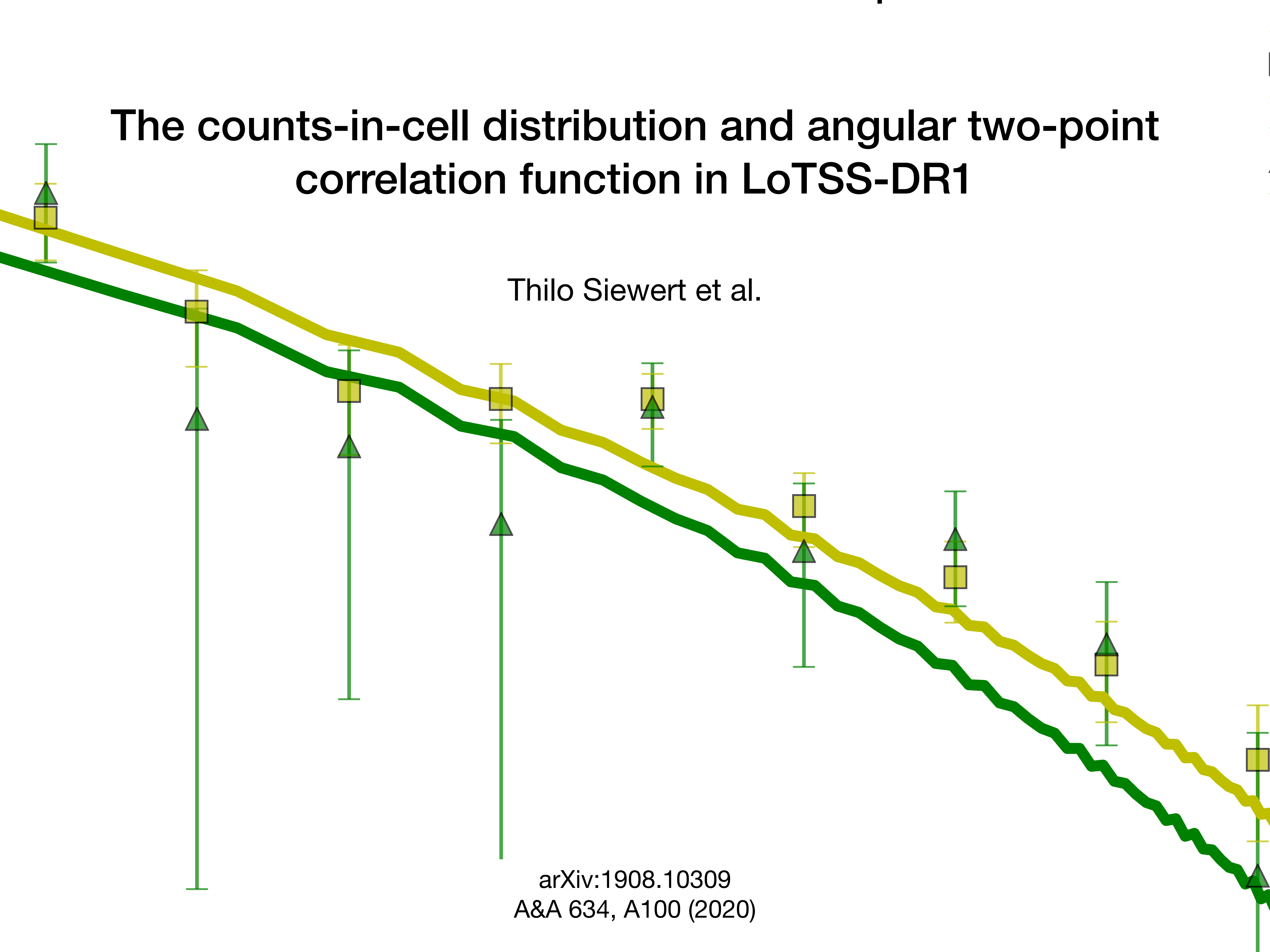
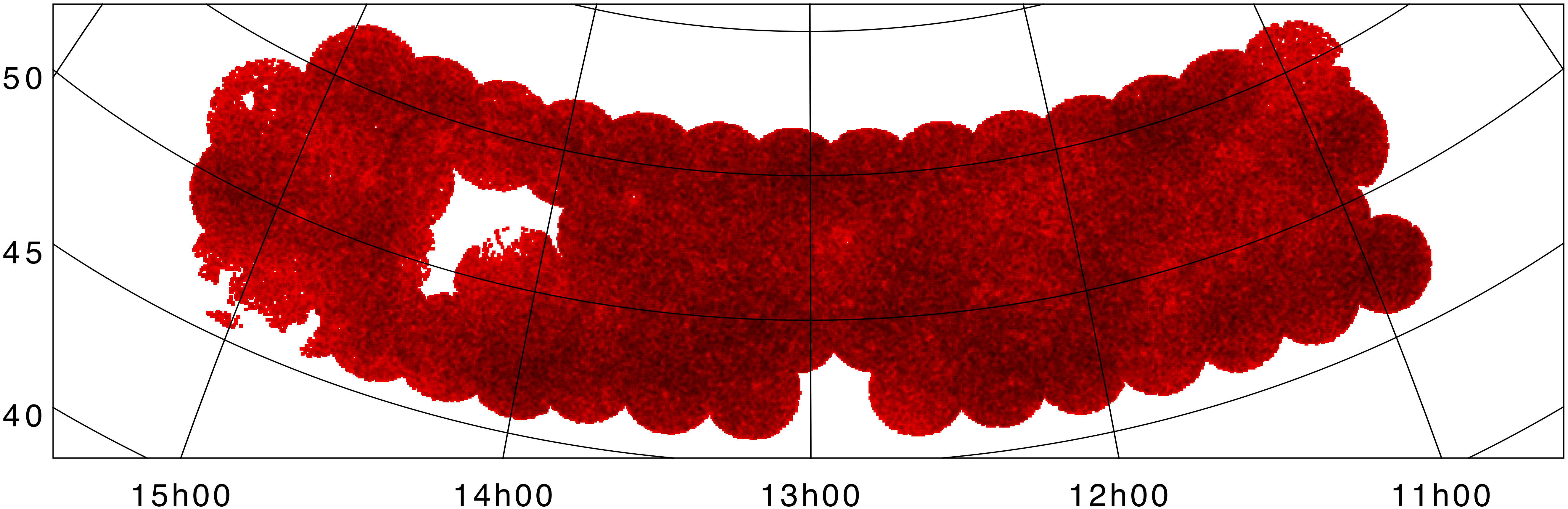
The counts-in-cell distribution and angular two-point correlation function in LoTSS-DR1

Thilo Siewert et al.



arXiv:1908.10309
A&A 634, A100 (2020)

LOFAR Two-metre Sky Survey (LoTSS-DR1)



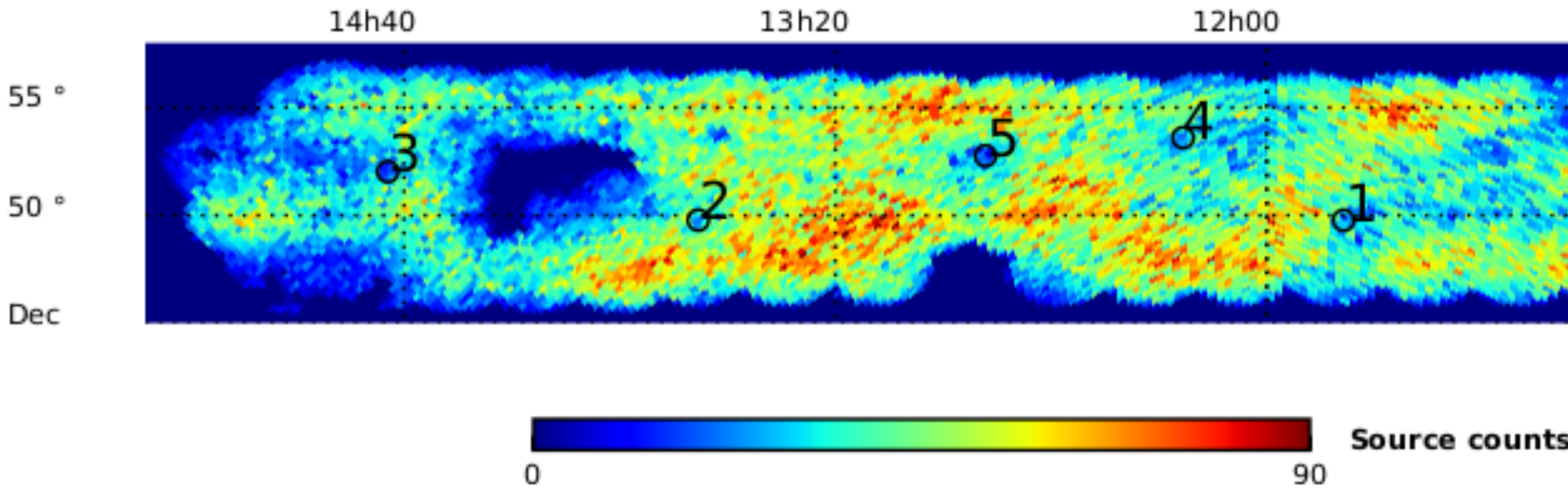
LoTSS-DR 1:

