ATCA XXL-S: Survey Description and Initial Results

International Centre for Radio Astronomy Research

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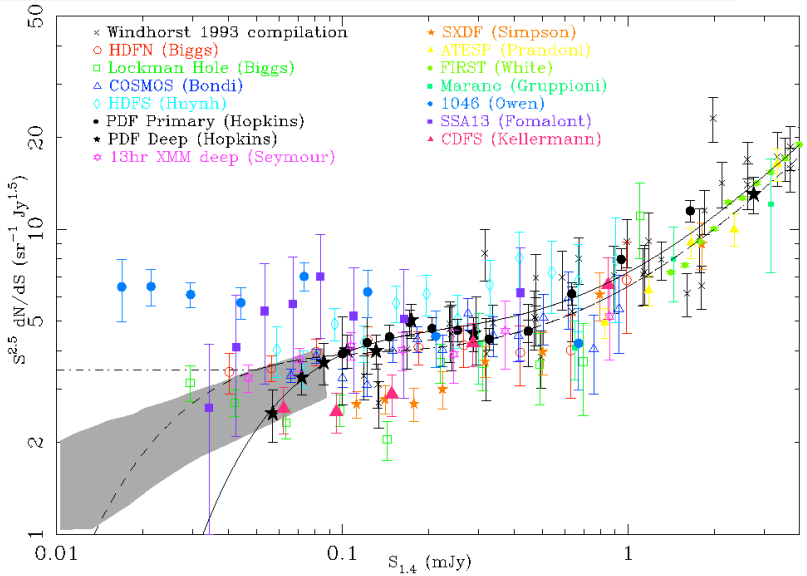
Radio surveys of galaxy evolution

Radio is a sensitive tracer of both SF and AGN activity, unaffected by dust

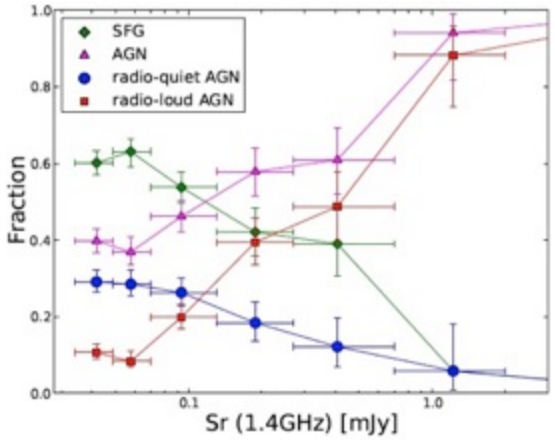
Radio-loud AGN dominate above 1 mJy

Significant population of low luminosity AGN, even at S < 0.1 mJy

Radio surveys are the best way to detect ‘radiatively-inefficient’ or radio-mode AGN



Norris et al. 2011



Bonzini et al. 2013

Radio AGN Classes

Property	HERGs	LERGs
Accretion rate	1-10% Eddington	<1% Eddington
Accretion material	Cold gas	Hot gas
AGN Radiation	X-ray, UV, optical, infrared, and radio signatures of AGN possible	High-excitation optical lines are missing, radio AGN signatures only
Radio Luminosity	More powerful, $L_{1.4GHz} >\sim 10^{26}$ W/Hz	Less powerful, $L_{1.4GHz} < \sim 10^{26}$ W/Hz
Host galaxies	Lower $M_{stellar}$, lower M_{BH}, bluer colours, associated with SF	Higher $M_{stellar}$, higher M_{BH}, redder colours
Feedback Mechanism	Quasar driven winds and/or kinetic energy from jets	Kinetic energy from jets

e.g. Best et al. 2005, 2012; Hardcastle et al. 2007

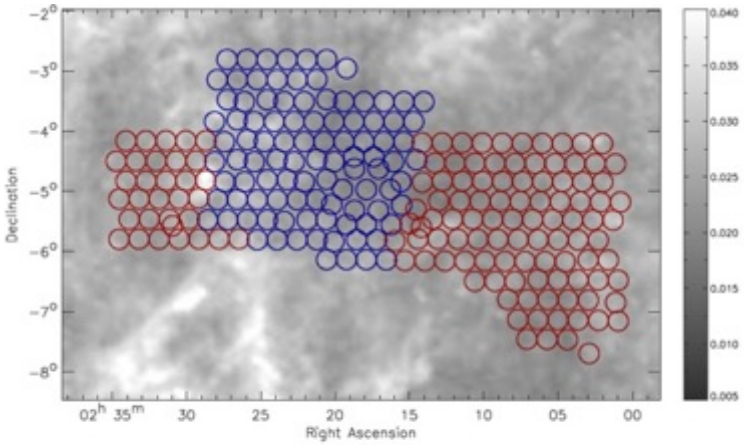
XMM Extragalactic Survey (XXL)

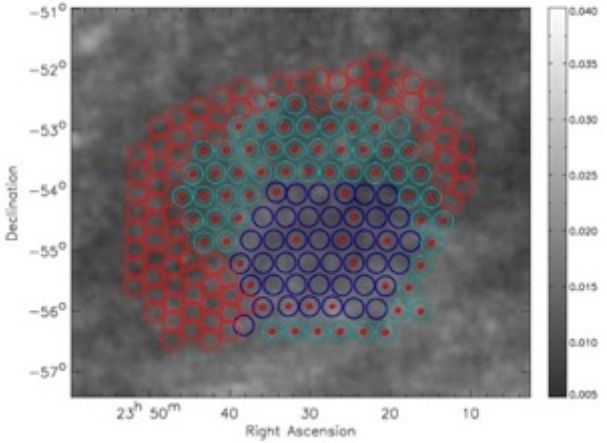
- The largest XMM programme ever, totalling 6.9 Ms (PI: M. Pierre)
- 2 x 25 sq deg fields with deep XMM data
- f >~5 x 10^{-15} erg /s /cm^2 in [0.2 – 2] keV band

