The ATCA XXL-S 2.1GHz Radio Survey:

First results and preliminary AGN luminosity functions

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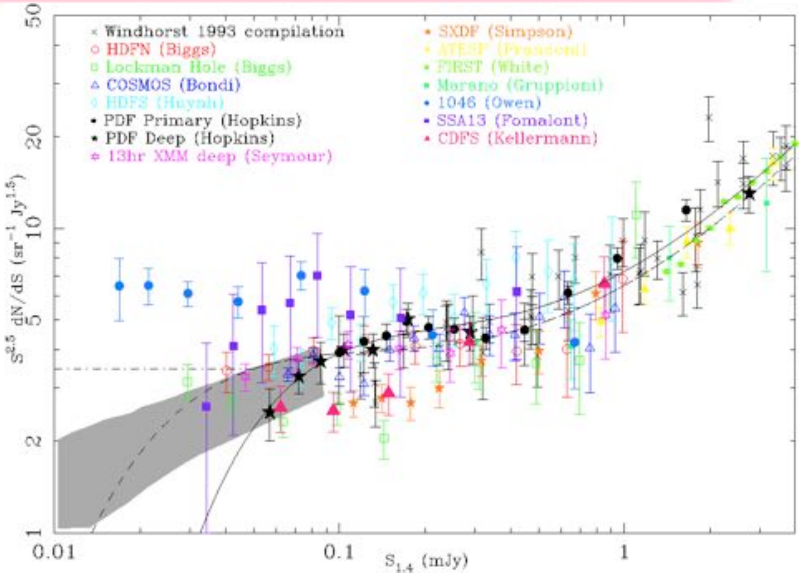
Why radio surveys?

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

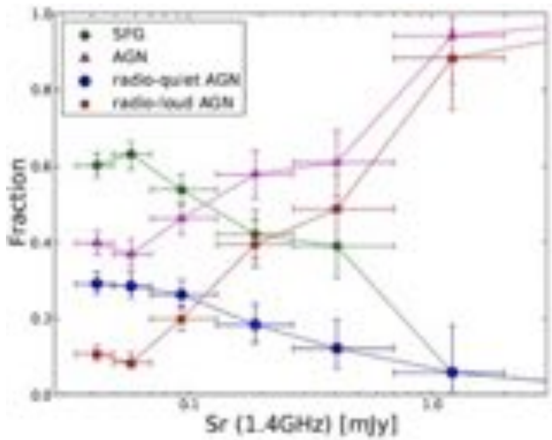
Radio-loud AGN dominate above 1 mJy

Significant population of faint 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

Why Radio + XRay?

For a full census on AGN feedback:

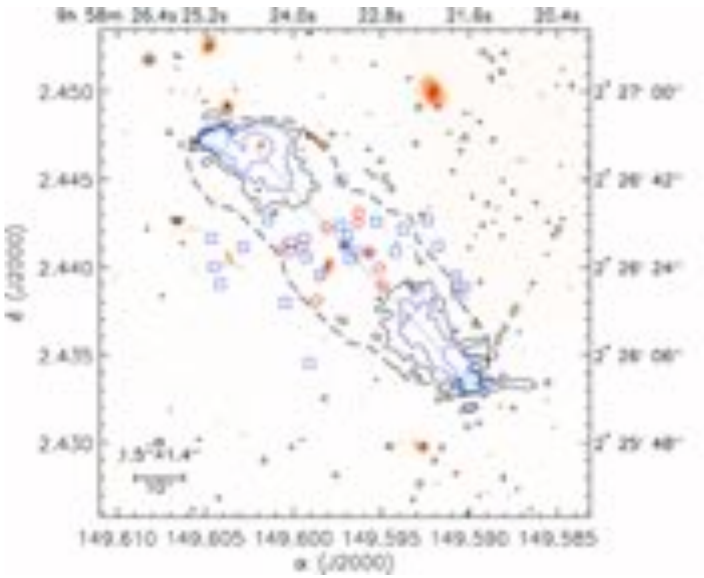
- X-ray = info on radiatively-efficient AGN
- Radio = info on radiatively-inefficient AGN

- Some AGN can only be identified in radio (LERGS)

- Mechanical energy from jets heats ICM and IGM: Radio-mode feedback.

- X-ray + radio combo = thermal + nonthermal processes

- Identify contamination of X-ray by nonthermal sources



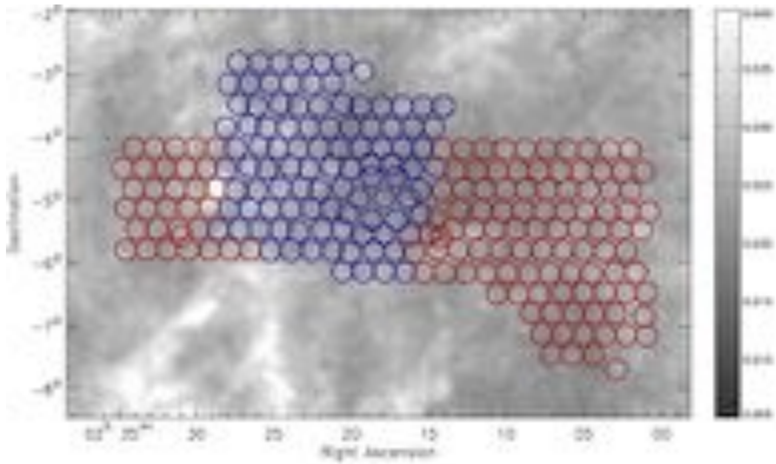
Xray and Radio emission from IC scattering candidate, Jelic et al. 2012