- 144 MHz central frequency
- 424 sqdeg coverage
- 58 pointings in HETDEX field
- 325 694 radio sources

LoTSS-DR 1 value added:

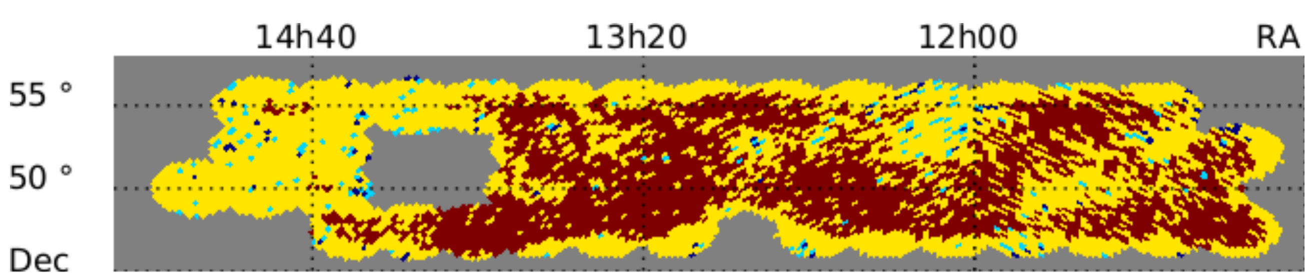
- removed artefacts & matched Gaussians
- 318 520 remaining/matched sources
- 231 716 with optical / IR counterpart
- cross match with Pan-STARRS & WISE

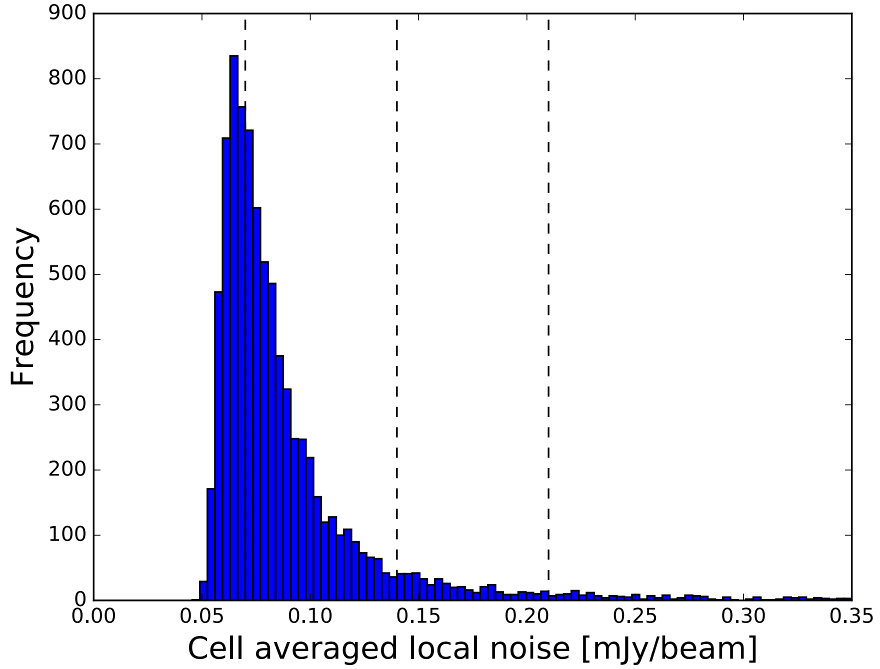
LoTSS-DR1 data preparation



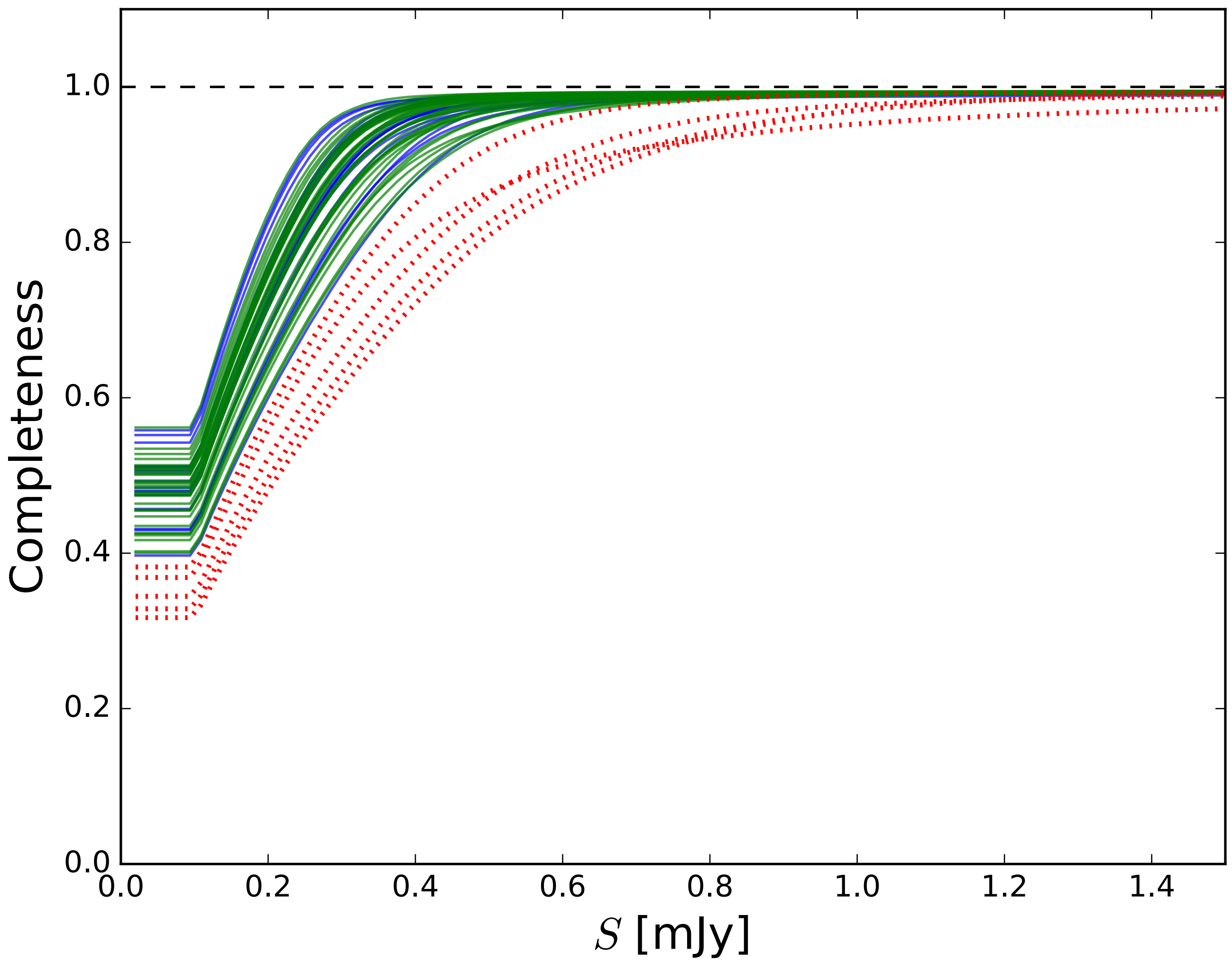
Using HEALPix with $N_{\mathrm{Side}} = 256$
-> cells with mean separation 0.23°

