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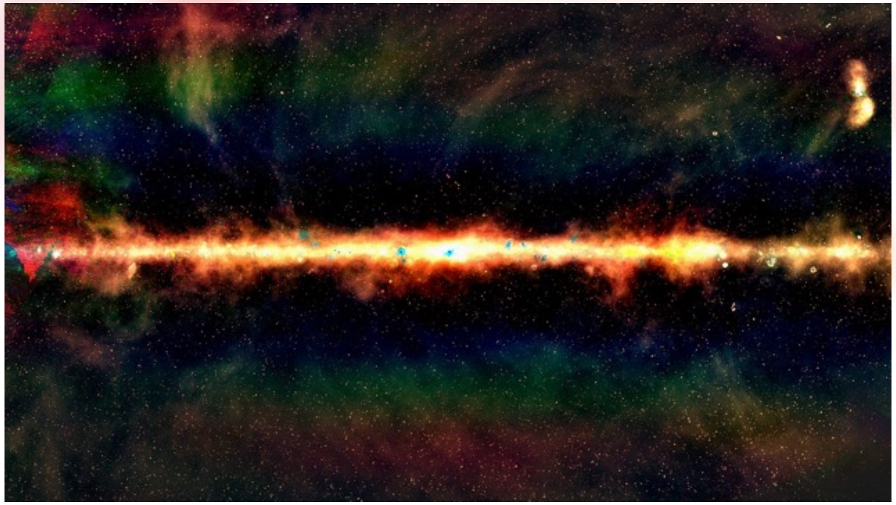

Source counts and confusion across the MWA GLEAM 72-231 MHz band

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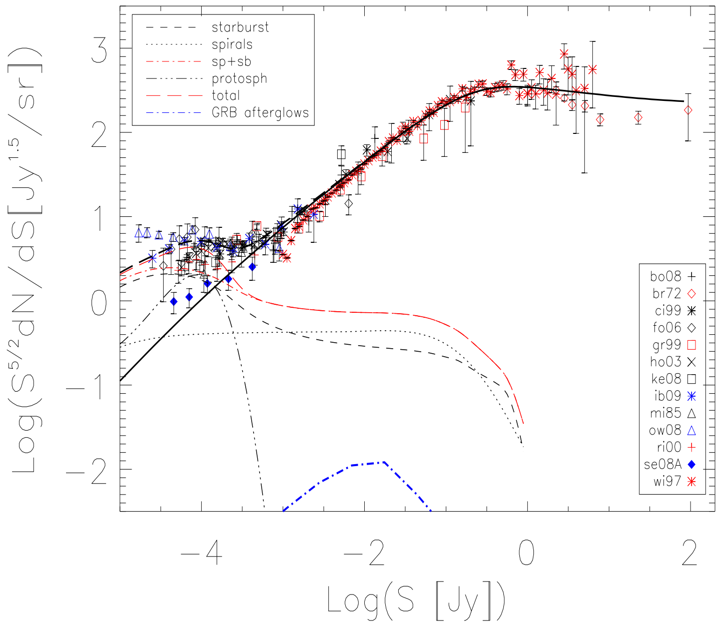
Outline

1. GLEAM source counts at 88, 118, 154 & 200 MHz as tracers of source population behaviour

2. Relative contribution of system noise, classical confusion & sidelobe confusion in GLEAM

Radio source counts

- Radio source counts embody information about extragalactic source populations and their evolution (i.e. space density) over cosmic time
- Knowledge of low-frequency sky (< 200 MHz) poor compared with that at 1.4 GHz
- Low-frequency surveys sensitive to sources with steep synchrotron spectra, unbiased by relativistic beaming effects - complementary view to GHz surveys
- Low-frequency counts useful for interpretation of EoR data