Main goals

- Clusters: cosmology, scaling relations
- AGN: study galaxy evolution with a large sample of AGN
- Expect ~30,000 Xray AGN, 100s of Xray-selected clusters

XXL-North (XXL-N)

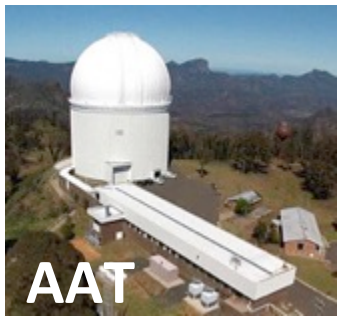




XXL-South (XXL-S)

XXL-S Multiwavelength Data

Survey / Telescope	Wavelength Regime	Filters & Depths	% of XXL-S
Spitzer South Pole Telescope Deep Field (SSDF)	Mid-Infrared	3.6μm=0.4μJy 4.5μm=0.84μJy	100%
Wide-field Infrared Survey Explorer (WISE)	Mid-Infrared	W1(3.4μm)=0.08 mJy W2(4.6μm)=0.11 mJy W3(12μm)=1 mJy W4(22μm)=6 mJy	100%
Vista Hemisphere Survey (VHS)	Near Infrared	J_{AB}=21.2, Ks_{AB}=19.8	100%
Dark Energy Survey (DES)	Optical	g=26.1, r=25.6 i=25.8, z=25.3	100%
Blanco Cosmology Survey (BCS)	Optical	g=23.9, r=24.0 i=23.6, z=22.1	<50%
XMM-Newton	X-ray	0.3-0.5 keV = 10 ks 0.5-2 keV = 10 ks 2.0-4.5 keV = 10 ks	100%
Australian Astronomical Telescope (AAT)	~3000 optical redshifts	N/A	~5-10% of 3000 sources



ATCA XXL-S Pilot Survey Observations

- Pilot observations in Sep-Nov 2012 of central ~6 sq deg of XXL-S
- 49 hours in 6km and 1.5km configurations
- Central frequency: 2.1 GHz (2 GHz bandwidth)
- 81 pointings
- ~50 μJy/beam rms, ~4.5 arcsec resolution

Australia Telescope Compact Array
in Narrabri, NSW, Australia

ATCA XXL-S Wide-field Wide-band Imaging

- Pointings reduced separately and combined in image plane

Wide-field wide-band imaging is not trivial

- 2 GHz bandwidth is challenging to image
  - Delta freq /freq ~ 1
  - Primary beam, synthesized beam and source flux density all vary with frequency
- Only 6 ATCA antennas
  - Selfcal improvement to gains will scale as (N – 1), N = number of baselines
  - ATCA vs VLA: 15 baselines vs 351 baselines.

ATCA XXL-S Wide-field Wide-band Imaging

- **Scheme 1: Full-band reduction** (e.g. Huynh et al. 2012)
  - Multi-frequency synthesis
  - Invert full 2 GHz band, mfclean, restor with mean beam of all pointings
  - 2 iterations of phase selfcal
  - Linmos (bw=2,10) uses ten frequency-averaged primary beams to handle PB correction

- **Scheme 2: Sub-band reduction** (e.g. Condon et al. 2012)
  - Multi-frequency synthesis
  - Split into 8 x 256 MHz sub-bands, but lowest sub-band discarded due to RFI
  - Sub-bands imaged with robust weighting factor to roughly match beams
  - 2 iterations of phase selfcal
  - Restor with mean beam for all 7 x 81 = 567 pointings
  - Linmos (bw=0.256,10) uses ten frequency-averaged primary beams to handle PB correction

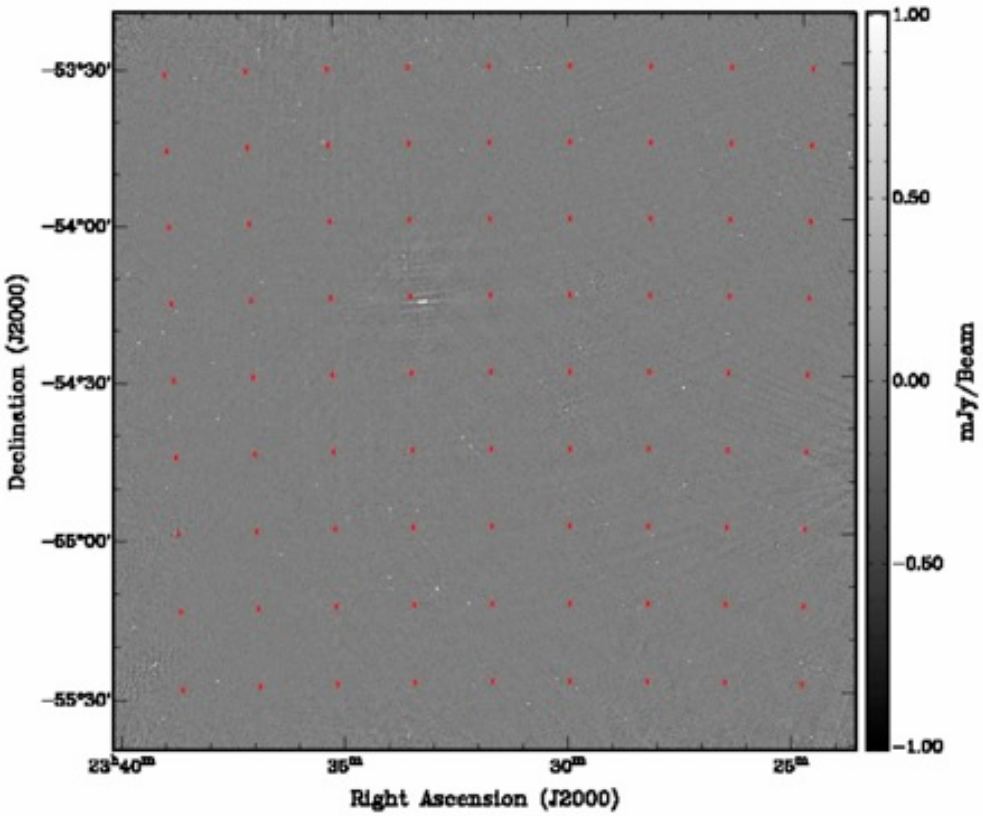
Performed both to check for systematics, and to derive spectral indices