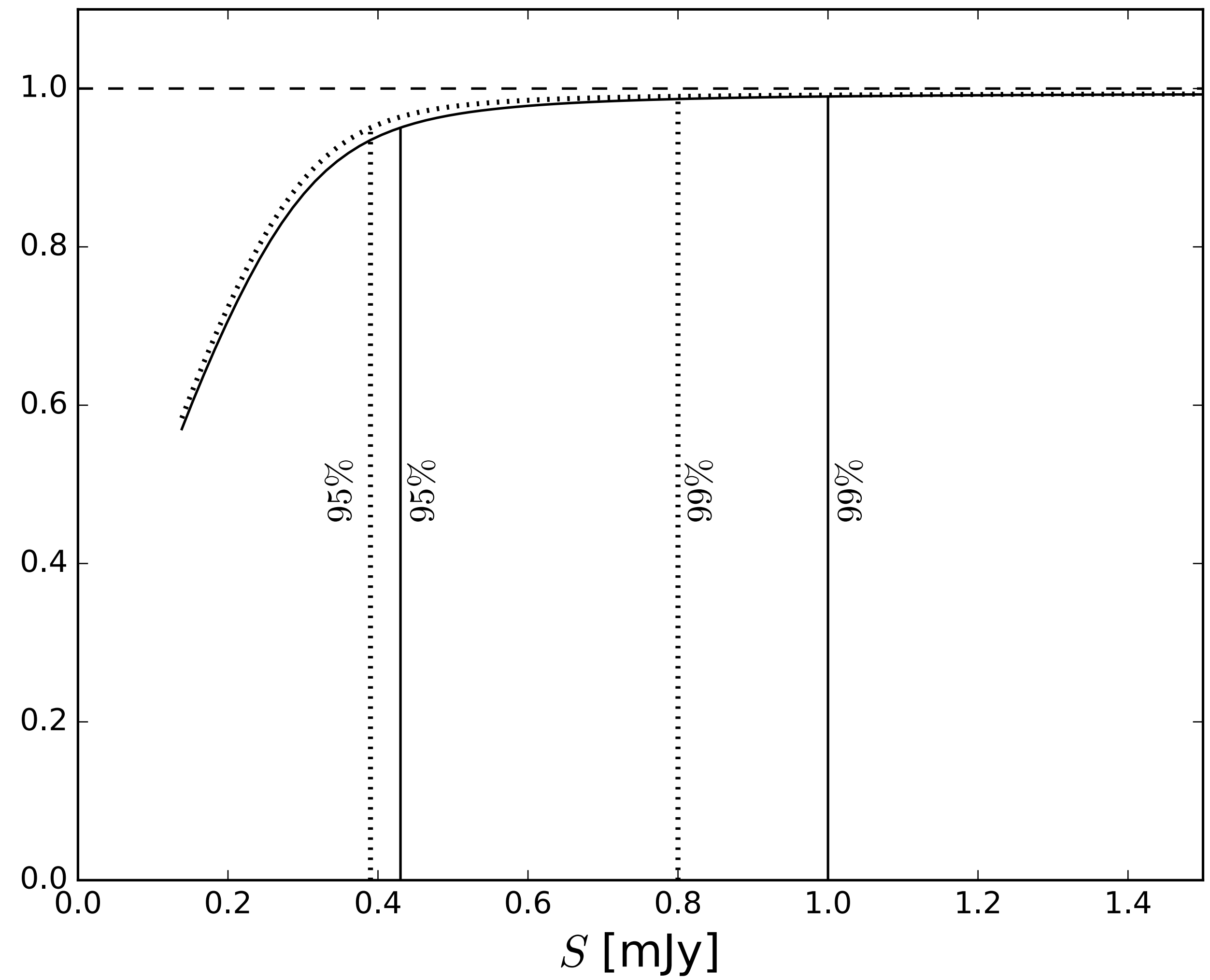
Define set of masks to reject uncovered and noisy regions
-> mask d, mask 1 - 3 (based on the median rms noise of 71 mJy/beam)





Point Source Completeness





Random sources injected into residual map

50x 6000 sources per pointing

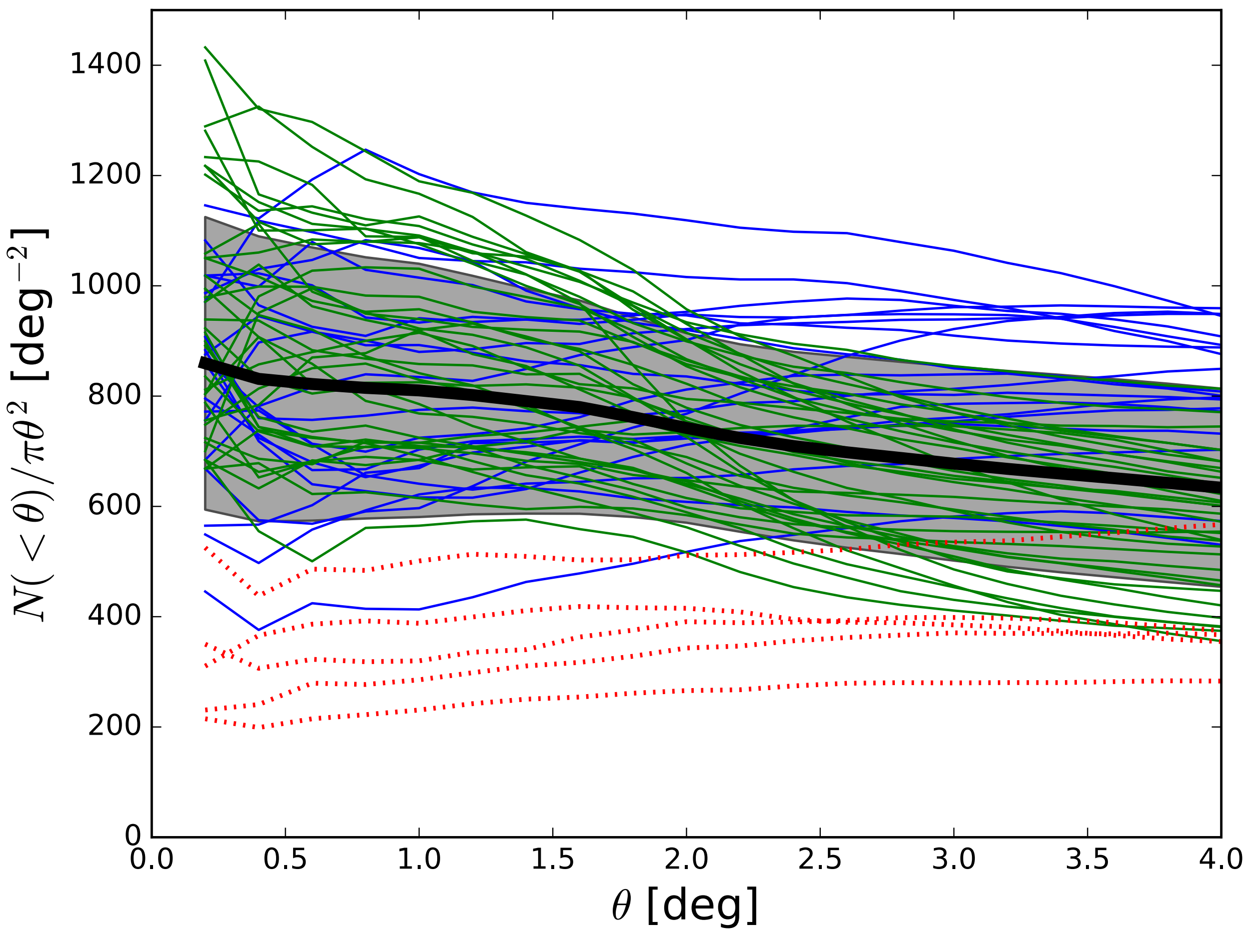
Recovering with PyBDSF and same settings as LoTSS DR1