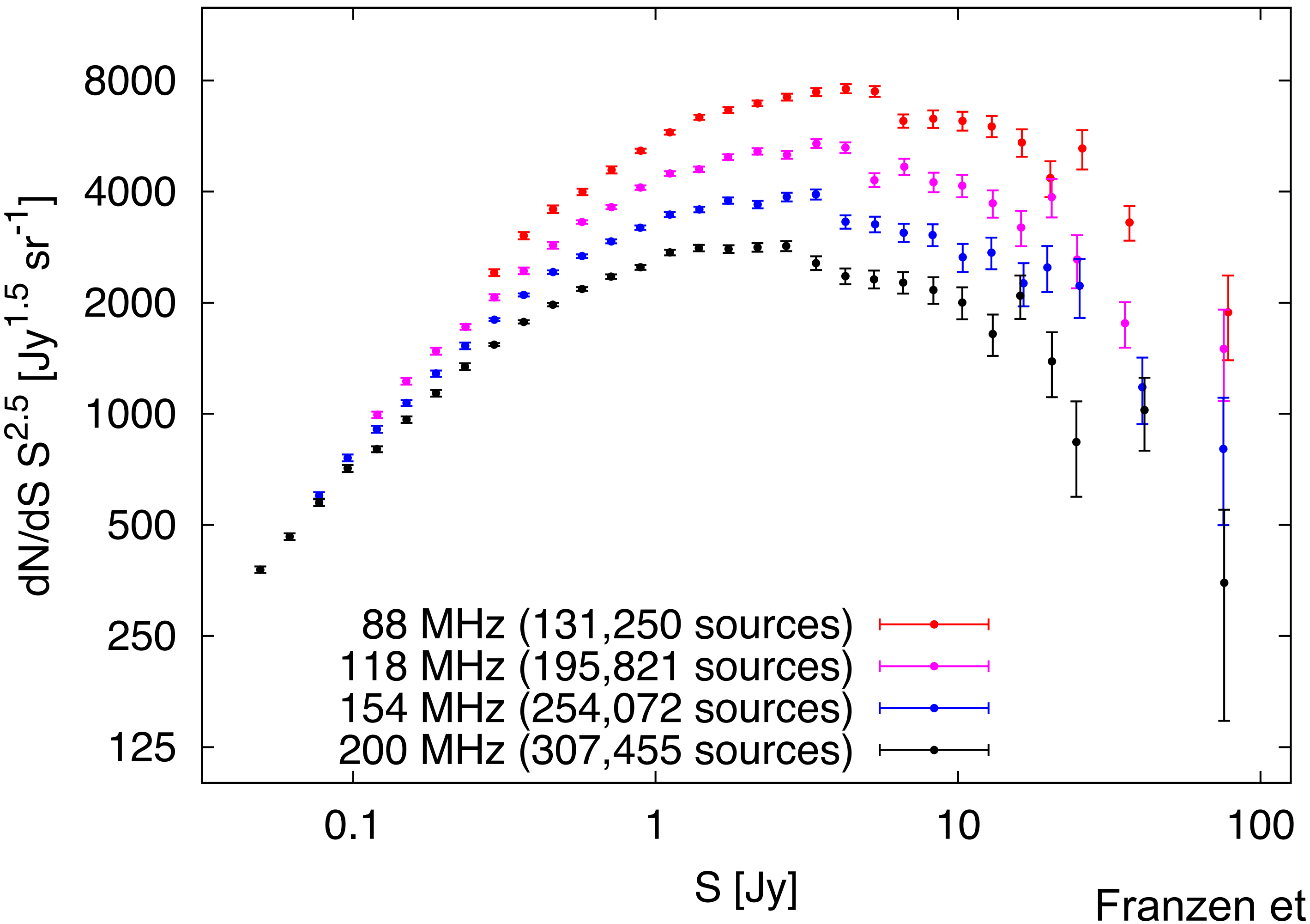


Compilation of 1.4 GHz counts by de Zotti et al. (2009)

Measuring the GLEAM counts

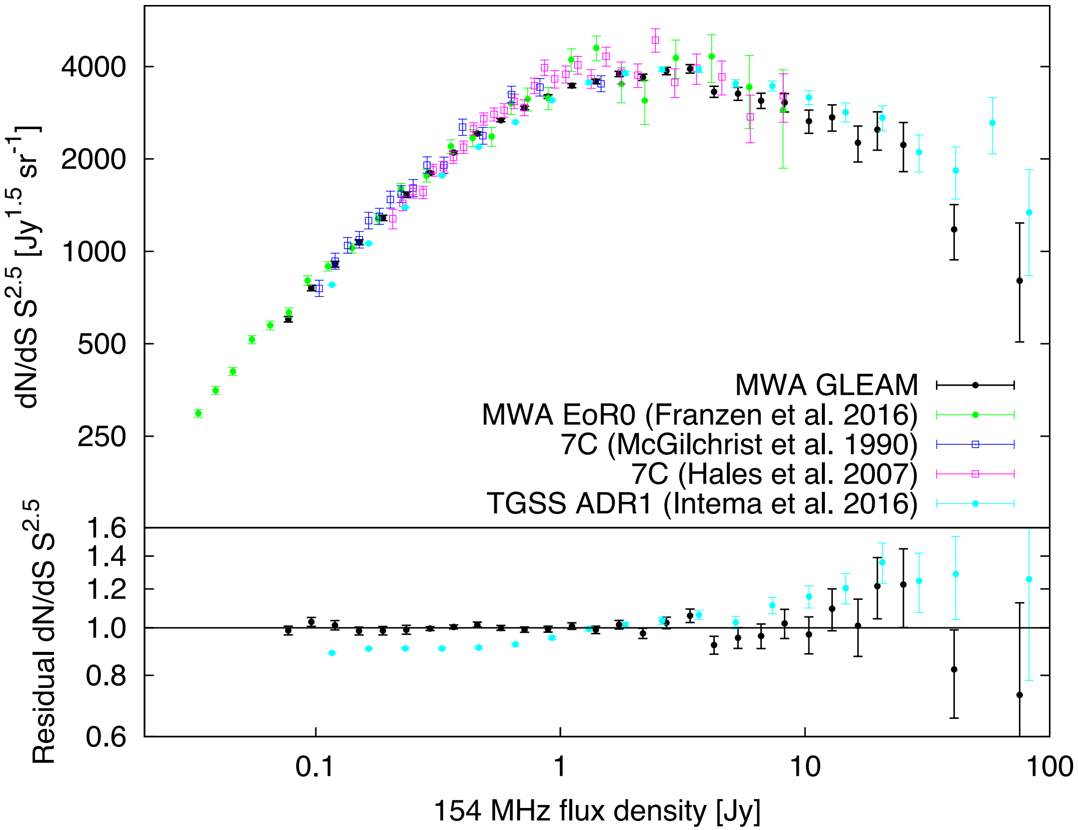
- Final GLEAM image products include 4 deep wideband mosaics centred at 88, 118, 154 and 200 MHz
- Use GLEAM extragalactic catalogue by Hurley-Walker et al. (2016) to measure counts at 200 MHz
  - 307,455 components detected in 200 MHz mosaic
  - Covers area of 24,831 deg^2 below Dec +30°
- Construct additional, complete source samples at 88, 118 & 154 MHz to measure counts at these frequencies
- Correct counts for incompleteness, Eddington bias and source blending using Monte Carlo simulations

