JVLA Lessons Learned and SKA1 Requirements

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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

The JVLA is a good SKA1 "precursor"

JVLA:

large instantaneous bandwidth and fractional bandwidth

continuous frequency coverage, $\nu \geq 1$ GHz

two-dimensional array with adjustable size (1, 3.2, 11, 35 km)

nearly Gaussian dirty beam with ~ natural weighting

JVLA < SKA1-survey: 100× smaller FOV, 50× smaller SSFoM

mitigation: the ratio sky is quite isotropic,

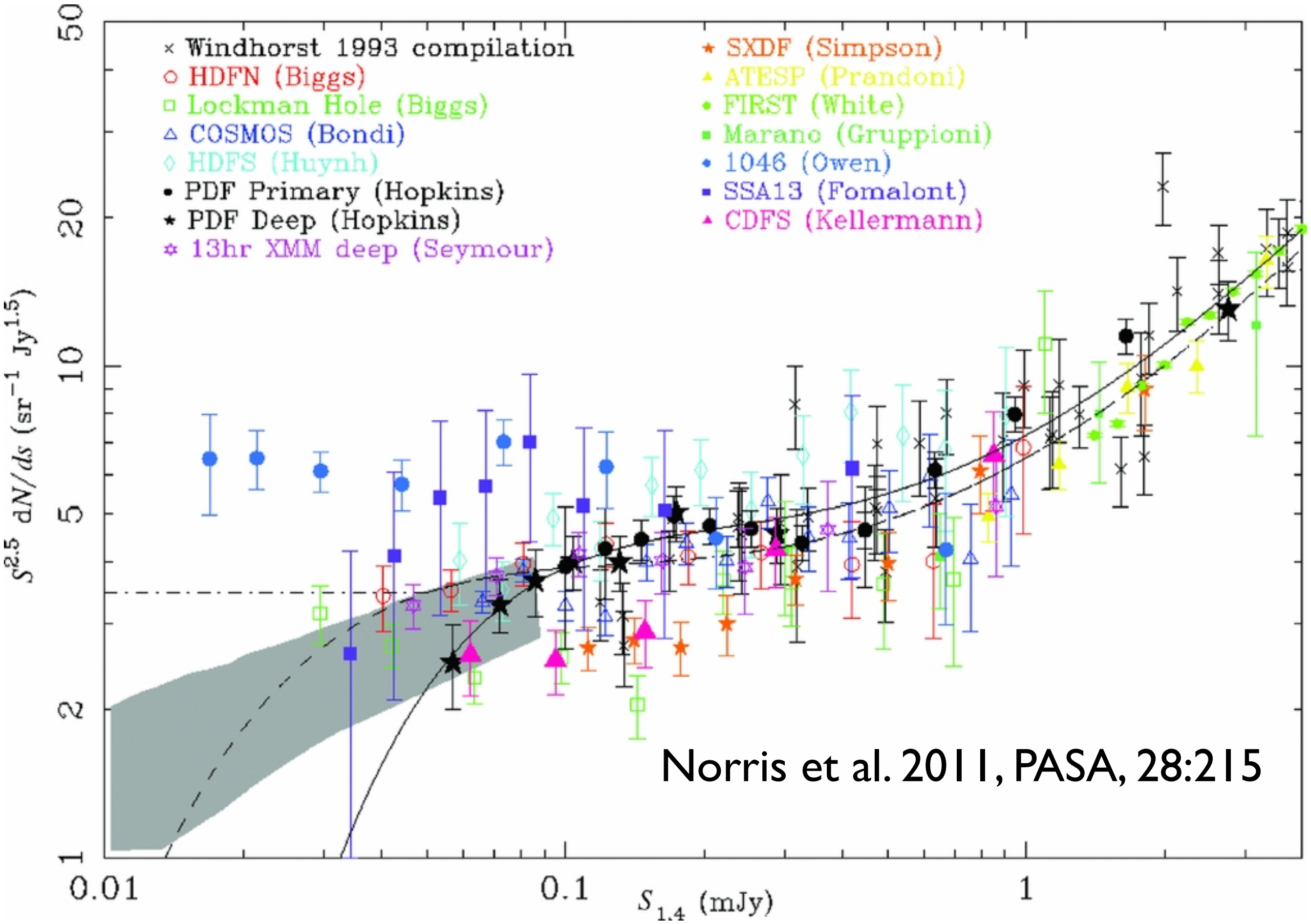
so even one JVLA FOV yields a fair sample of the μJy sky

JVLA < SKA1-mid: 5× worse continuum sensitivity

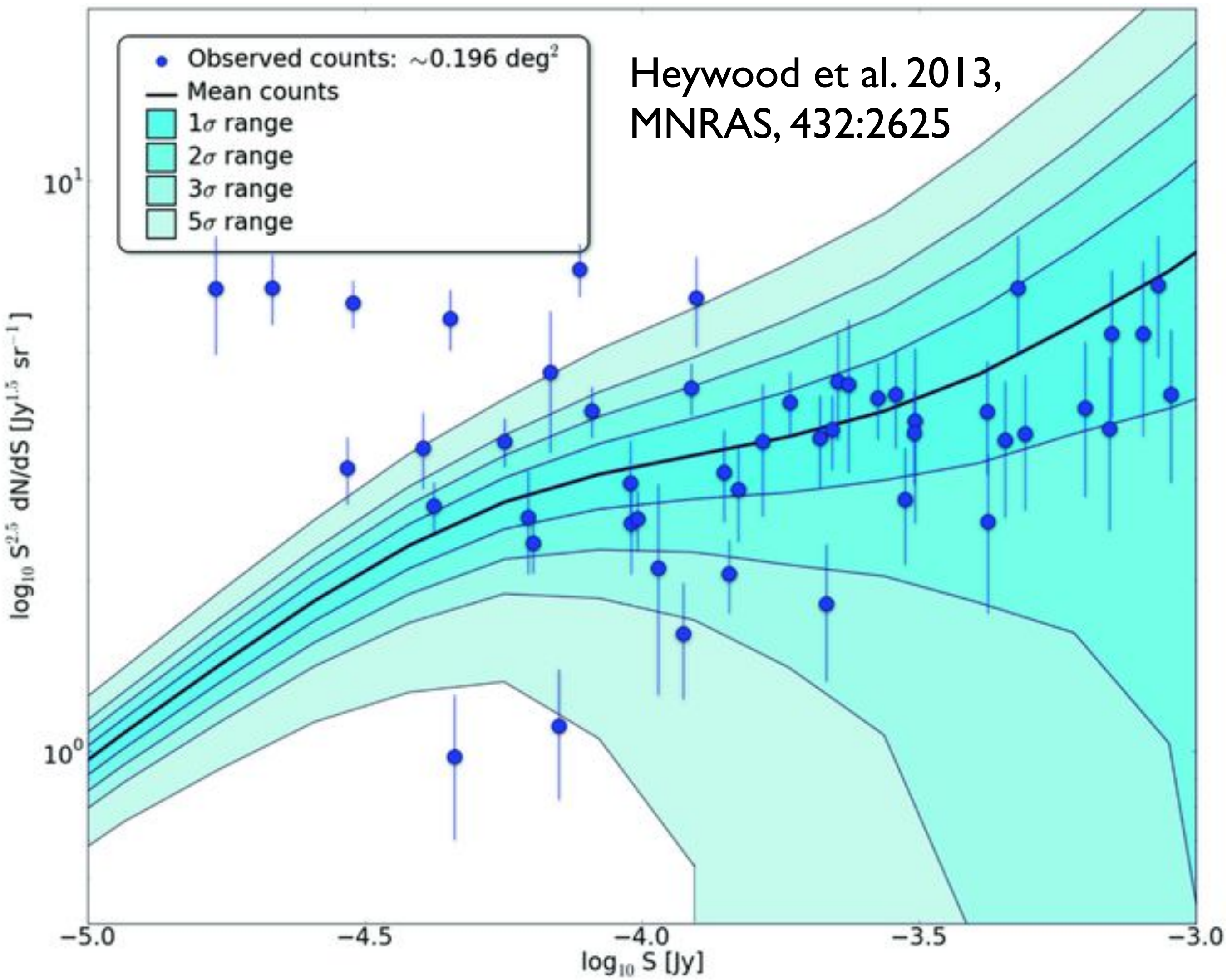
mitigation: confusion-limited images constrain source populations

