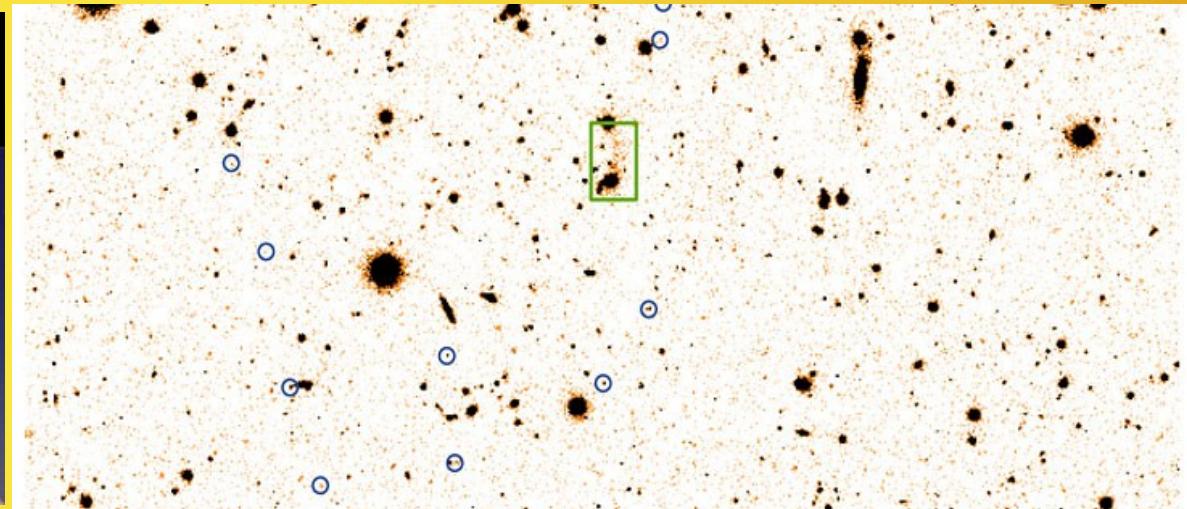


Search for High-redshift radio galaxies in deep fields



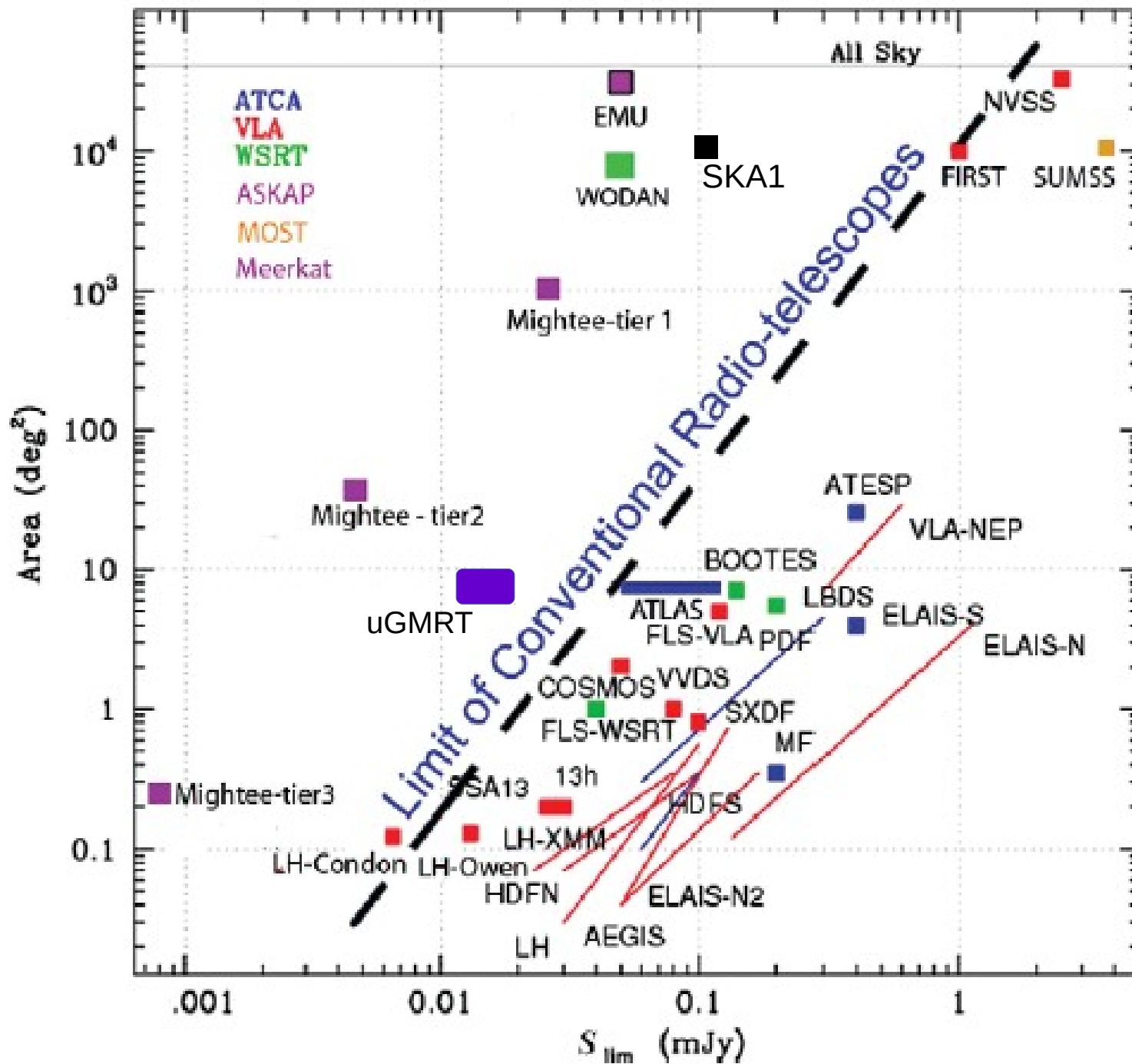
Veeresh Singh
(PRL, Ahmedabad)

