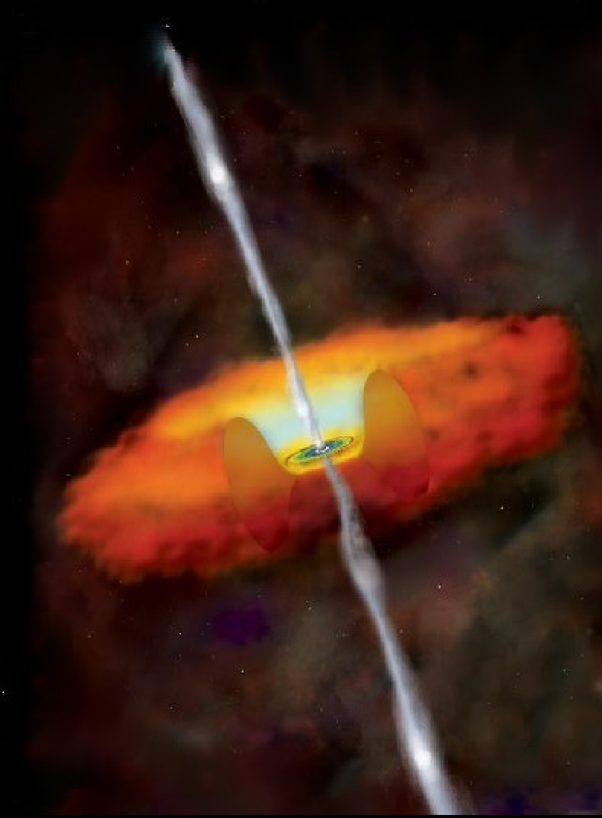
DEEP RADIO OBSERVATIONS:
THE NATURE OF THE SUB-MJY RADIO POPULATION

Ibar et al. (2009) arXiv:0903.3600



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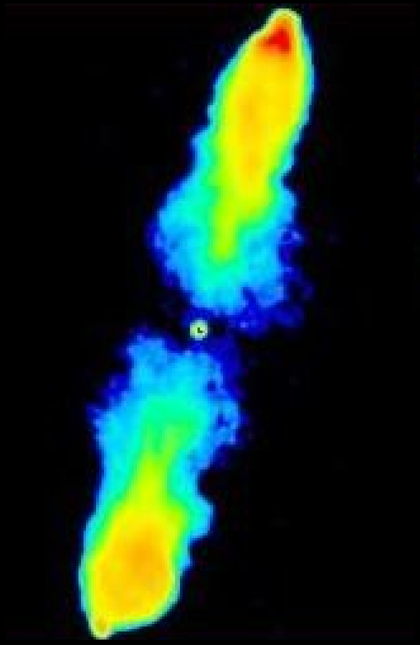
Introduction

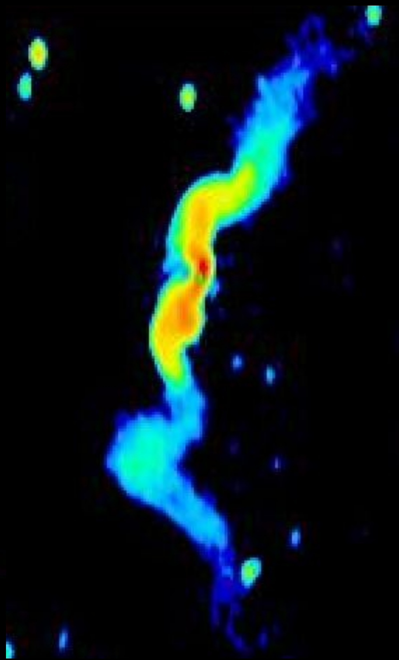
Why radio?

(1) Interferometry provides accurate positions and sub-arcsecond resolution.
(2) Extinction is not an issue at long wavelengths (e.g. SMGs, Type II AGN).
(3) It provides clear evidence of recent star formation in normal galaxies.

