International Centre for Radio Astronomy Research

Using GLEAM to unravel the nature of the low-frequency radio source population

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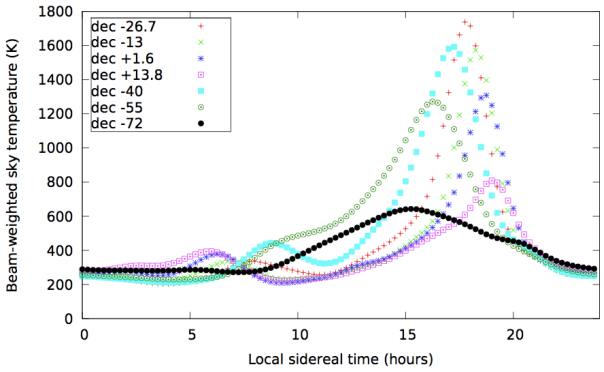
Outline

1. Introduction
   - Confusion in interferometric images
2. GLEAM extragalactic source catalogue
   - Limits on classical & sidelobe confusion in GLEAM images
3. Source count analysis in MWA EoR image at 154 MHz
   - Low-frequency spectra of star-forming galaxies

Introduction

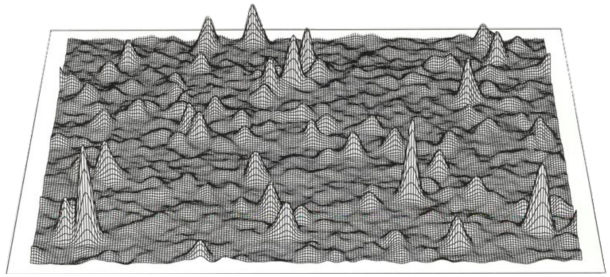
3 basic sources of error in a low-frequency image formed with an array:

- System noise
- Classical confusion
- Sidelobe confusion

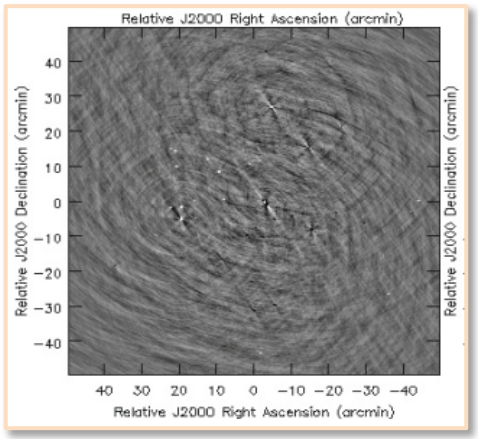


Sky temperature at 154 MHz

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



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

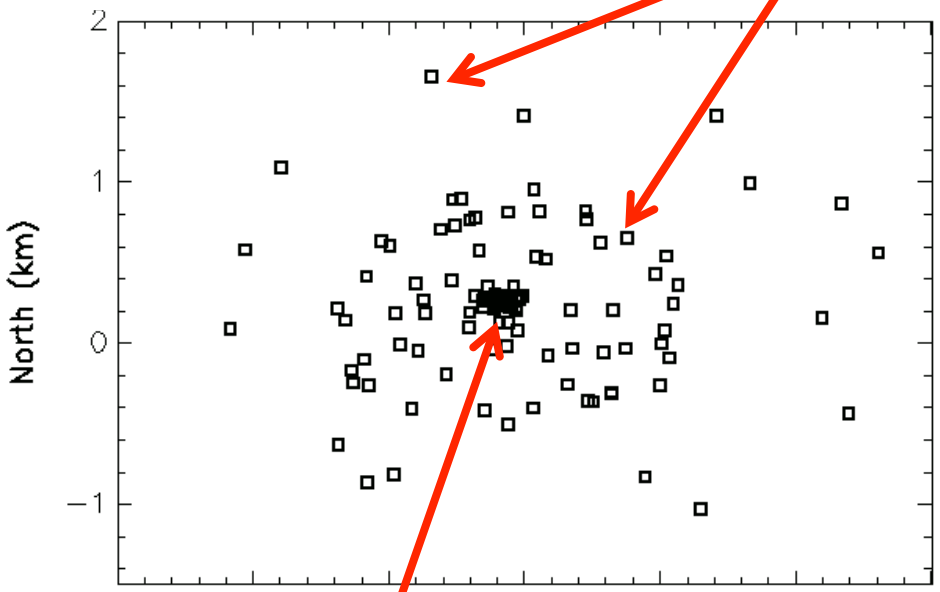


Bhatnagar et al. (2008)