<u>All pointings:</u>
95% Completeness at 0.43 mJy
99% Completeness at 1.0mJy

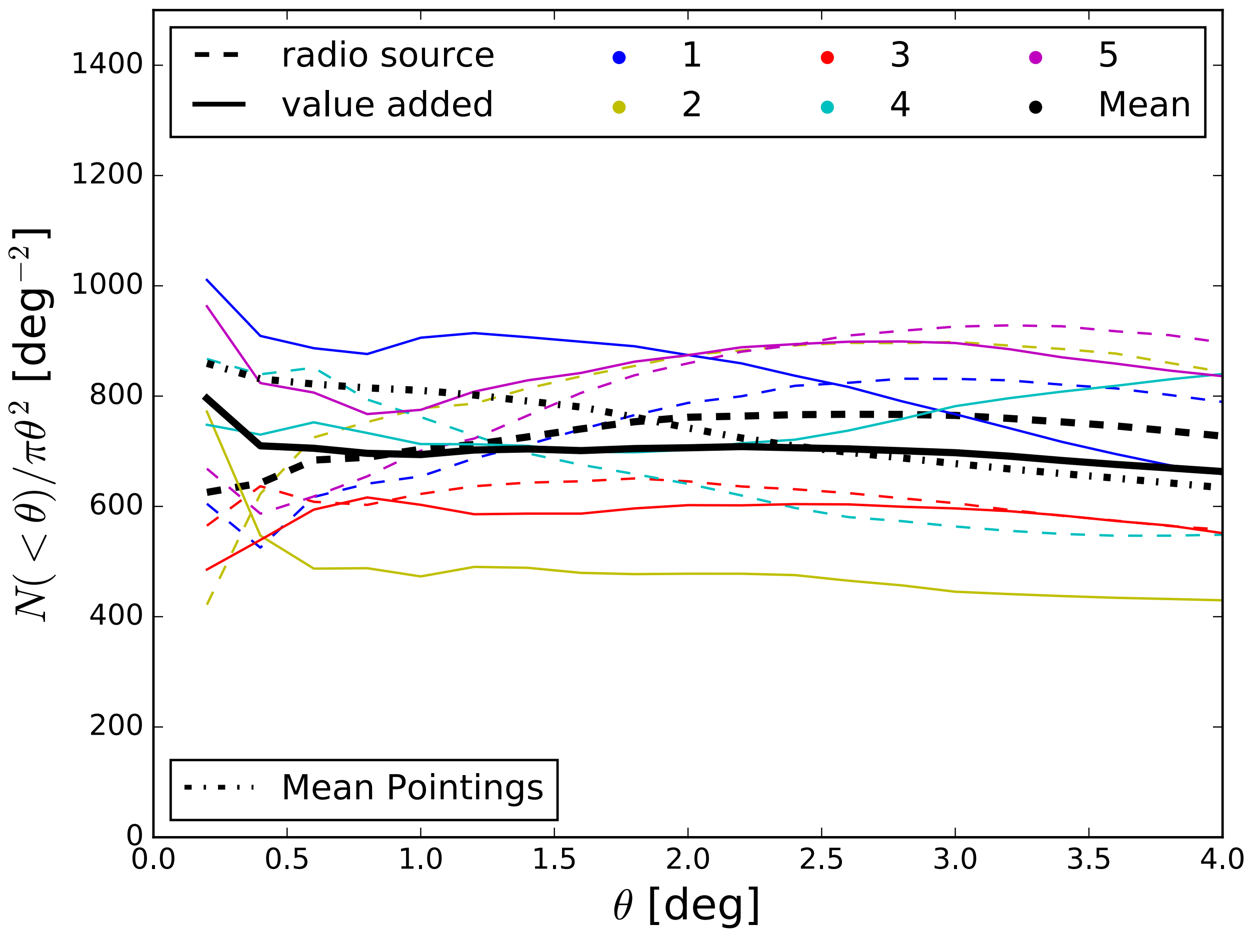
<u>Most complete pointings:</u>
95% Completeness at 0.39 mJy
99% Completeness at 0.8 mJy

Source counts

Pointings



Brightest sources



Statistical properties of LoTSS-DR1

Clustering coefficient:

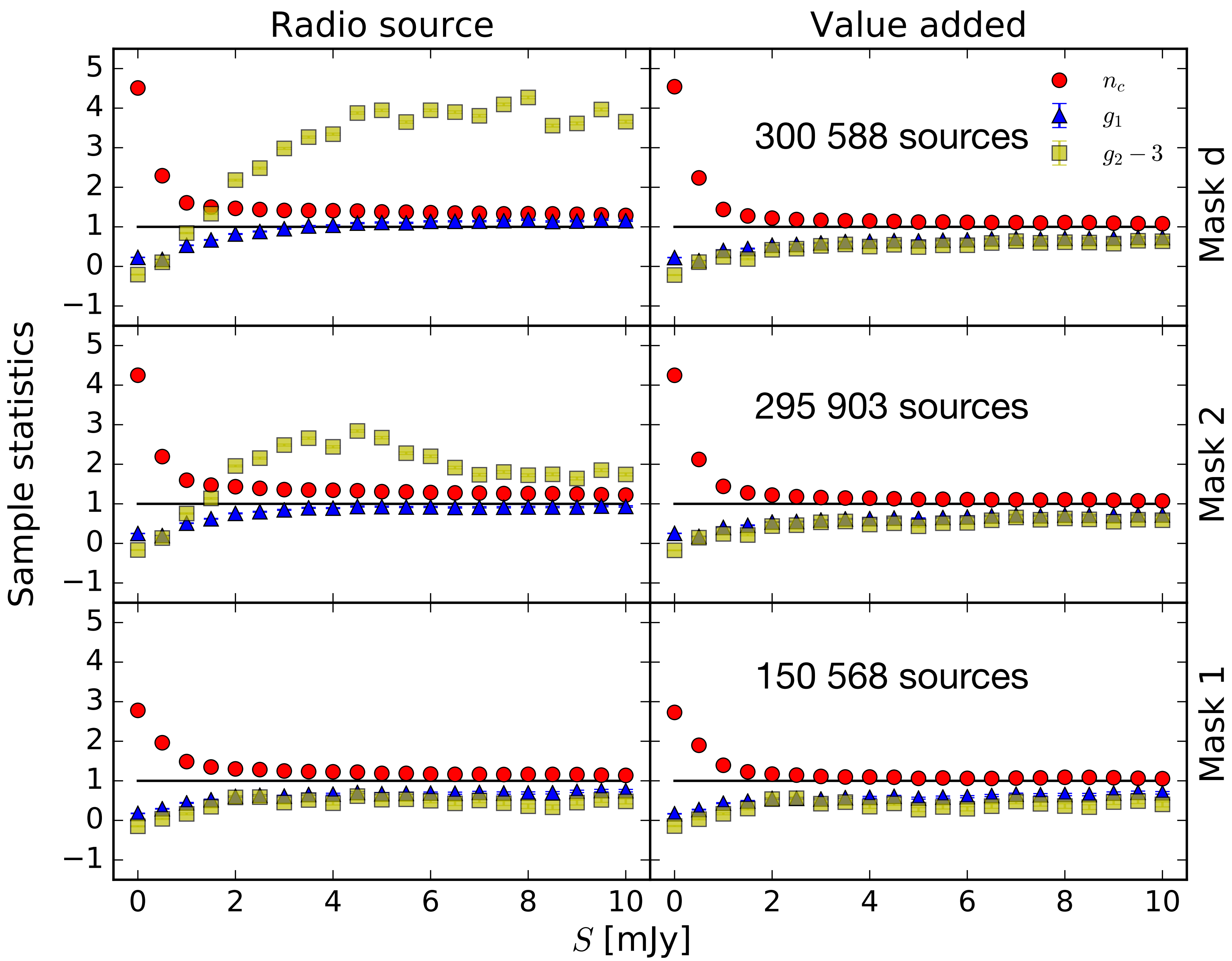
$$n_c = \frac{\sigma^2}{\mu}$$

Skewness:

$$g_1 = \frac{m_3}{m_2^{3/2}}$$

Excess curtosis:

$$g_2 - 3 = \frac{m_4}{m_2^2} - 3$$



Poisson: $n_c = 1$

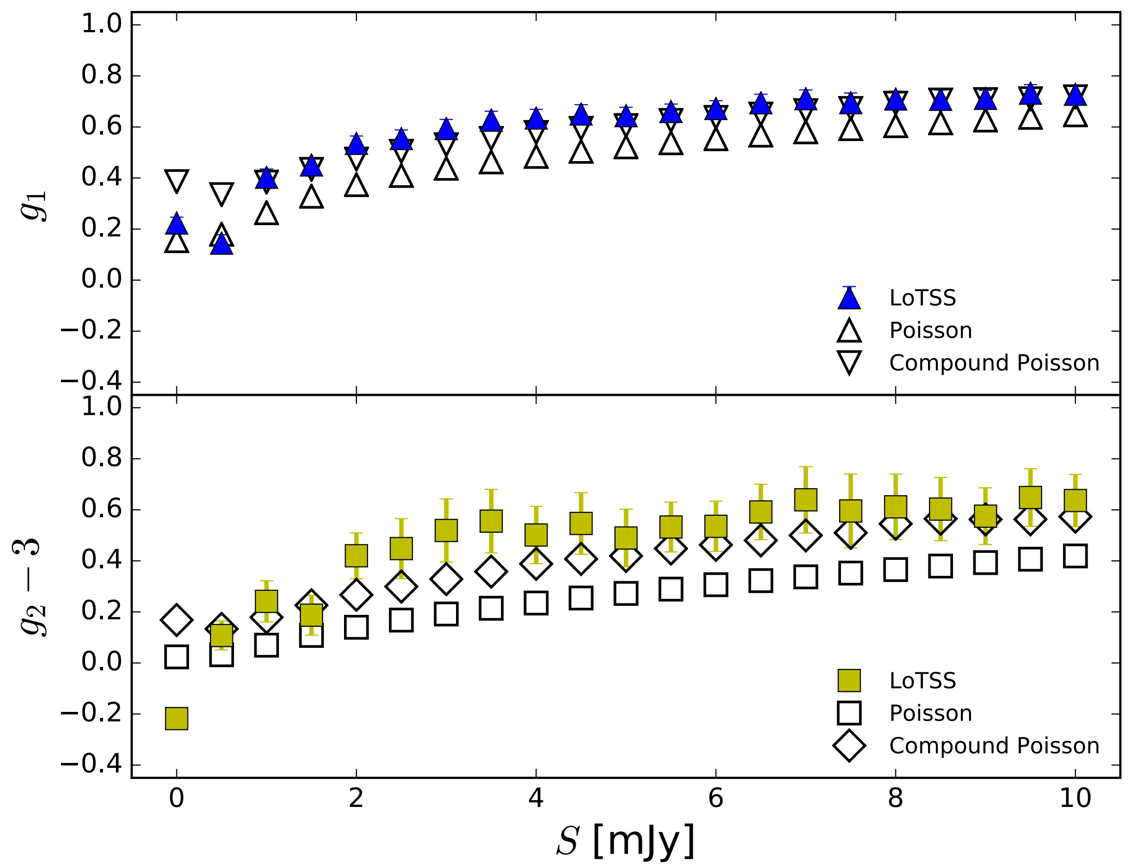
From now on: only value added source catalogue