~5× fainter than the detection limit for individual sources

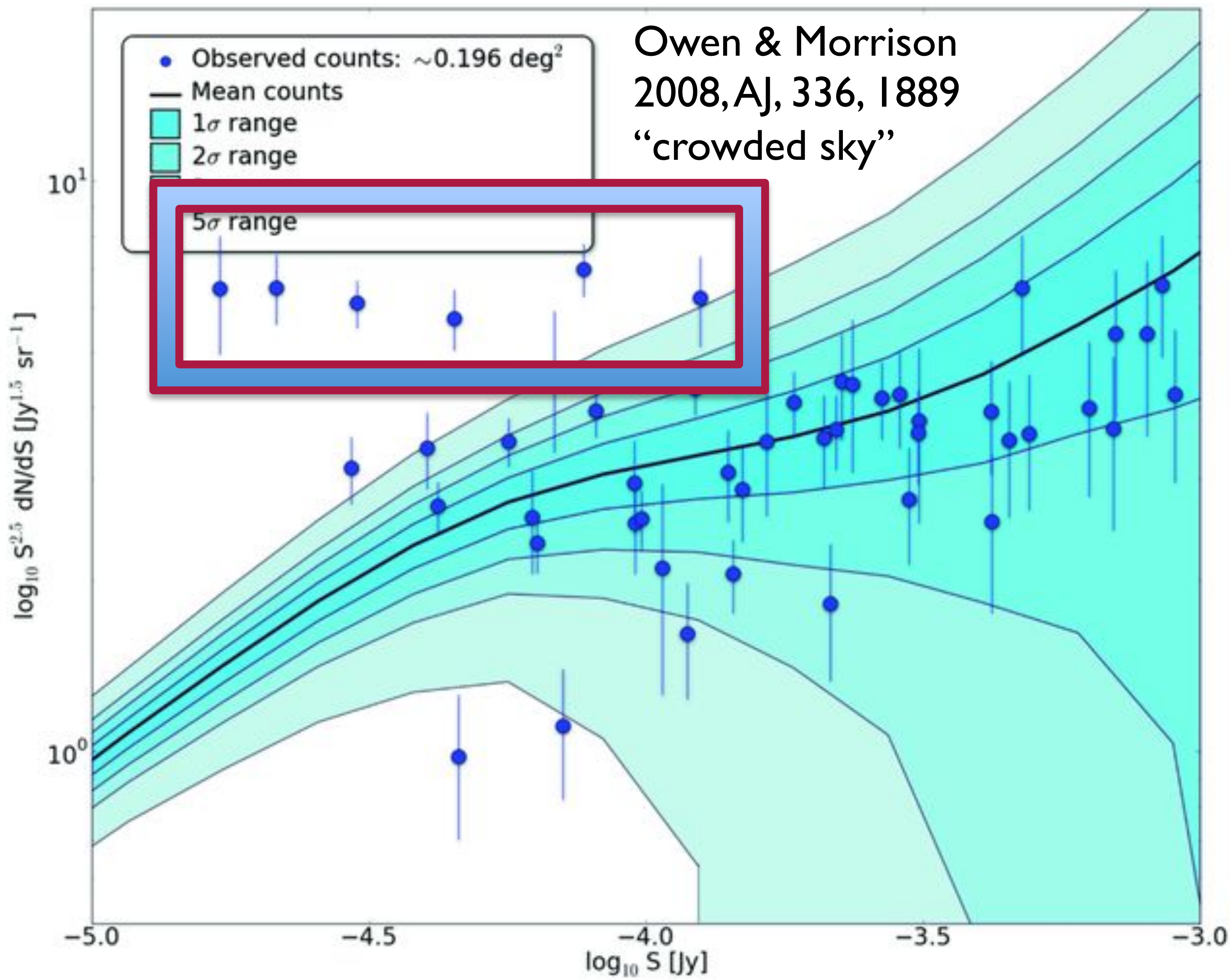
µJy sources: we have a problem



and we can't blame it on clustering.



The deepest count from the (old) VLA



Owen & Morrison 2008, AJ, 336, 1889
"crowded sky"

Why does the O&M field seem to be so "crowded"?

The faint-source count simulations are very wrong?

Galaxy clustering is much stronger than expected?

More than half of the faint O&M sources are spurious?

The O&M flux densities of faint sources were overestimated?

The O&M median angular size $<\Phi>$ ~ 1.2 arcsec was overestimated?

The O&M count corrections for partial resolution in their θ = 1.6 arcsec FWHM beam are too large?

To answer these questions: reobserve the O&M field

with larger θ = 8 arcsec >> $<\Phi>$ to minimize resolution corrections.

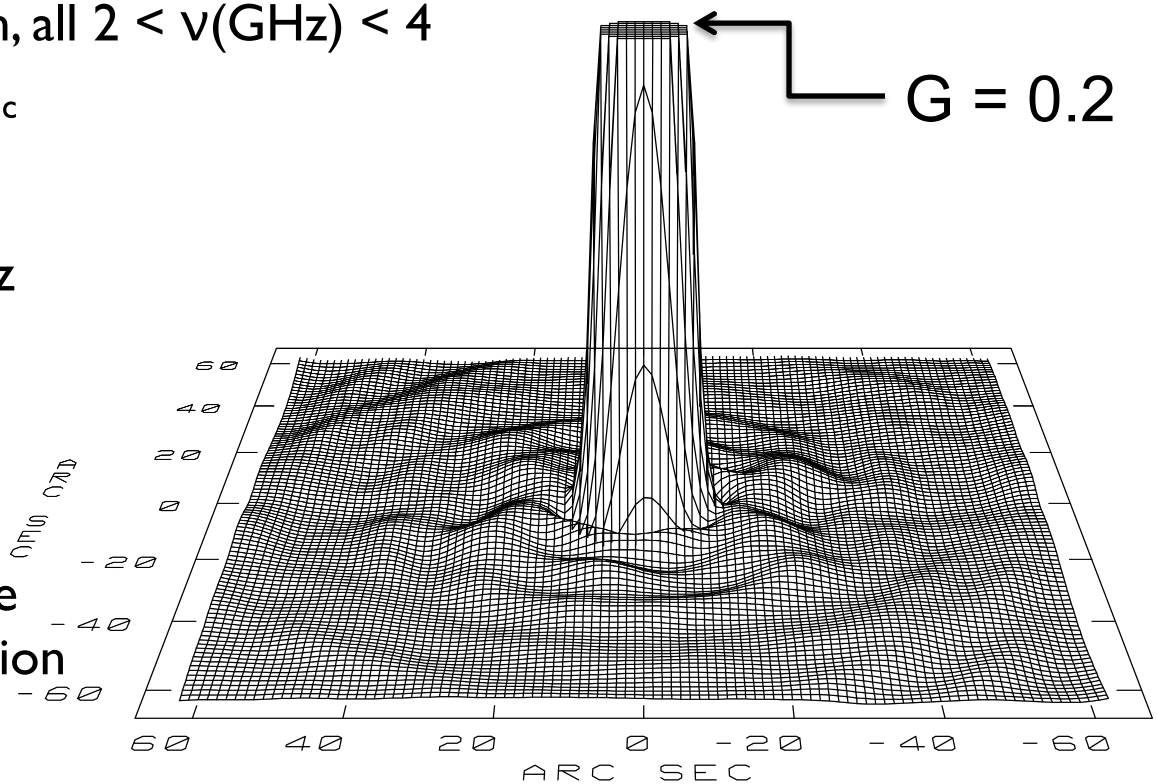
JVLA 3 GHz confusion-limited image of the O&M field

Condon et al. 2012, ApJ, 758:23

θ = 8.0 arcsec resolution, all 2 < ν(GHz) < 4
σ_n = 1.0 μJy beam^{-1} ≈ σ_c
τ ~ 50 hours

Going from 1.4 to 3 GHz lowers the required dynamic range by ~ 10 ×

Dirty-beam sidelobes < 1% are needed because you can't CLEAN confusion



Dirty beam, truncated at 20% of peak to show < 1% sidelobes

Large fractional bandwidths

Pro:

- Lower noise (but not by the usual √BW)
- Bandwidth synthesis

Con:

- RFI
- Feed/OMT polarization
- Weighting: N^{-2} or $(S/N)^2$
- ν is ill defined
- FoV is ill defined
- *S* is ill defined
- The PSF may be ill defined