GMRT surveys of extragalactic fields

Frequency	rms	Area	Field	Reference
610 MHz	15 $\mu\text{Jy}/\text{b}$	0.2 deg^2	Lockman Hole	Ibar+2009
610 MHz	50 $\mu\text{Jy}/\text{b}$	1.0 deg^2	VLA-VVDS	Bondi+2007
610 MHz	30 $\mu\text{Jy}/\text{b}$	4 deg^2	xFLS	Garn+2007
610 MHz	80 $\mu\text{Jy}/\text{b}$	8 deg^2	Lockman Hole	Garn+2010
610 MHz	40 – 70 $\mu\text{Jy}/\text{b}$	9 deg^2	ELAIS - N1	Garn+2008
325 MHz	40 $\mu\text{Jy}/\text{b}$	1.1 deg^2	ELAIS - N1	Sirothia+2009
325 MHz	60 – 150 $\mu\text{Jy}/\text{b}$	40 deg^2	HerMES	Wadadekar+
325 MHz	1.0 mJy/b	90 deg^2	H-ATLAS	Mauch+2013
150 MHz	5 mJy/b	36900 deg^2	TGSS	TGSS Team & Intema+16

Deep small area + shallow wide-area surveys.

uGMRT and other radio surveys



AGN science with deep radio continuum surveys

- Nature of μ Jy radio population (SFGs Vs. AGN)
- Unveils radio-loud and radio-quiet AGN at high-z
- With rms $\sim 10 \mu$ Jy/b at 1.4 GHz we can detect a radio-quiet AGN of $L_{1.4 \text{ GHz}} \sim 10^{23} \text{ W Hz}^{-1}$ at $z \sim 3$.
- Detection of radio galaxies at higher redshifts
- Cosmic evolution of radio AGN activity at high-z
- AGN hosted in intensely star-forming galaxies (e.g. ULIRGs, SMGs) can be efficiently detected

High-redshift radio galaxies (HzRGs)

- ◆ Hosted in massive galaxies with very high star formation rates (few 100 - few 1000 M_{\odot} yr⁻¹)
(Jarvis et al. 2001a; Willott et al. 2003)
- ◆ Likely to be progenitor of massive elliptical galaxies in local universe
(Best et al. 1998; McLure et al. 2004)
- ◆ Often associated with over-densities i.e., proto-clusters and clusters
(Stevens et al. 2003; Venemans et al. 2007); Galametz et al. 2012)

HzRGs are important to understand the formation and evolution of galaxies at higher redshifts and in denser environments.

How to search high-z radio galaxies

Step 1: Wide and deep low-frequency continuum radio surveys



Step 2: Probable HzRG candidates (e.g, USS, faint K-band counterparts)