MWA instantaneous *uv* coverage

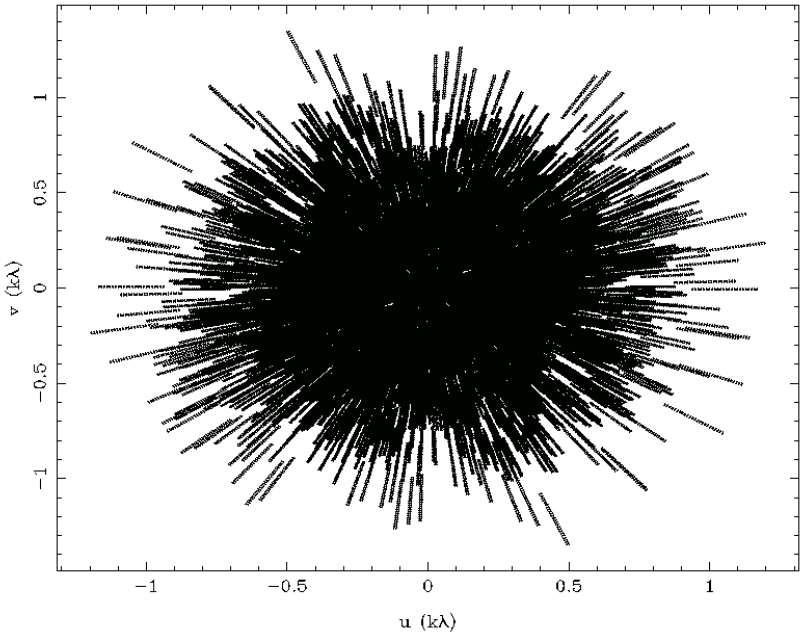
Mid/outer regions
Resolution, calibration
uv coverage

Array layout



Compact core
(surface brightness)