THE VLA TELESCOPE



3C223, FRII



3C31, FR I

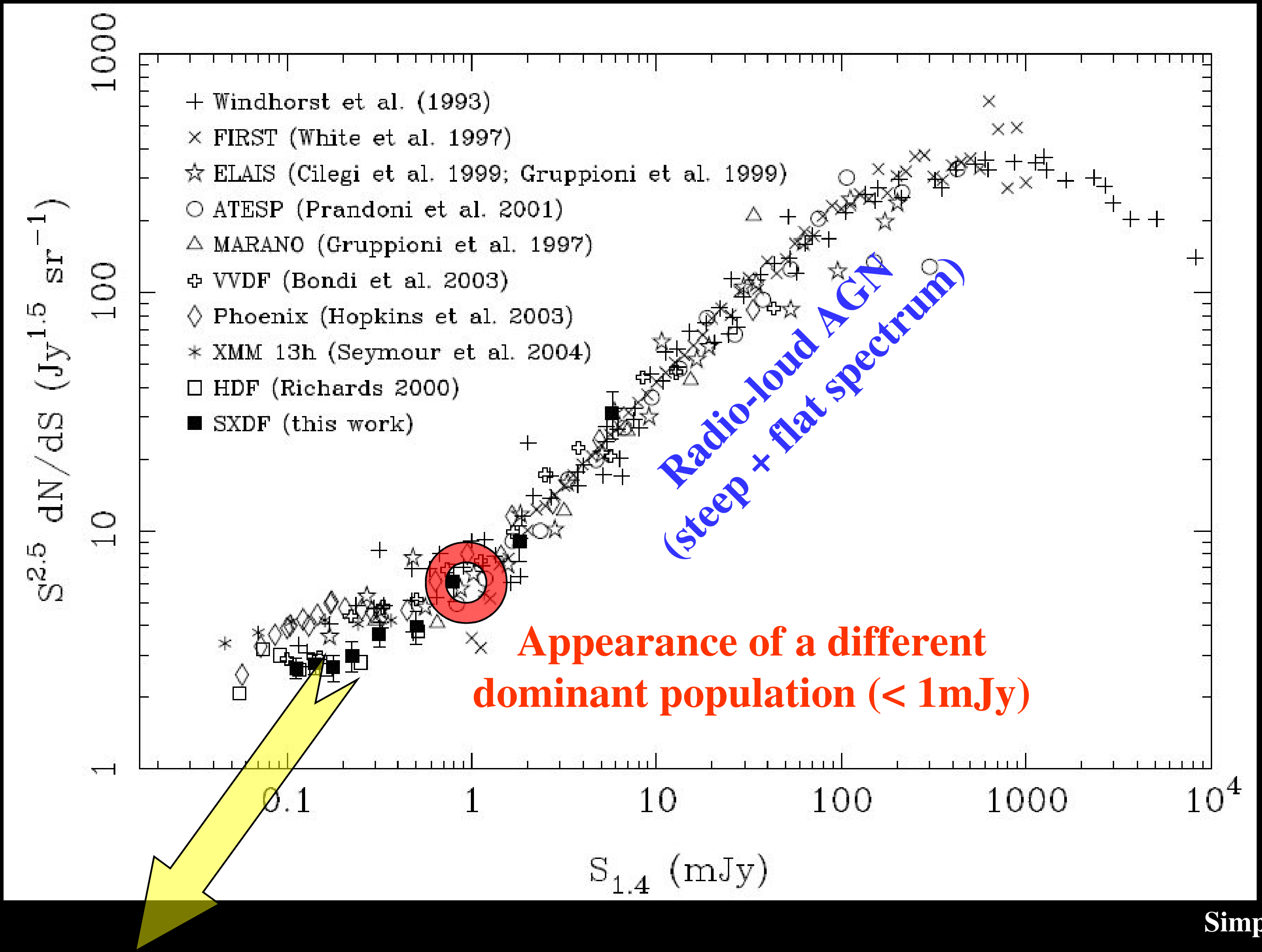
In early studies, radio observations were restricted to powerful (>1mJy) radio sources, typically associated with optically bright quasars and rare luminous galaxies.

(Condon 1984; Willott et al. 2002)

In the mid 1980s the Westerbork Synthesis Radio Telescope (WSRT) and the Very Large Array (VLA) began to shed light on the mJy and sub-mJy radio regime.

(Windhorst et al. 1985; Mitchell & Condon 1985)

Introduction



Simpson et al. (2006)