Step 3: Identify optical, IR counterparts



Step 4: Redshifts from spectroscopic/photometric observations

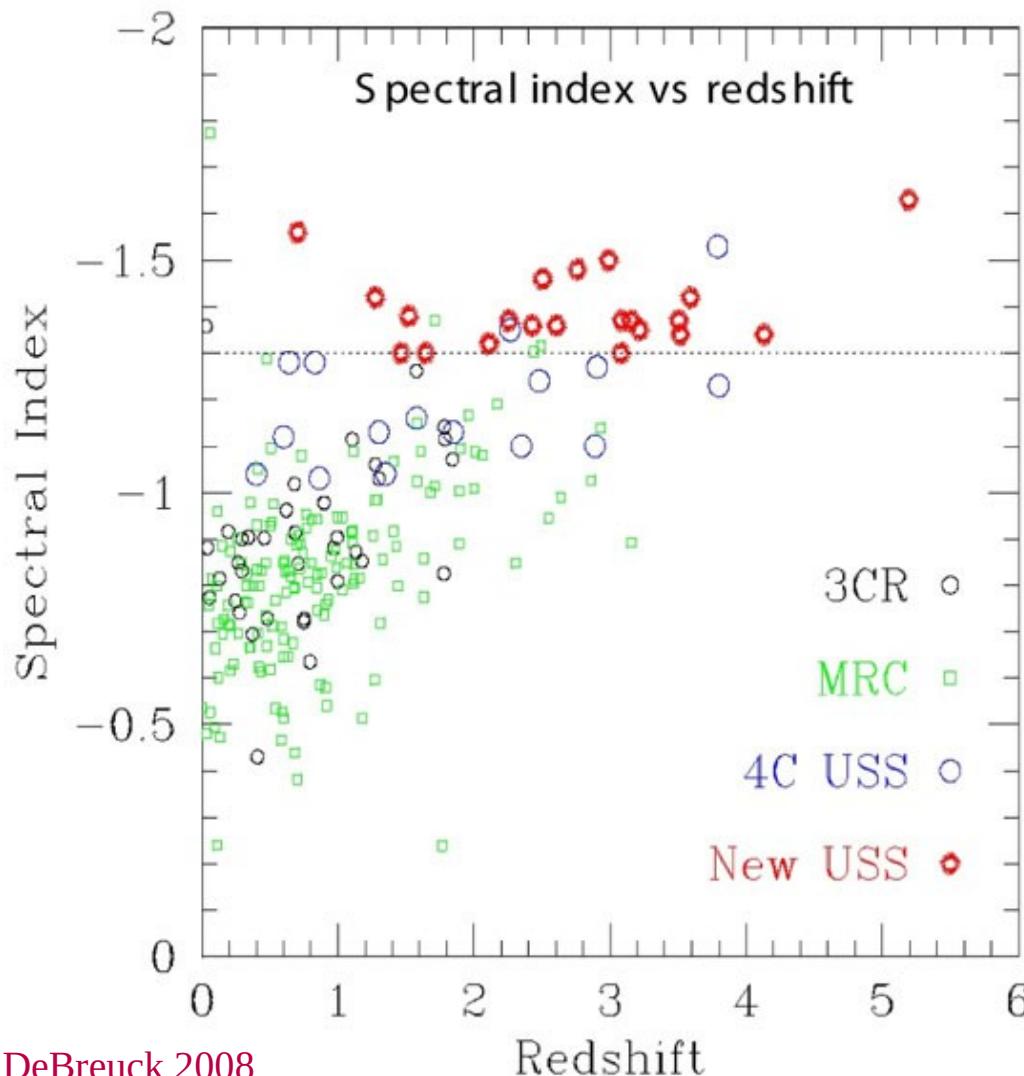
(Jarvis et al. 2004, Ishwara-Chandra et al. 2010, Singh et. 2014)