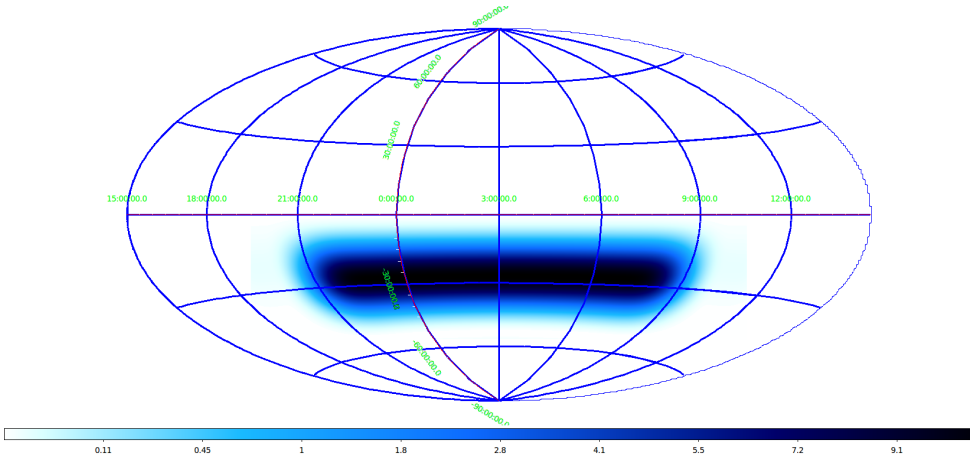
Snapshot, full bandwidth *uv* coverage

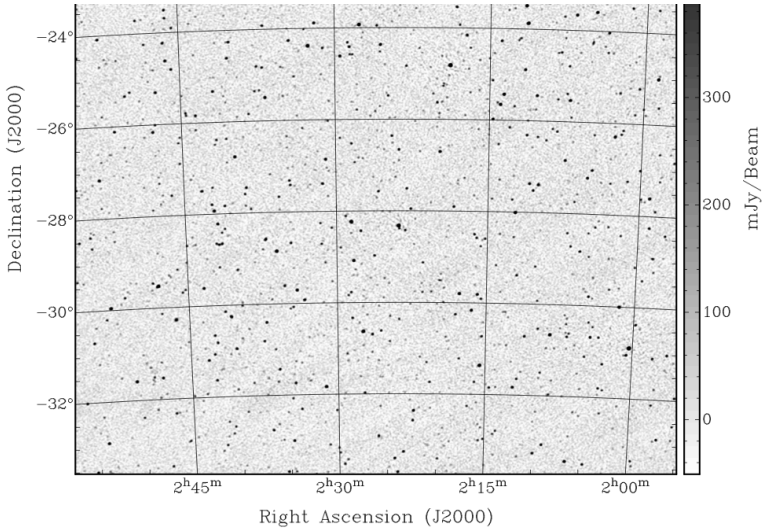


See Tingay et al, 2013. PASA 30 7T

Imaging strategy - snapshot imaging

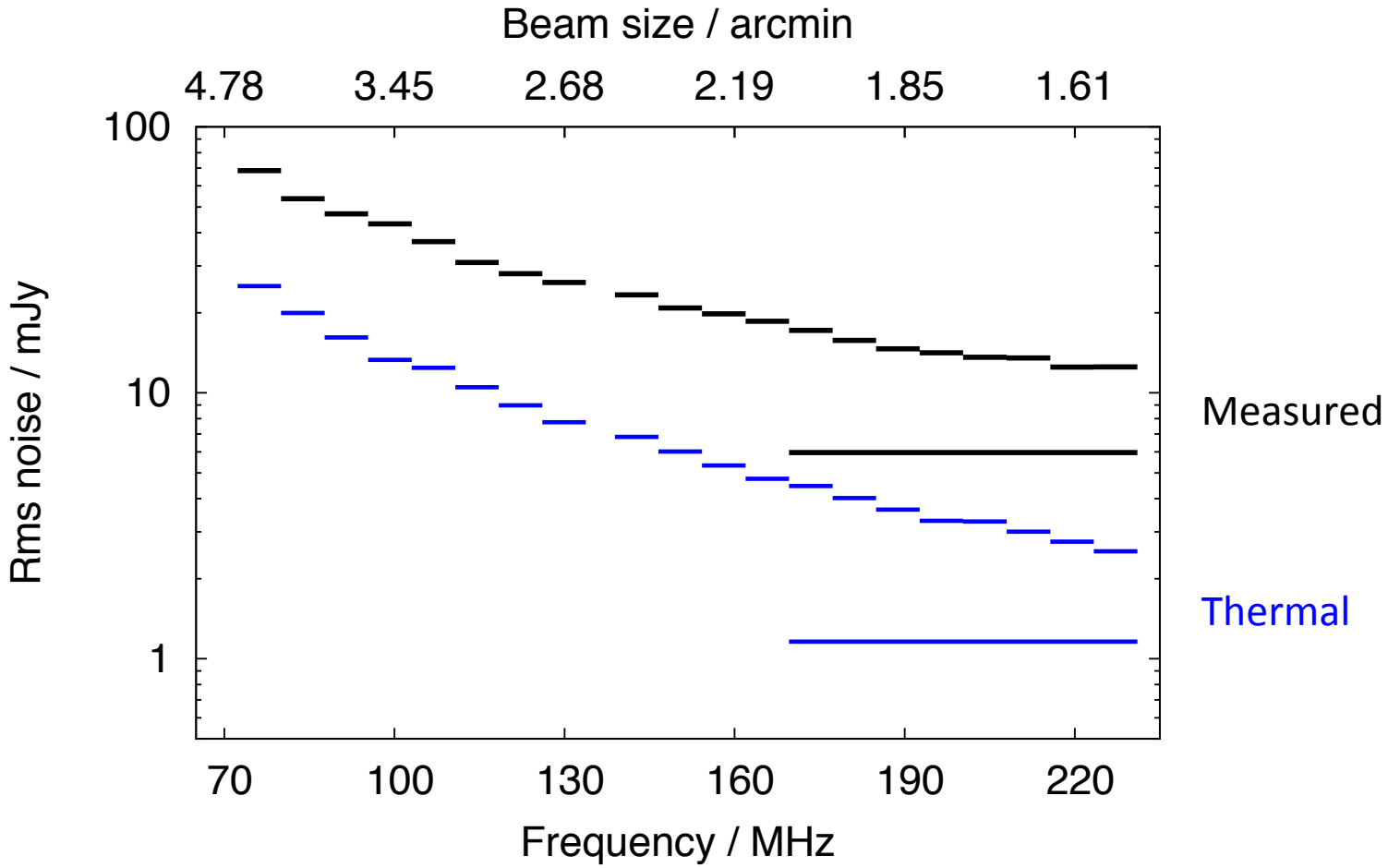
- Meridian drift scans as 2-minute snapshots, cycling through frequencies
  - 7 DEC bands: 18.6, 1.6, -13.0, -26.7, -40.2, -55.0, -72.0
  - 5 frequency ranges covering 73-230 MHz
- In a 2-minute snapshot, MWA is close to coplanar - small *w*-terms can be fixed with appropriate imager
- CLEAN each snapshot separately using WSClean (Offringa et al. 2014)
- Generate mosaics via image-plane co-addition after correcting for bulk ionospheric shifts and primary beam





Example snapshot (full bandwidth)

Sensitivity across MWA band close to zenith



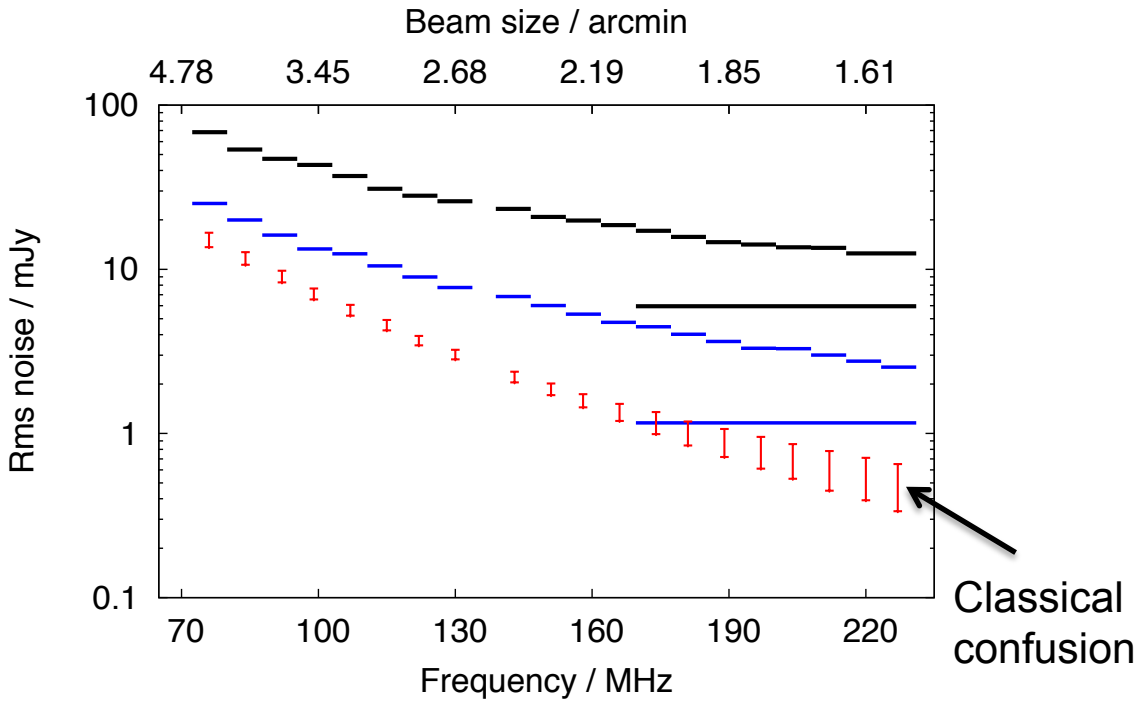
Thermal noise contribution negligible at all frequencies (Wayth et al. 2015)