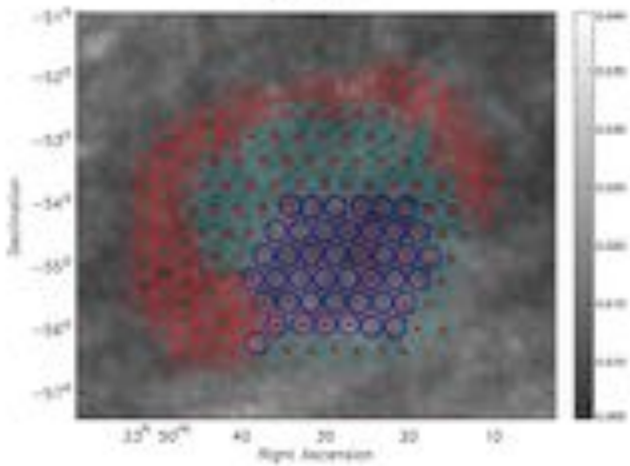
XXL Survey

XMM Extragalactic Survey (XXL) is the largest XMM program ever, totalling 6.9 Ms

- 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
- Expect ~30,000 Xray AGN

XXL-N (XMM-LSS)





XXL-S (XMM-BCS)

XMM-Newton, www.esa.int

XXL-S Multiwavelength Data

Survey / Telescope	Wavelength Regime	Filters & Depths	% of XXL-S
Spitzer South Pole Telescope Deep Field (SSDF)	Mid-Infrared	3.6μm=7.0μJy 4.5μm=9.4μJy	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	~95%
Dark Energy Survey (DECam)	Optical	g=26.1, r=25.6 i=25.8, z=25.3	g≈95%, r≈66% i≈66%, z=100%
Blanco Cosmology Survey (BCS)	Optical	g=23.9, r=24.0 i=23.6, z=22.1	~99%
XMM-Newton	X-ray	0.5-2 keV = 10 ks 2-10 keV = 10 ks	100%
Australian Astronomical Telescope (AAT)	7232 optical redshifts	N/A	1100 redshifts

Radio Followup of XXL

XXL-N (AKA XMM-LSS)

- 40 x 40 arcmin region (supercluster area) covered by JVLA @ 3 GHz to 20 μJy rms
- Almost full 25 sq deg area covered by GMRT @ 610 MHz to 100-300 μJy rms

Australia Telescope Compact Array in Narrabri, NSW, Australia

XXL-S

- Full 25 sq deg region covered by Australia Telescope Compact Array @ 2.1 GHz to 40 μJy rms

Australia Telescope Compact Array

Located near Narrabri, about 500km northwest of Sydney

6 x 22m dishes in east-west array, but with short north-south spur.

Maximum baseline of 6km

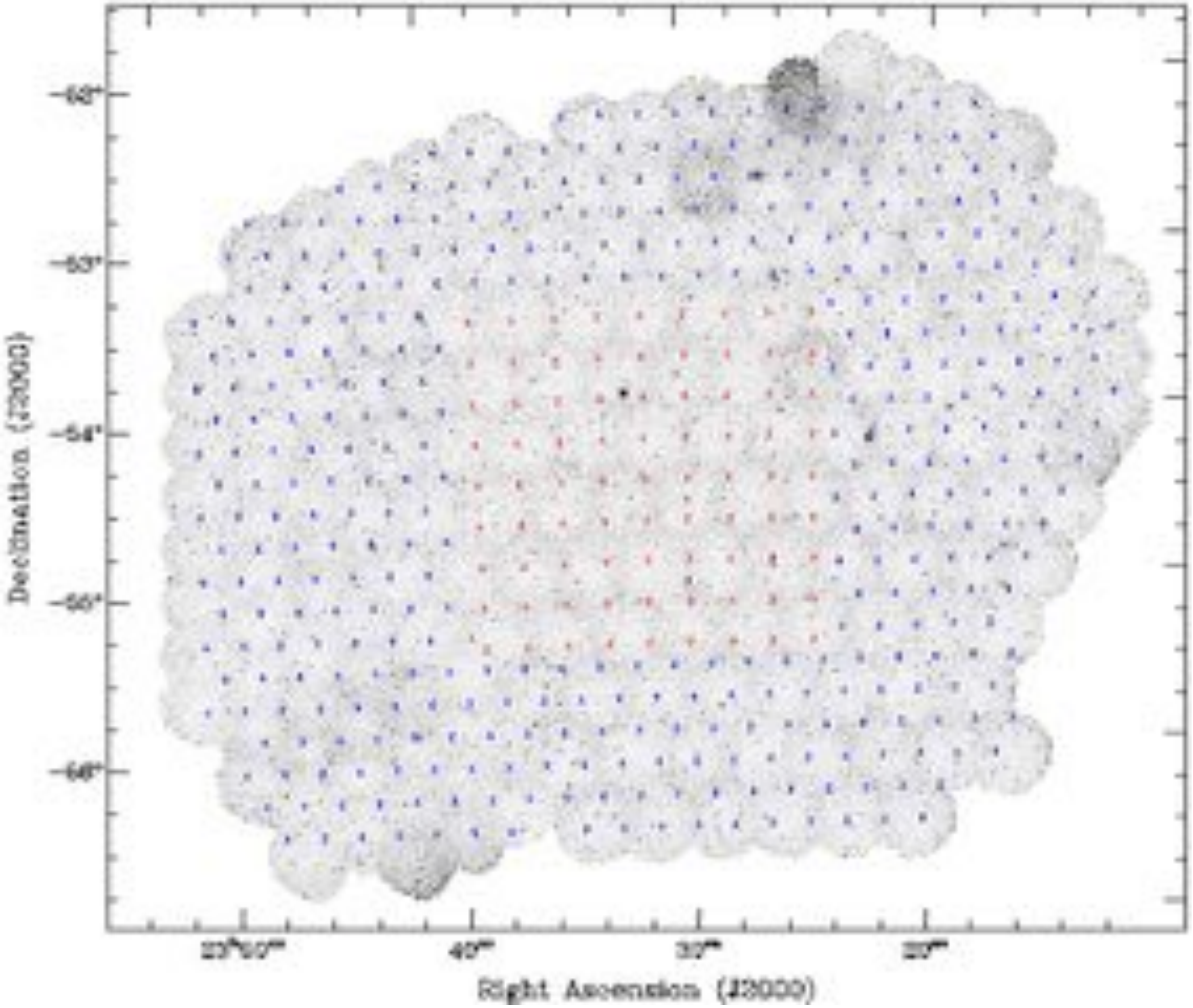
Operates in several bands from 1.1 to 105 GHz.