Ultra Steep Spectrum (USS) radio sources => HzRG candidates

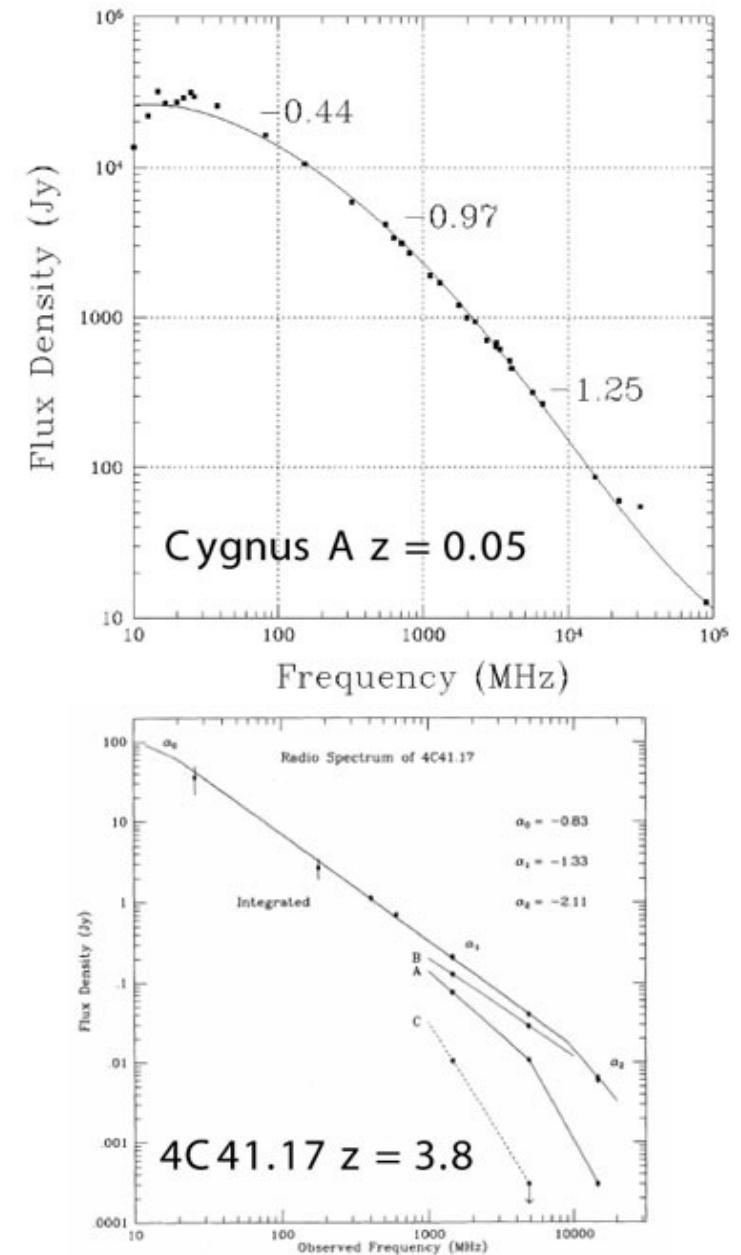
The conventional explanation

- a concave radio spectrum coupled with a radio K-correction
- radio jets expand in denser environments,
a scenario more viable in (proto)-cluster environments

(Klamer et al. 2006; Bryant et al. 2009; Bornancini et al. 2010)



Miley & DeBreuck 2008



Multiwavelengths observations in XMM-LSS

Search for HzRGs

VLA-VVDS

(VIMOS VLT Deep Survey)

SXDF

(Subaru XMM-N Deep Field)

Optical : Subaru, VLT, CFHTLS

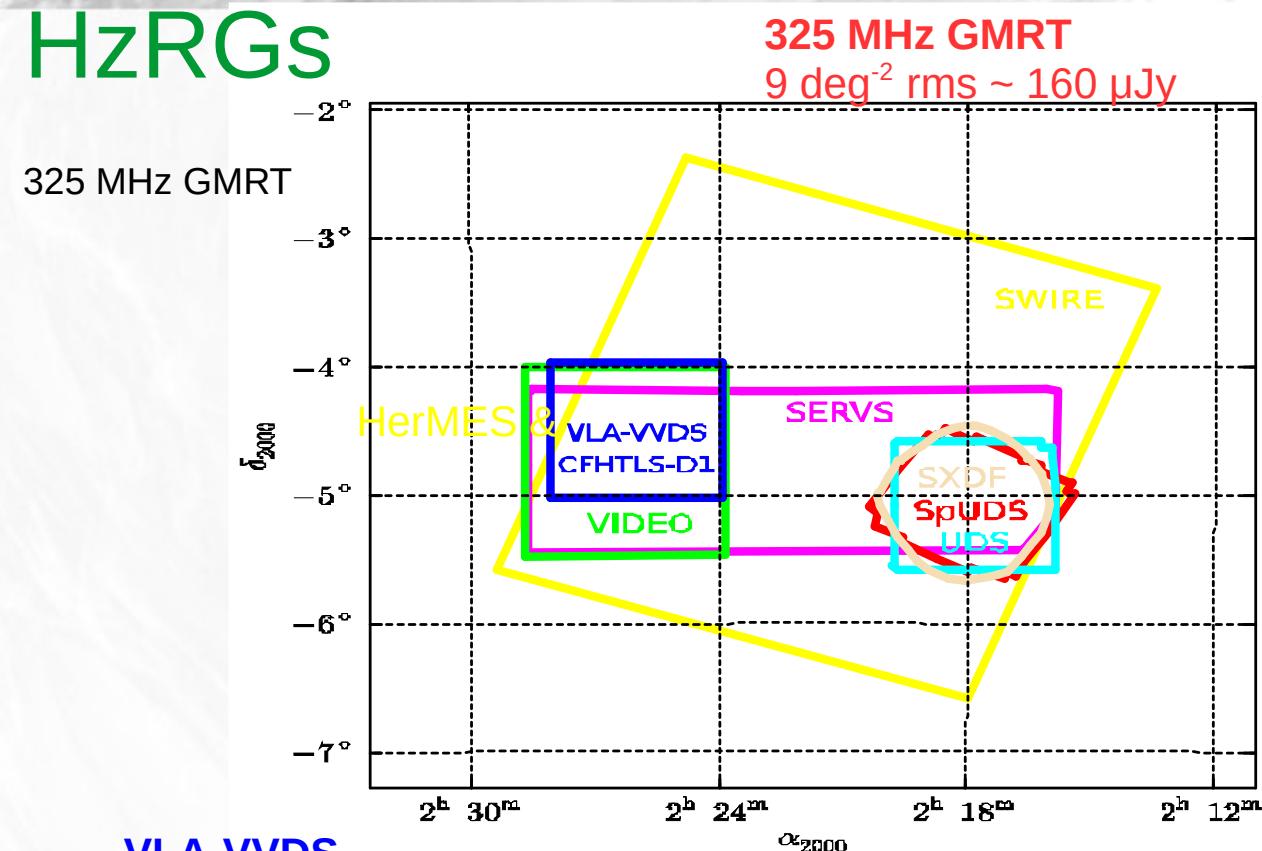
($m_R \sim 25, 27$ mag)