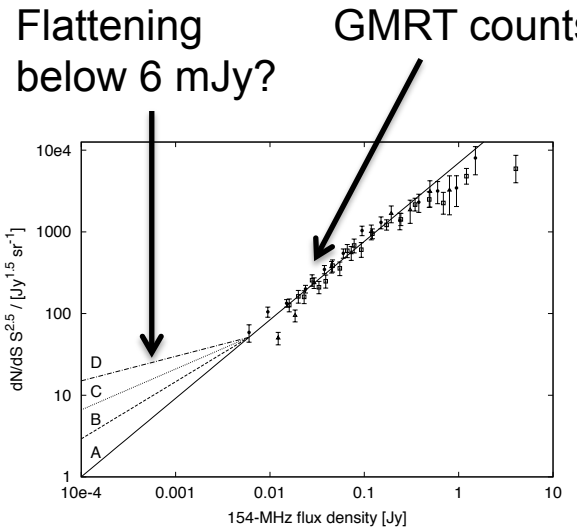
→ Excess background noise due to a combination of classical & sidelobe confusion

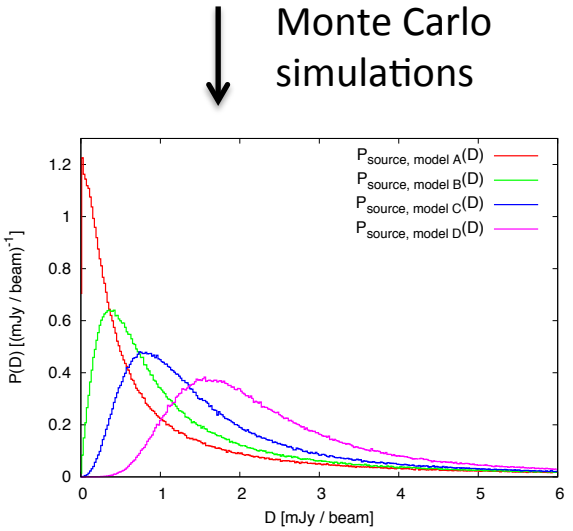
Classical confusion noise across MWA band

Estimate classical confusion noise across MWA band using deep GMRT counts at 154 MHz (Williams, Intema & Röttgering 2013, Intema et al. 2011 & Ghosh et al. 2012)

- Explore effect of flattening in 154 MHz counts below 6 mJy
- Assume typical spectral index lies between -0.5 and -0.9



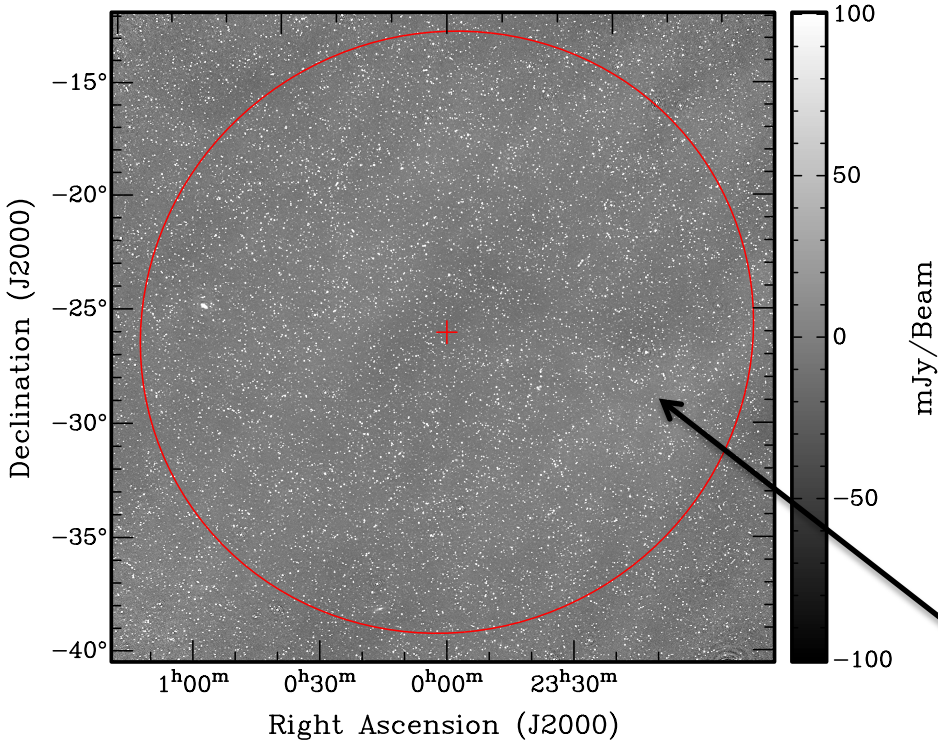




Background noise primarily due to sidelobe confusion

Confusion-limited MWA EoR image at 154 MHz

- 12-hour integrated image, centred on J2000 α=00^h, δ=-27°(courtesy of A. Offringa)
- Central frequency = 154 MHz (bandwidth = 30 MHz)
- Synthesized beam FWHM = 2.3 arcmin
- Primary beam FWHM ~ 27 deg
- Corrected for primary beam
- Rms background noise in map centre ~ 4-5 mJy