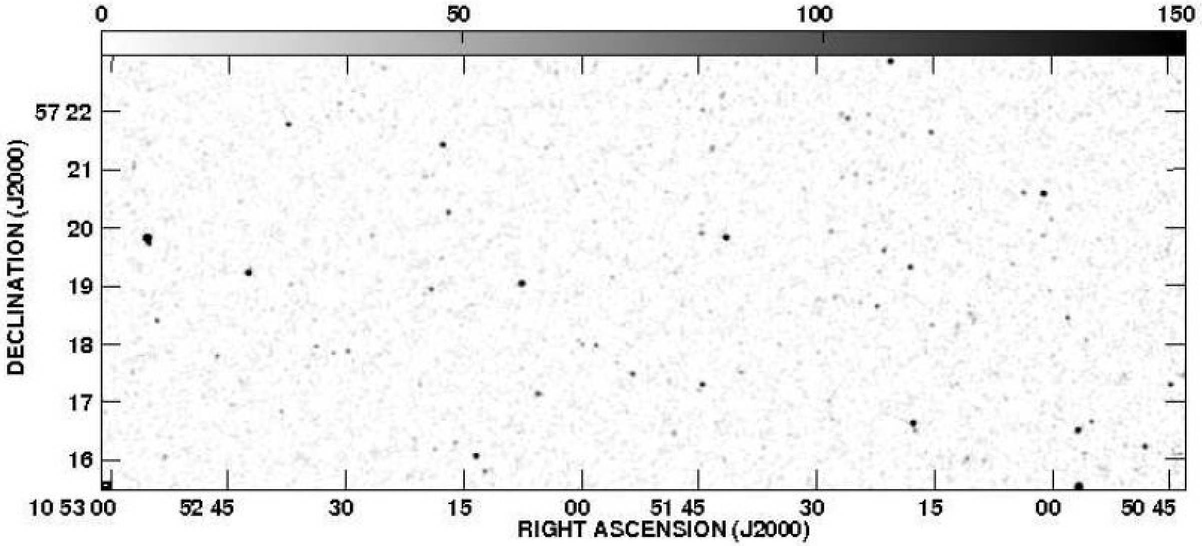
This population is mainly composed by radio-quiet AGN and star-forming galaxies, although their relative fractions are unknown.

Introduction

How can we disentangle the nature of the sub-mJy radio population?

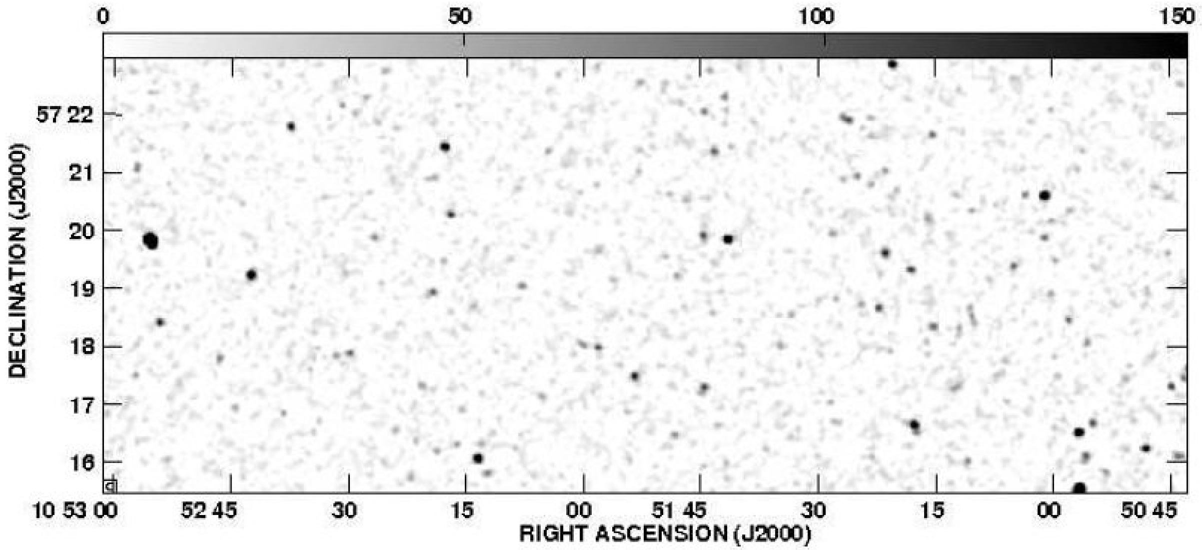
- **Deviations from the FIR/radio correlation** (e.g. Donley et al. 2005; Ibar et al. 2008)
- **The radio spectral index** (e.g. Clemens et al. 2008)
- **Morphology from sub-arcsecond observations** (e.g. Muxlow et al. 2005)
- **Cross-match with X-ray surveys** (e.g. Simpson et al. 2006; Barger et al. 2007)
- **Optical/NIR identification of the host galaxy:**
  - **Morphology** (e.g. Padovani et al. 2007)
  - **Spectroscopy** (e.g. Barger et al. 2007)
  - **Colour-colour diagrams** (e.g. Ciliegi et al. 2005)