Counts-in-cell distribution

Possible contributions to source count distribution:

- **multi-component sources**
- **fluctuations of the calibration**
- **confused sources**
- **cosmic structure**

→ Compound Poisson ?



$$p_k^{\mathrm{CP}} = \sum_{n=0}^{\infty} \left[\frac{(n\gamma)^k e^{-n\gamma}}{k!} \frac{\beta^n e^{-\beta}}{n!} \right]$$

$$\rightarrow n_{\mathrm{c}} = 1 + \gamma$$

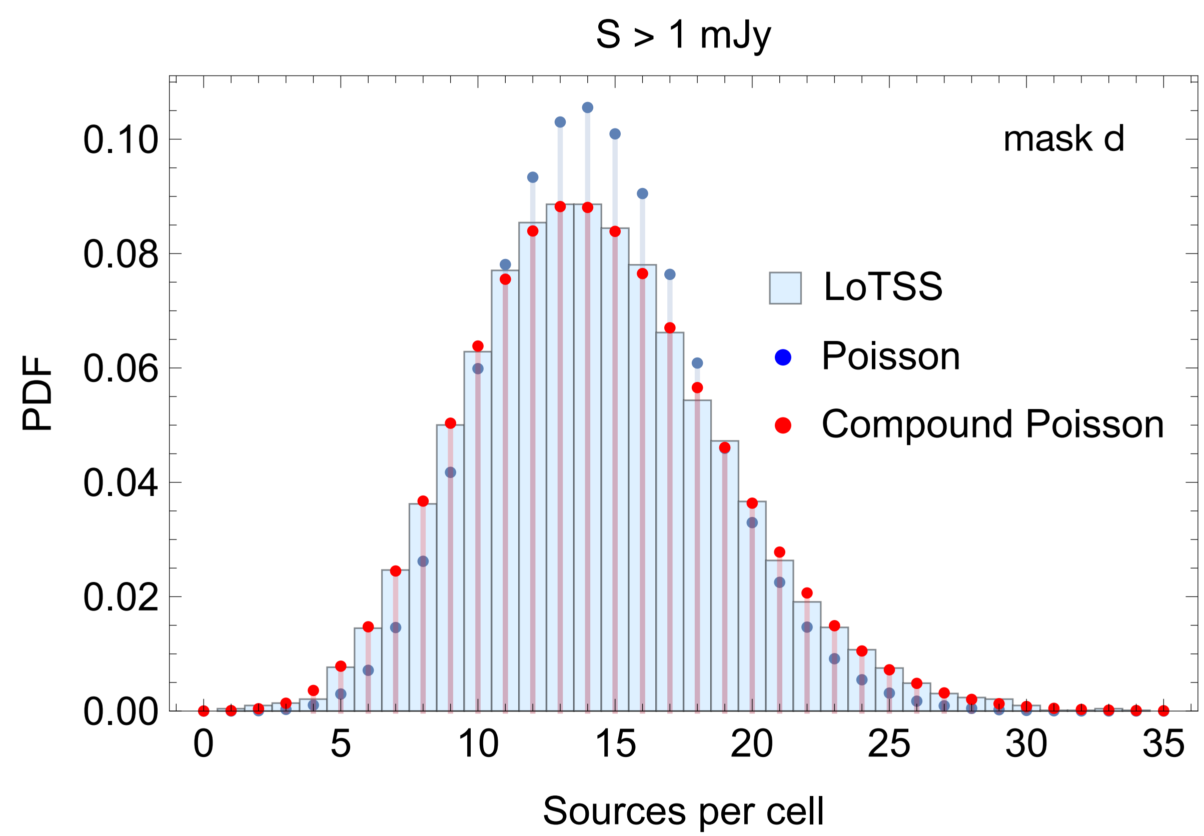
$$g_1^{\mathrm{P}} = \mu^{-1/2}$$

$$g_2^{\mathrm{P}} - 3 = \mu^{-1}$$

$$g_1^{\mathrm{CP}} = \frac{1}{\sqrt{\mu}} \left[\frac{n_{\mathrm{c}}^2 + n_{\mathrm{c}} - 1}{n_{\mathrm{c}}^{3/2}} \right]$$

$$g_2^{\mathrm{CP}} - 3 = \frac{1}{\mu} \left[\frac{n_{\mathrm{c}}^3 + 3n_{\mathrm{c}}^2 - 2n_{\mathrm{c}} - 1}{n_{\mathrm{c}}^2} \right]$$

Counts-in-cell distribution



$S_{\rm min}$ (mJy)	N	n_c	$\frac{\chi^2_P}{\rm dof_P}$	$\rm dof_P$	$\frac{\chi^2_{CP}}{\rm dof_{CP}}$	$\rm dof_{CP}$
1	102 940	1.44	30.67	32	0.76	31
2	51 288	1.22	11.67	20	1.12	19
4	30 556	1.15	7.69	14	1.38	13
8	19 612	1.11	3.52	11	0.46	10

→ Compound Poisson distribution preferred by sample source count distribution

Estimating the two-point correlation function

Using Landy&Szalay (1993) estimator:

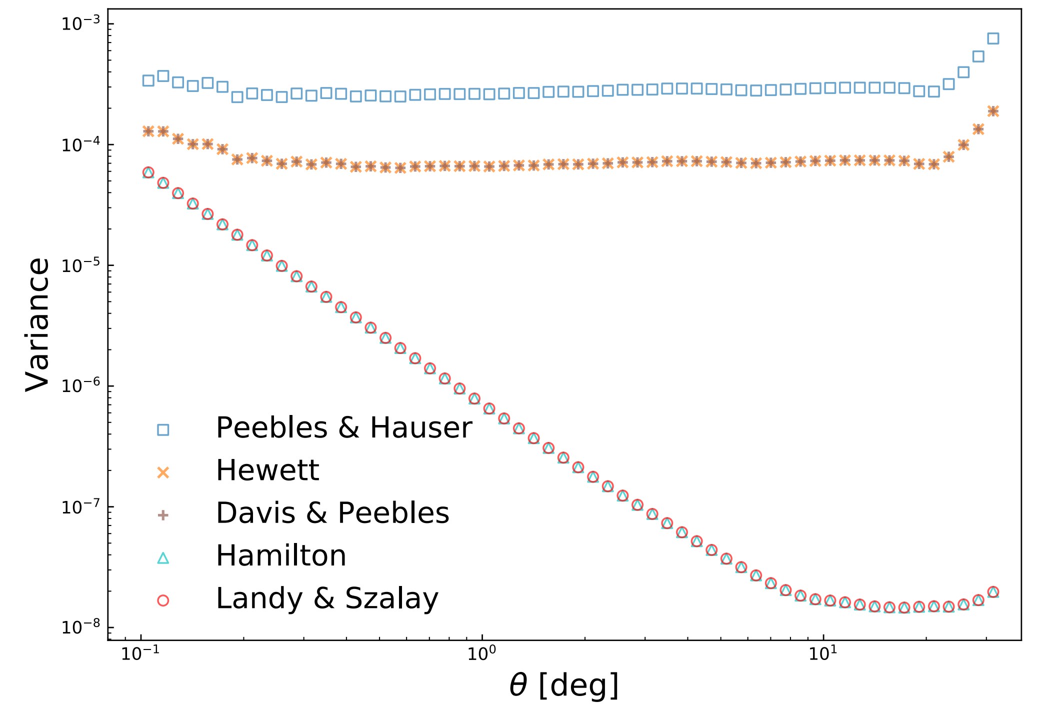
$$\hat{w}(\theta) = \frac{DD - 2DR + RR}{RR}$$