ATCA XXL-S Pilot Survey Image

Sub-band reduction:

- ~50 μJy/beam rms
- 4.7 x 4.2 arcsec beam
- ~6 sq deg

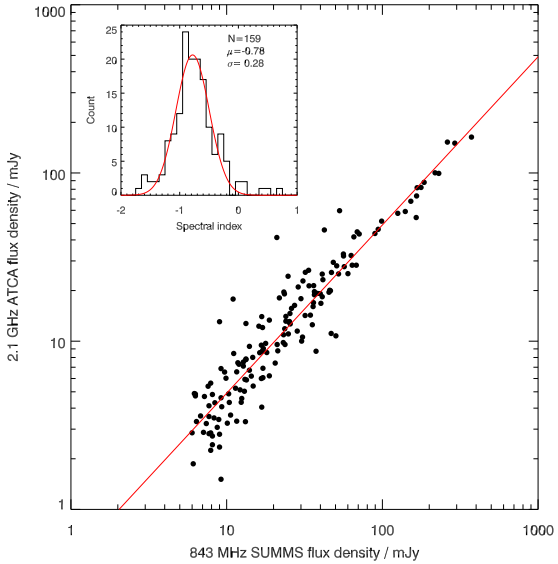
- Contains 1389 radio sources (>5σ), of which 77 are multiple component