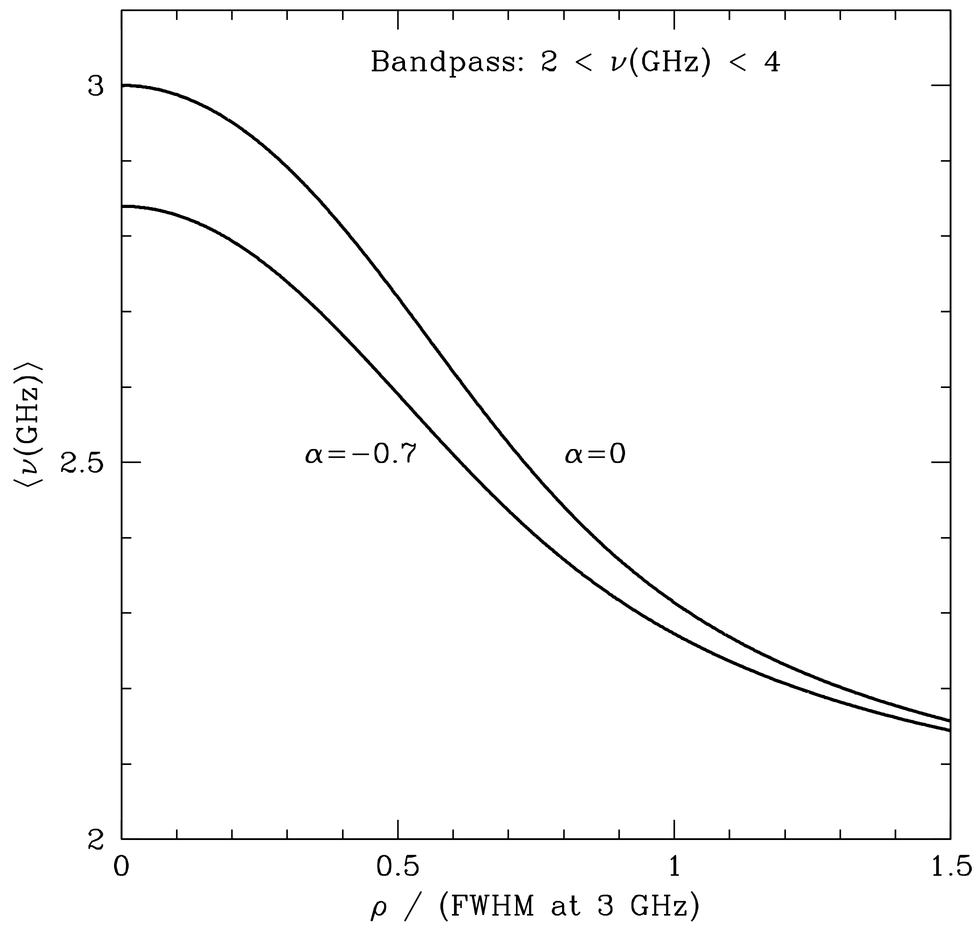
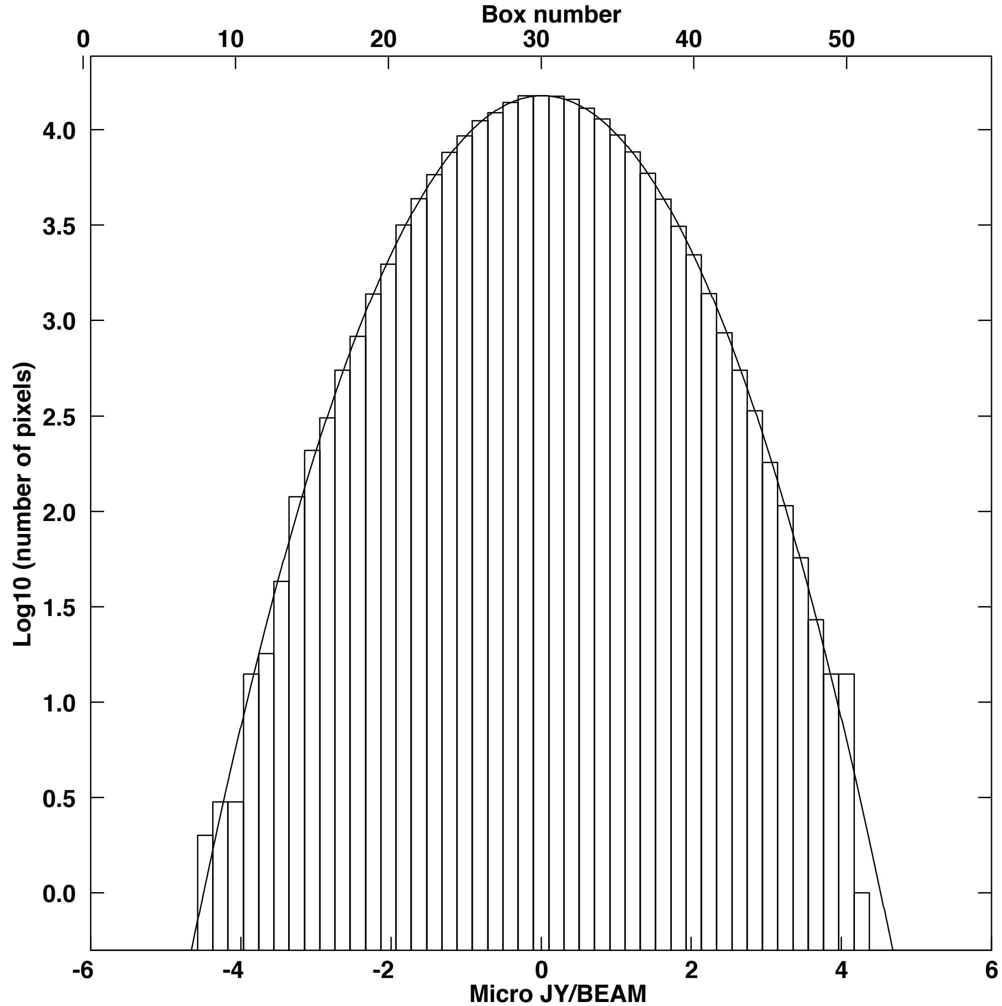


Image noise

Perfectly Gaussian noise (parabola on log scale)
σ = 1.012 μJy beam^{-1} after τ ~ 50 hours