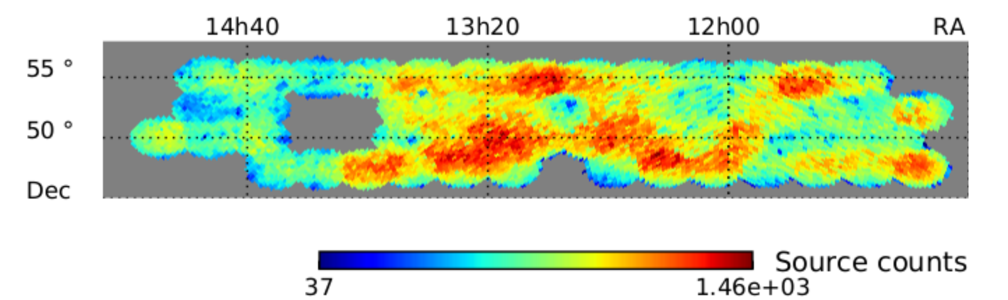
Mock catalogues as random sample:

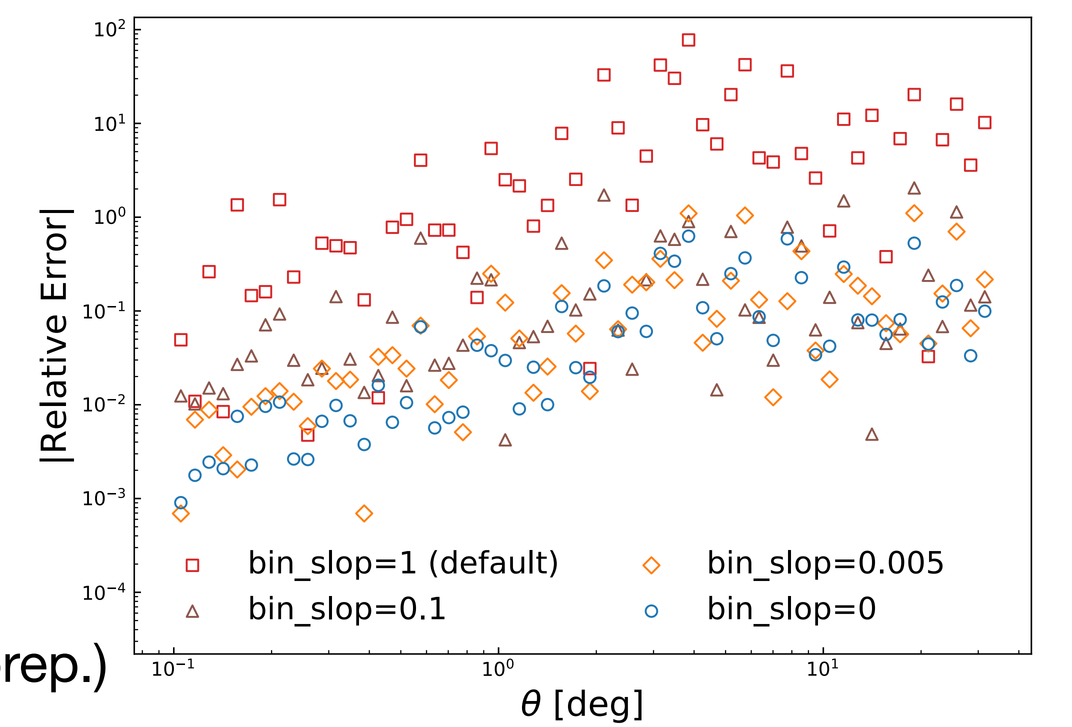
- 20x point sources
- random position in rms map
- flux density from SKADS

TreeCorr Code for the fit:

- ‚Arc' metric
- $\Delta \ln(\theta / 1\,\mathrm{deg}) = 0.1$
- ‚bin_slop = 0'

