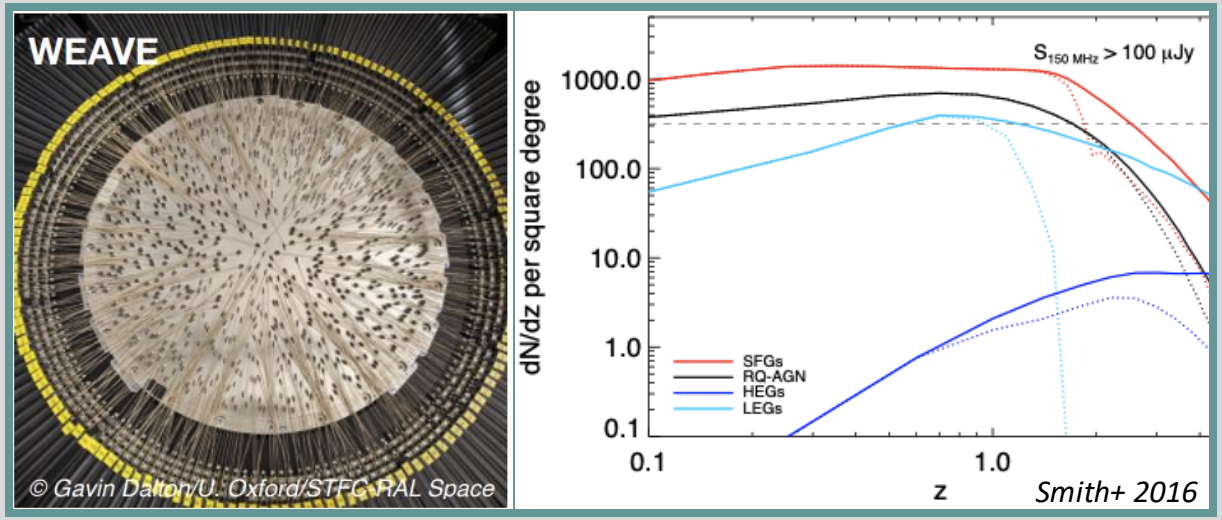


Morabito+ 2022

LOFAR Follow up Redshift Survey: WEAVE-LOFAR



Combination of **High-resolution** imaging (better classification + host galaxy association → more reliable photo-z) and **spectroscopic redshifts (**for all $S > 8$ mJy sources) will be crucial in improving **cosmology** studies **with LOFAR** in the future.