GLEAM multi-frequency counts



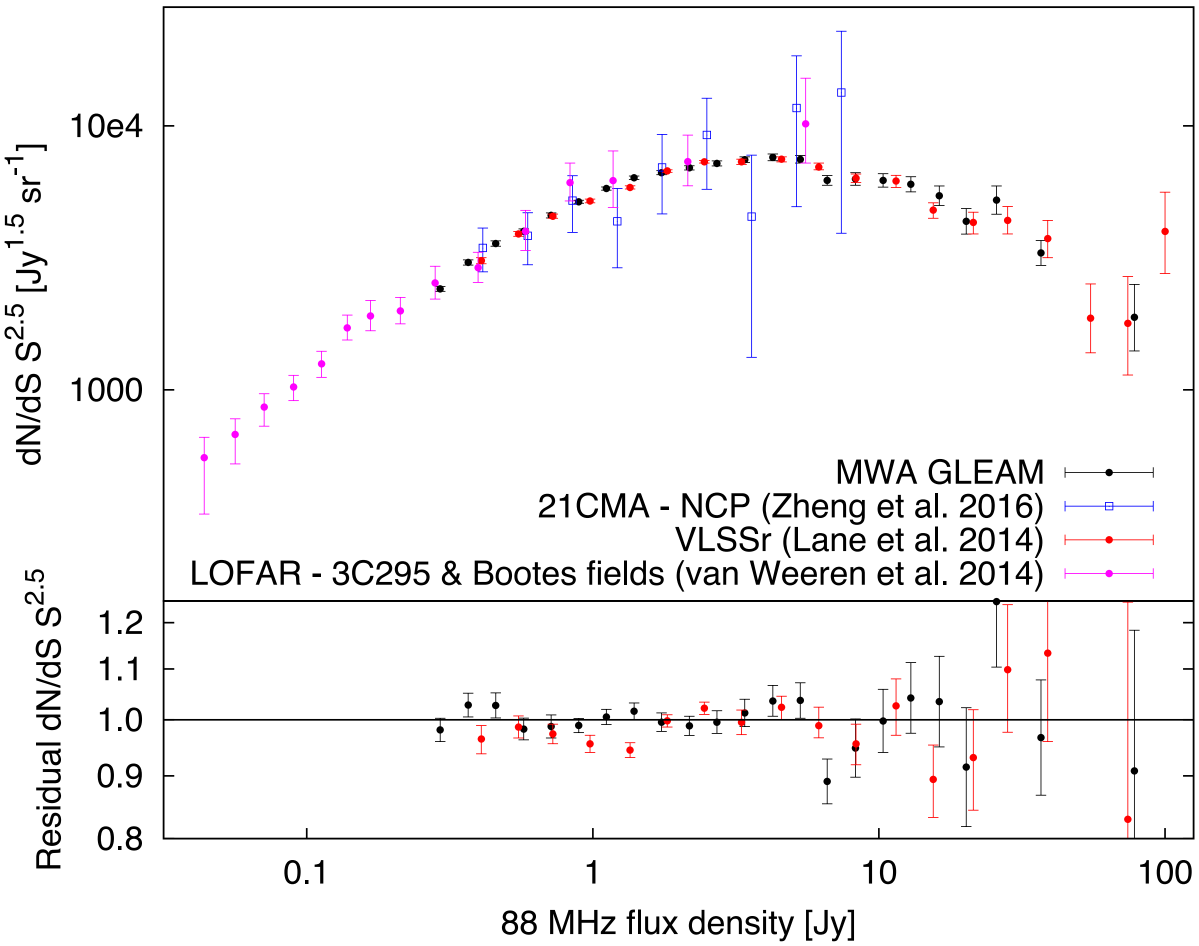
Franzen et al., in prep.

Comparison with other counts at 154 MHz



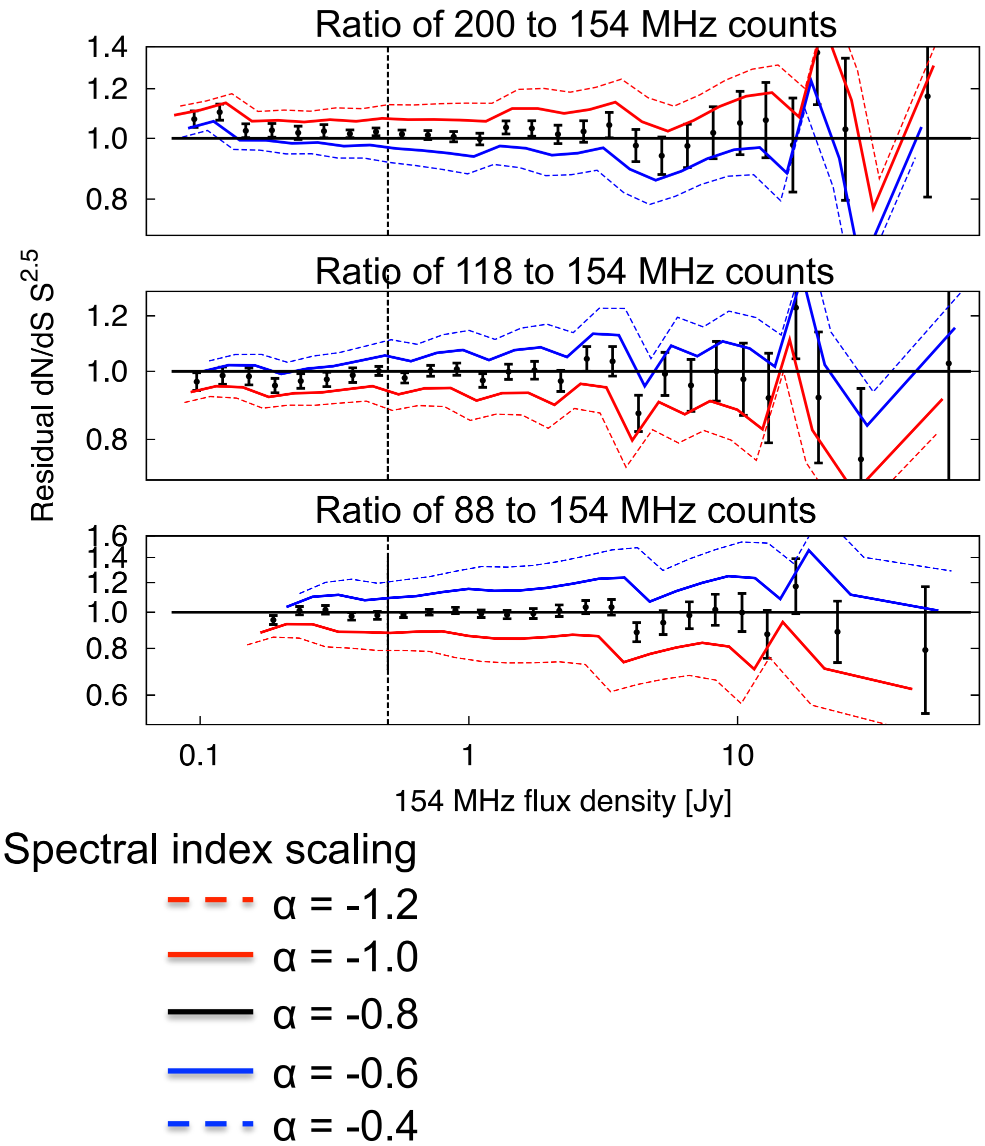
- Below ~1 Jy, TGSS counts are ≈ 10% lower than GLEAM counts
- May be due to missing low surface brightness emission in TGSS
- GLEAM resolution at 154 MHz is ≈ 3 arcmin
- TGSS resolution is 25 arcsec

Comparison with other counts at 88 MHz



- TGSS and VLSSr counts agree within 2-3%
- GLEAM resolution at 88 MHz is ≈ 5 arcmin
- VLSSr resolution is 75 arcsec