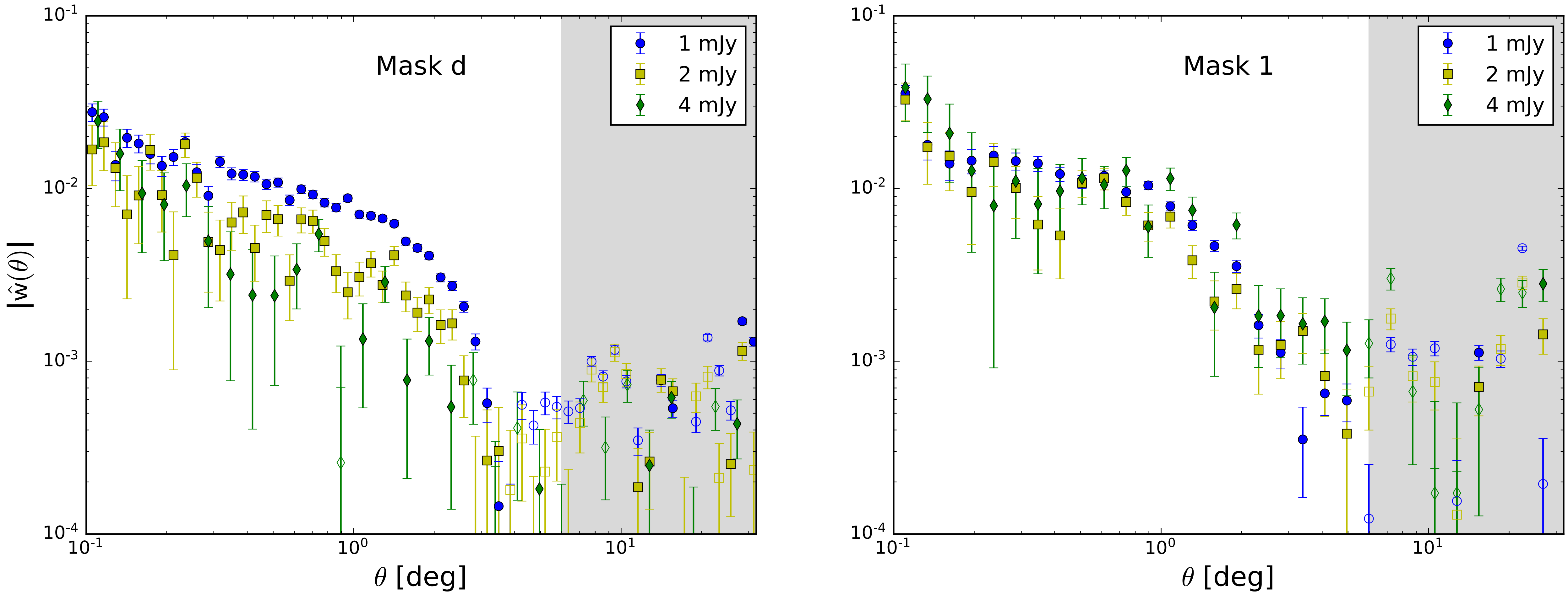






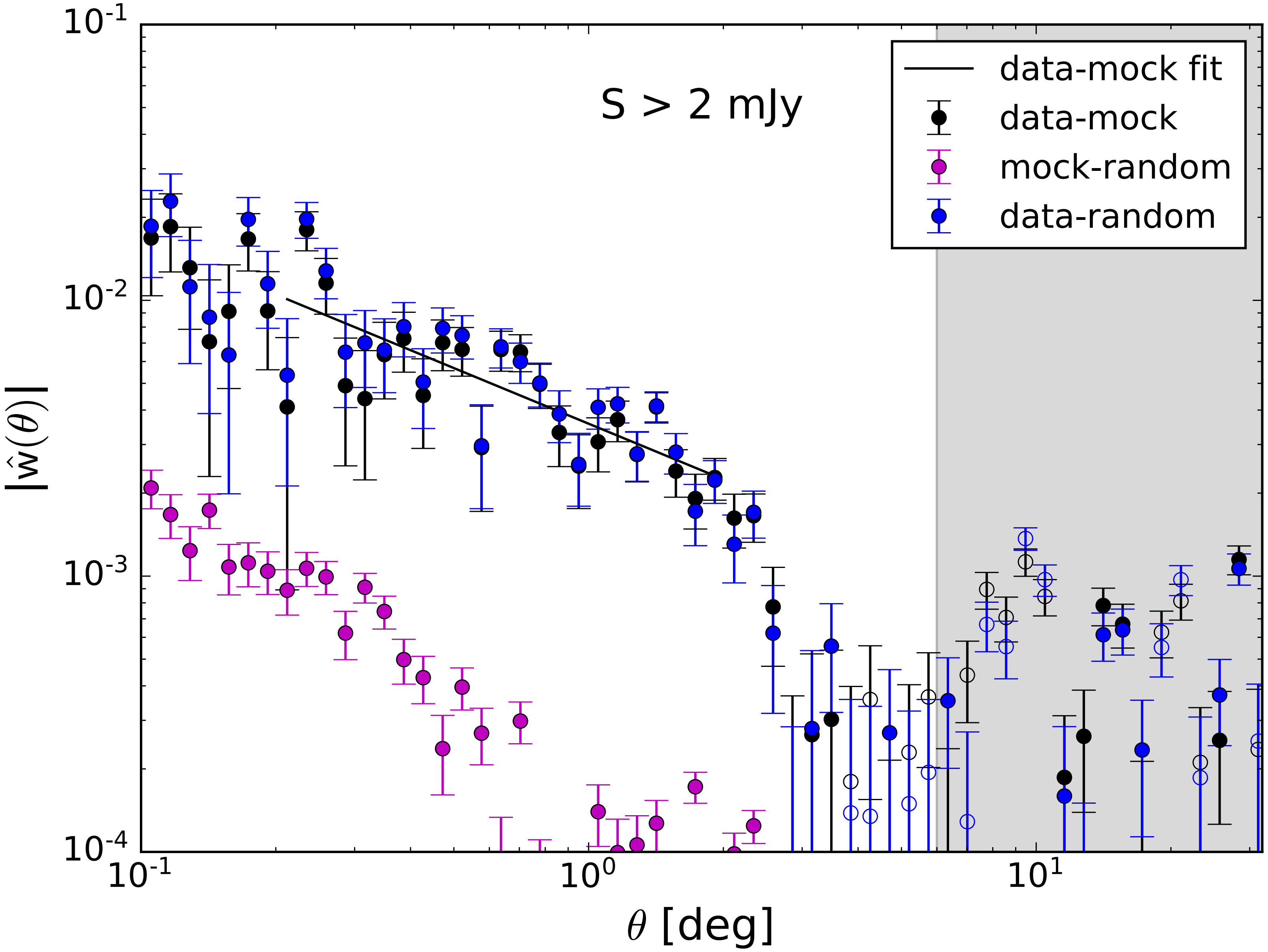
More details of the algorithm test in Biermann&Schwarz (in prep.)

Estimating the two-point correlation function



Cleanest region shows more consistent correlation

Estimating the two-point correlation function



Fitting the two-point correlation function

Survey	S_{min} (mJy)	$A(\times 10^{-3})$	γ	χ^2/dof	N
LoTSS-DR1	1	$7.00^{+0.18}_{-0.18}$	$0.58^{+0.04}_{-0.04}$	4.47	102 940
mask d	2	$3.51^{+0.24}_{-0.25}$	$0.74^{+0.10}_{-0.10}$	1.88	51 288
	4	$1.97^{+0.27}_{-0.27}$	$0.78^{+0.21}_{-0.20}$	0.68	30 556
LoTSS-DR1	1	$7.20^{+0.42}_{-0.42}$	$0.68^{+0.08}_{-0.08}$	5.78	40 599
mask 1	2	$5.11^{+0.59}_{-0.60}$	$0.74^{+0.16}_{-0.16}$	2.70	19 719
	4	$7.45^{+0.95}_{-0.95}$	$0.46^{+0.21}_{-0.20}$	2.34	11 269

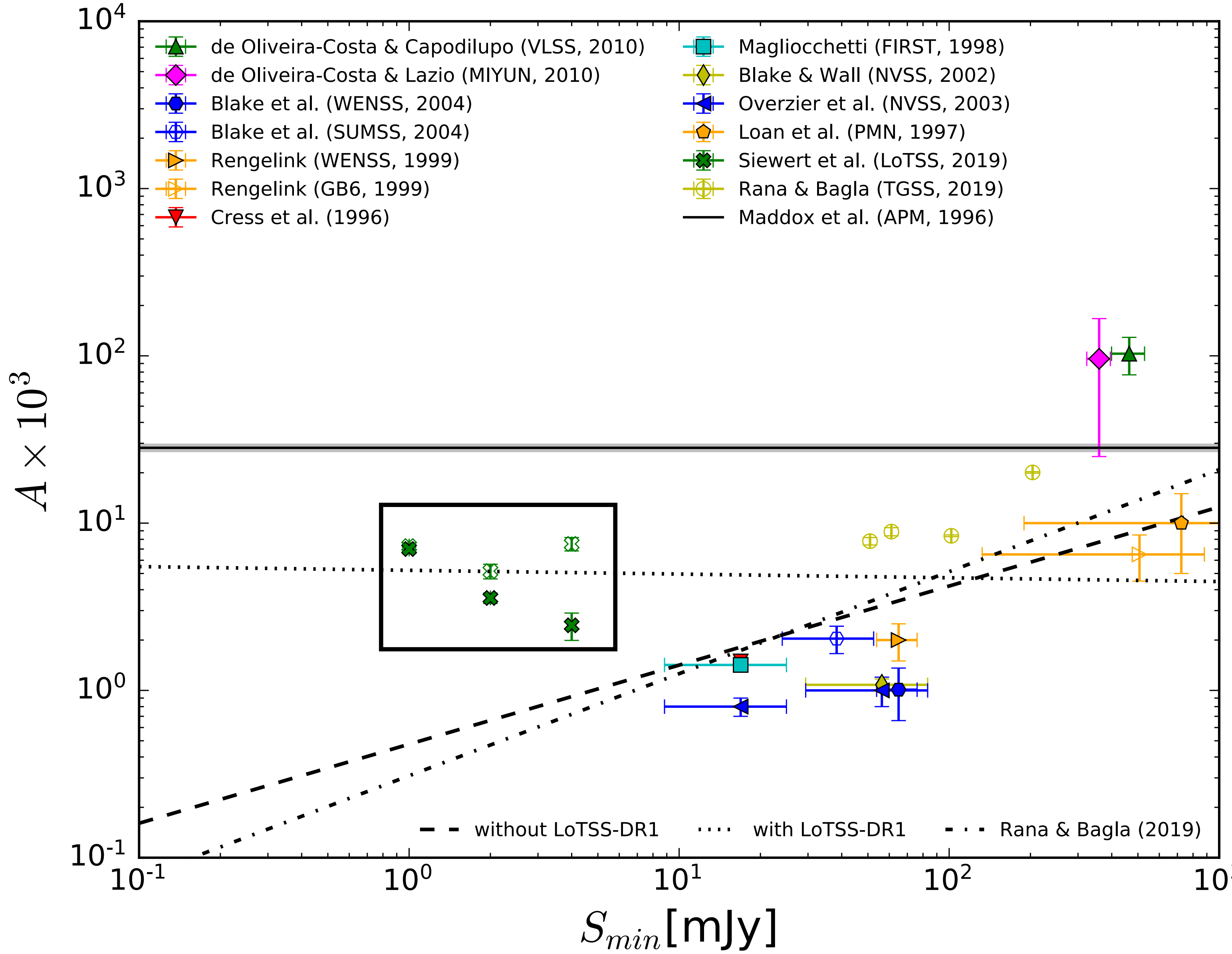
Fitting: $w(\theta) = A\,(\theta/1\ \mathrm{deg})^{-\gamma}$