New backend installed in 2009 provides up to 2 x 2 GHz bandwidth

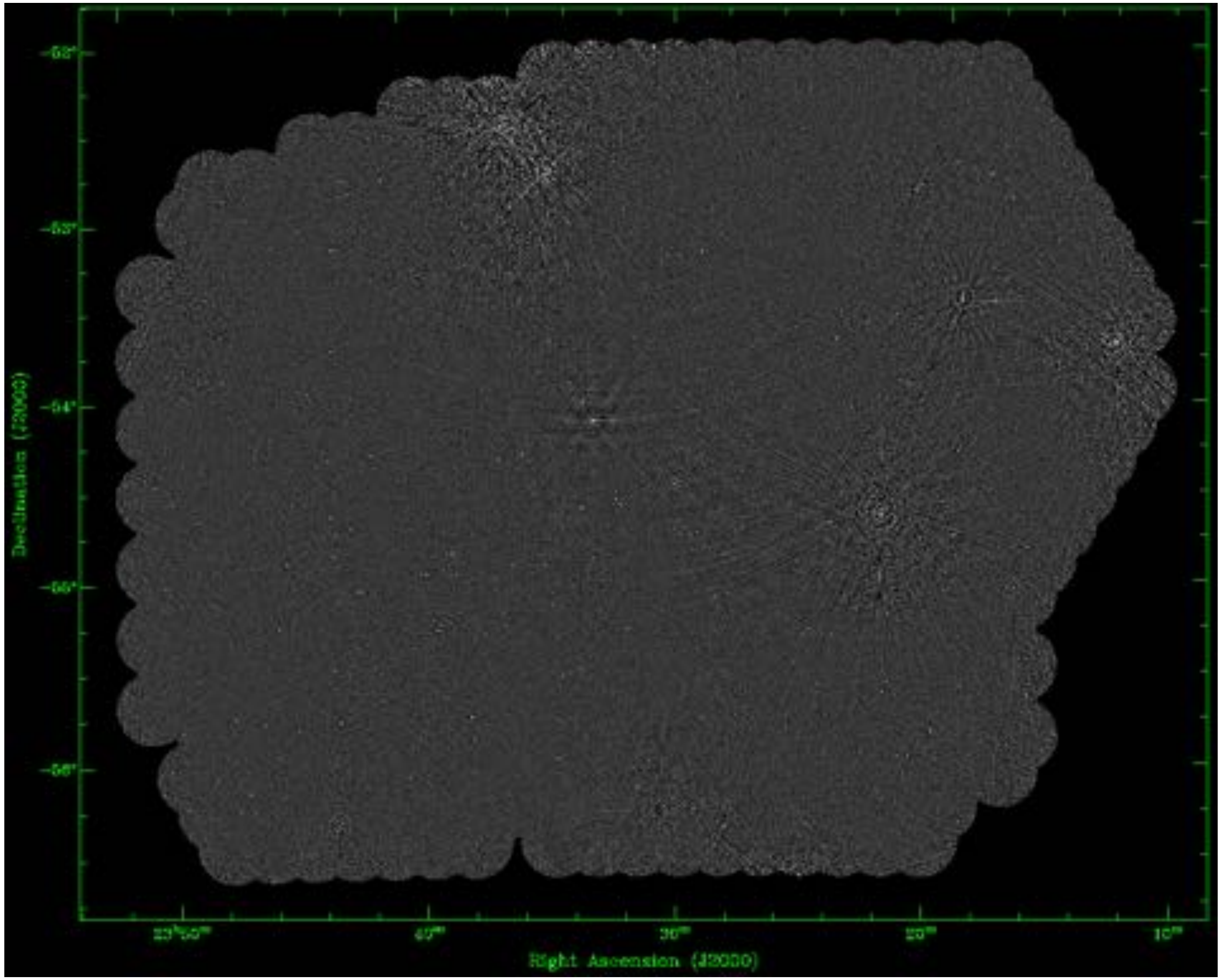
ATCA XXL-S Observations

- 290 hours awarded in 2012 (pilot) and 2014
- 471 pointings total for full 25 sq deg
- Hexagonal ATCA mosaicing pattern in 2014, grid pattern in 2012
- Both 6km and 1.5 km configurations.
- Central frequency: 2.1 GHz (1.1 – 3.1 GHz band)
- Median noise 41 μJy/beam rms
- 5.4 x 4.2 arcsec synthesized beam