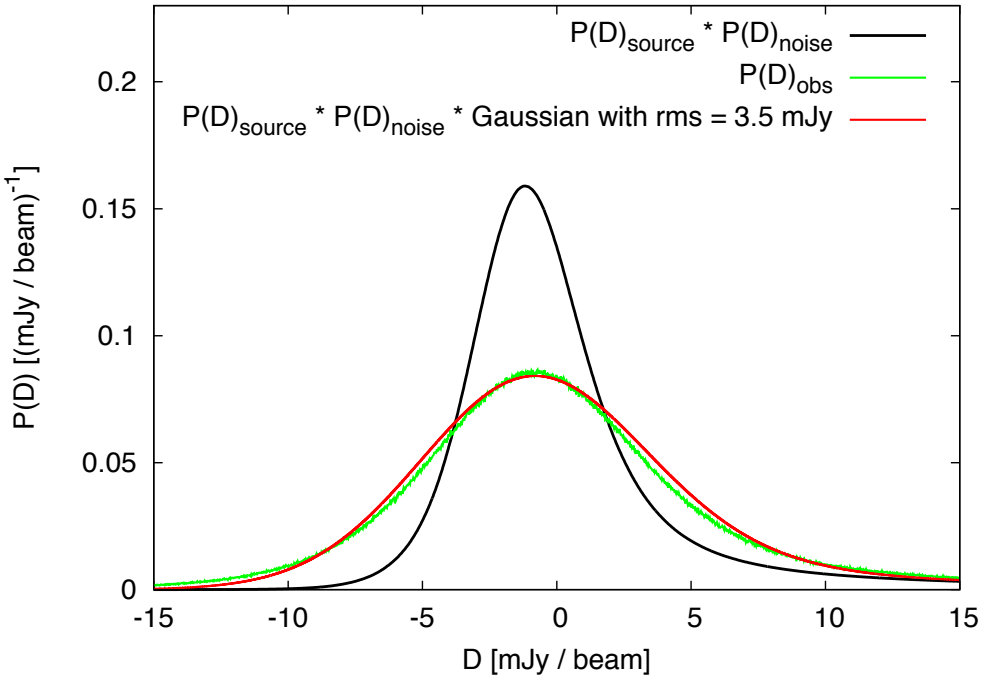


13,446 sources > 5σ

FoV = 570 deg^2

P(D) analysis in MWA EoR image

- Using deepest available source count data at 154 MHz, classical confusion noise ≈ 1.7 mJy and sidelobe confusion noise ≈ 3.5 mJy
- Possible origins for sidelobe confusion: limited CLEANing depth, source smearing due to ionosphere, far-field sources that have not been deconvolved