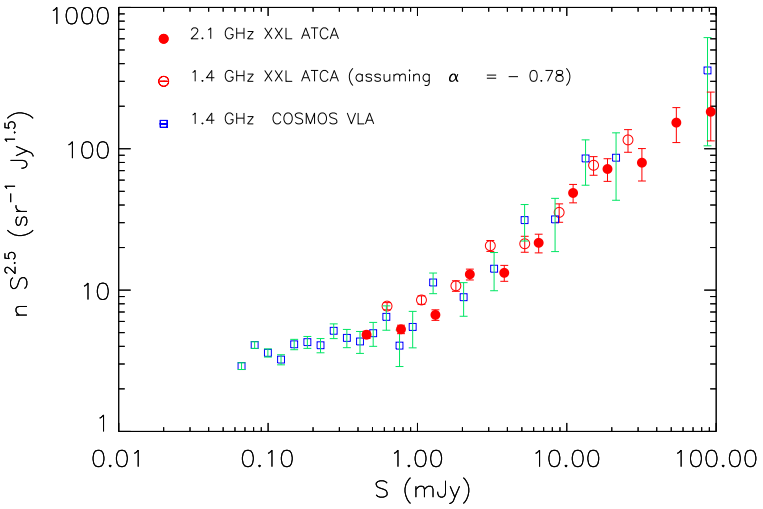


XXL Paper XI: Smolcic et al. submitted

ATCA XXL-S Pilot Survey Results

XXL Paper XI: Smolcic et al. submitted





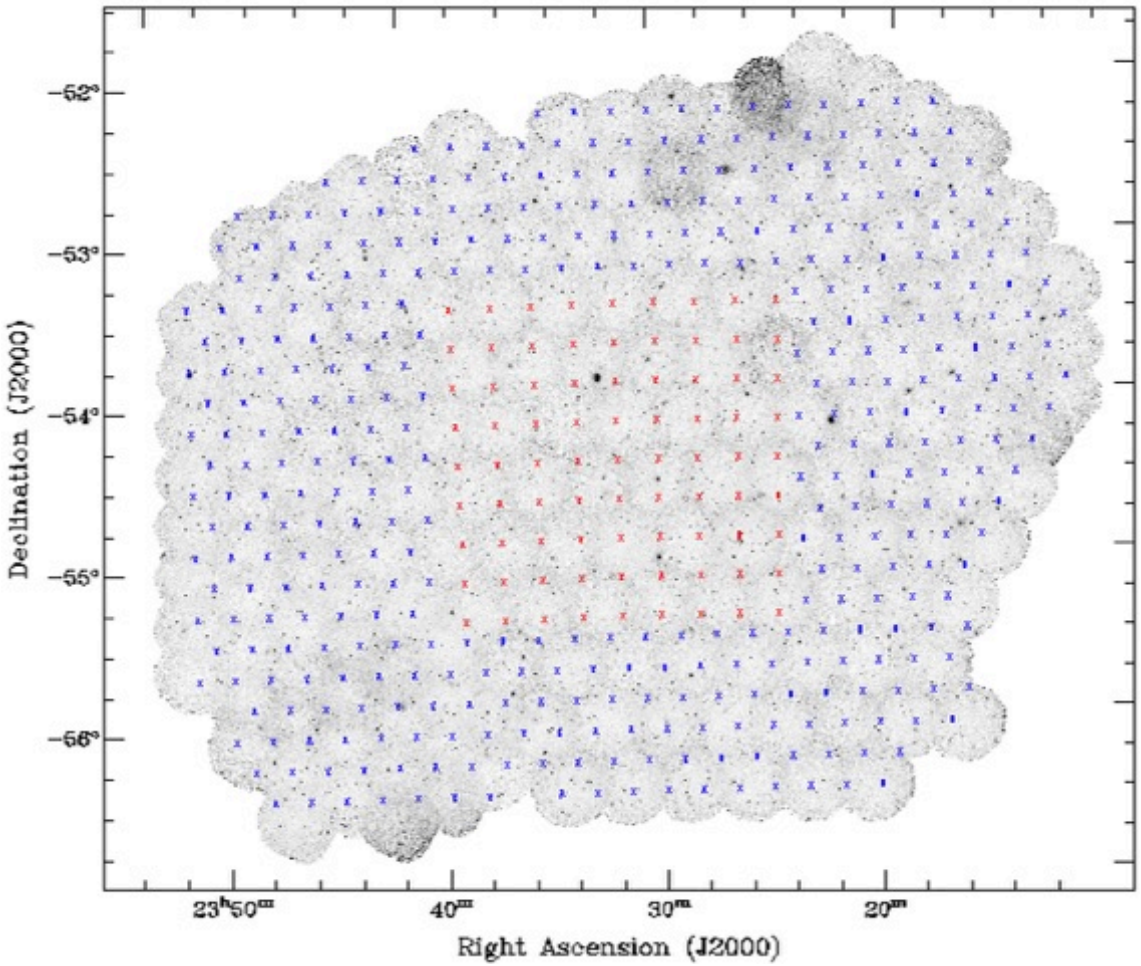
- Sources matched to SUMSS 843 MHz all sky survey
  - S843 MHz > 6 mJy
  - 159 SUMSS sources overlap with pilot survey
- Mean α = -0.78 ± 0.28, ($S \propto \nu^{\alpha}$)
- Source counts consistent with 1.4 GHz counts from COSMOS

ATCA XXL-S New Observations

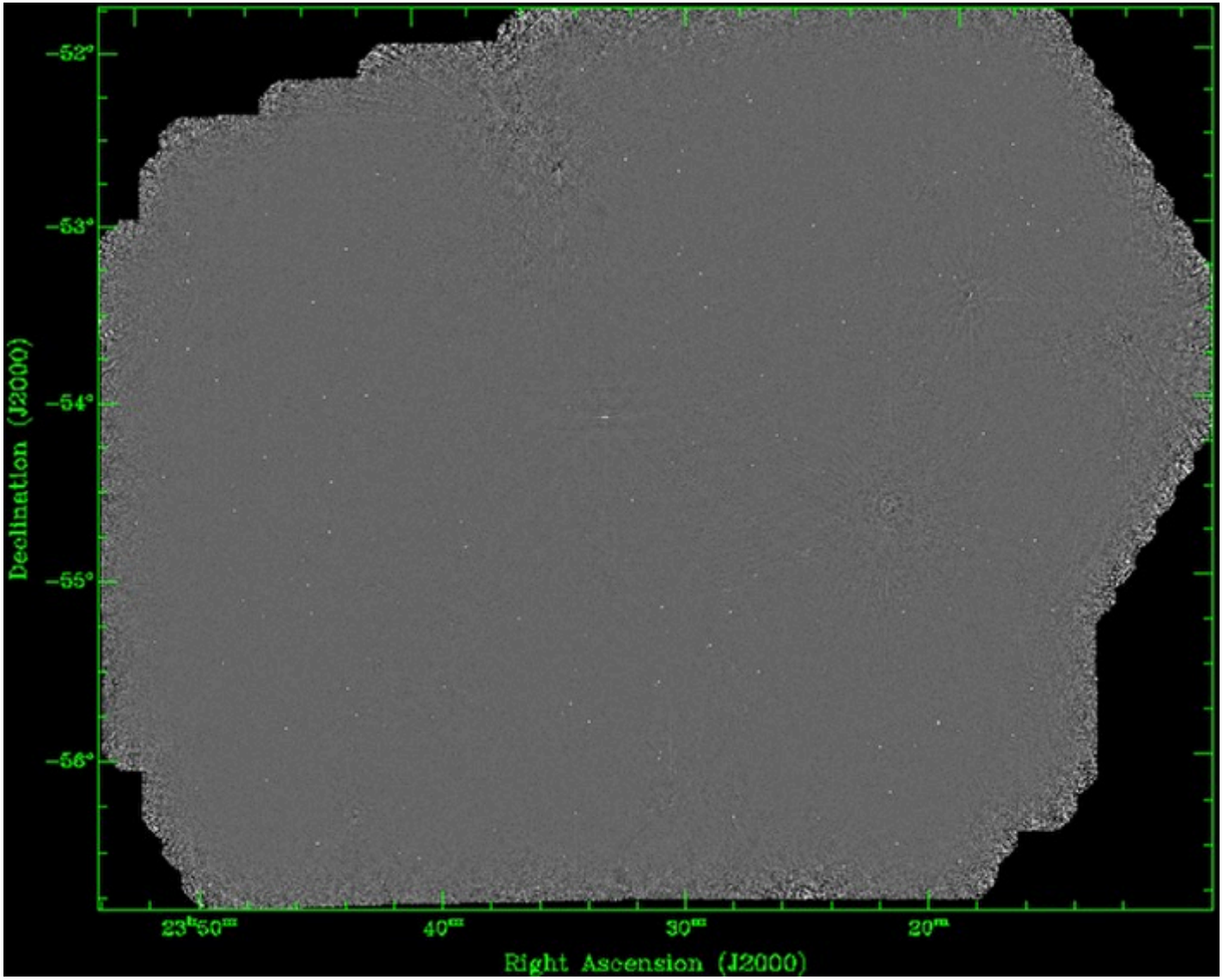
- 240 hours awarded in Nov-Dec 2014 to reach same depth in full 25 sq deg XXL-S to cover rest of XXL-S
- 390 new pointings, 471 pointings total (including pilot observations) for full 25 sq deg XXL-S
- Both 6km and 1.5 km configurations
- Hexagonal ATCA mosaicing pattern
- Central frequency: 2.1 GHz (1.1 – 3.1 GHz band)
- Goal of ~45 μJy rms, ~5 arcsec resolution