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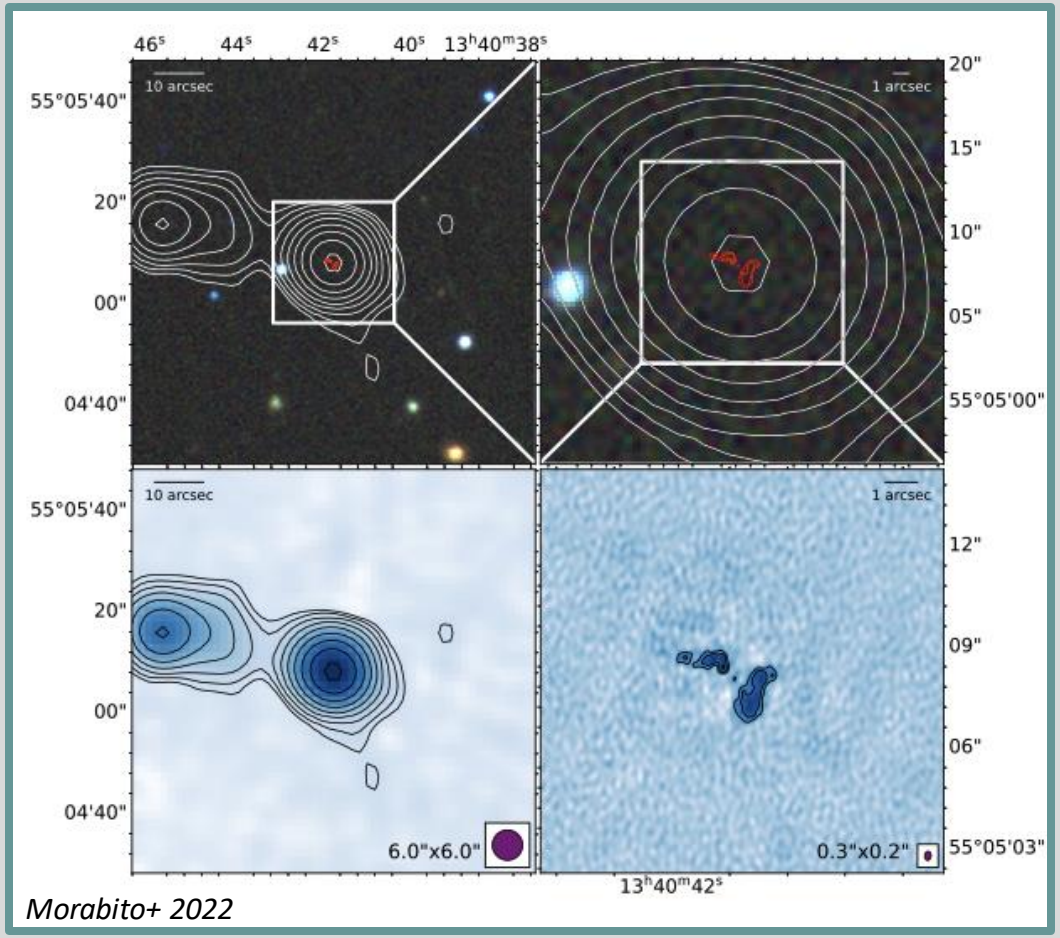

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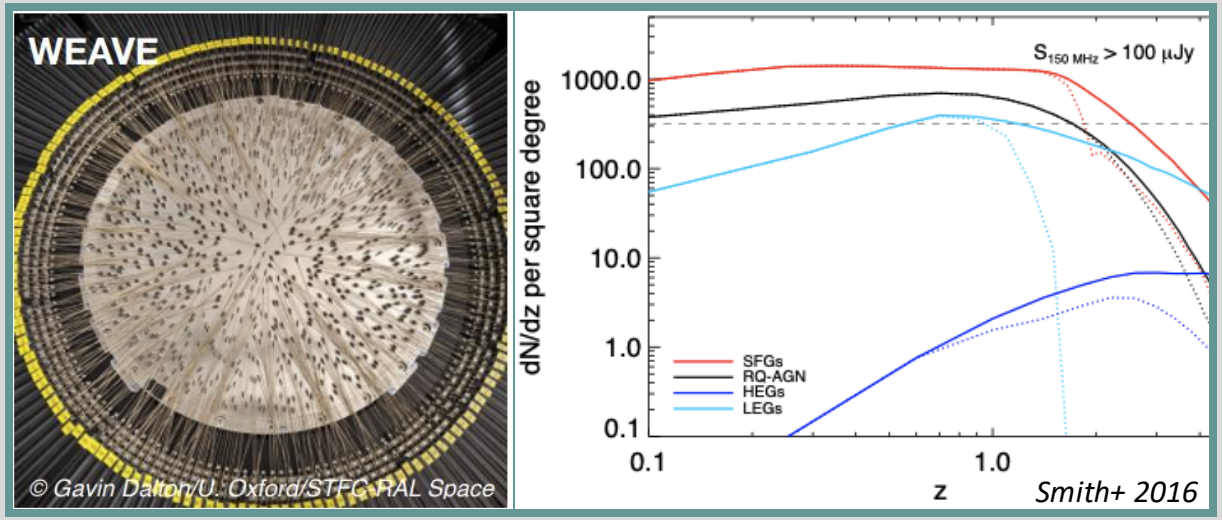

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+ **LOFAR 2.0** Upgrade (and associated surveys)
+ **LoLSS** (54 MHz wide area survey)

Future with LOFAR

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- **Heneka et al. (in prep.)** combines all these studies to measure a set of cosmological parameters.