Radio observations in the Lockman Hole



VLA-1.4GHz

3 pointings (A+B configuration)
r.m.s. pointings ~ 7 - 11 μJy/beam
Area mosaic = 0.56 deg^2
FWHM = 4.3 x 4.2 arcsec^2
r.m.s. mosaic = 6.0 μJy/beam
Dyn. Range ~ 2,300:1
1,425 sources (> 5-σ)



GMRT-610MHz

3 pointings (2 IFs 602 & 618 MHz)
r.m.s. pointings ~ 24 -34 μJy/beam
Area mosaic = 0.98 deg^2
FWHM = 7.1 x 6.5 arcsec^2
r.m.s. mosaic = 14.7 μJy/beam
Dyn. Range ~ 2,200:1
1,587 sources (> 5-σ)

Results

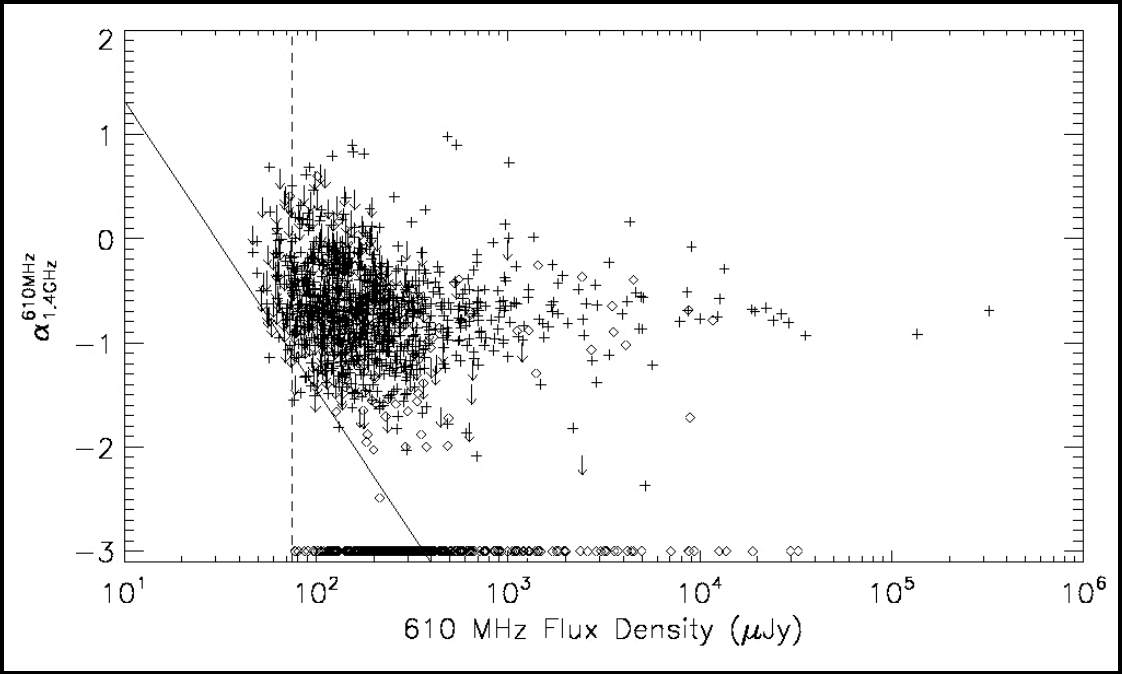
THE RADIO SPECTRAL INDEX

We find a wide non Gaussian distribution of spectral indexes ($\Delta\ \alpha \sim 0.4$ at all flux levels) and error dominated at $S_{1.4GHz} < 100\ \mu$Jy flux densities.

-Lobe-dominated AGN and Star-forming galaxies
[$\alpha \sim -0.7$ spectrum]
Optically thin synchrotron emission

$$S_\nu \sim \nu^\alpha$$

Deviations:



-Core-dominated radio-quiet AGN
[flat spectrum]
Compact synchrotron emission + Thermal bremsstralhung
(Blundell & Kuncic 2007)

-GHz-peaked sources (GPS)
[flat spectrum]
From scales < 1kpc, "a young FR source"
(Snellen et al. 2000)