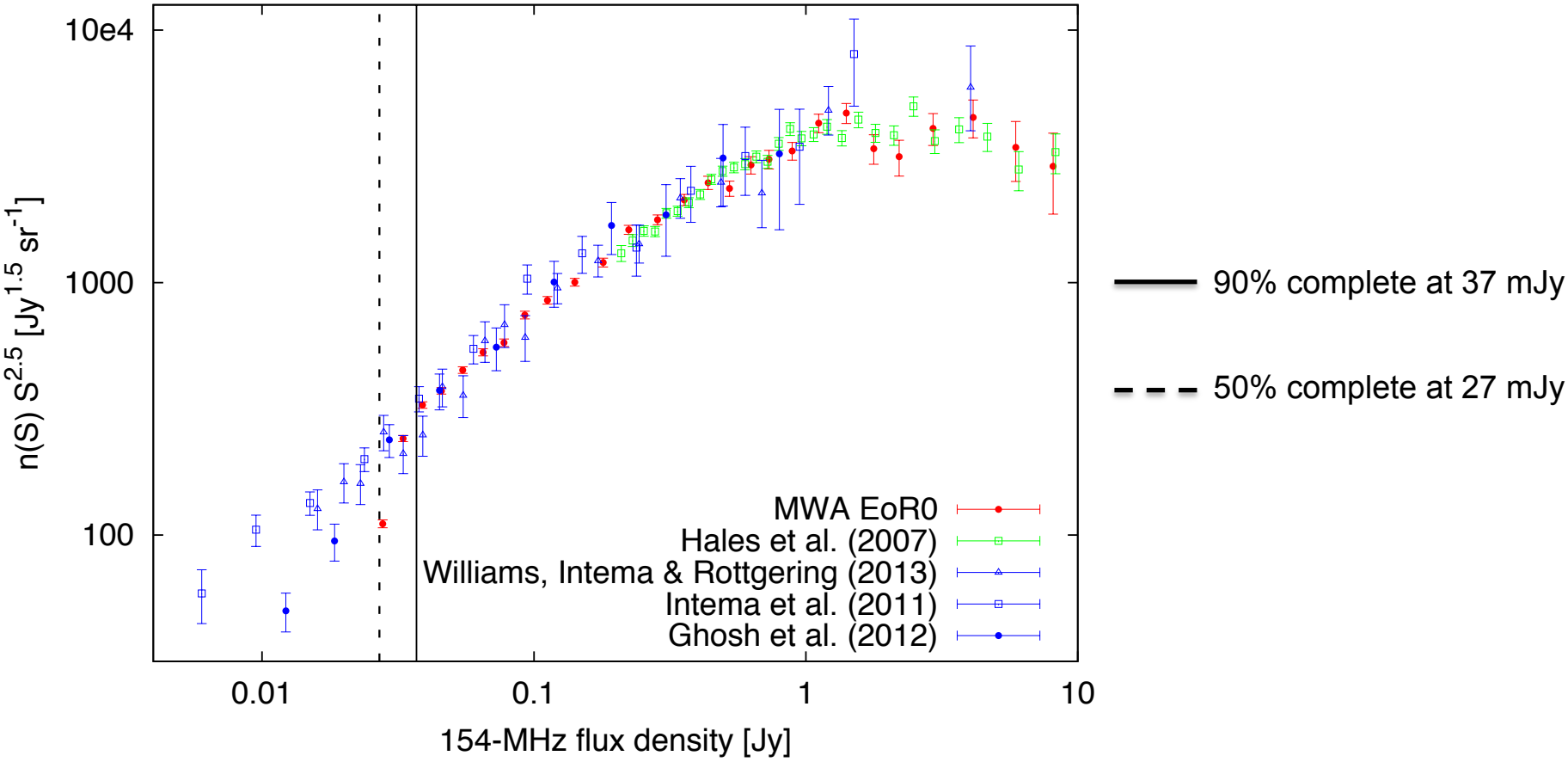
Franzen et al., in prep.

- $P(D)_{obs}$ - observed P(D) distribution
- $P(D)_{noise}$ - system noise distribution
- $P(D)_{source}$ - P(D) distribution resulting from all sources present in image, given beam size
- $P(D)_{sidelobes}$ - P(D) distribution from sidelobes (taken to include image artefacts due to calibration errors)