ATCA XXL-S Observations



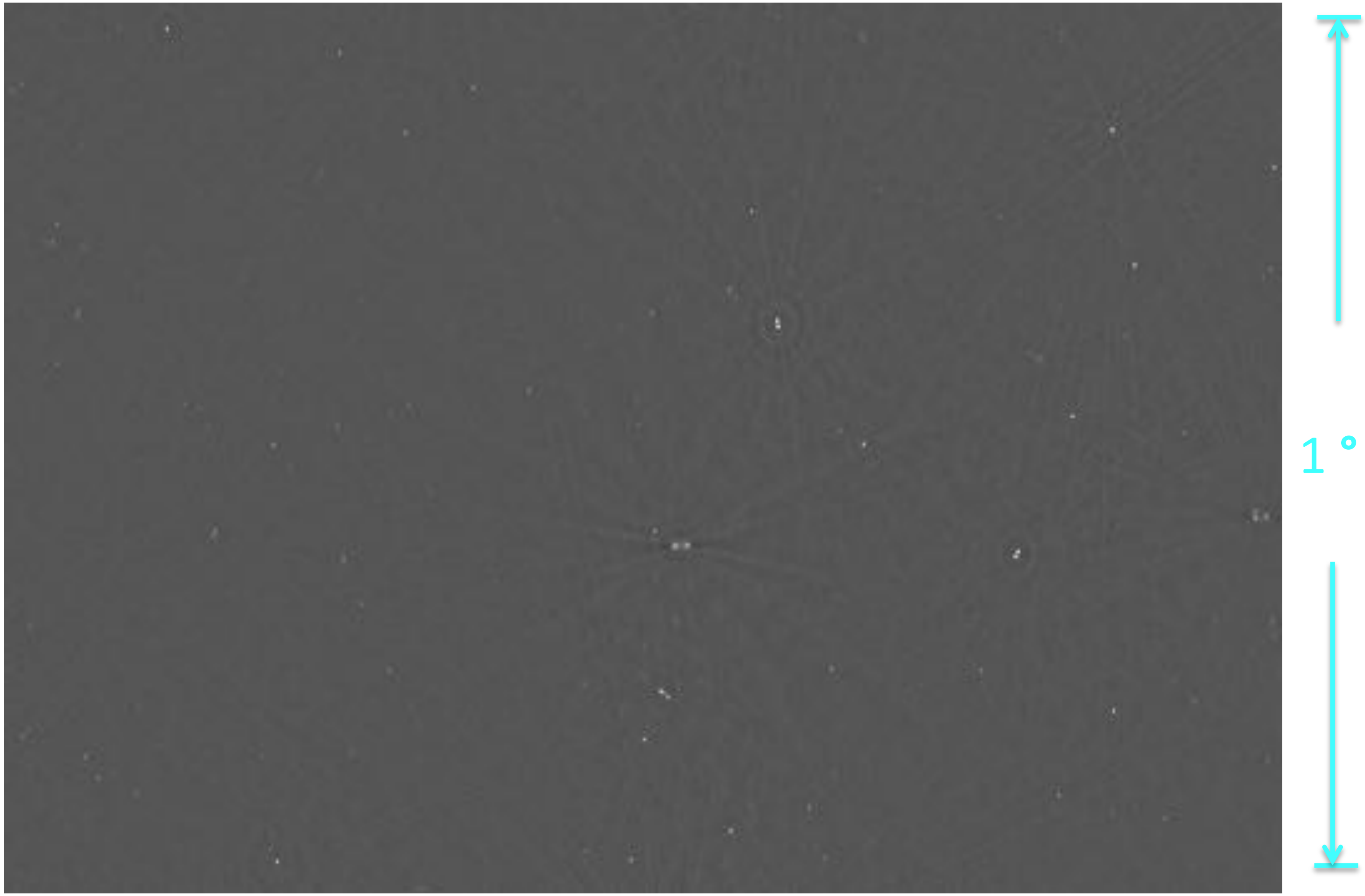
ATCA XXL-S Mosaic



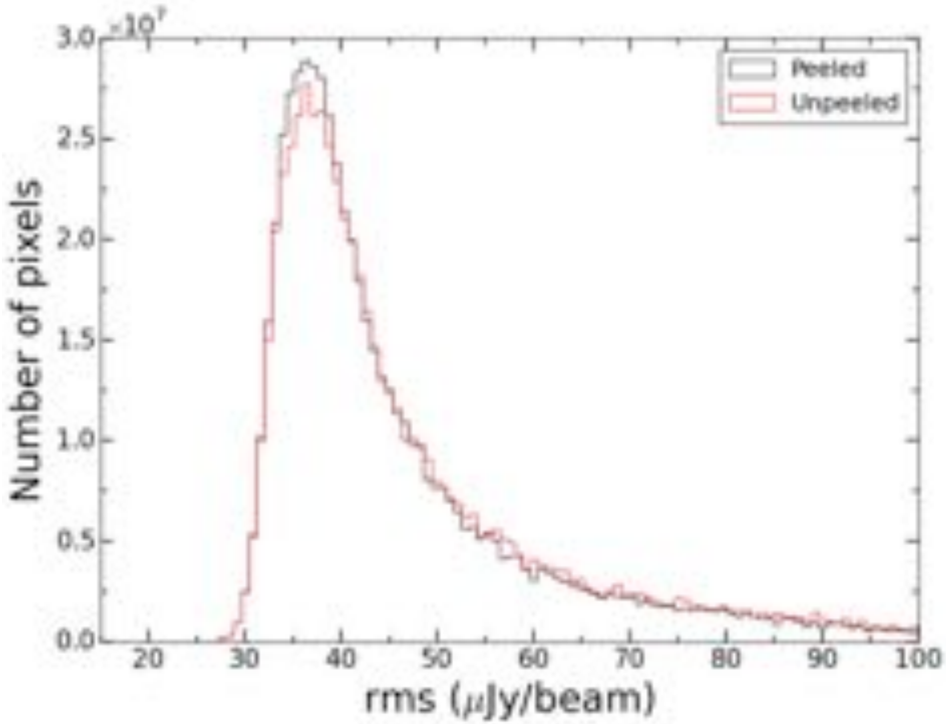
4.7°

5.9°

Typical Region of the Mosaic



Mosaic Noise Properties

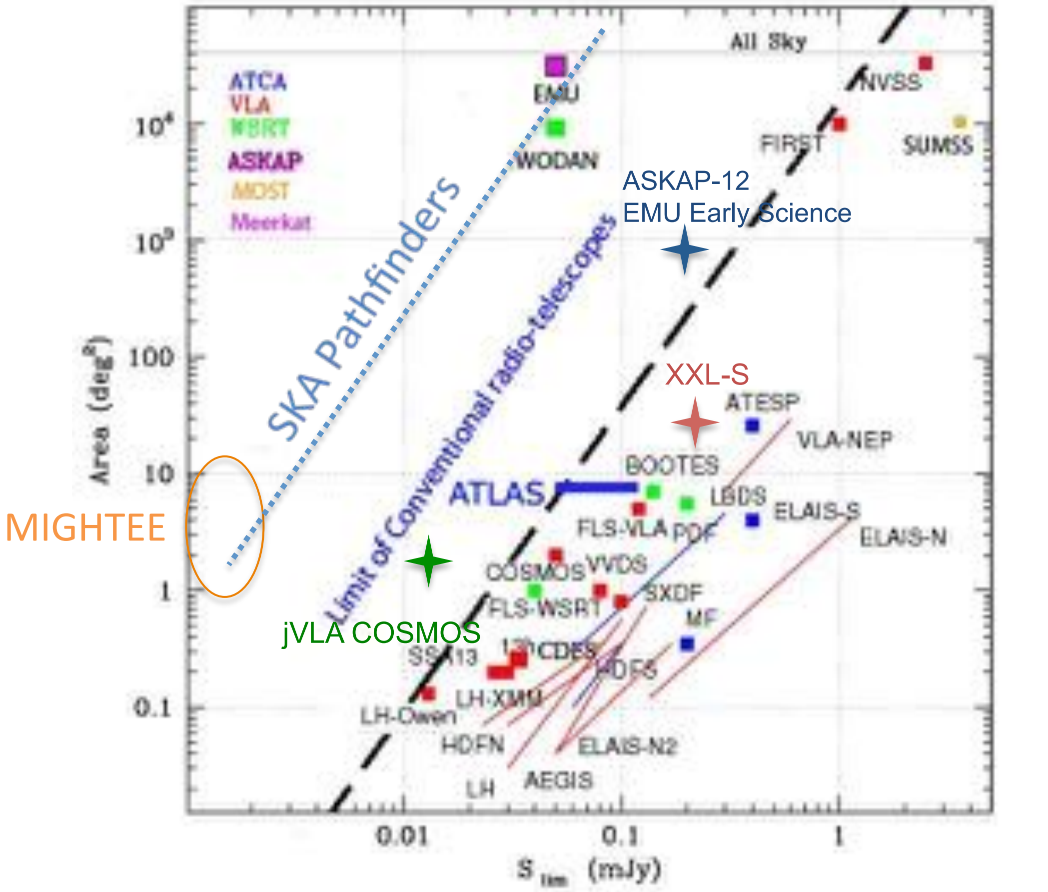


- Noise distribution peaks at 37 μJy/beam
- Median noise of 41 μJy/beam