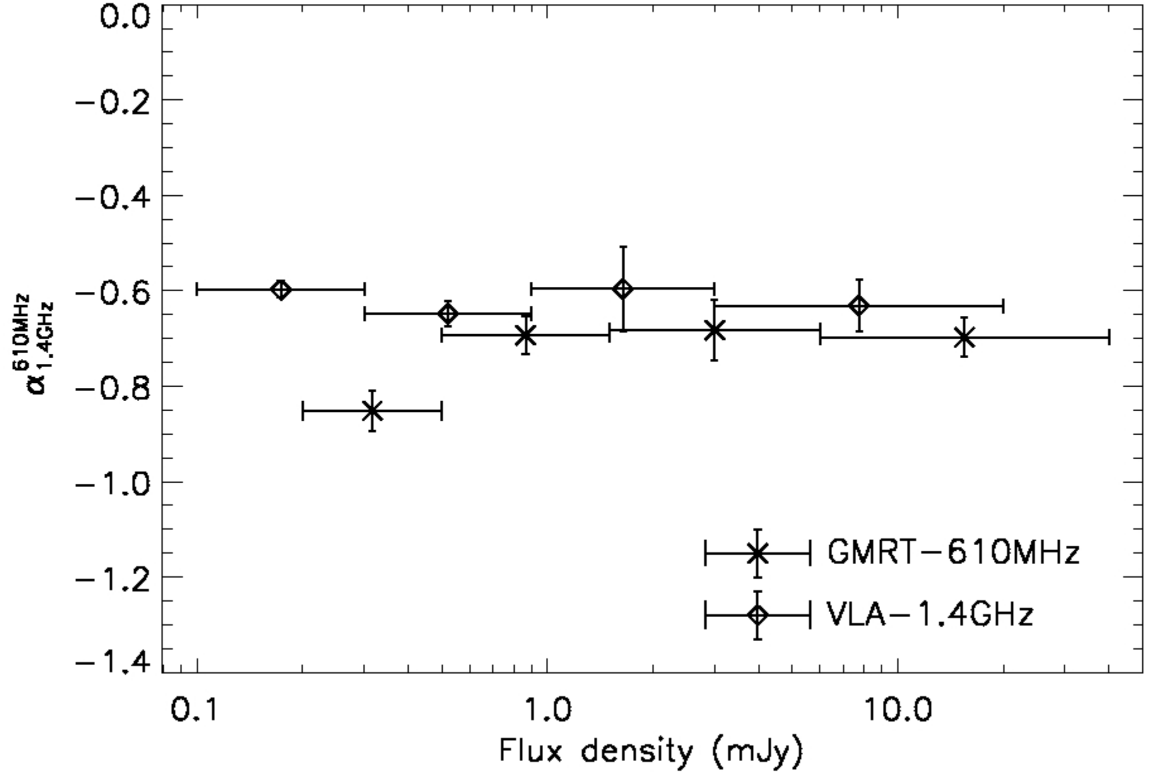
-Ultra steep spectrum sources (USS)
[steep spectrum]
Old optically thin synch. emission, or at high redshift
(Jarvis et al. 2001)

Results

THE RADIO SPECTRAL INDEX

There is no compelling evidence for an evolution in radio spectral index down to ~100 μJy at 1.4GHz.

Bootstrapped median, α , between -0.6 and -0.7



We conclude the principal mechanism responsible of the radio emission in the sub-mJy radio population is given by optically thin synchrotron radiation: star-forming galaxies or lobe-dominated radio-quiet AGN.