Noise only

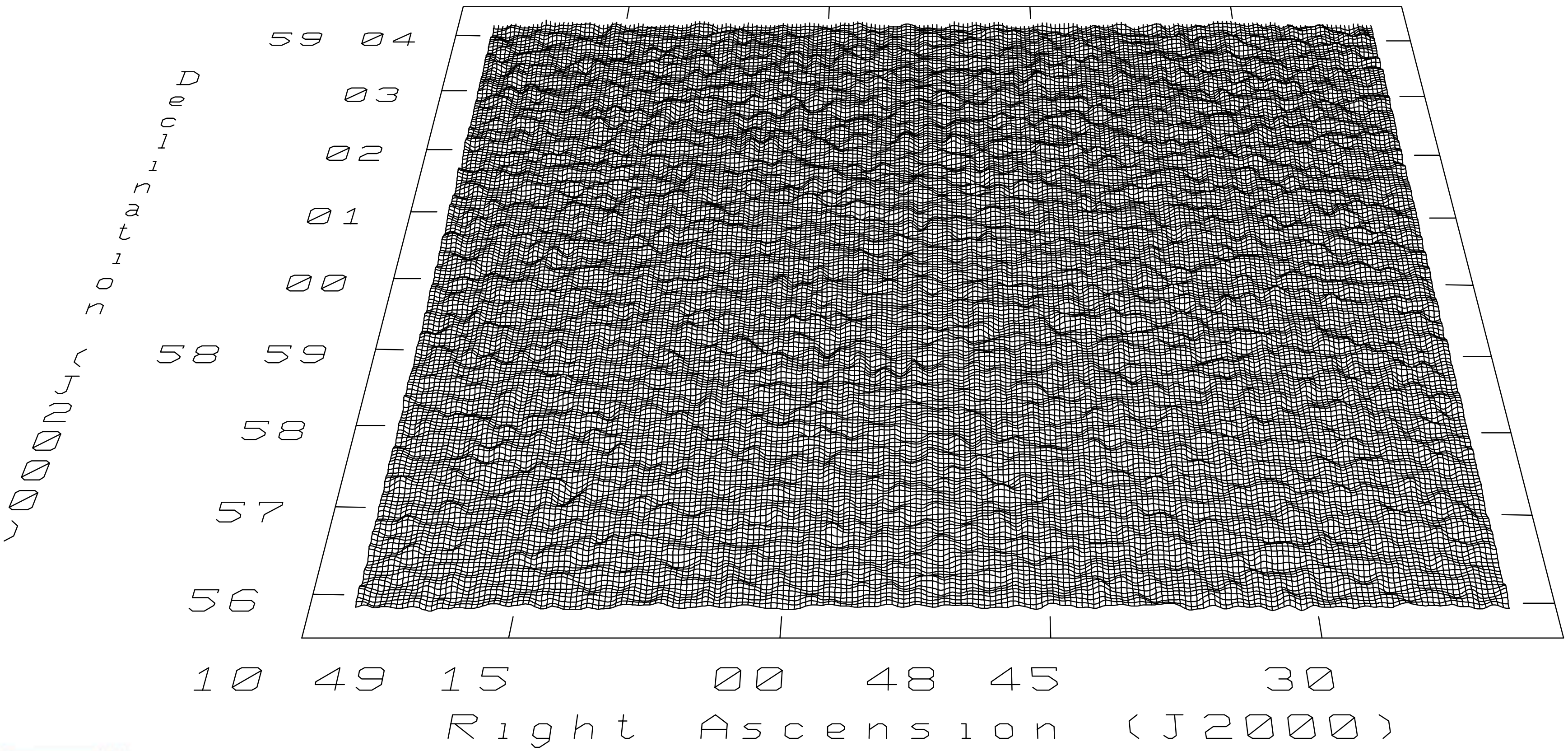
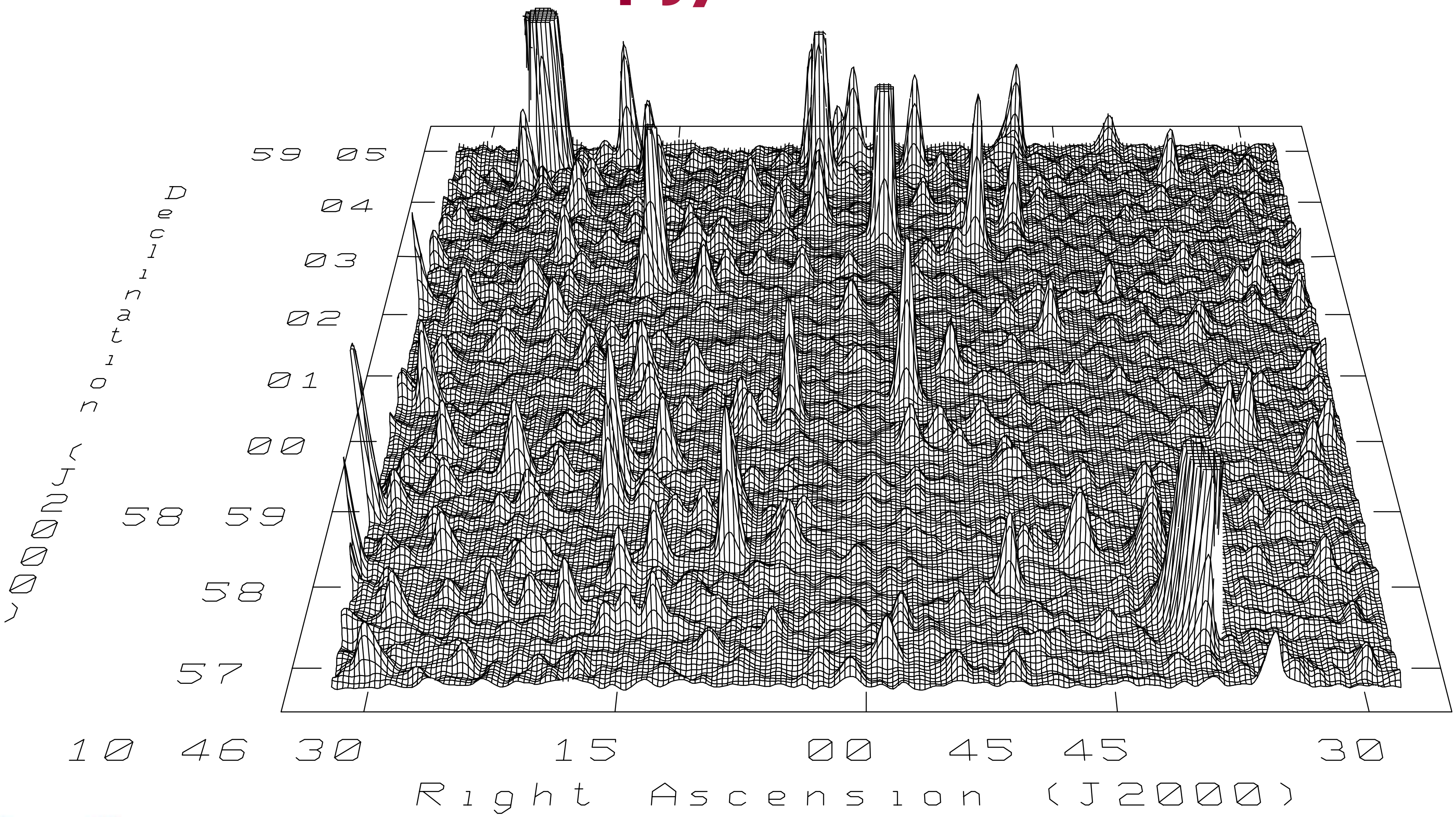
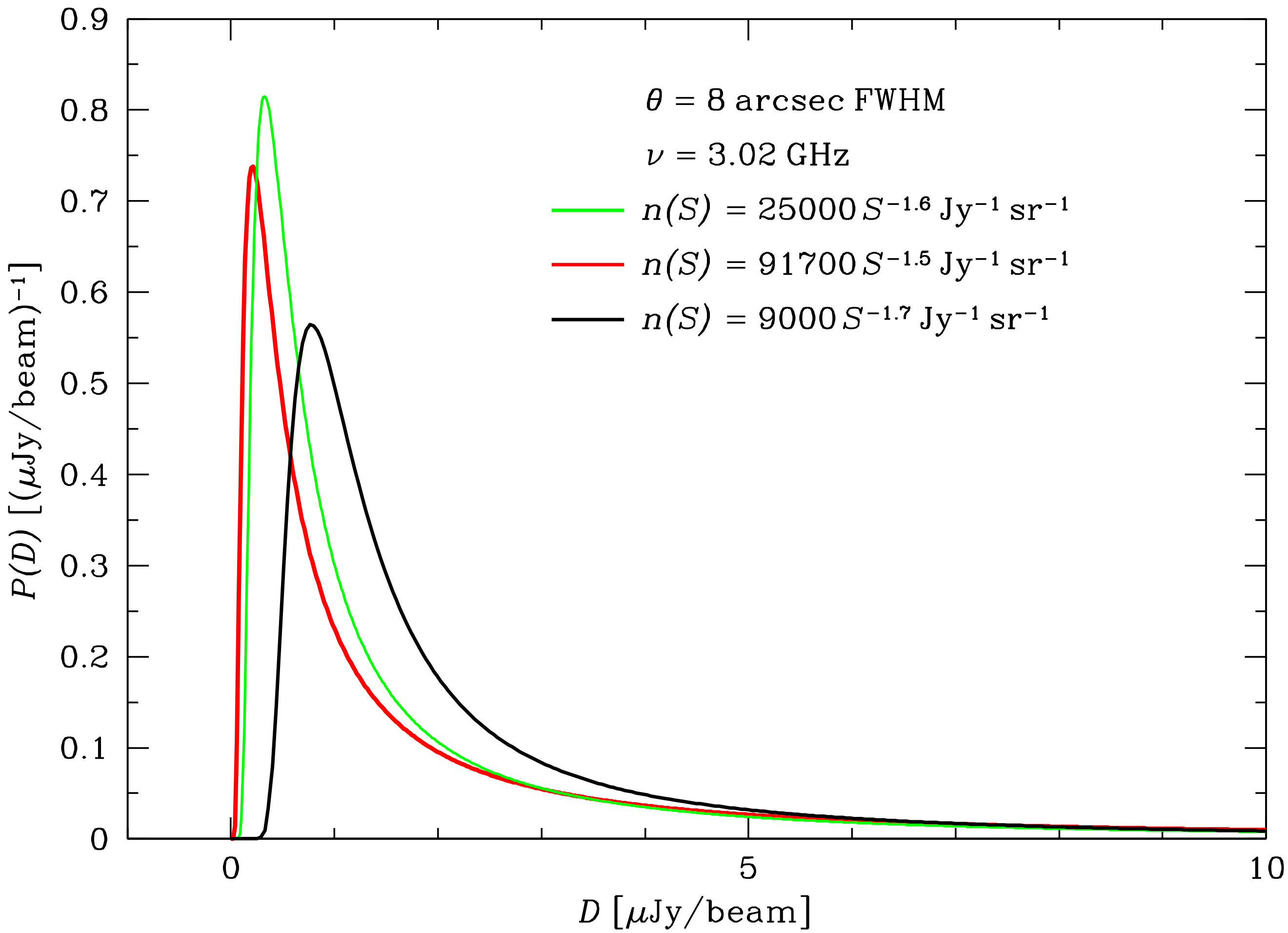

59 04
03
02
01
00
58 59
58
57
56
Declination (J2000)
10 49 15
00
48 45
30
Right Ascension (J2000)

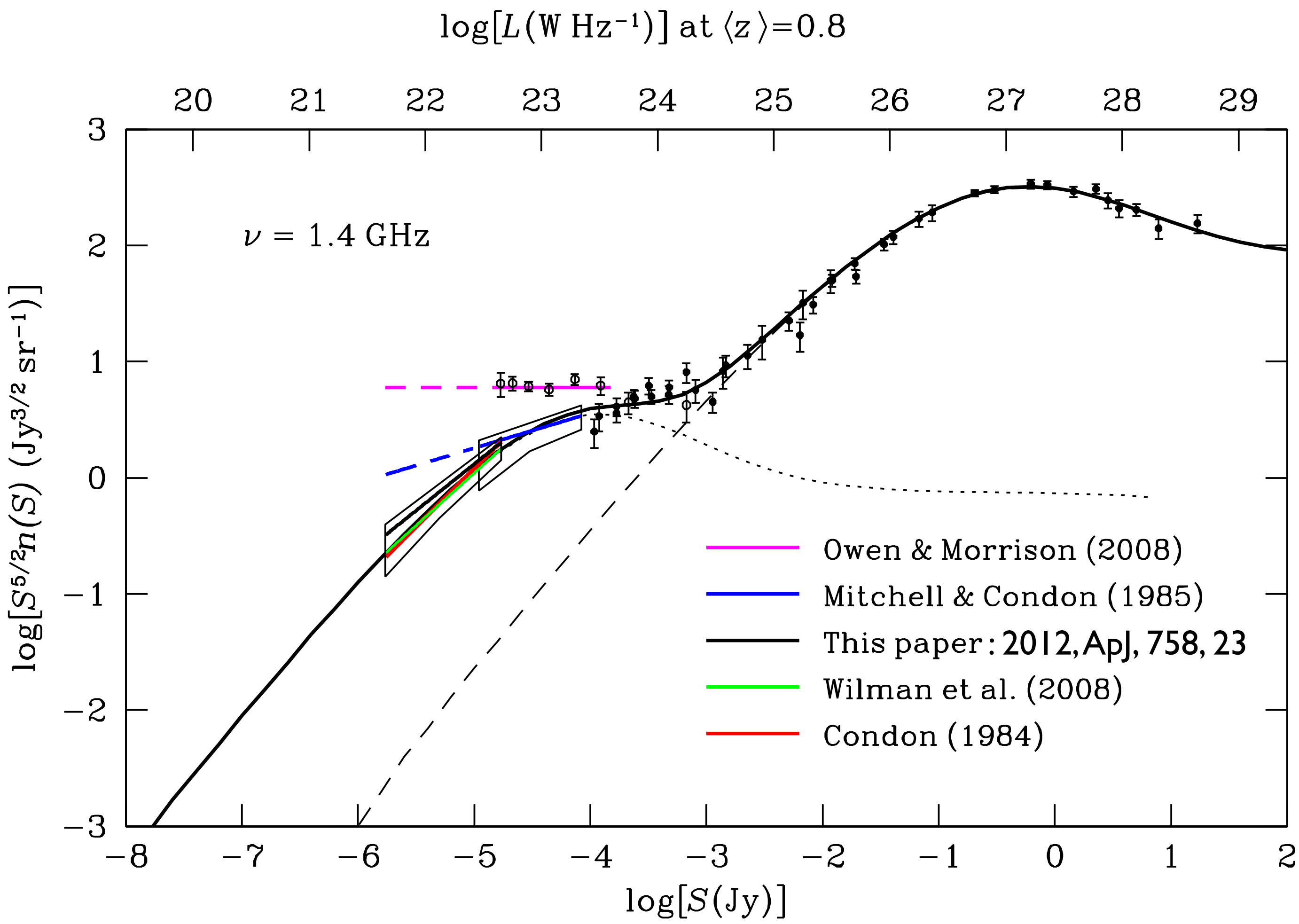
Image noise plus sources, same scale, truncated at 100 μJy / beam