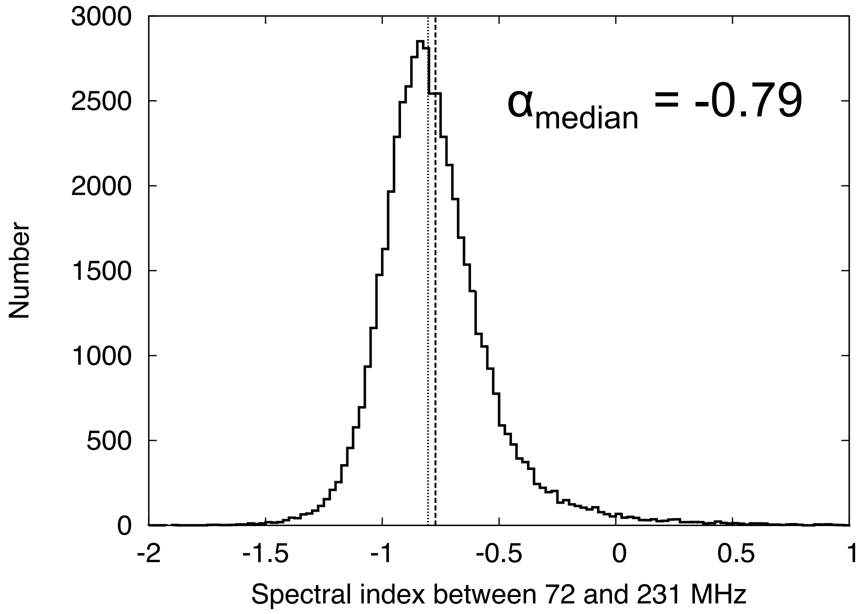
Dependence of spectral index on flux density and frequency

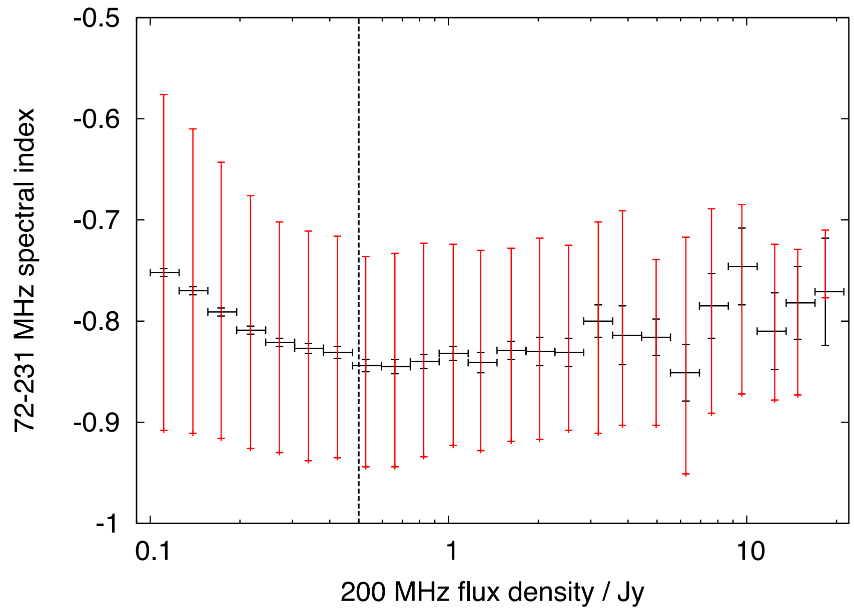


- At S_{154} > 0.5 Jy, no significant change in shape of GLEAM counts at 88, 118, 154 and 200 MHz
- Spectral index scaling of ≈ -0.8 provides remarkably good match between counts
- No evidence of any flattening in average spectral index with decreasing frequency
- Below 0.5 Jy, tentative evidence that flatter spectral index provides better match between counts

Spectral index properties

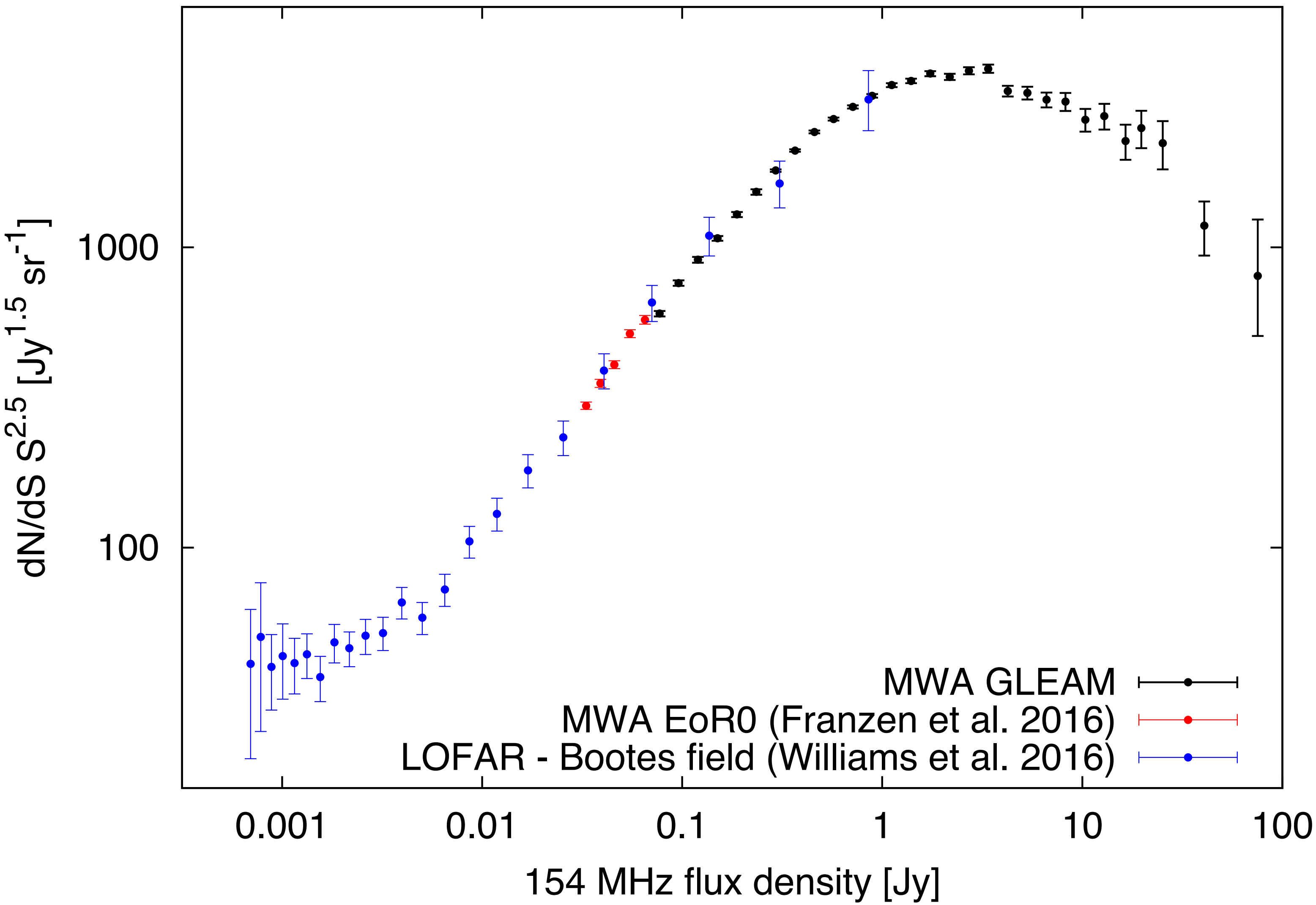
- Select 53,079 sources with S_{200} > 0.1 Jy in deepest ≈ 6,500 deg^2 region of GLEAM
- Statistically complete sample with good quality sub-band fluxes
- 97% of these sources have 70-230 MHz spectra that are well fit by power law