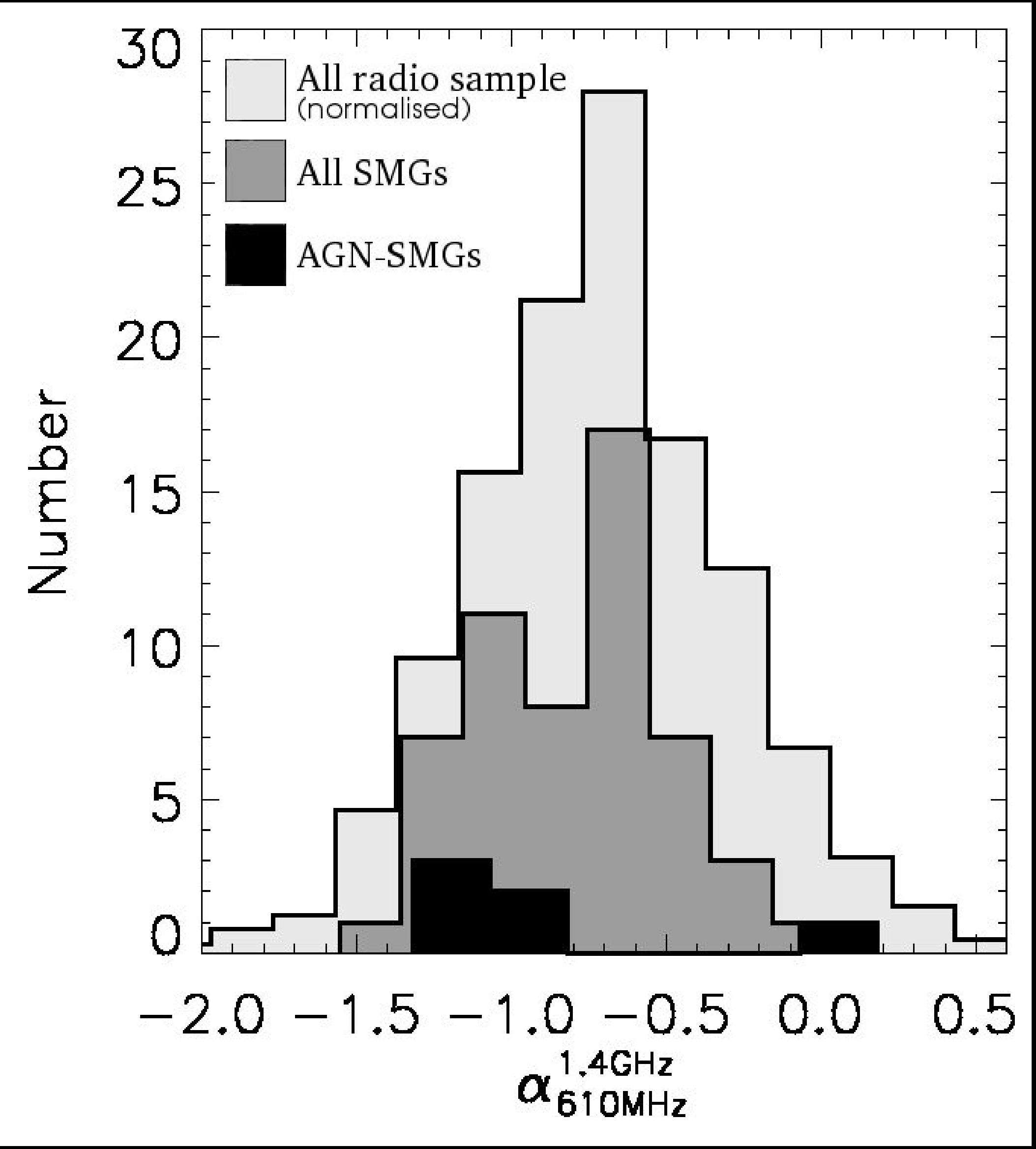
Preliminary results

THE RADIO SPECTRAL INDEX OF SMGs

LOCKMAN HOLE:
AzTEC, SCUBA, MAMBO and Bolocam detections.

Slight evidence for steeper radio spectral indexes in SMGs.

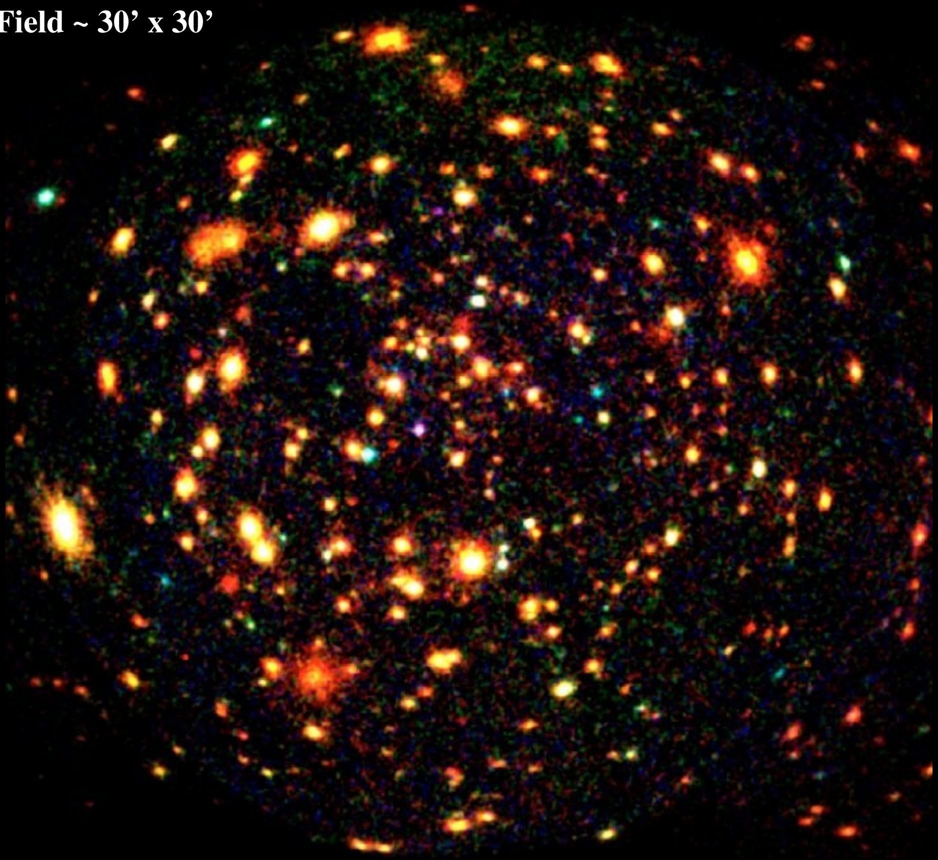
α might be used as an indicator for AGN activity as suggested by those SMGs identified by having AGN activity from IRS spectra.