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

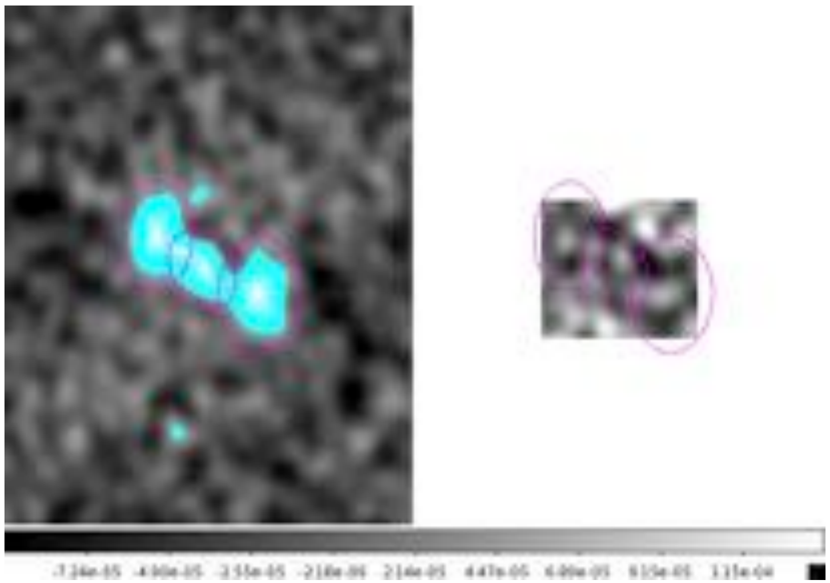
How ATCA XXL-S Compares

Based on Fig 1 of Norris et al. 2011

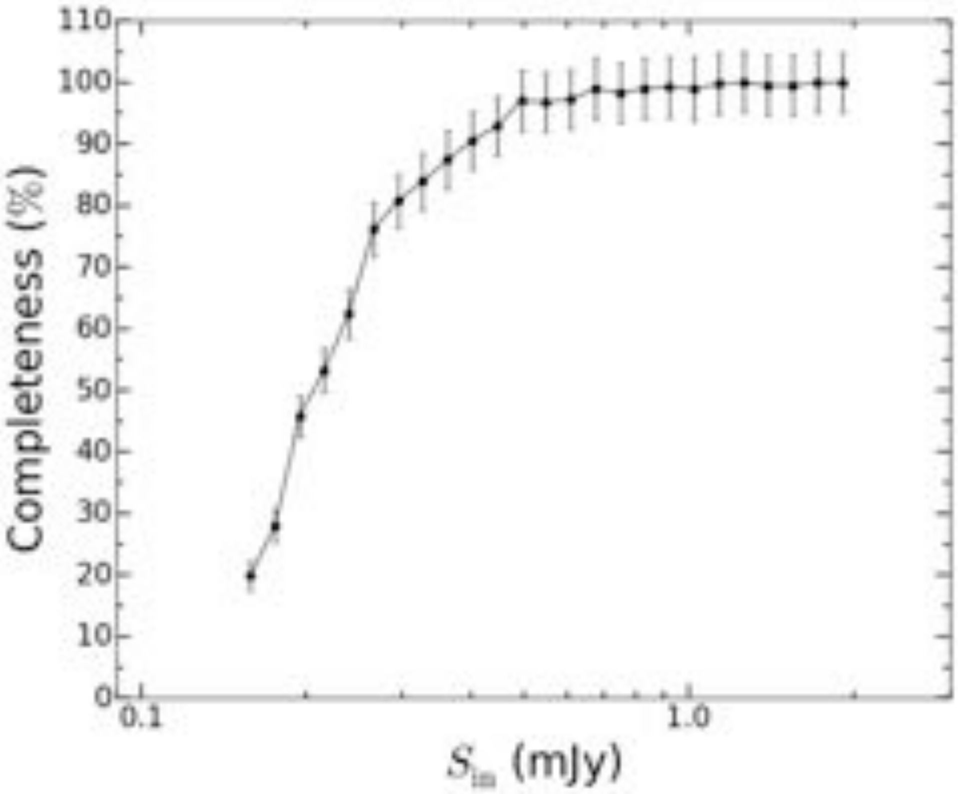


Source Extraction

- 6200 sources > 5 sigma extracted with BLOBCAT (Hales et al. 2012)