- Expect > 7000 radio sources (>5σ)

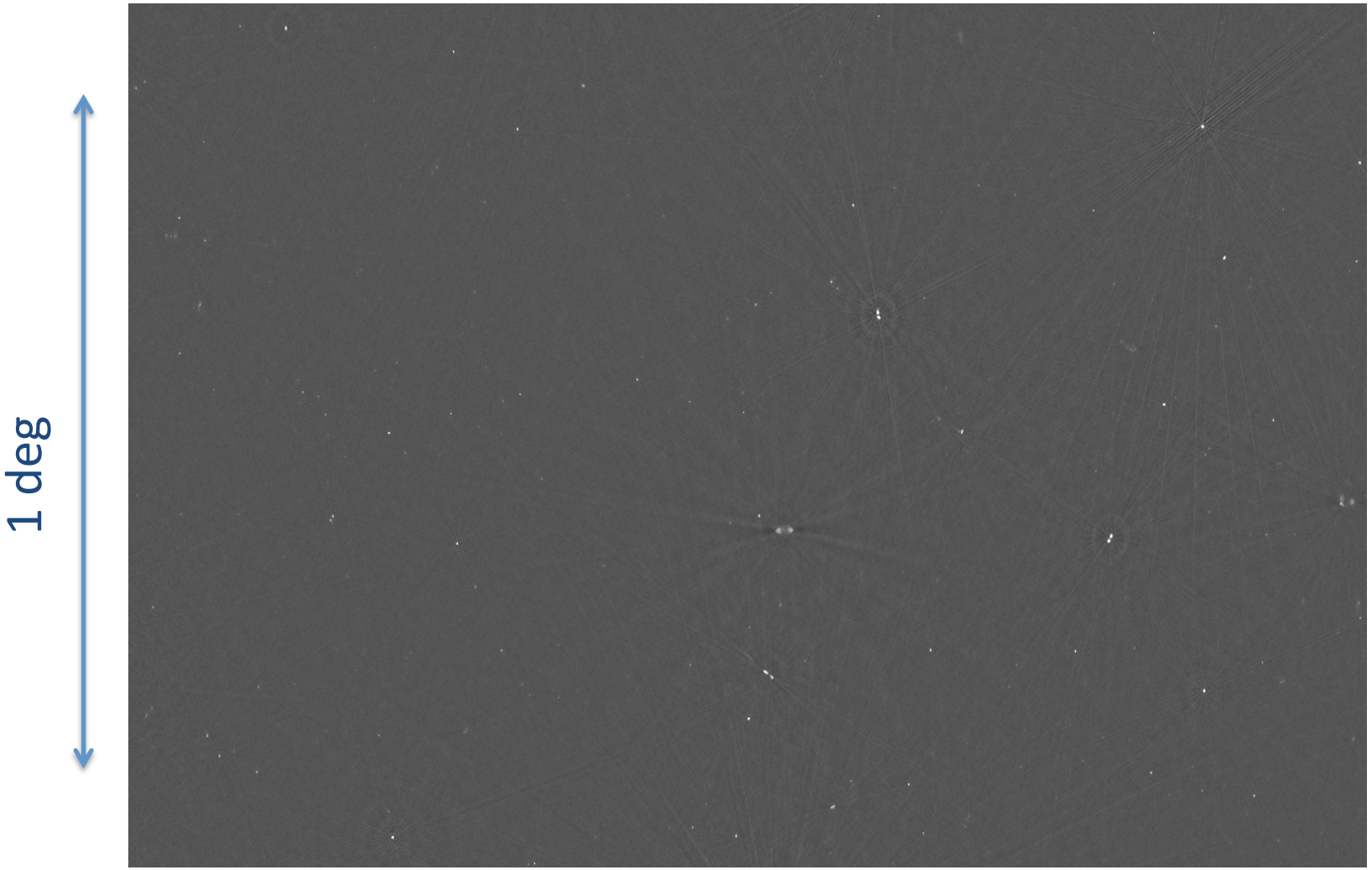
ATCA XXL-S New Observations



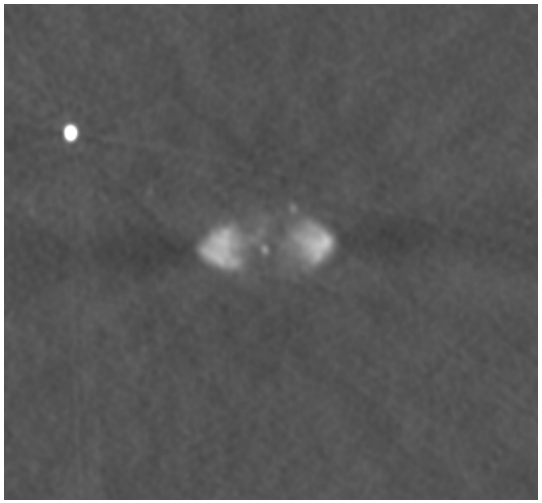
Preliminary Full Mosaic: Full-band reduction