Near -IR : VIDEO, UKIDSS

($m_K \sim 23, 24$ mag)

Mid-IR : Spitzer surveys
rms @ 3.6 μm ~ 1.3 – 2 microJy

Far-IR : Herschel surveys
rms@ 250 μm ~ 9 mJy



VLA-VVDS

1.4 GHz VLA

1.0 deg⁻²

rms ~ 16 μJy

1054 sources
(Bondi+ 2003)

SXDF

1.4 GHz VLA

0.8 deg⁻² rms ~ 20 μJy

512 sources

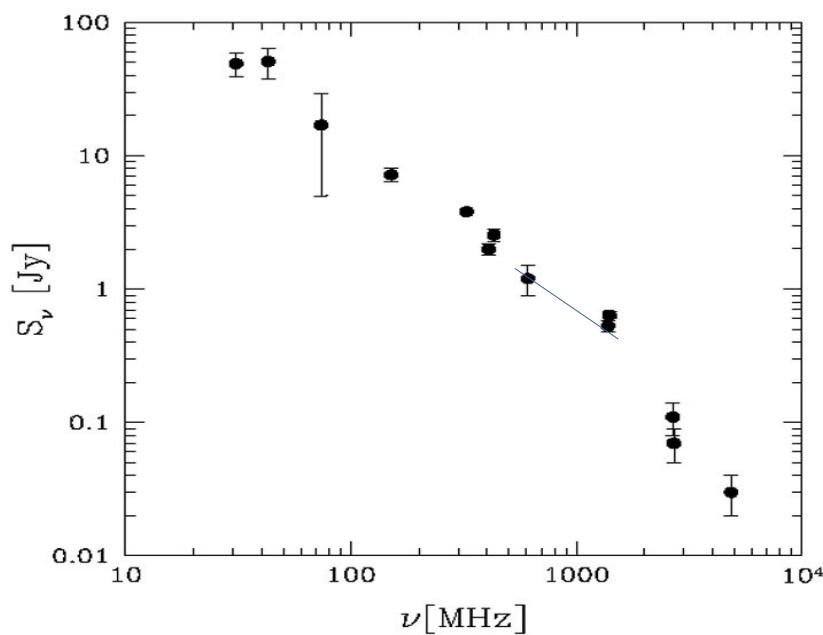
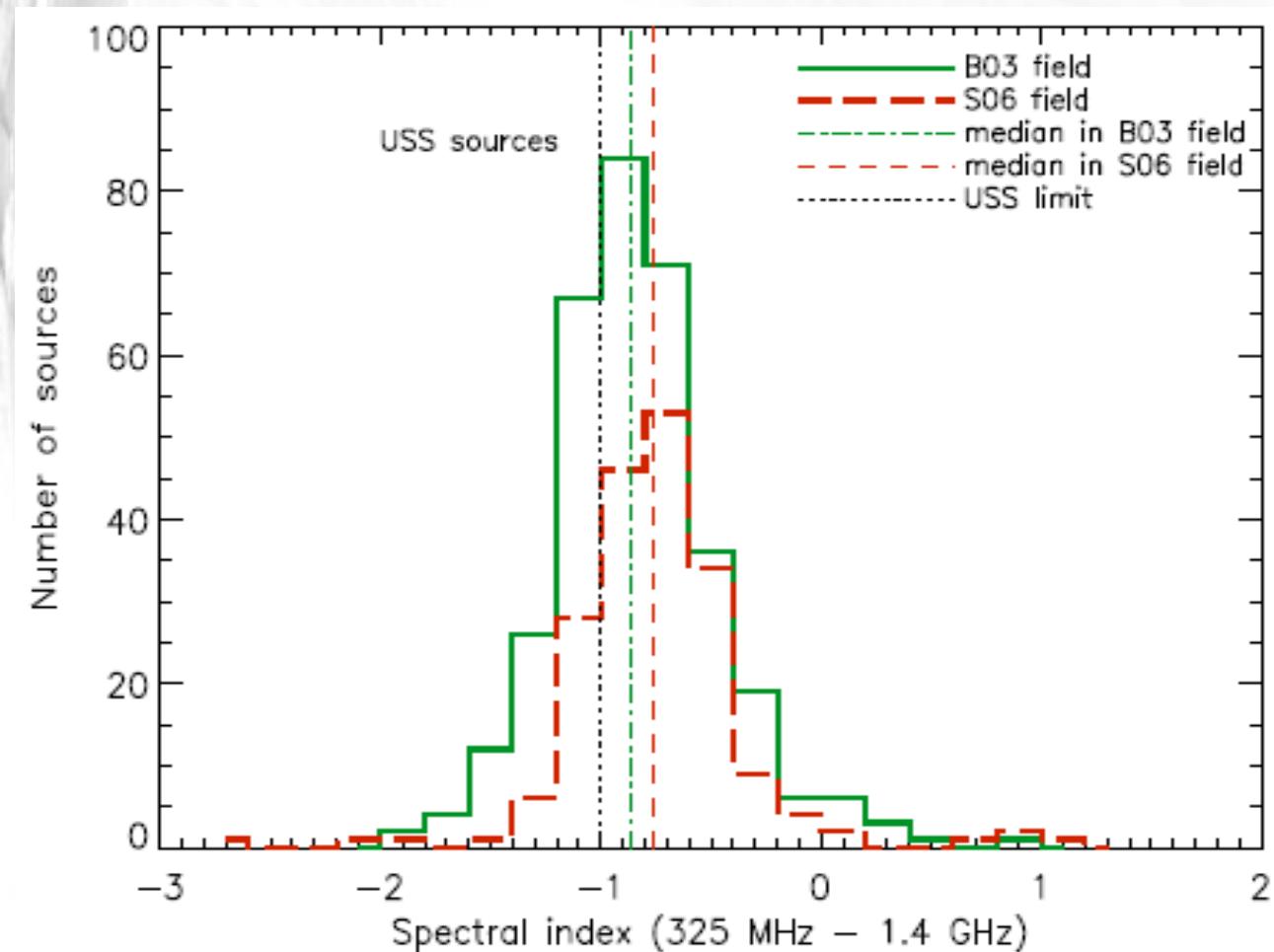
(Simpson+2006)