α_{median} flattens by ≈ 0.1 between 0.5 and 0.1 Jy

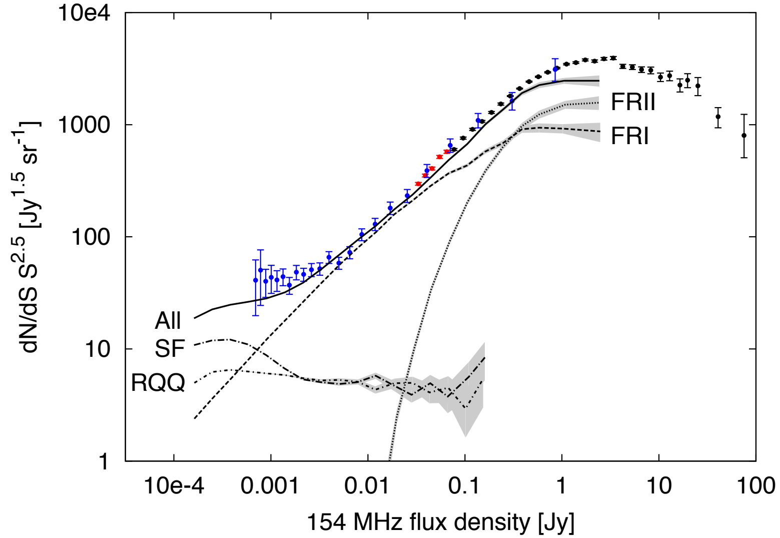
LOFAR + MWA counts at 154 MHz



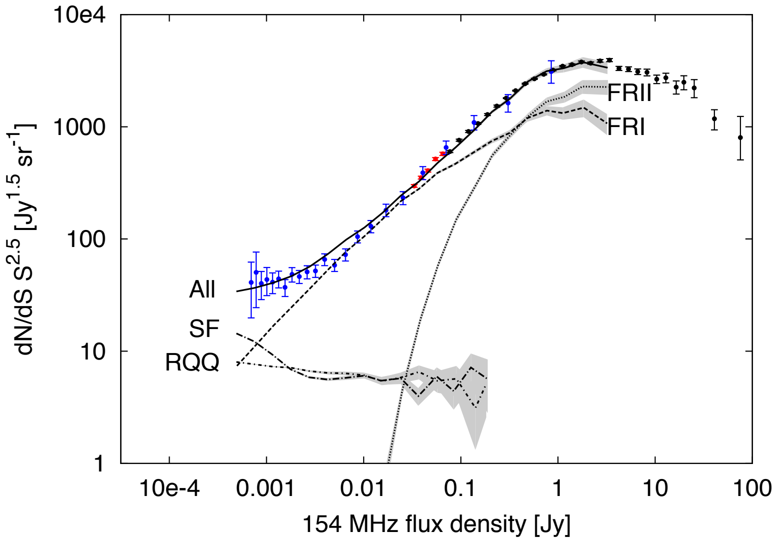
SKA Design Study (SKADS) model predictions

- SKADS model by Wilman et al. (2008) in wide use to optimise SKA design
- Also valuable tool in interpretation of existing radio surveys
- 151 MHz SKADS model significantly underpredicts GLEAM counts
  - Number of sources underpredicted by ≈ 50% at 2 Jy
- Possible explanations:
  - Excessive curvature assumed in spectra of simulated sources
  - Limited volume being sampled biases against rare, bright sources

Comparison with 151 MHz SKADS model



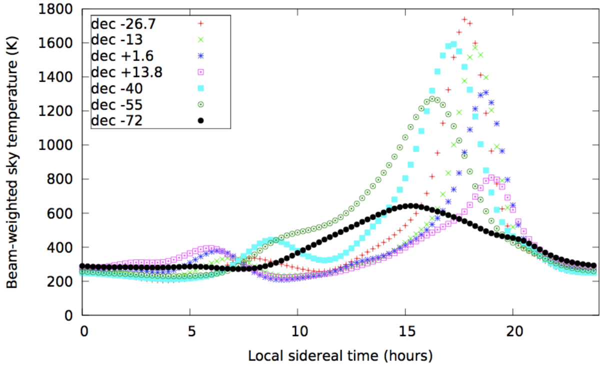
Comparison with 610 MHz SKADS model extrapolated to 154 MHz assuming α = -0.8



Limits of noise and confusion in GLEAM

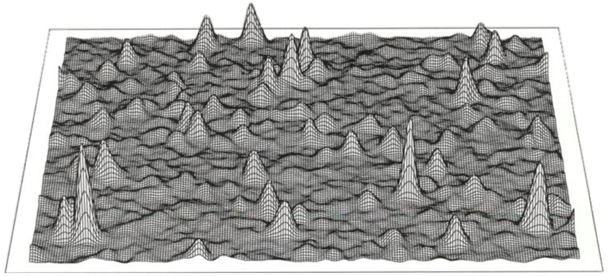
Errors in low-frequency images

3 basic sources of error in a low-frequency image formed with an array:
- System noise
- Classical confusion
- Sidelobe confusion