- About 600 complex/multi-component sources fit and extracted manually



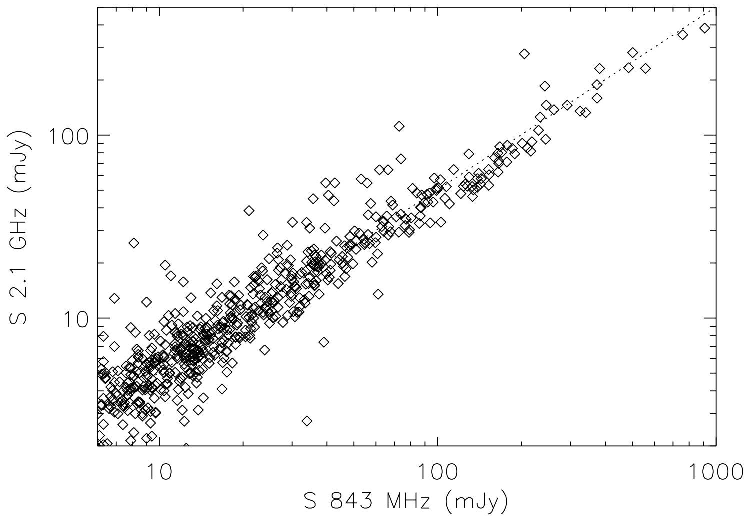
Completeness

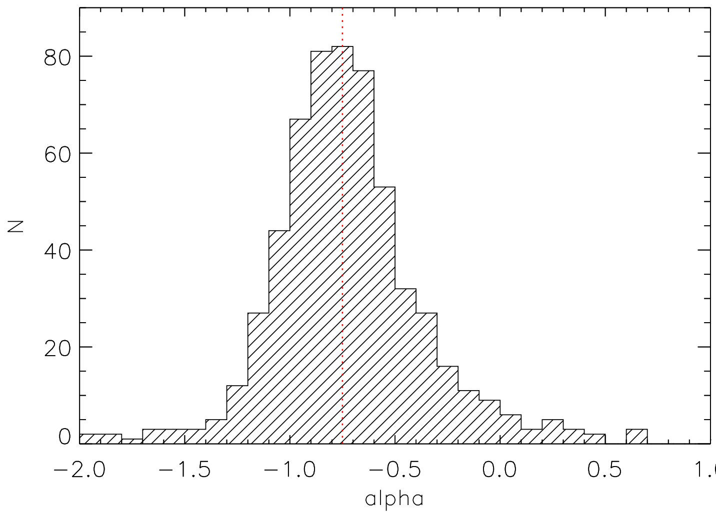


- Monte-carlo like simulation with 10,000 sources
- 45% complete at ~0.2 mJy (5 x median rms)
- 90% completeness level is ~0.4 mJy