$$P(D)_{obs} = P(D)_{noise} * P(D)_{source} * P(D)_{sidelobes}$$

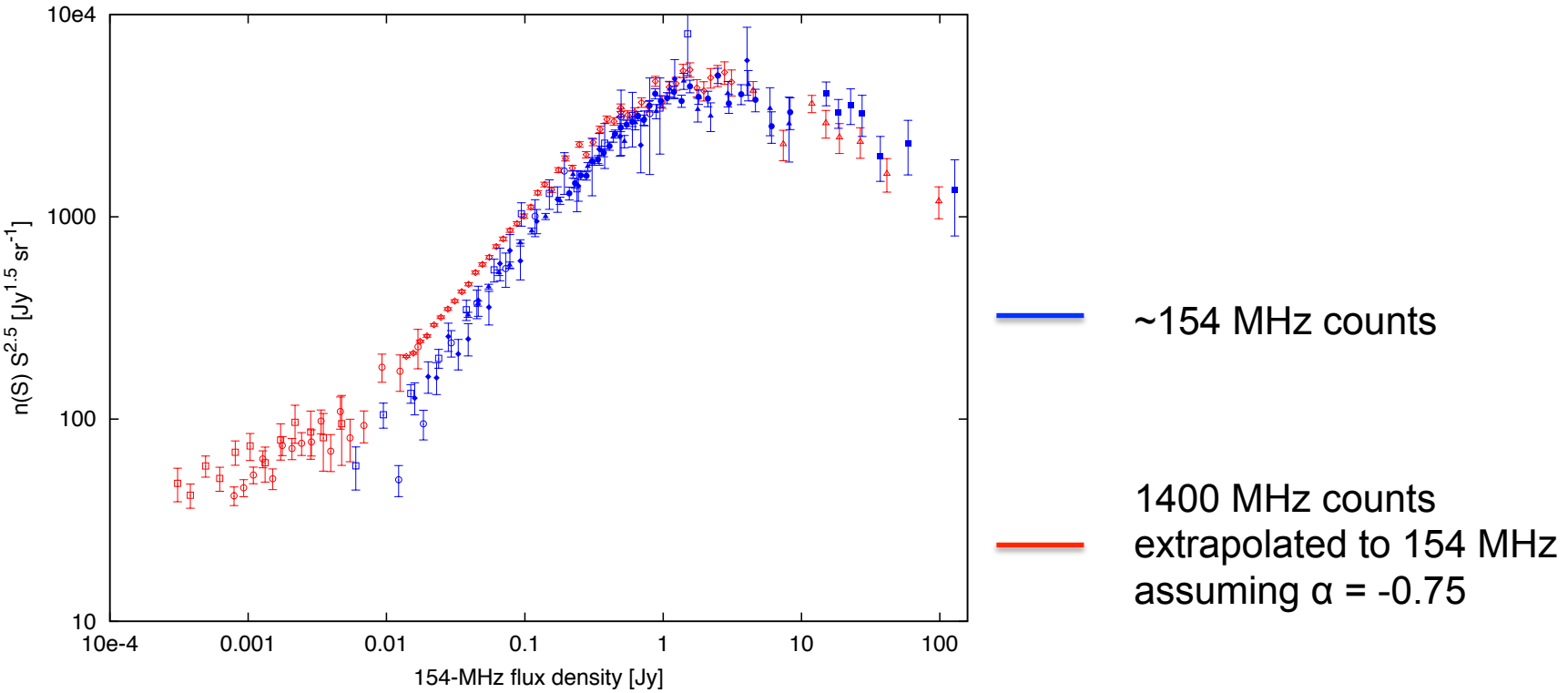
Source counts in MWA EoR image

- Counts down to 40 mJy in excellent agreement with 7C and GMRT counts
  - By far the most precise in flux range 40-200 mJy thanks to large area of sky covered
  - Sudden drop in MWA counts in lowest flux bin (25-30 mJy) due to incompleteness



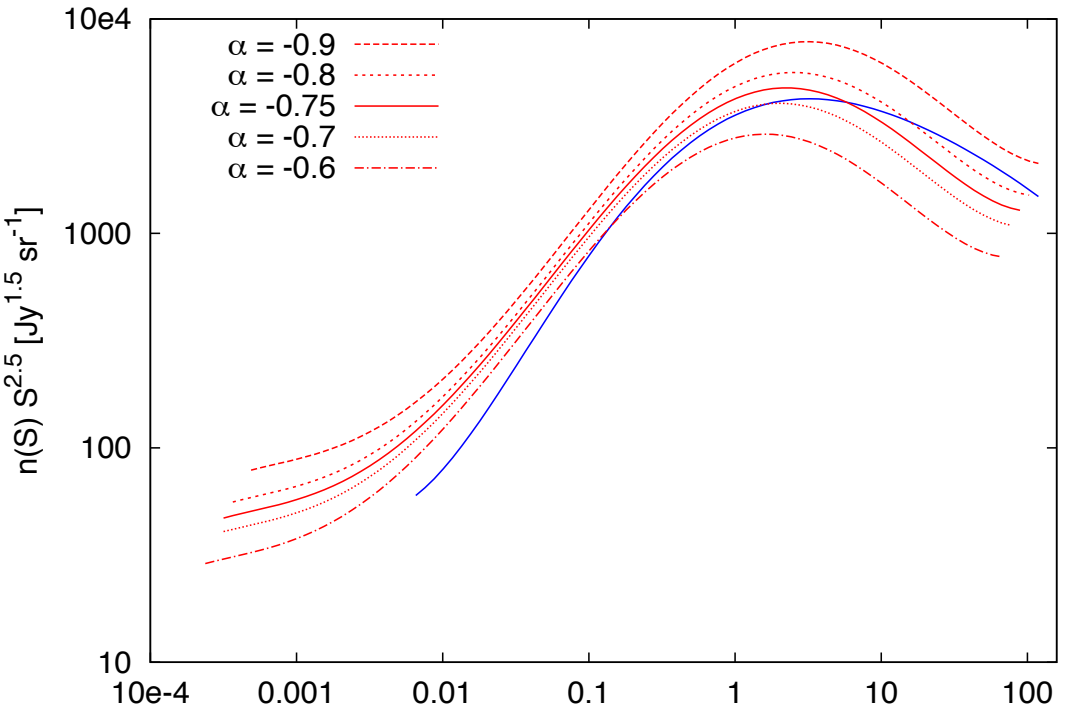
Extending the observed 154 MHz source counts

- Previous work has adopted α ≈ -0.7 to extrapolate from 1400 to 154 MHz but this is unreliable
  - Significantly overpredicts 154 MHz counts below ~500 mJy
  - Density of sources at S_{154} = 6 mJy overpredicted by a factor of ~2



Extending the observed 154 MHz source counts

- 154 MHz counts cannot be accurately reproduced from extrapolation of 1400 MHz counts using *any* spectral index
  - Best results obtained using α = -0.75