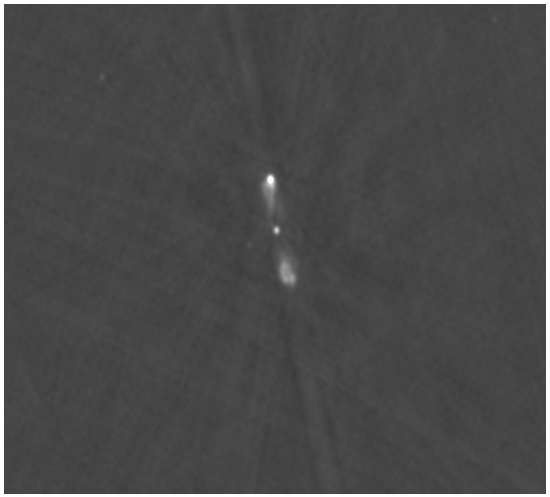


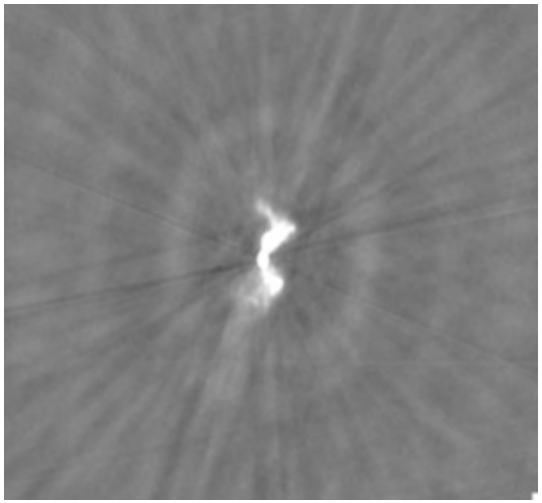
Typical Region of the Preliminary Mosaic