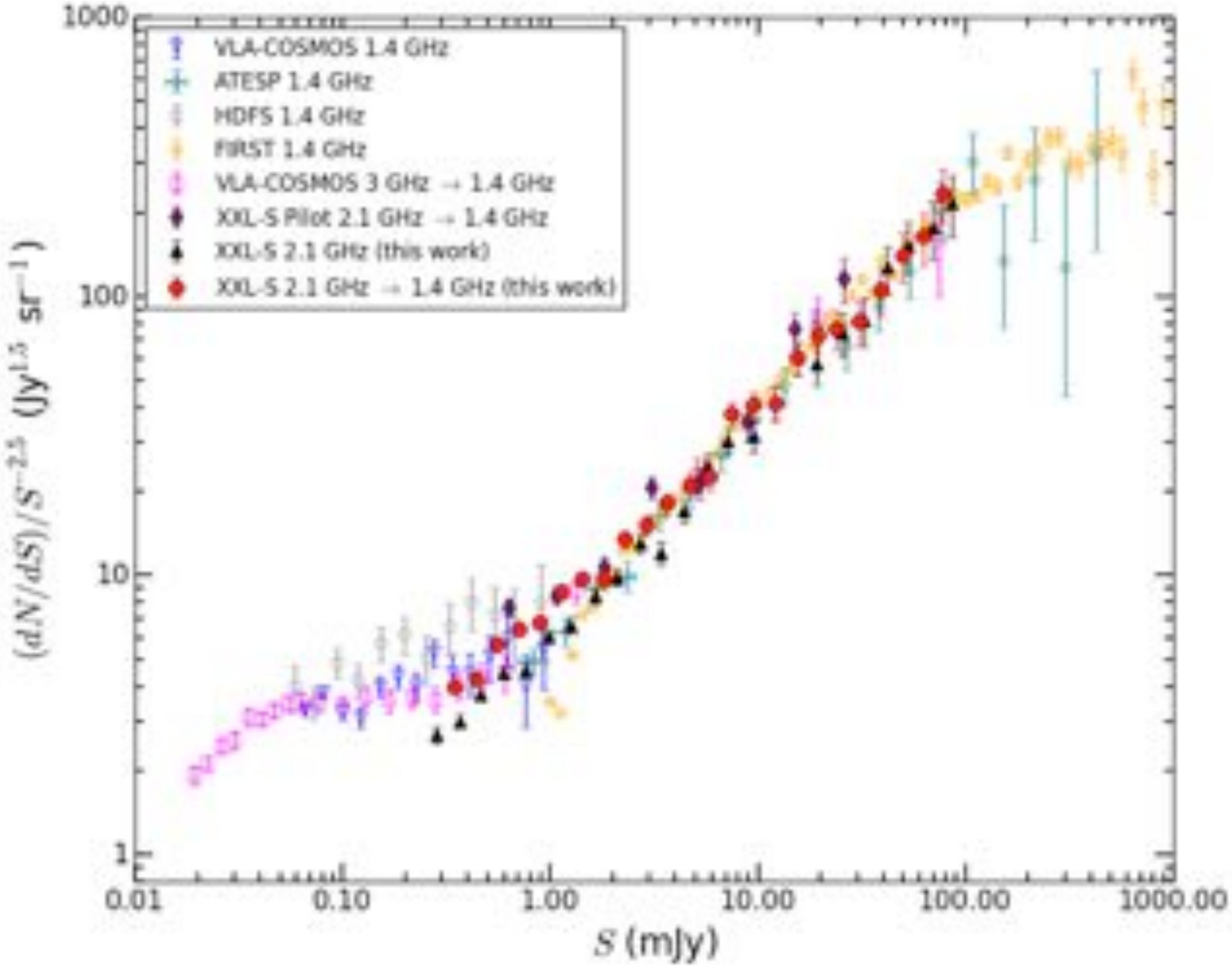
Spectral Indices

- Sources matched to SUMSS 843 MHz all sky survey
  - S843 MHz > 6 mJy
  - 586 SUMSS sources in XXL-S
- Median α = -0.75, ($S \propto \nu^{\alpha}$)