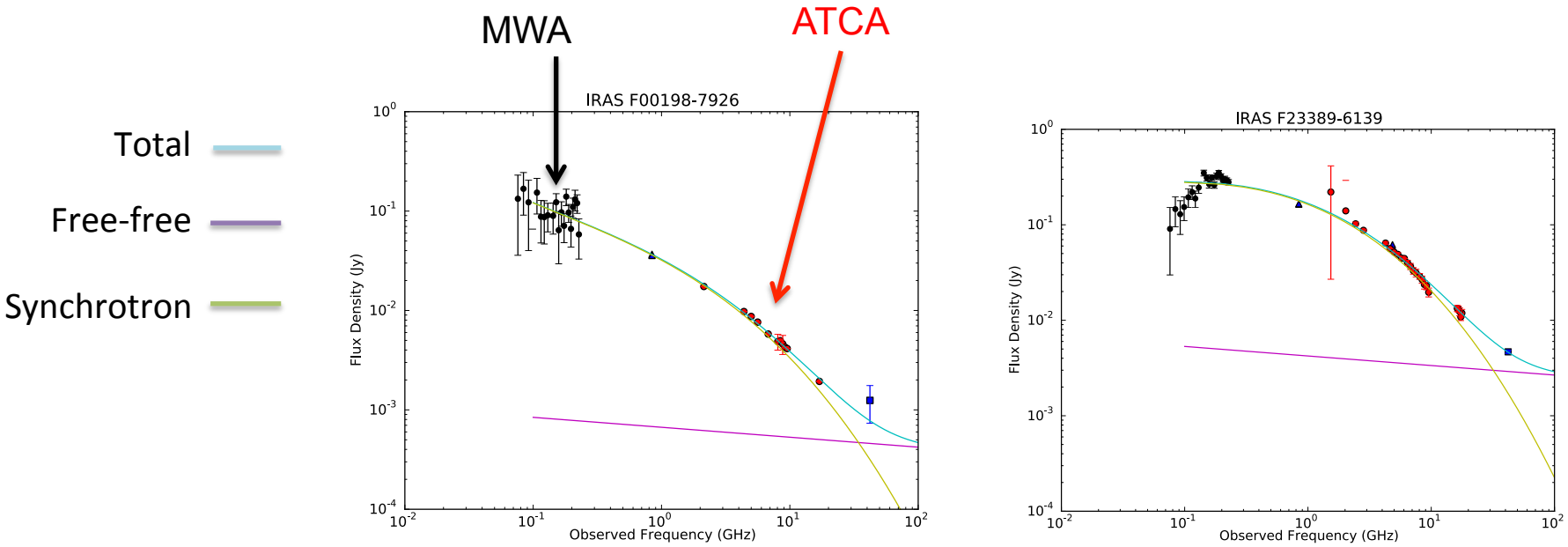


Polynomial fit to ~154 MHz counts

Polynomial fit to 1400 MHz counts extrapolated to 154 MHz assuming different spectral indices

Low-frequency spectra of star-forming galaxies

- Low-frequency emission from star-forming galaxies largely unstudied
  - Systematic study of this radio emission useful for understanding physical processes which contribute to radio emission from star formation
  - Can construct better low-frequency counts based on observed SEDs (rather than simple power-laws). Invaluable for planning deep low-frequency surveys with future facilities.



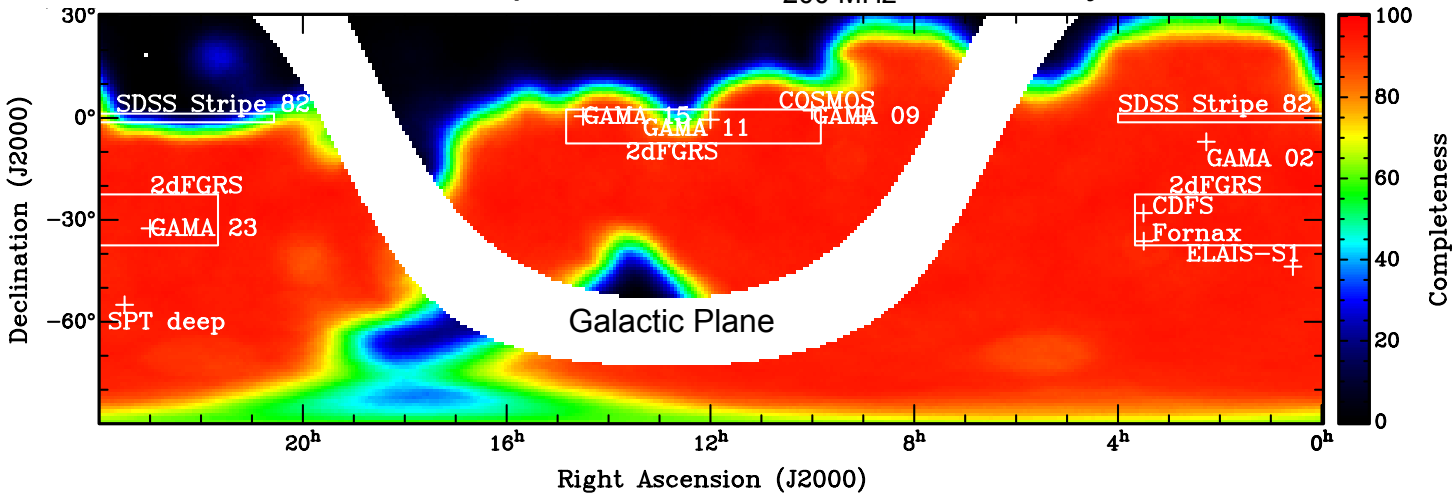
Galvin, Seymour et al., in prep.

Conclusions

- Catalogue containing > 300,000 compact, extragalactic (|b| > 10 deg) sources expected to be published in early 2016
  - Spectra between 73 and 230 MHz
- 154 MHz counts in EoR image down to ~40 mJy in excellent agreement with 7C and GMRT counts - **by far the most precise in flux range 40-200 mJy thanks to large area of sky covered**
  - Shape of low-frequency counts, including any flattening, cannot be directly determined from higher frequency data
- Excess background noise in GLEAM images primarily due to sidelobe confusion
  - Highlights need for further improvements in deconvolution imaging techniques
  - MWA will be upgraded, roughly doubling the array resolution; raises possibility of conducting large-area, sub-mJy continuum surveys

Completeness

Completeness at $S_{200\ MHz}$ = 100 mJy



Completeness at $S_{200\ MHz}$ = 50 mJy