Noiseless *P(D)* distributions



The new counts agree with simulations

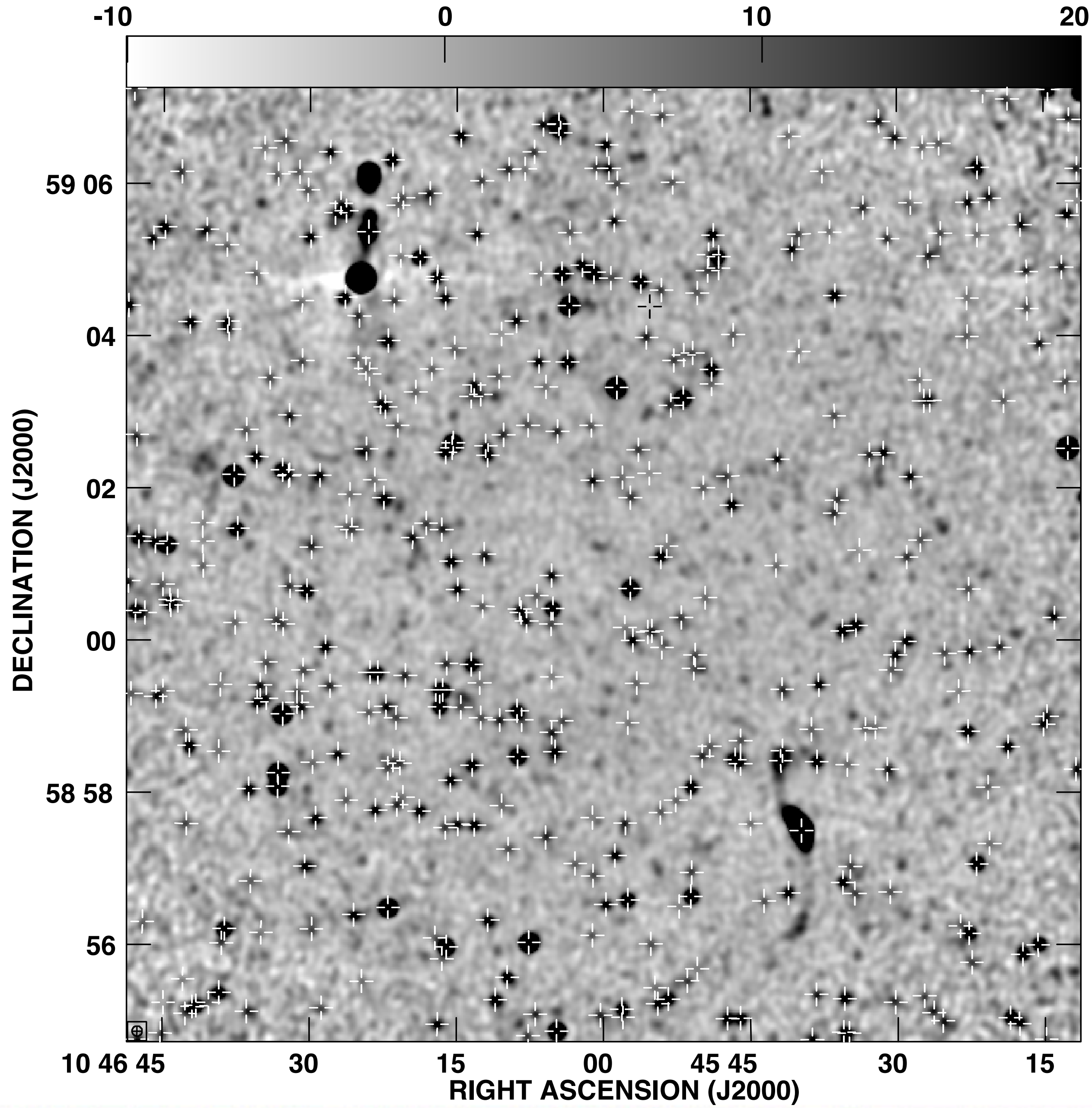


Crowded?

The Owen & Morrison (2008) sources (white crosses) are not spurious.

The uncorrected O&M count is not high and is consistent with the simulations.

The field is not "crowded" by clustering.

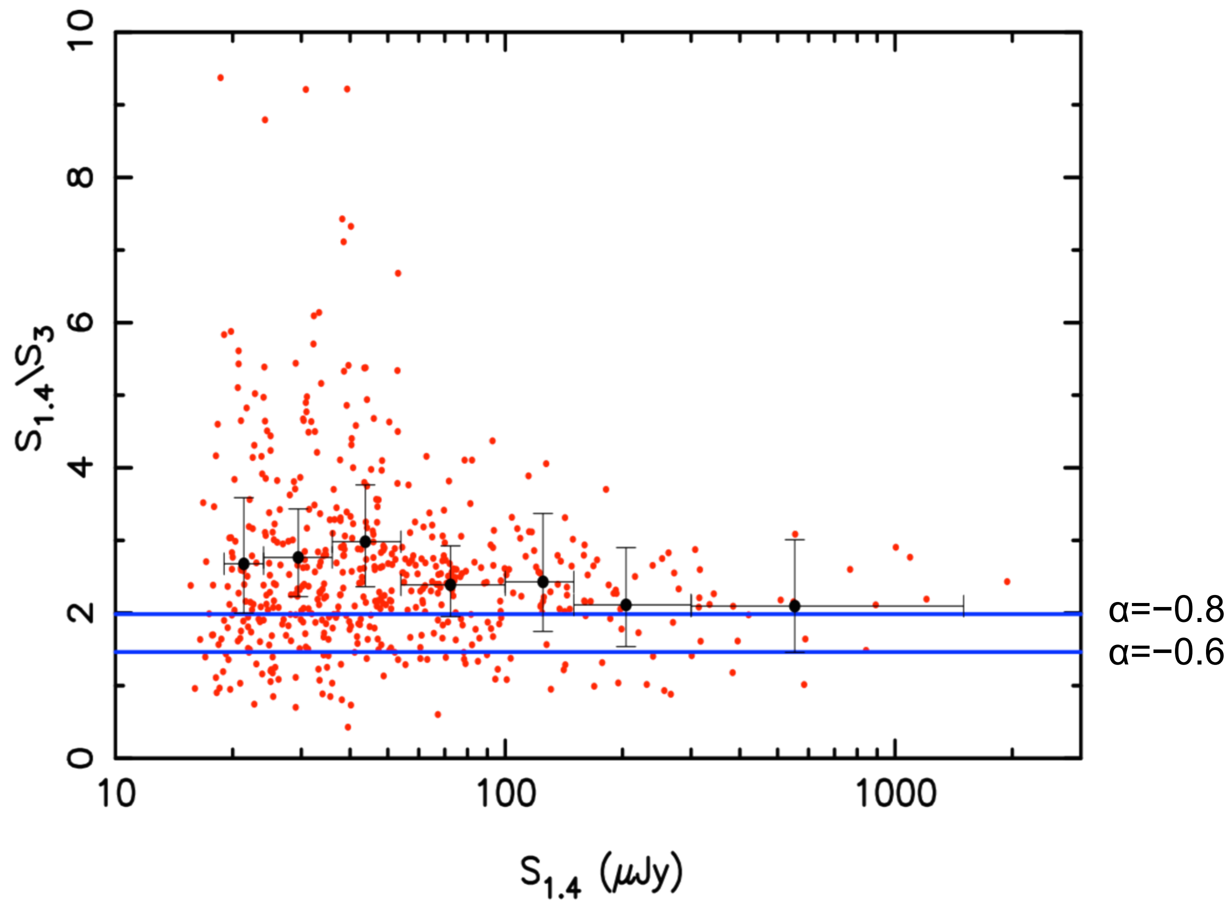


The O&M flux densities seem high

Overestimated source sizes when resolution θ ~ source size <Φ>?