X-ray Observations

The Lockman Hole has the lowest Galactic line-of-sight column density
$N_H = 5.7 \times 10^{19}$ cm^{-2}

Red: 0.5-2.0 keV; Green: 2.0-4.5 keV; Blue: 4.5-10 keV
Field ~ 30' x 30'



Brunner et al. (2008)

Brunner et al. (2008) published the deepest XMM-Newton observation for a total of 1.16 Ms (18 pointings). The maximum final effective exposure was 637 ks in the mosaic centre.

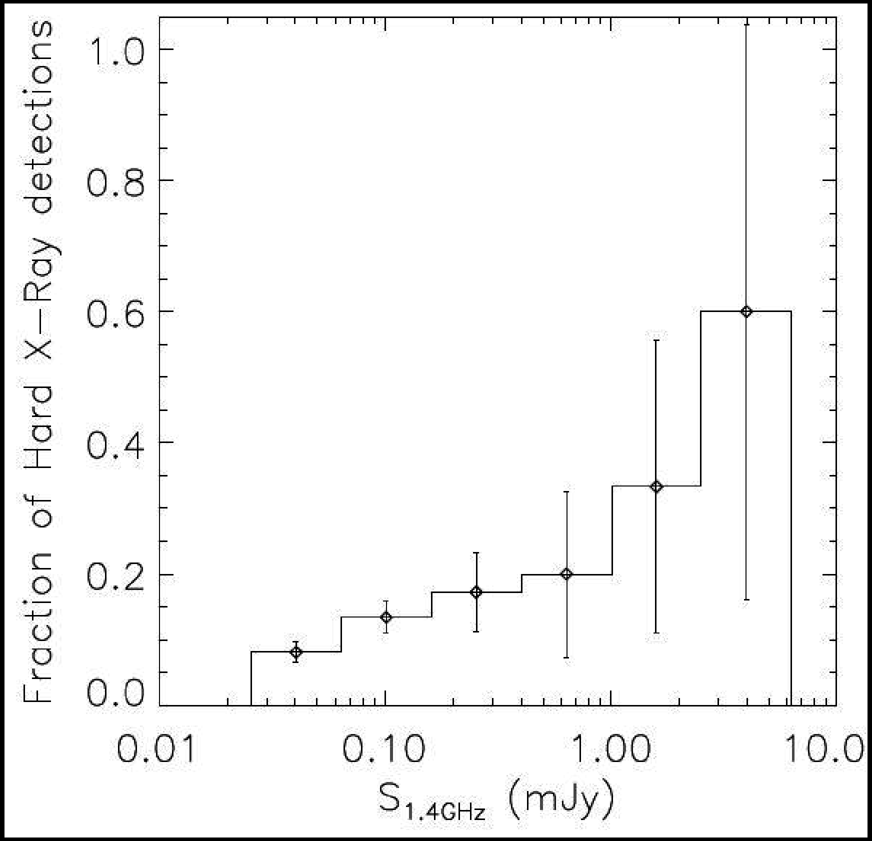
Area mosaic = 0.196 deg^2
Sources with a Likelihood > 10:
340 in the Soft X-ray band (0.5-2.0 keV)
266 in the Hard X-ray band (2.0-10.0 keV)

X-ray Observations

We find a decreasing trend for the number of radio sources detected in the hard X-ray catalogue.

This may suggest a dominant star-forming galaxy population in the sub-mJy radio regime.

There is, however, an spectroscopic/ photometric classification for the X-ray sources (Lehmann et al. 2001; Szokoly et al. 2009, *in preparation*).