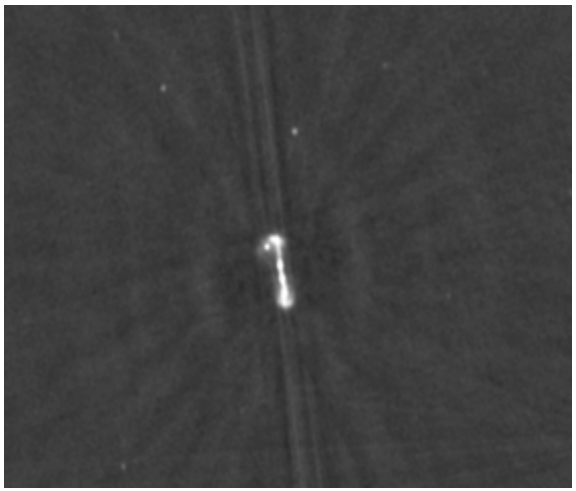


Some interesting sources

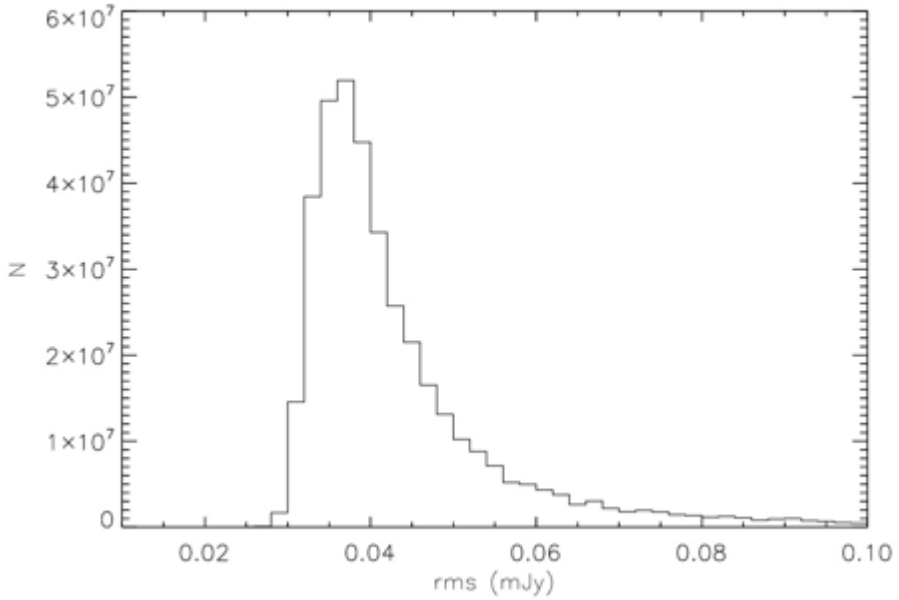








Preliminary Full Mosaic Noise Properties

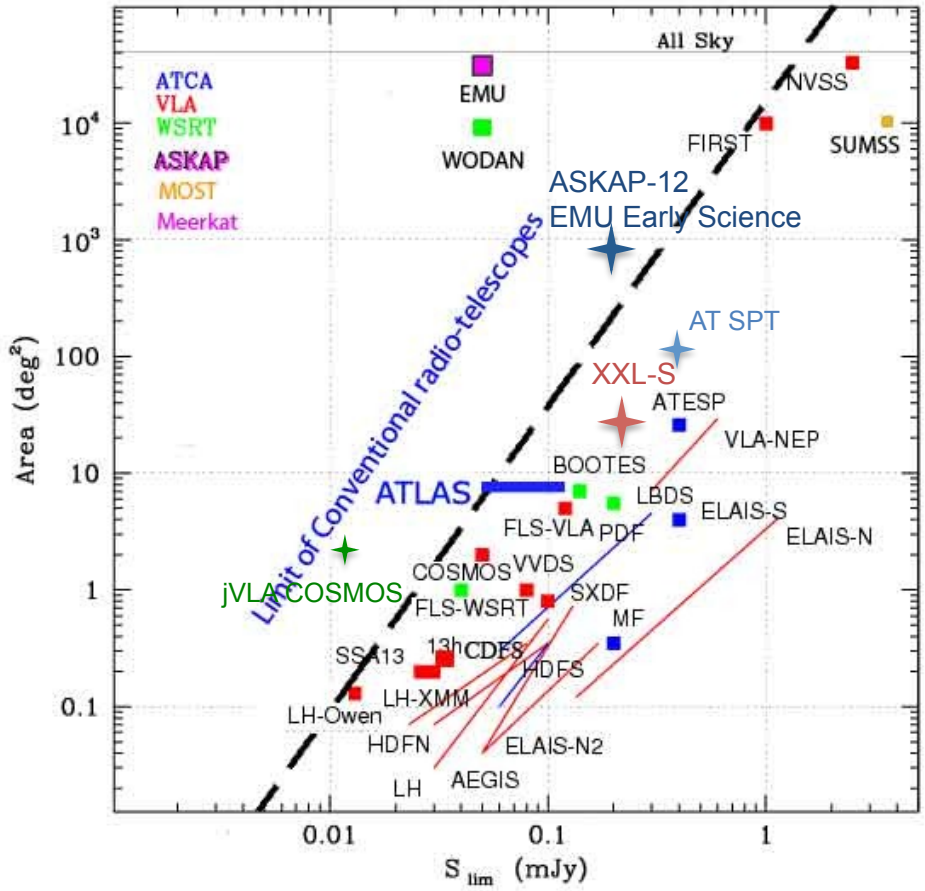


- Noise distribution peaks at 36 μJy/beam
- Median noise of 40 μJy/beam

- Tail to higher values at edges of mosaic due to primary beam correction and artefacts around bright sources

How ATCA XXL-S Compares

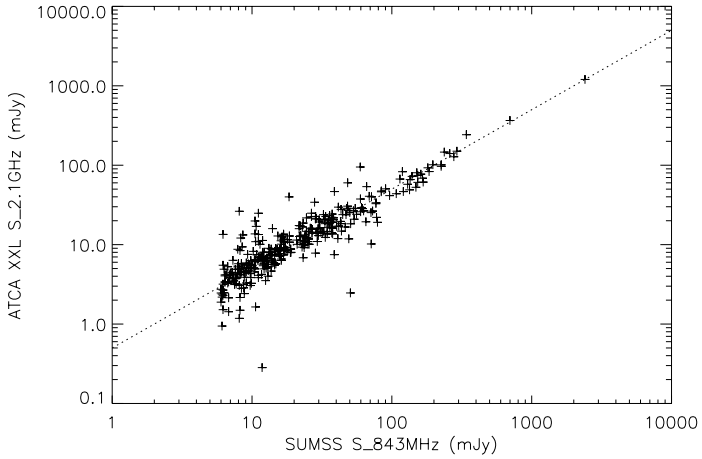
Based on Fig 1 of Norris et al. 2011

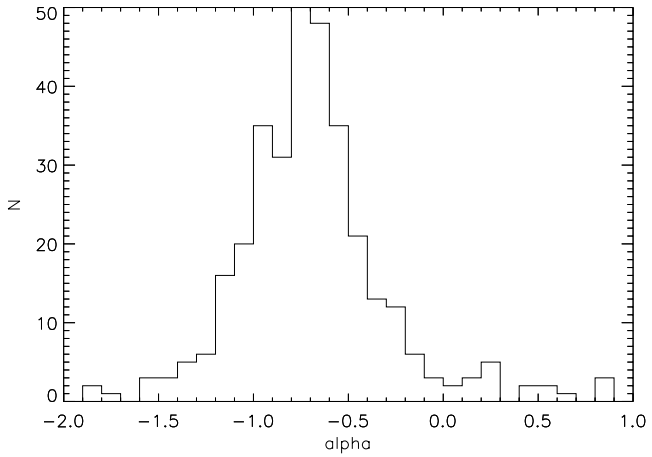


Preliminary Full XXL-S Results: Spectral Indices

- 3700 sources extracted in inner 16 sq deg (> 6σ)
- Expect > 7000 sources (> 5σ) in final catalogue of 25 sq deg region

- Sources matched to SUMSS 843 MHz all sky survey
  - S843 MHz > 6 mJy
  - 335 SUMSS sources overlap with preliminary list of sources
- Median α = -0.72, ($S \propto \nu^{\alpha}$)