Range: $0.2 \leq \theta \leq 2.0$ deg

using least-squares and *lmfit*

Mask 1 and 2 mJy most reliable sample

Fitting the two-point correlation function



Flux density scaled to 144 MHz, using spectral index α = 0.76

Expectations from CAMB Sources

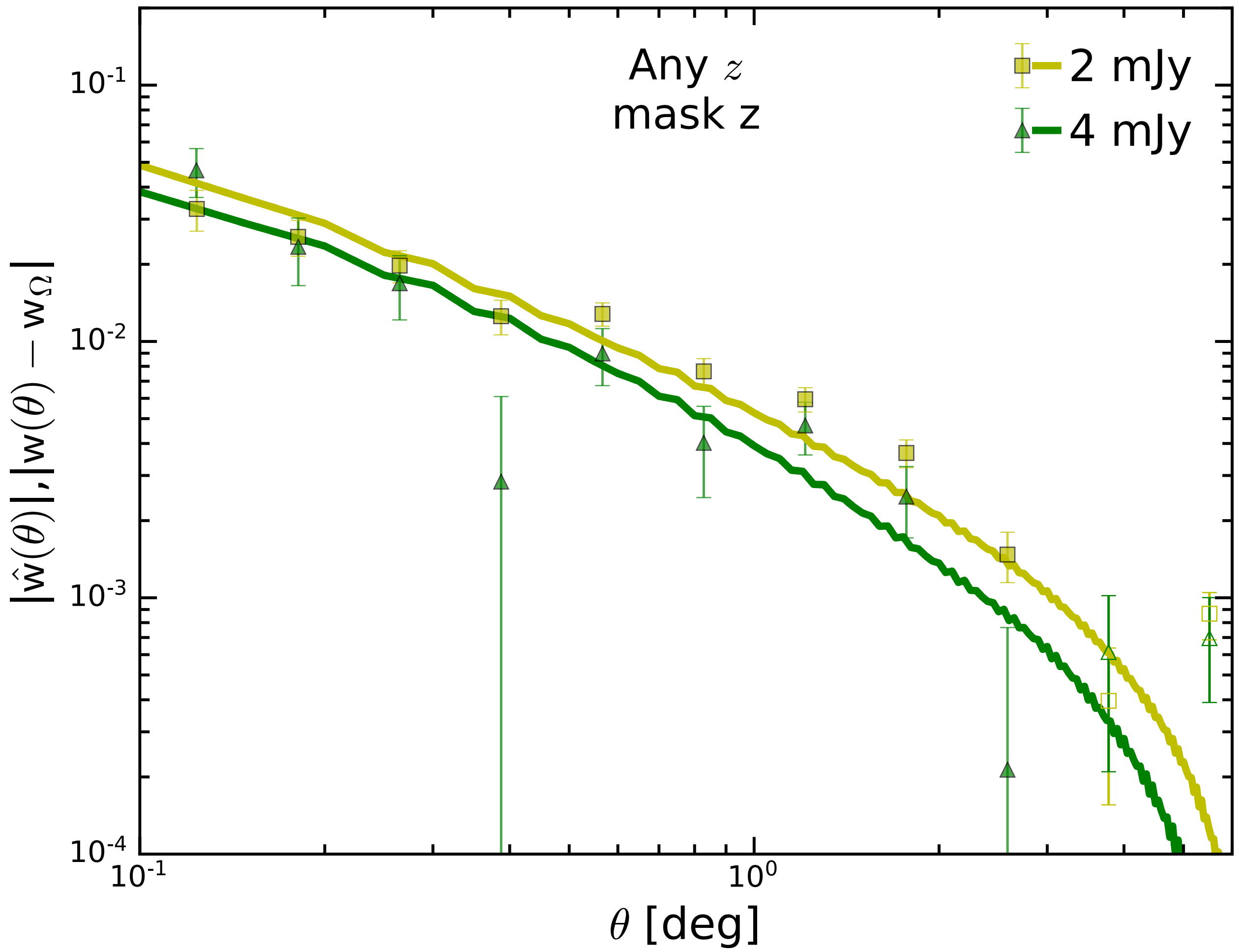
$$w(\theta, S) = \frac{1}{4\pi}\sum_{\ell=0}^{\infty}(2\ell+1)C_\ell(S)P_\ell(\cos\theta)$$

Calculate $C_\ell(S)$ using CAMB Sources

ΛCDM cosmology from Planck 2018

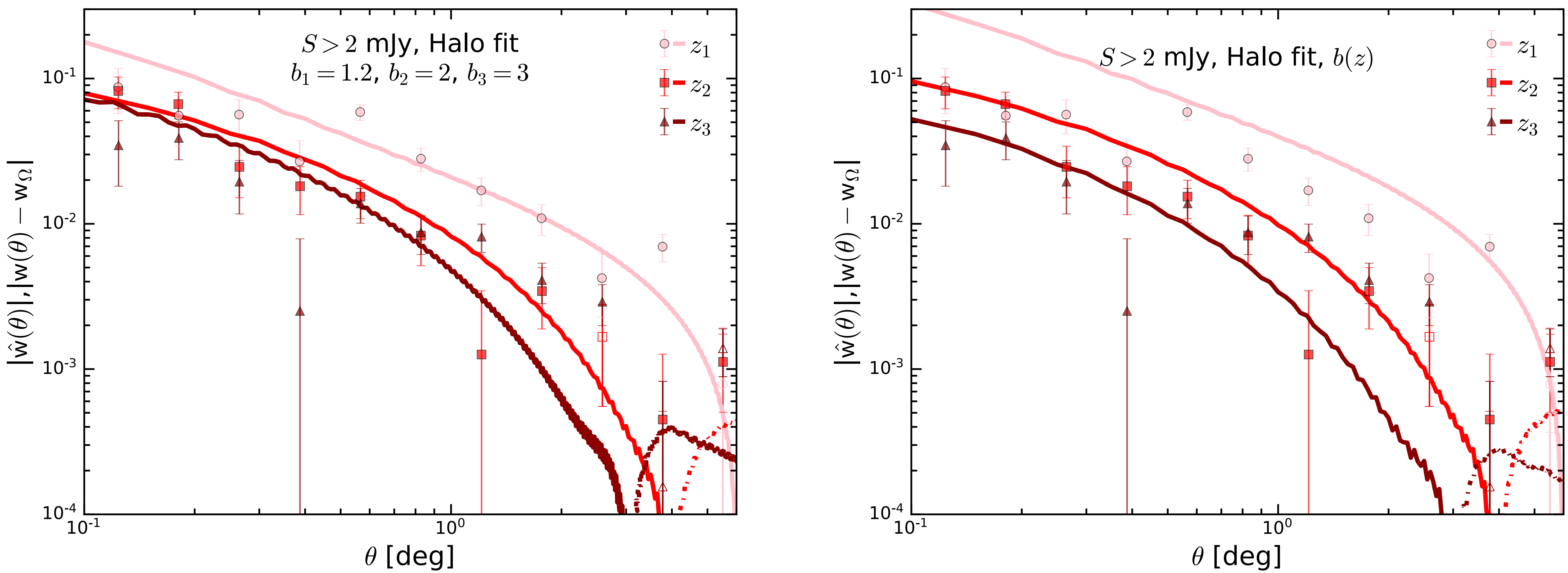
non-linear theory + w/o Limber approx.
+count lensing + redshift distribution
+ bias model [Tiwari&Nusser2016]

$$b(z) = 1.6 + 0.85z + 0.33z^2$$



Survey	$S_{\rm min}$ (mJy)	z	$A(\times 10^{-3})$	γ	χ^2/dof	N
LoTSS-DR1	2	Any z	$6.58^{+0.42}_{-0.43}$	$0.84^{+0.08}_{-0.08}$	1.25	24 420
mask z	4	Any z	$4.65^{+0.78}_{-0.80}$	$0.84^{+0.25}_{-0.24}$	1.45	14 506
LoTSS-DR1	2	Any z	$6.68^{+0.93}_{-0.94}$	$0.92^{+0.18}_{-0.18}$	1.27	9 505
mask z1	4	Any z	$6.48^{+1.18}_{-1.19}$	$0.64^{+0.28}_{-0.26}$	0.70	5 432

Expectations from CAMB Sources for redshift sub samples



$$z_1 < z_{33} = 0.376 \le z_3 < z_{66} = 0.705 \le z_3$$

Survey	$S_{\min}$ (mJy)	z	$A(\times 10^{-3})$	γ	χ^2/dof	N
LoTSS-DR1	2	$z < 0.376$	$23.02^{+1.59}_{-1.59}$	$0.82^{+0.09}_{-0.09}$	2.13	8 430
mask z	2	$0.376 \le z < 0.705$	$6.50^{+0.10}_{-0.10}$	$0.99^{+0.18}_{-0.19}$	0.60	7 189
	2	$0.705 \le z$	$7.30^{+0.90}_{-0.90}$	$0.74^{+0.18}_{-0.17}$	0.77	8 801
LoTSS-DR1	2	$z < 0.376$	$21.50^{+4.65}_{-4.72}$	$0.84^{+0.29}_{-0.29}$	4.18	3 420
mask z1	2	$0.376 \le z < 0.705$	$4.77^{+2.09}_{-2.09}$	$1.03^{+0.45}_{-0.52}$	0.35	2 693
	2	$0.705 \le z$	$9.82^{+1.43}_{-1.43}$	$0.38^{+0.26}_{-0.23}$	0.41	3 399

Conclusions

Faint radio source distribution deviates from a Poisson dist.

-> better described by Compound Poisson

-> multi-component sources / groups of sources

Two-point correlation function shows slight differences between different masks

-> Most reliable sample ,mask 1', 2 mJy

-> Good agreement to expectations between 0.1° and 6°