X-ray Observations

THE NATURE OF THE SUB-MJY RADIO POPULATION

At $S_{1.4GHz} < 300$ μJy, there are 72 sources detected in the hard X-ray band, from which:

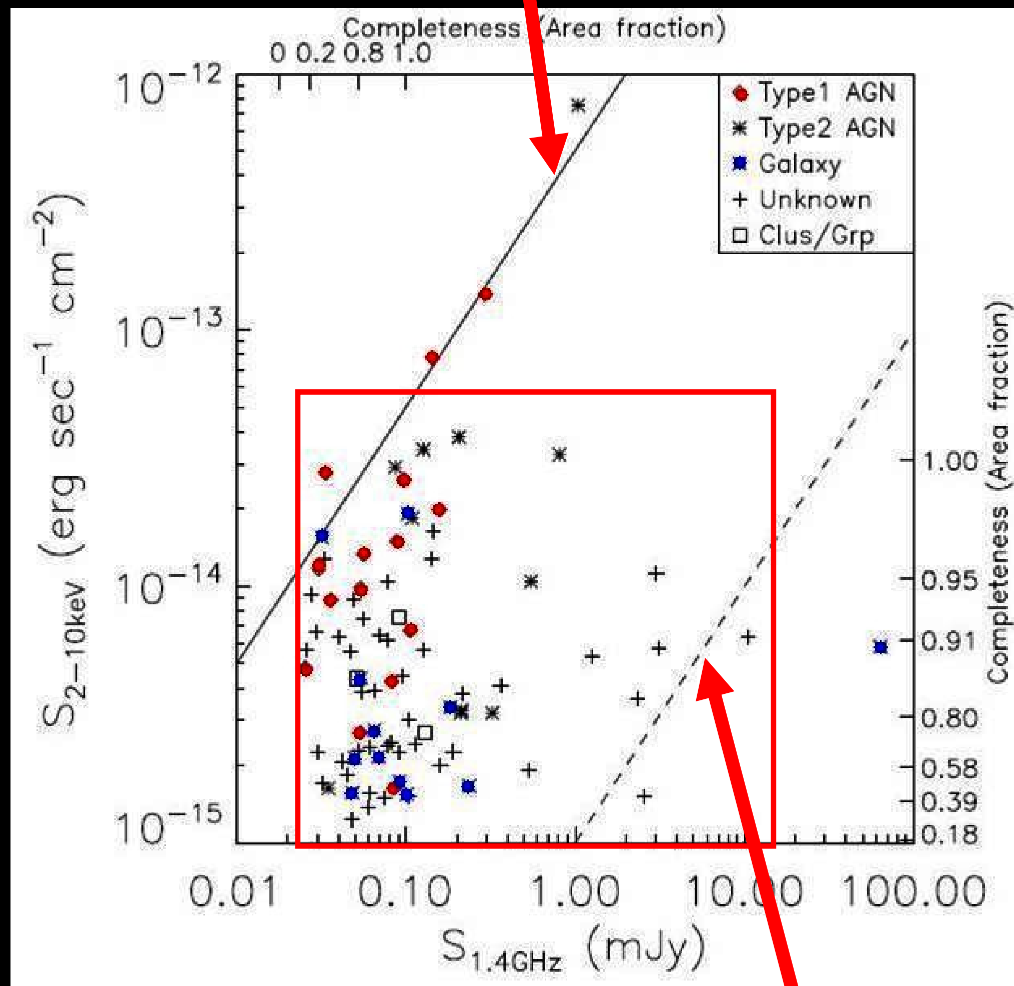
Class	Number
Type 1 AGN	16
Type 2 AGN	7
Galaxy	11
Clus/Grp	3
Unknown	35

Not all hard X-ray detections are AGN. Indeed, at fainter X-ray fluxes there is a large fraction of normal galaxies!.

Based on these fractions, we estimate a fraction between 15 and 35 per cent of radio-quiet AGN contaminating the sub-mJy radio regime.

For radio-quiet AGN

(Brinkmann et al. 2000)



For star-forming galaxies

(Condon 1992; Ranalli et al 2003)

Conclusion

We conclude the principal mechanism responsible of the radio emission in the sub-mJy radio population is given by optically thin synchrotron radiation: star-forming galaxies or lobe-dominated radio-quiet AGN.

Based on a spectroscopic/photometric classification of radio sources detected in the hard X-ray band, we estimate a fraction between 15 and 35 per cent of radio-quiet AGN in the 30 μJy $< S_{1.4GHz} <$ 300 μJy radio regime.