ATCA XXL-S Planned Work

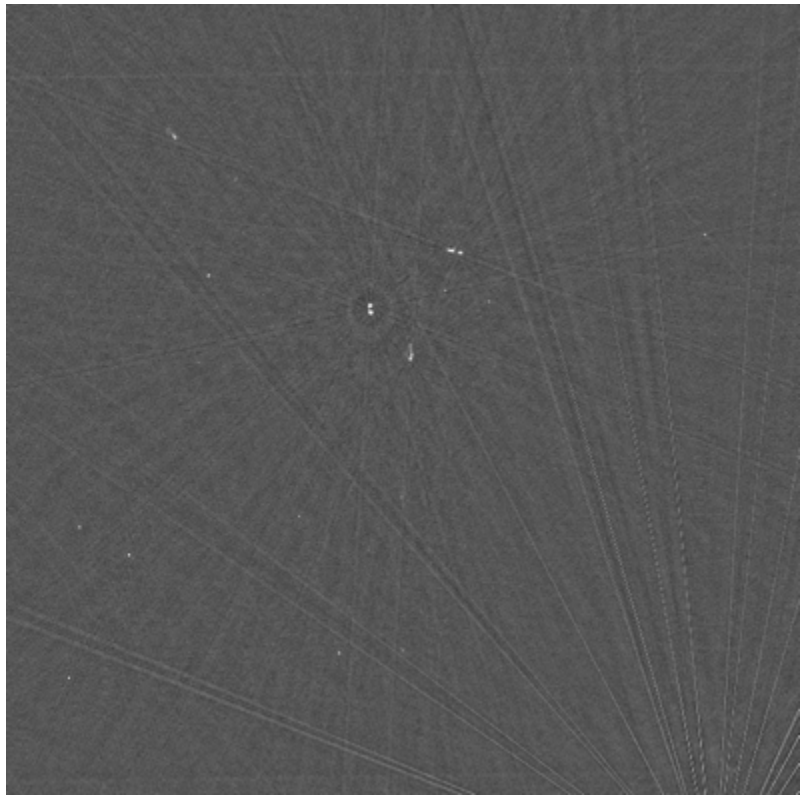
- Improve full-band reduction by subtracting artefacts (“peeling”) from bright ~1 Jy level sources (almost done)
- Sub-band reduction
- Source extraction, v1.0 of catalogue
- Match to optical/MIR/Xray data in field
- AGN vs SF and LERG vs HERG classification
- SCIENCE !
  - Radio luminosity functions
  - Evolution of radio AGN, esp. LERG vs HERG evolution
  - Feedback from radio AGN
  - Radio galaxies – hosts and environments, FRIs vs FRIIs and hybrids?
  - Clusters – radio haloes and radio relics?

Credit: ESA/NASA, AVO project

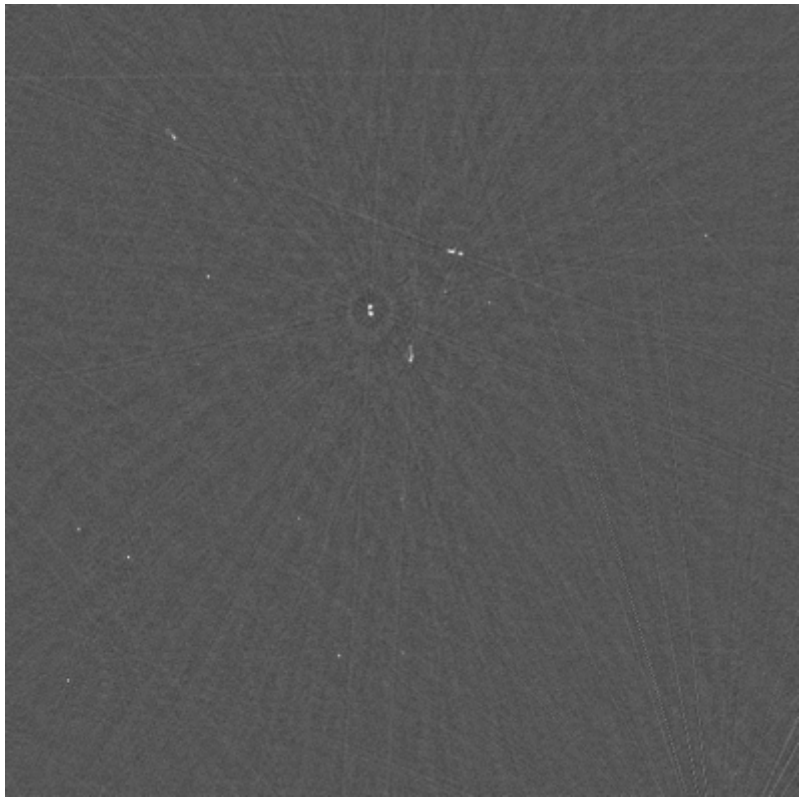
Example of Peeling Improvement

- Bright off-center sources need to be ‘peeled’ to remove artefacts
- Progress on this underway, final images will be of better quality than the preliminary mosaic.

Before Peeling



After Peeling



Summary

- Deep (<0.1 mJy rms) wide-area radio surveys are essential for understanding AGN

- Now have preliminary mosaic
  - Central freq of 2.1 GHz, (2 GHz bandwidth)
  - ~40 μJy rms over full XXL-S, 25 sq deg
  - ~5 arcsec resolution

- Ongoing imaging work in sub-bands, to compare with preliminary full-band reduction

- Will provide a sample of >7000 radio sources (of which >5000 radio AGN)