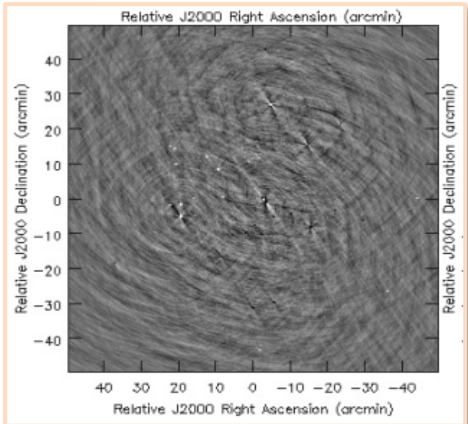


Sky temperature at 154 MHz

***CLASSICAL** confusion:*
Combined signal from many random faint sources within synthesised beam

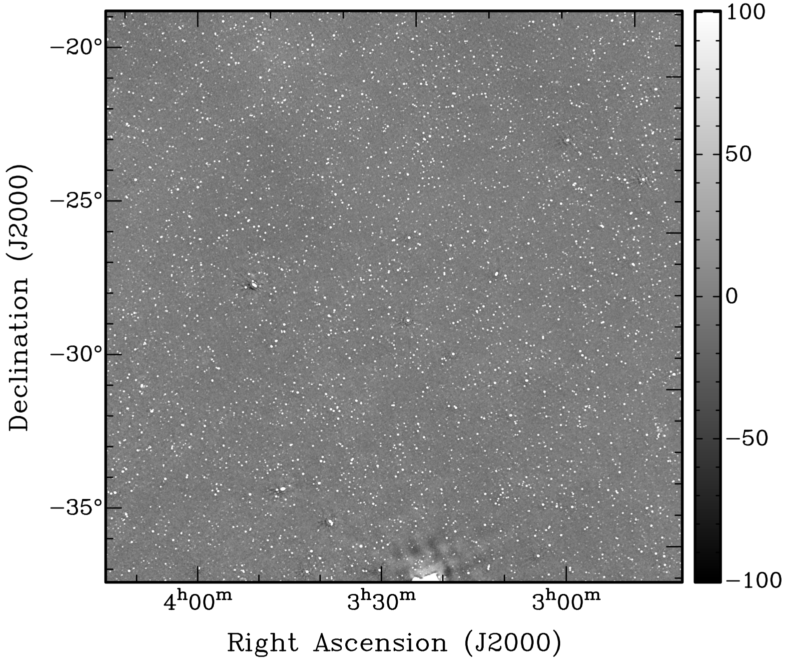


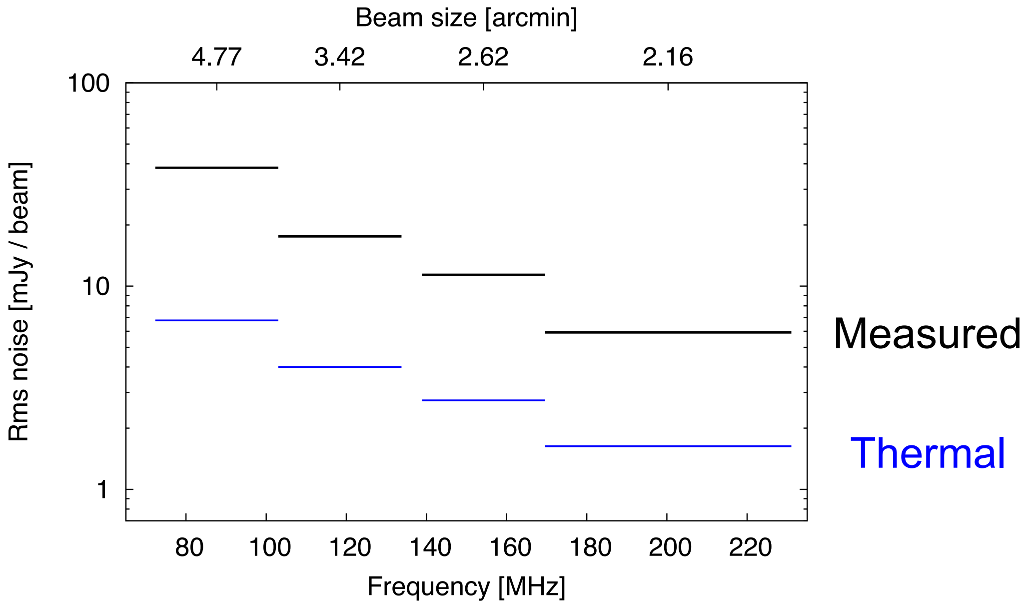
***SIDELOBE** confusion:*
Noise in image due to undeconvolved (or poorly deconvolved) sources.



Bhatnagar et al. (2008)

Sensitivity across MWA band close to zenith





Section of 170-231 MHz GLEAM image centred on CDFS - cold region of extragalactic sky

Thermal noise estimated from Stokes *V* mosaics - negligible at all frequencies
→ Excess background noise due to a combination of classical & sidelobe confusion

Estimating the classical confusion noise

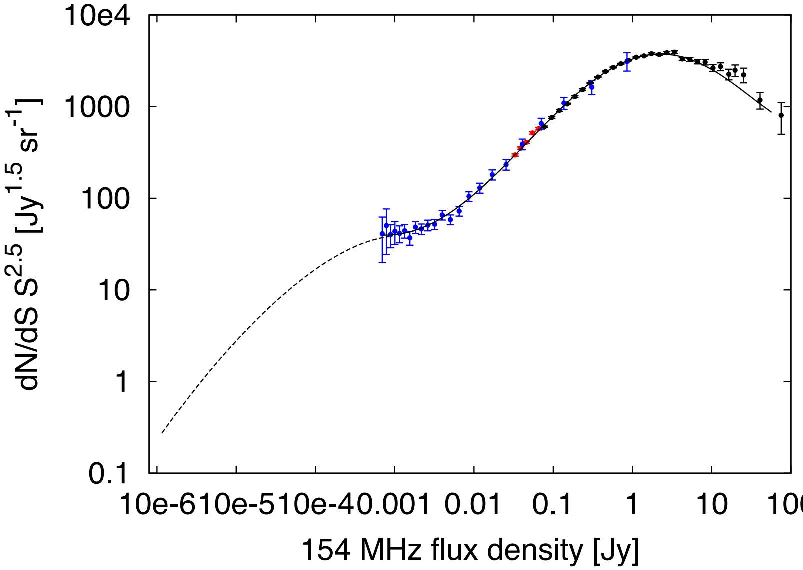
Method of probability of deflection or P(D) analysis

$$R\,(x)\;dx = \int_{\Omega} \frac{dN}{dS}\left(\frac{x}{B(\theta,\phi)}\right)\,B(\theta,\phi)^{-1}\,d\Omega\,dx$$

$$P(D) = \mathcal{F}^{-1}\left[\exp\left(\int_0^{\infty} R\,(x)\exp\,(i\omega x)\,dx - \int_0^{\infty} R\,(x)\,dx\right)\right]$$