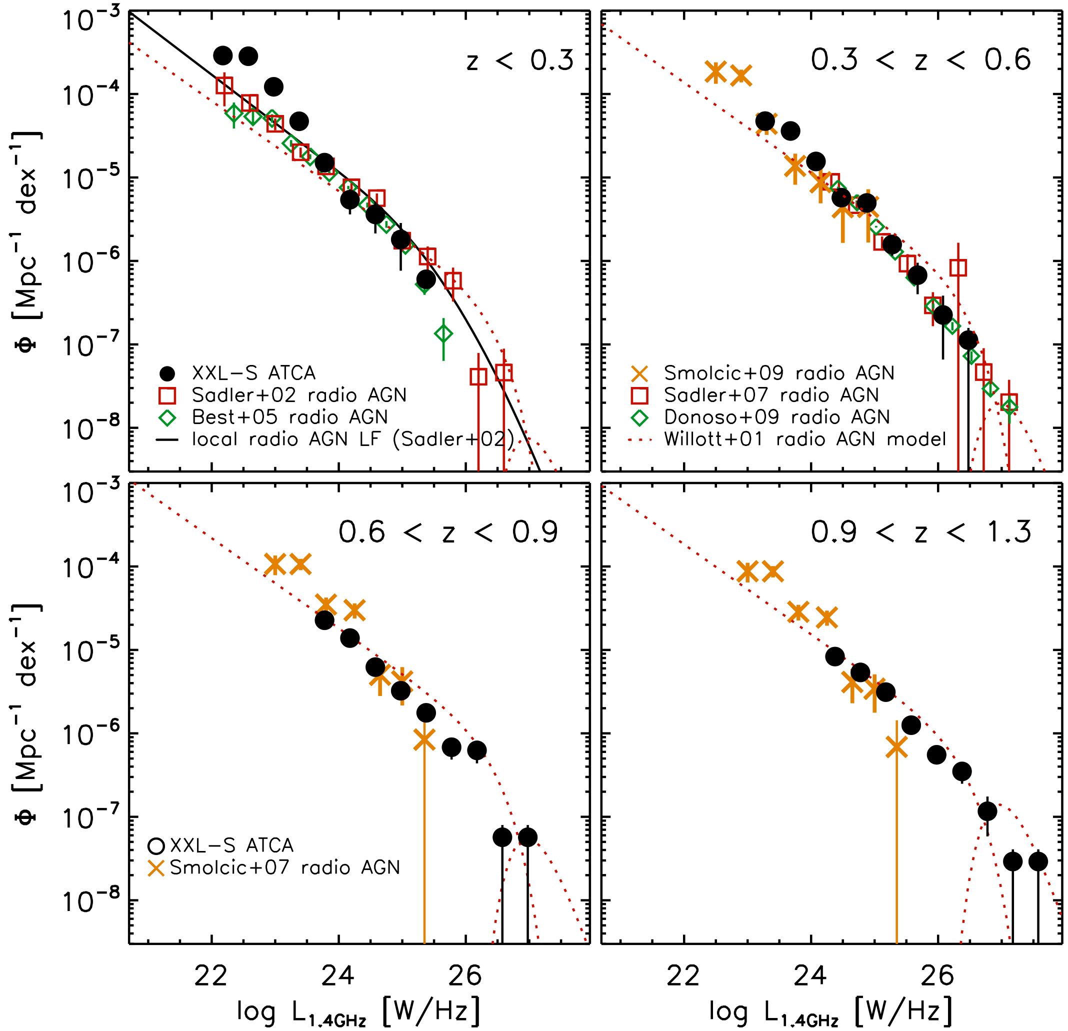




Radio Source Count



Preliminary Radio Luminosity Functions

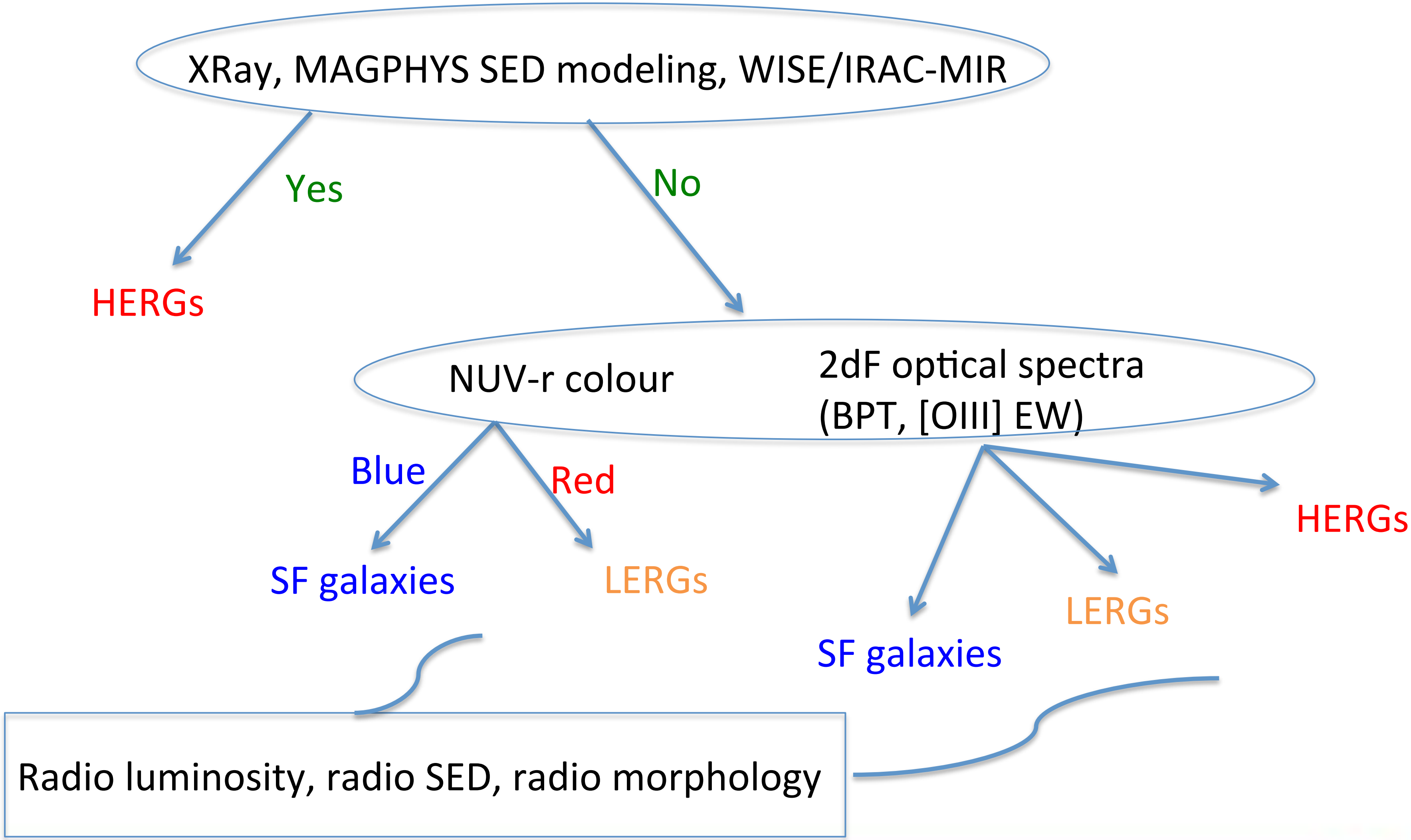


AGN Classification

Separating SF galaxies and identifying HERGs/ LERGs:

- Optical spectra (if available)
  - [OIII] emission line luminosity and EW
  - BPT diagram ([OIII]/Hbeta vs [NII]/Halpha)
- Mid-IR (WISE/IRAC)
  - IR radio correlation, $q_{22obs} = \log_{10}(S_{22\mu m}/S_{1.4GHz})$
  - WISE colours (W1 - W2 vs W2 - W3, Jarrett et al.)
  - WISE W3 luminosity
  - IRAC colours (Donley et al., Stern et al.)
- X-rays (XMM Newton)
  - $L_X > 10^{42}$ erg/s, hardness ratio
- MAGPHYS SED modeling
- Rest-frame colours, NUV-r, g-i
- Radio luminosity, spectral index and morphology

XXL-S SF-AGN Classification



Summary

- Deep (<0.1 mJy rms) wide-area (10s sq deg) radio surveys are essential for understanding AGN

- ATCA observations of XXL-S 25 sq deg
  - Central freq of 2.1 GHz, (2 GHz bandwidth)
  - Median ~40 µJy rms
  - ~5 arcsec resolution
  - 6200 radio sources identified

- Radio source counts and spectral indices in general consistent with previous findings

- Preliminary radio lum functions show power of these observations
  - Constrain bright end of radio AGN luminosity function up to z >~ 1

- Source classification ongoing, future RLFs by AGN type