Radio : GMRT, VLA

Cross-matching of 325 MHz and 1.4 GHz radio sources

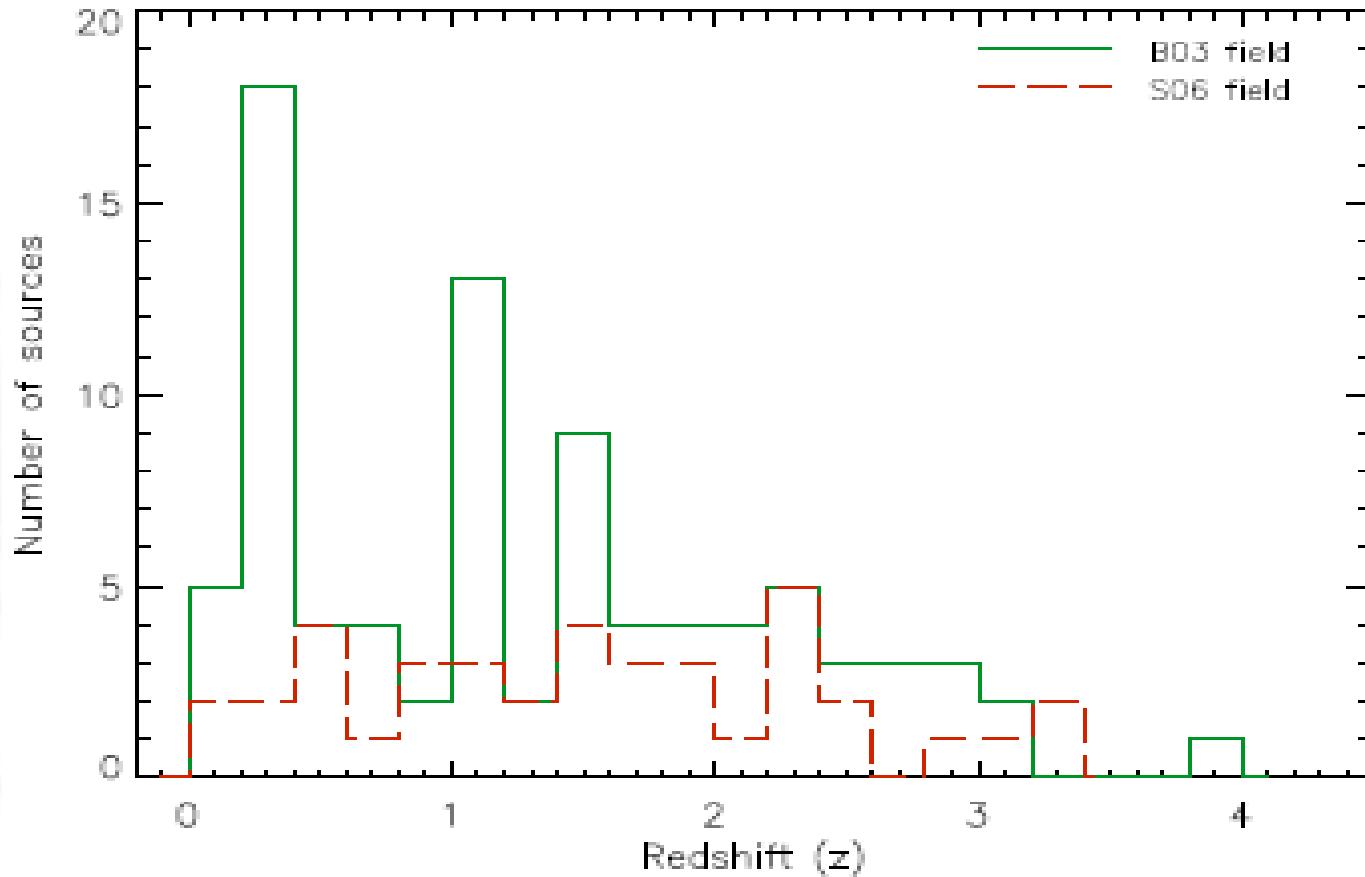
Radio spectrum a power law : $S_\nu \propto \nu^\alpha$