Vernstrom et al. (2014)

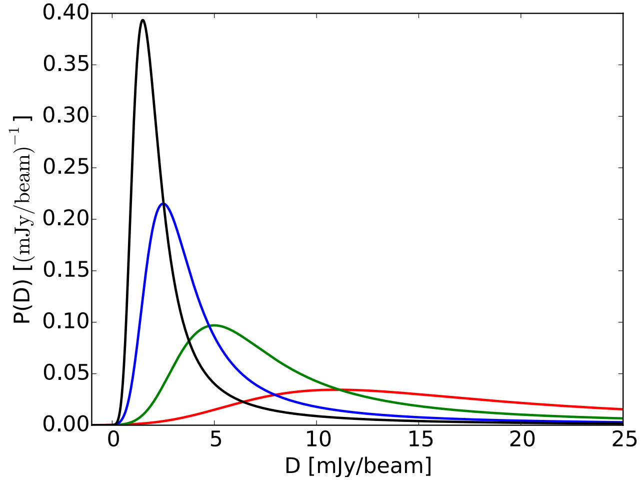
154 MHz source count model



Fit to 154 MWA + LOFAR counts

610 MHz SKADS model extrapol. to 154 MHz

Source P(D) distributions



200 MHz (beam size = 2.2 arcmin)

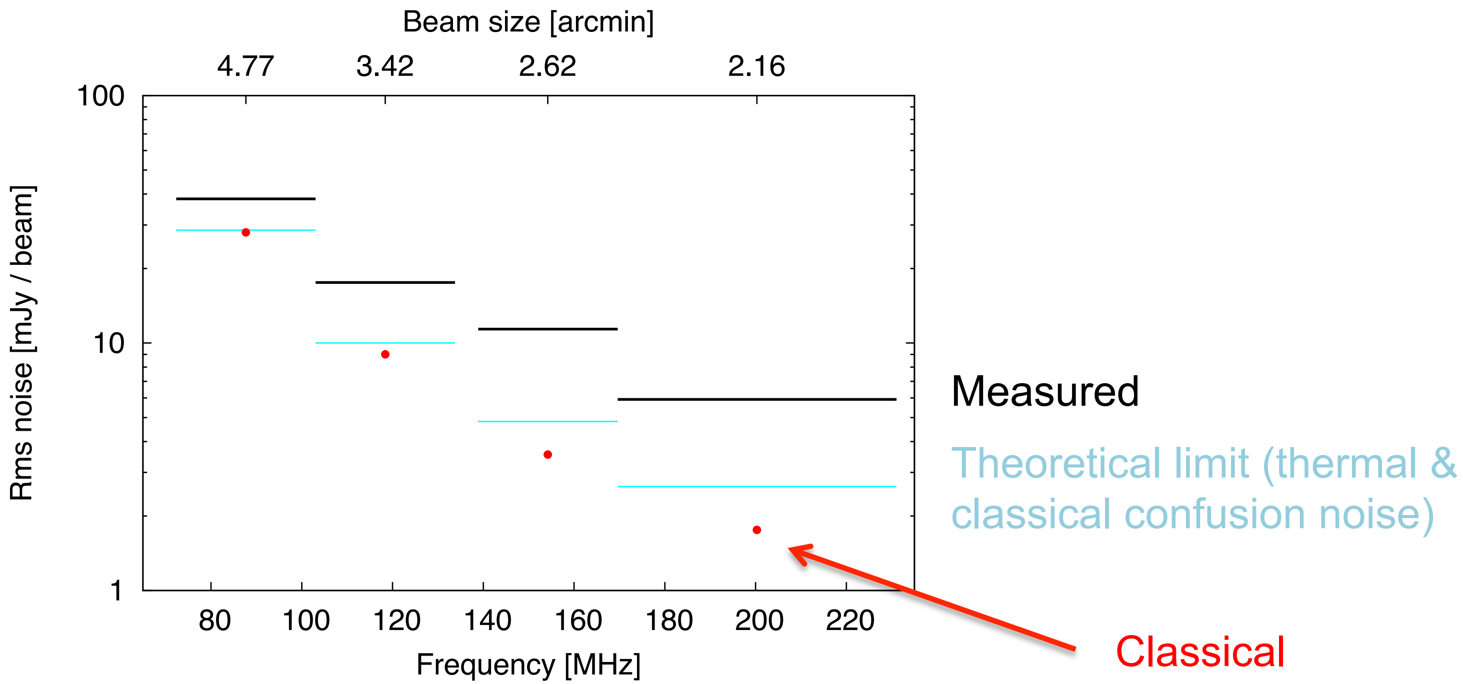
154 MHz (beam size = 2.6 arcmin)

118 MHz (beam size = 3.4 arcmin)

88 MHz (beam size = 4.8 arcmin)

Theoretical noise limit

- Estimate classical confusion noise from core width of source P(D) distribution
- Convolve source P(D) distribution with Gaussian representing thermal noise to obtain theoretical noise limit