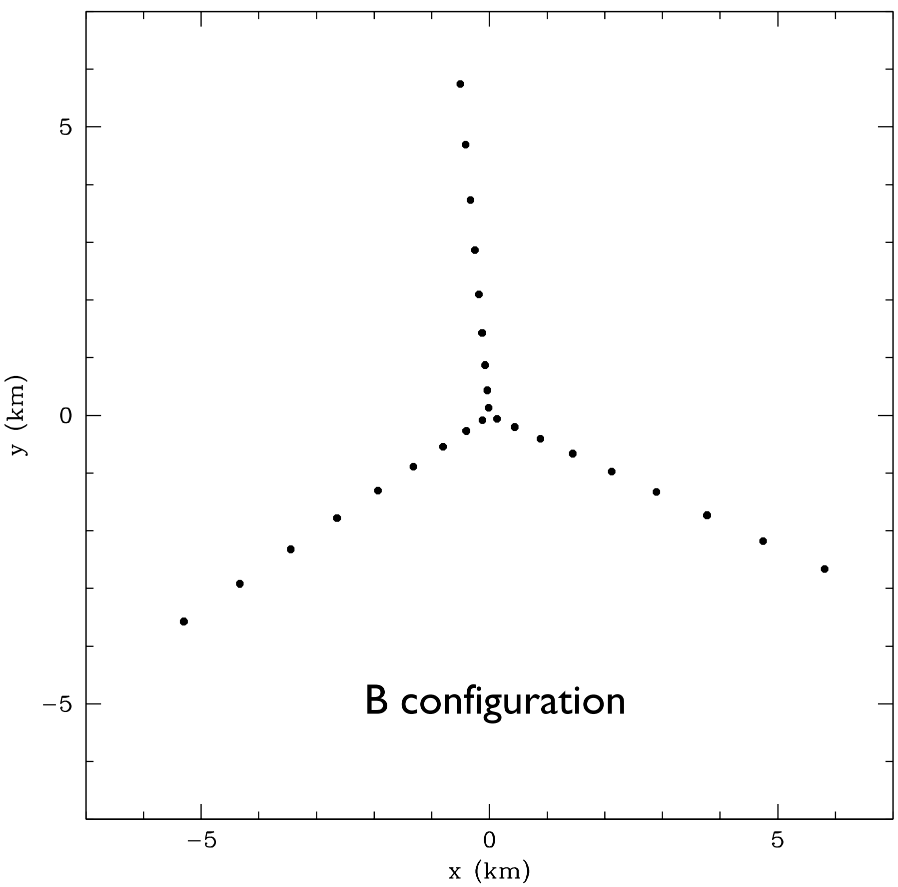
Pedestal on dirty beam from multiconfiguration data (104, 27.5, 6.5, 1.6h in A, B, C, D) degrades Gaussian fits?

Should SKA1 tune (u,v) coverage to get nearly Gaussian dirty beams?

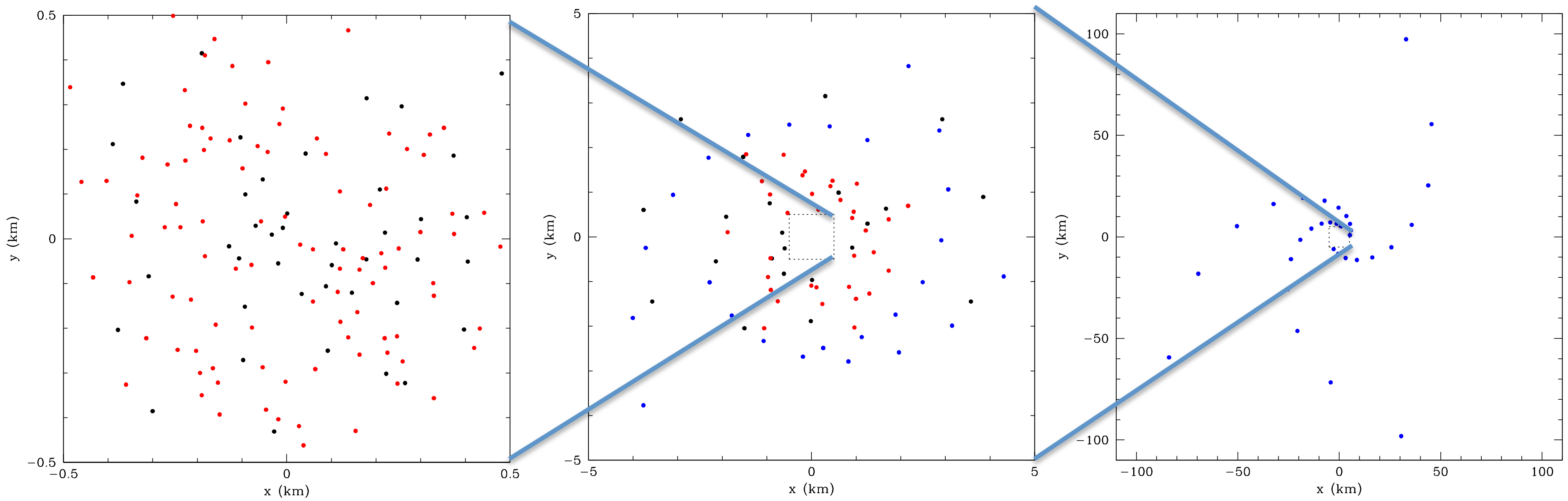


VLA antenna distribution

Power-law radial distribution
$r_n \sim n^{1.716}$
➔ scale-free arrays for good "natural" PSFs.
Four arrays scaled × 3.285 for matched PSFs at different frequencies.