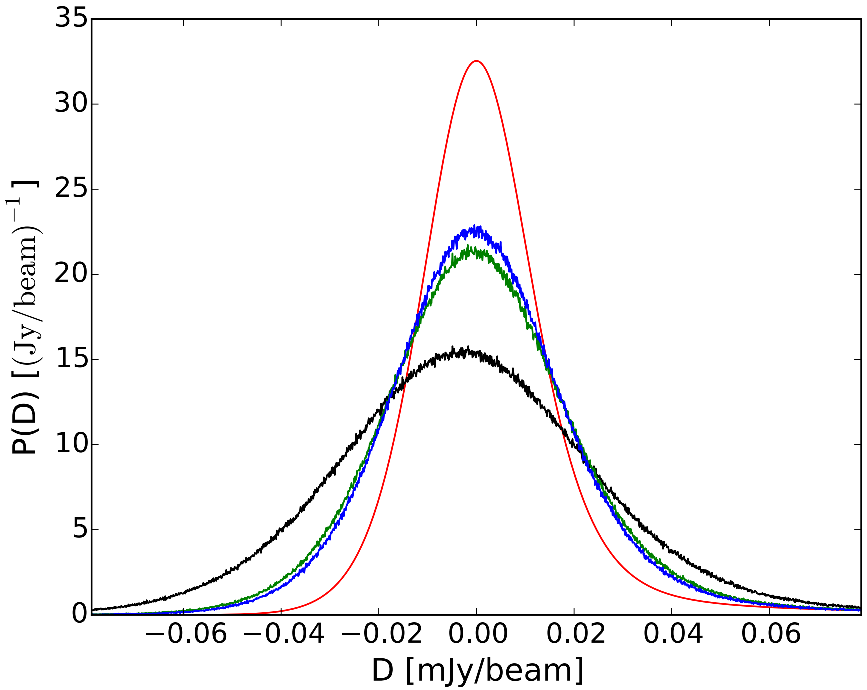
→ **Background noise primarily due to sidelobe confusion at higher frequencies**

Possible origins for sidelobe confusion: limited CLEANing depth, source smearing due to ionosphere, far-field sources that have not been deconvolved

Improvements using WSClean 2.4

- WSClean 2.4 faster thanks to Clark optimisation
- CLEAN snapshots deeper & increase size of region CLEANed
- CLEAN entire image to 3σ, then CLEAN with mask from identified components to 1σ
- Results in ≈ 30% reduction in noise
- Implemented in GLEAM year 2 data reduction pipeline

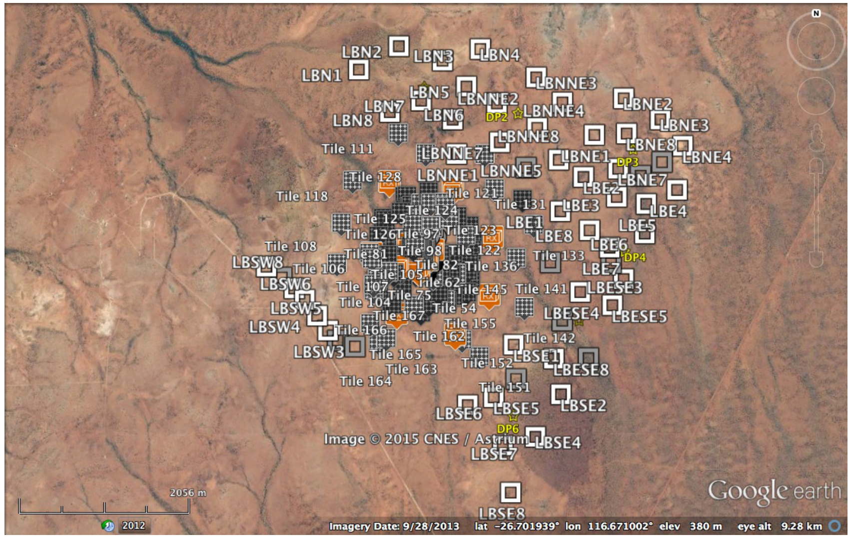
2 min snapshot at 154 MHz

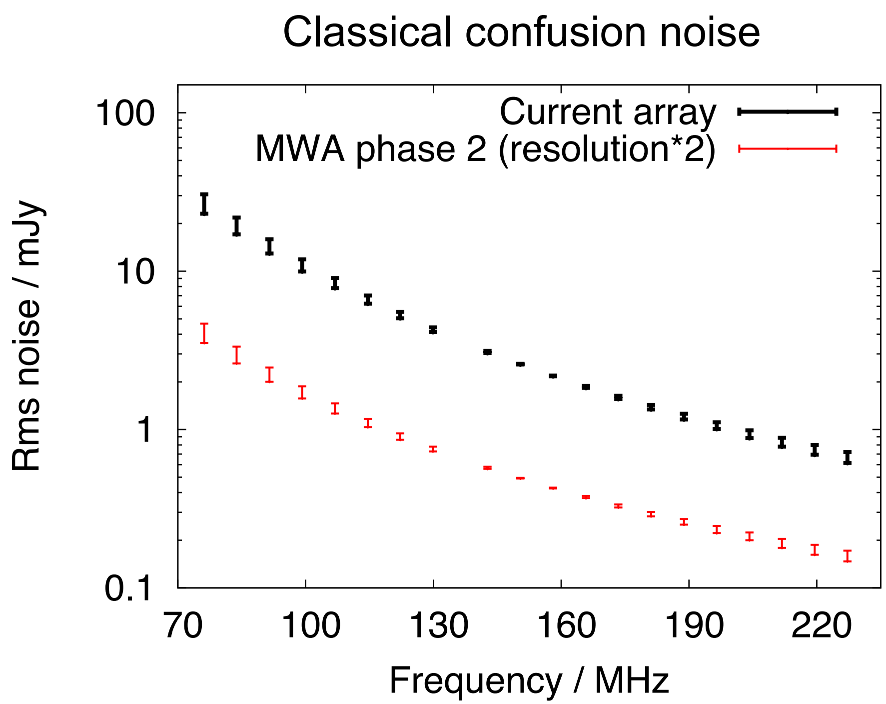


- WSClean 1.10 (≈ 25,000 iterations, 40 deg image size)
- WSClean 2.4 (≈ 220,000 iterations, 40 deg image size)
- WSClean 2.4 (≈ 250,000 iterations, 55 deg image size)
- Theoretical limit

MWA phase 2

128 new tiles
- 72 in two compact hexagons in core for enhanced EoR capability
- 56 on baselines up to 6 km for enhanced survey & imaging capability
- Commissioning to start end of this year





Summary

- Derive GLEAM source counts at 200, 154, 118 & 88 MHz to high precision
  - Sensitive to extended emission missed by other surveys
  - Spectral index scaling of ≈ -0.8 provides remarkably good match between counts
- SKADS model significantly underpredicts 154 MHz counts
- Future work: measure local radio luminosity function of AGN and star-forming galaxies at 154 MHz
- Excess background noise in GLEAM primarily due to sidelobe confusion
  - highlights need for further improvements in deconvolution imaging techniques
- Possibility of conducting sub-mJy continuum surveys with MWA phase 2