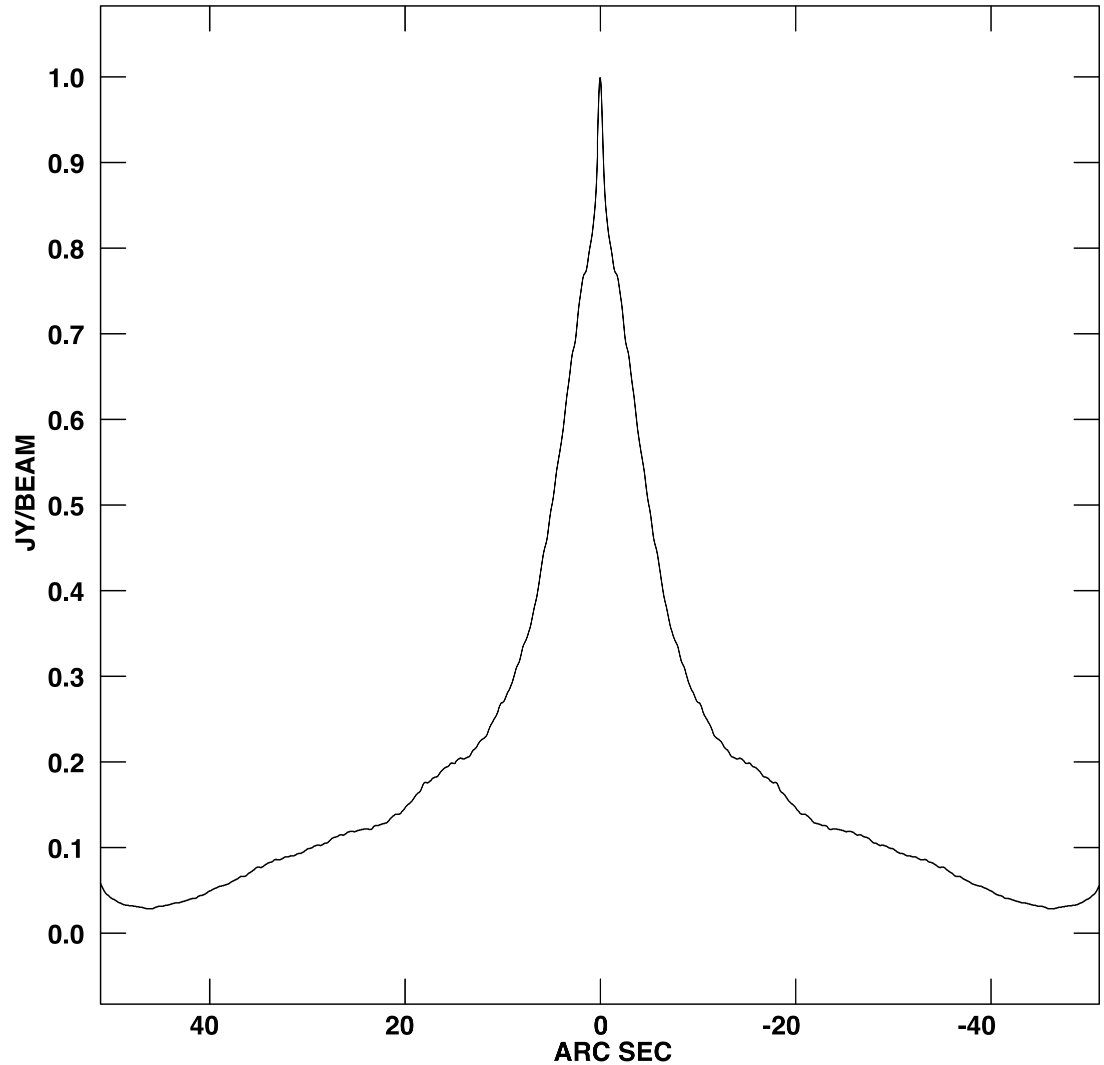
SKA1-mid antenna distribution



SKA1-mid synthesized beam

natural weighting

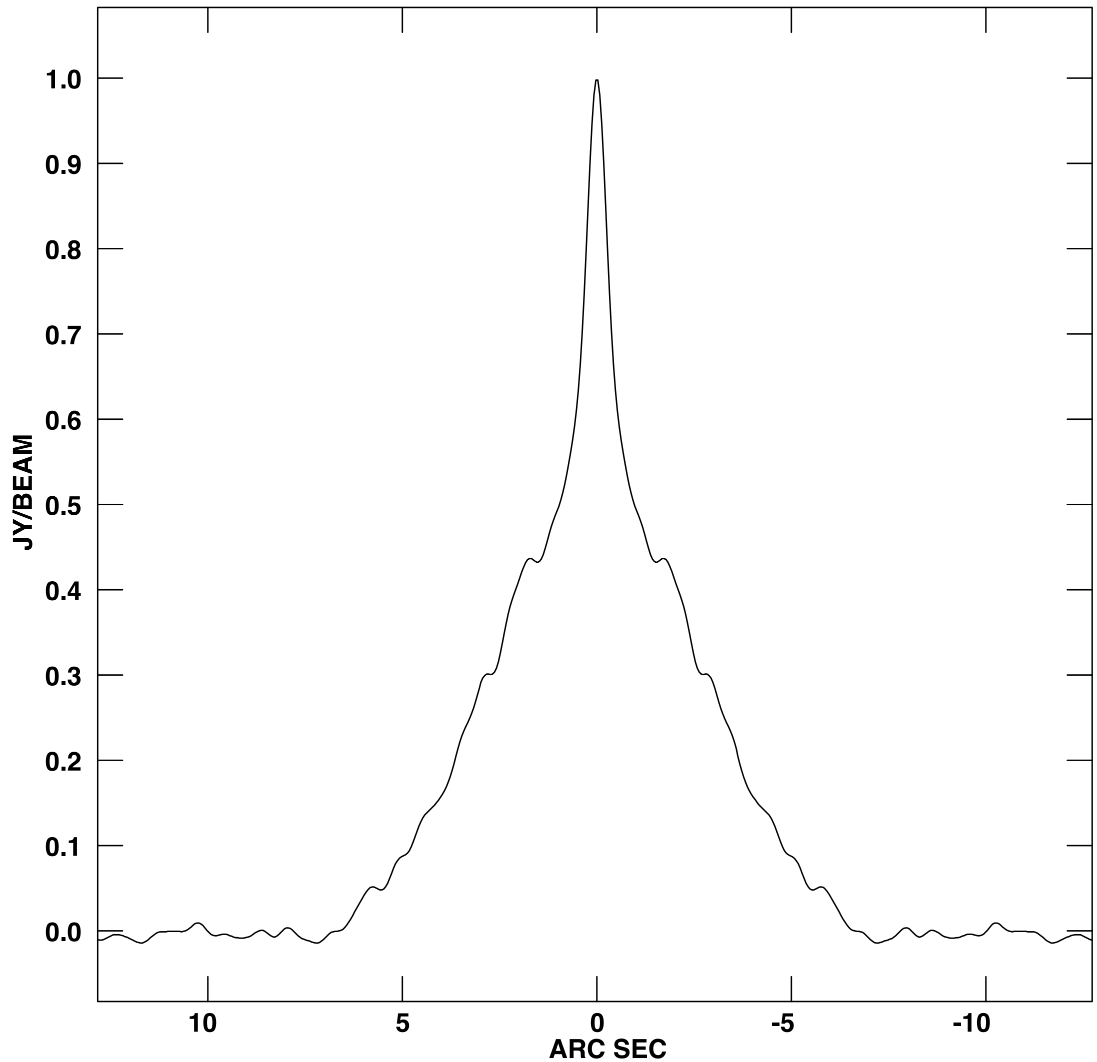
8h synthesis at $\delta = -30°$
ν = 1.2 GHz
$\Delta\ \nu$ = 50 MHz



SKA1-mid synthesized beam

robust=0 weighting

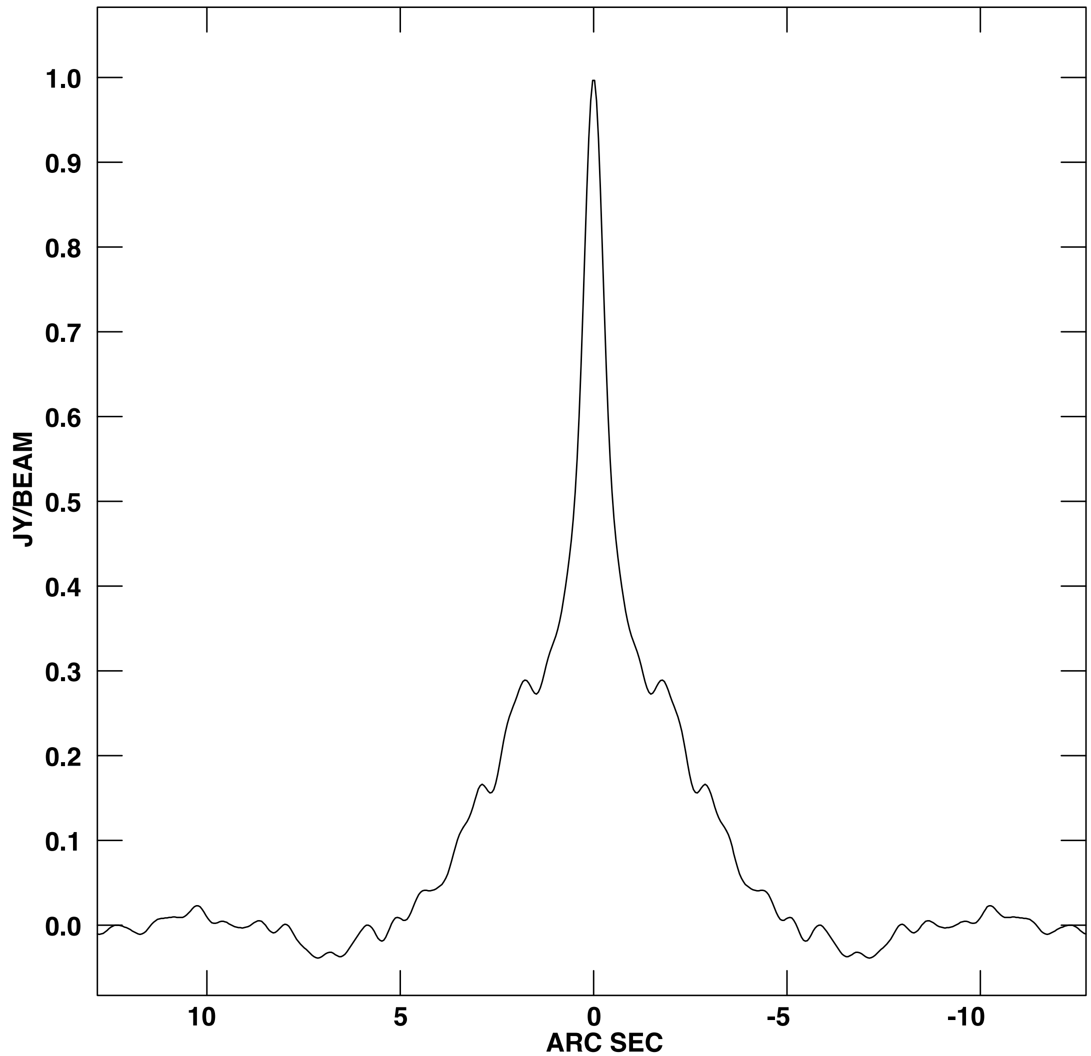
8h synthesis at $\delta = -30°$
ν = 1.2 GHz
$\Delta\ \nu$ = 50 MHz



SKA1-mid synthesized beam

uniform weighting

8h synthesis at δ=−30°
ν = 1.2 GHz
Δ ν = 50 MHz



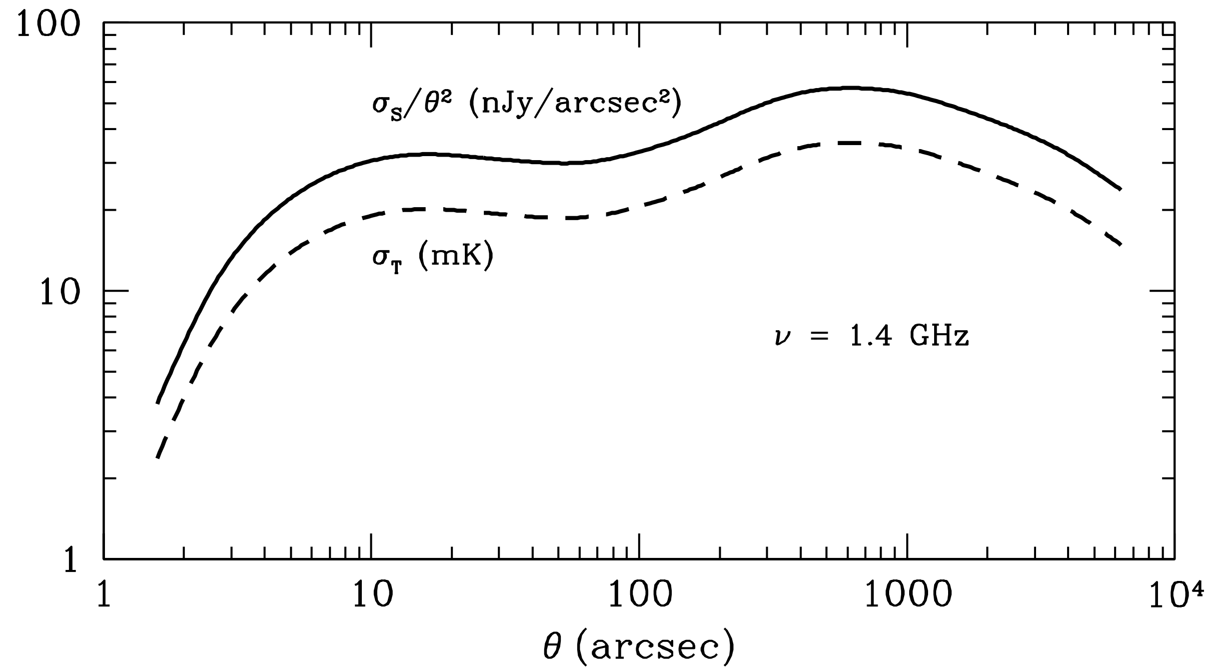
Dirty-beam sidelobes and confusion

Faint-source confusion is low in Gaussian beams, but

$$\Omega_e = \int G^{\gamma-1} d\Omega \approx \int G^{0.6} d\Omega$$

$$\sigma_c \propto \Omega_e^{1/(\gamma-1)} \approx \Omega_e^{1/0.6}$$

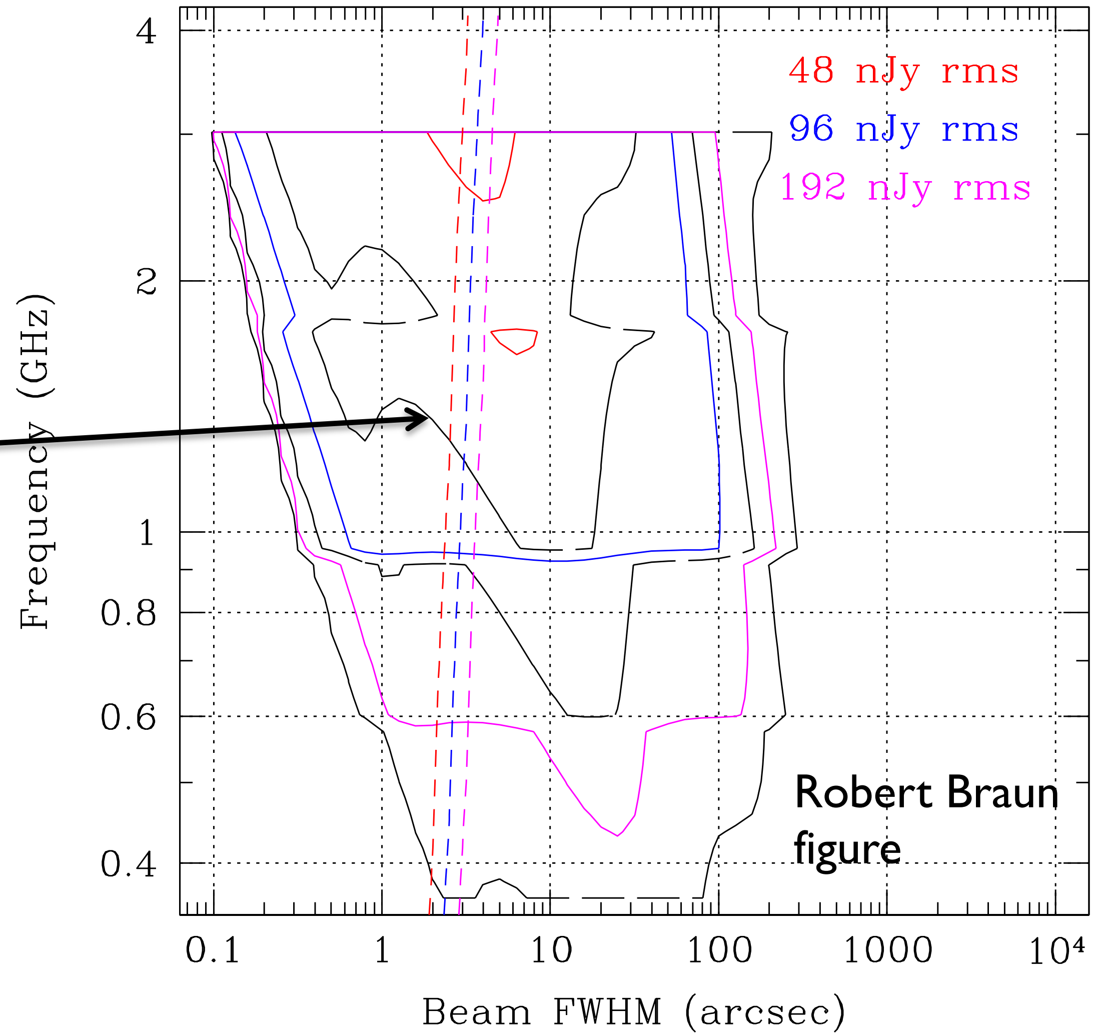
so "pedestals" and other sidelobes significantly increase the rms confusion.



SKA1-mid noise at 2 arcsec resolution

"natural" rms noise
σ_n ~ 23 nJy/beam (τ = 1000h)

"uniform" tapered noise for
~2 arcsec FWHM
σ_n ~ 3× higher

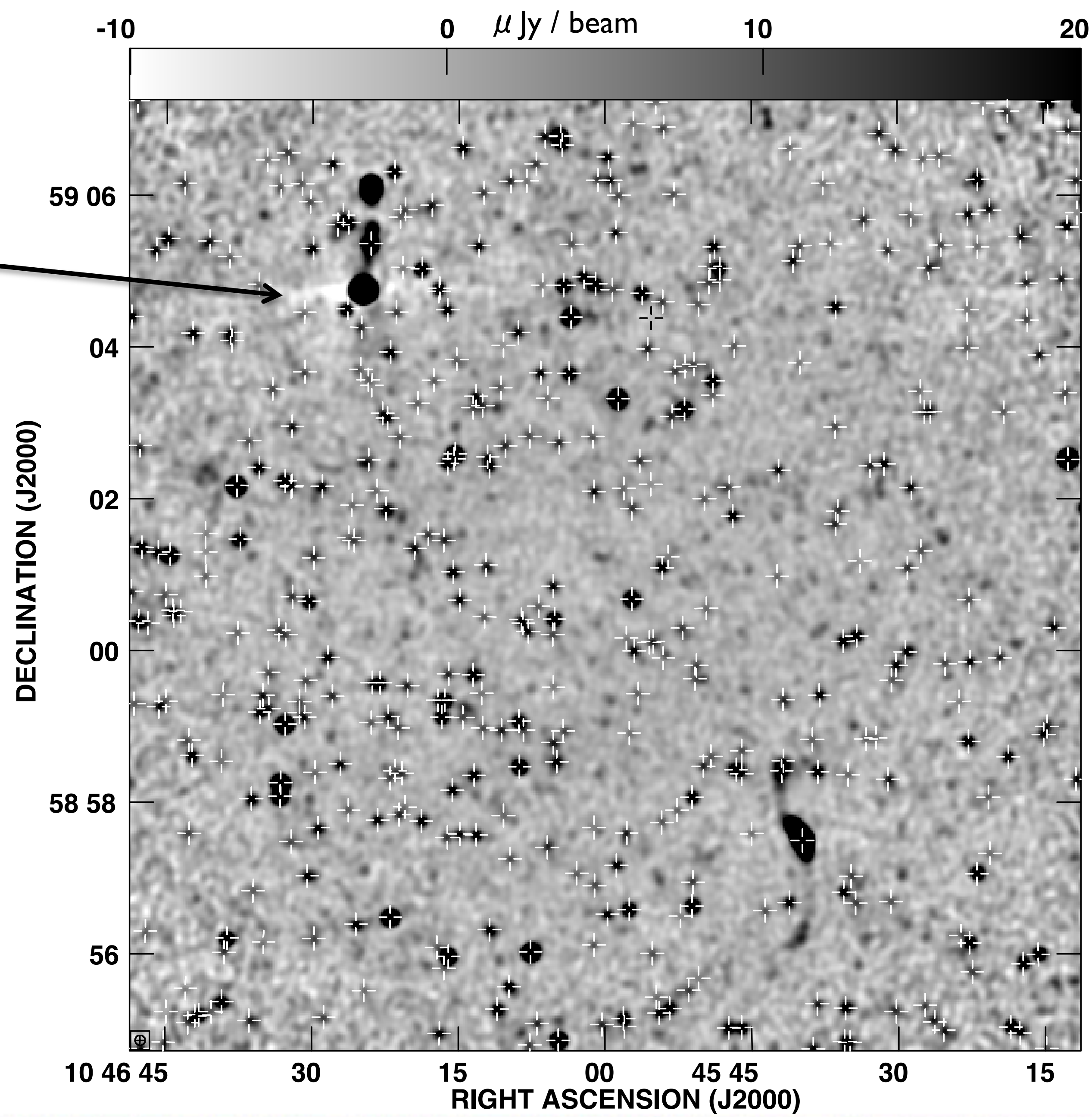


DR limits

Limited dynamic range (DR) even at 3 GHz (required $DR \propto \nu^{-2.7}$)

Primary beam instability: parallactic rotation pointing errors

Feed/OMT polarization



Summary:

The source count converges below S ~ 10 μJy and agrees with simulations.

- Confusion will not limit SKA1 sensitivity if the dirty beam is nearly Gaussian but will cause trouble if the beam has a pedestal.

Dynamic range limits JVLA sensitivity below ν ~ 3 GHz.

- The JVLA FoV is asymmetric and the LCP/RCP beam squint is large.
- Editing polarized RFI exacerbates the effects of squint.
- Feed/OMT instrumental polarization is high for large Δν / ν.
- A pedestal beam CLEANs badly and biases source fluxes.

The SKA1 will need

- A nearly Gaussian dirty beam with low sidelobes and θ ~ 2 arcsec for low confusion and low noise
- A symmetric or at least constant FoV and low instrumental polarization for high dynamic range
- Frequencies > 1.4 GHz because the required $DR \propto \nu^{-2.7}$?

SKA1-survey antenna distribution