No. of sources	VVDS	SXDF
1.4 GHz	1054	512
325 MHz	343	200
Cross-matched	338	191
USS ($\alpha \leq -1.0$)	116	44



USS sample :
325 MHz – 1.4 GHz spectral index (α) ≤ -1.0
Total 160 USS sources

USS : High-z galaxies



Peak at $z \sim 0.3$: 6 known X-ray clusters at $z \sim 0.26 - 0.35$ (Pacaud et al. 2007; Adami et al. 2011)

VVDS field : median $z \sim 1.18$, $53/86 \sim 61.5\%$ are at $z \geq 1.0$

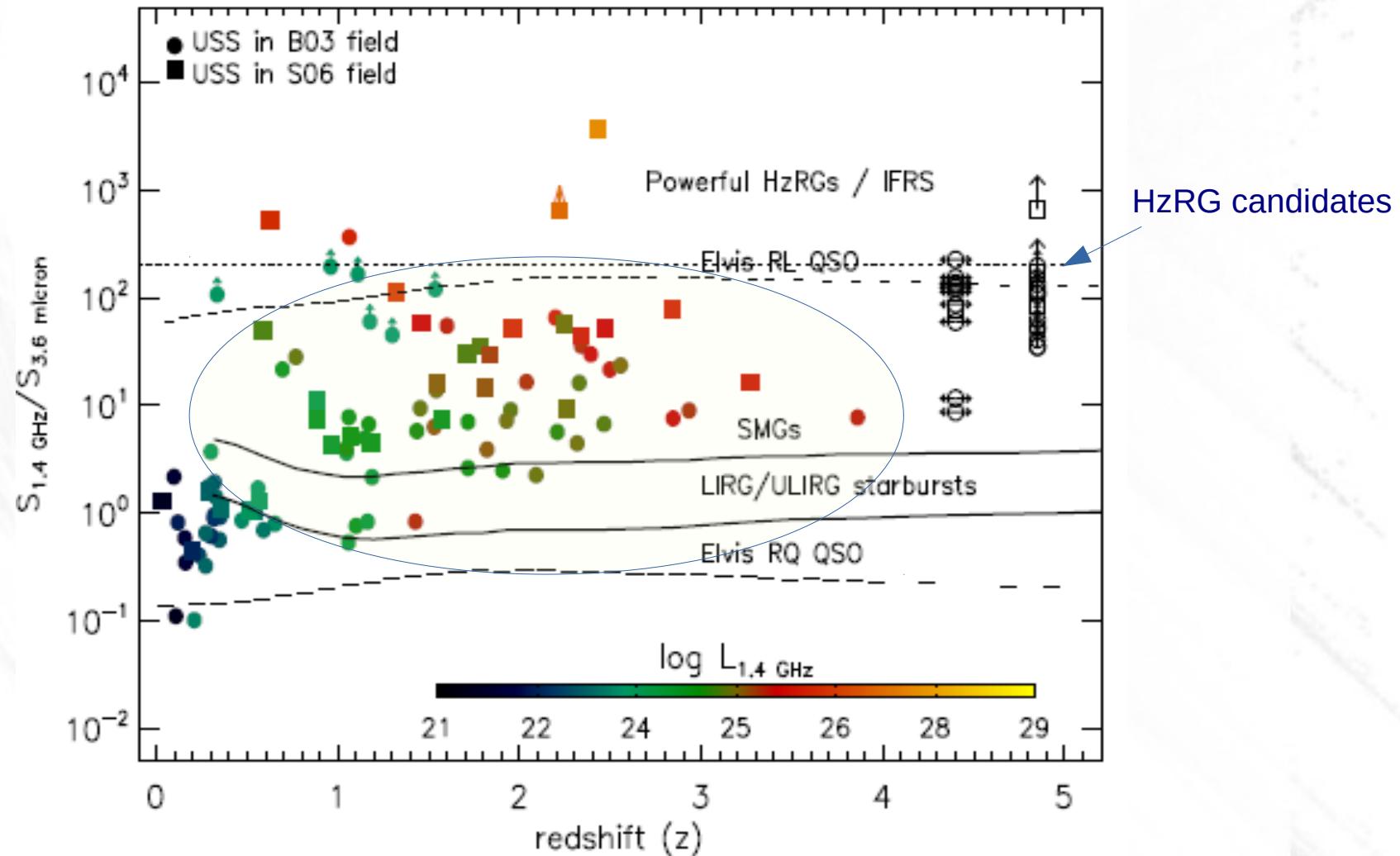
86/116 (74%) photo-z, 11/86 Spec-z

SXDF : median $z \sim 1.57$, $26/32 \sim 72\%$ are at $z \geq 1.0$

39/44 (~89%) photo-z 16/39 Spec-z

A fraction of sources without redshifts Possible HzRG candidates.

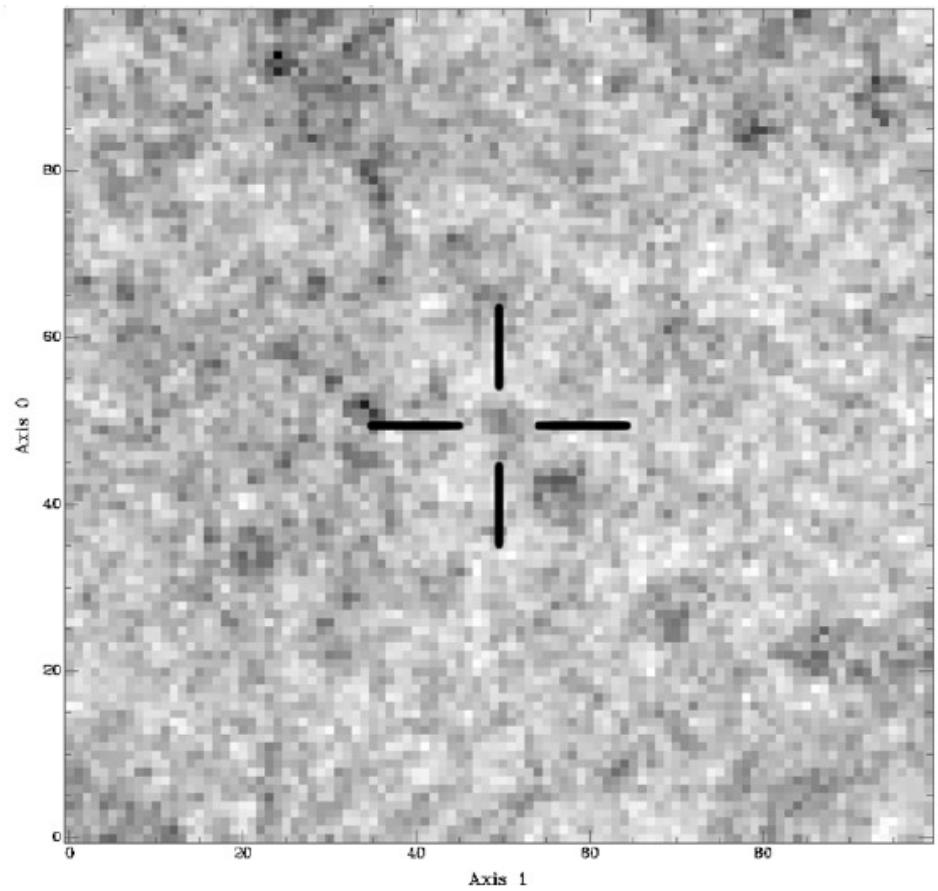
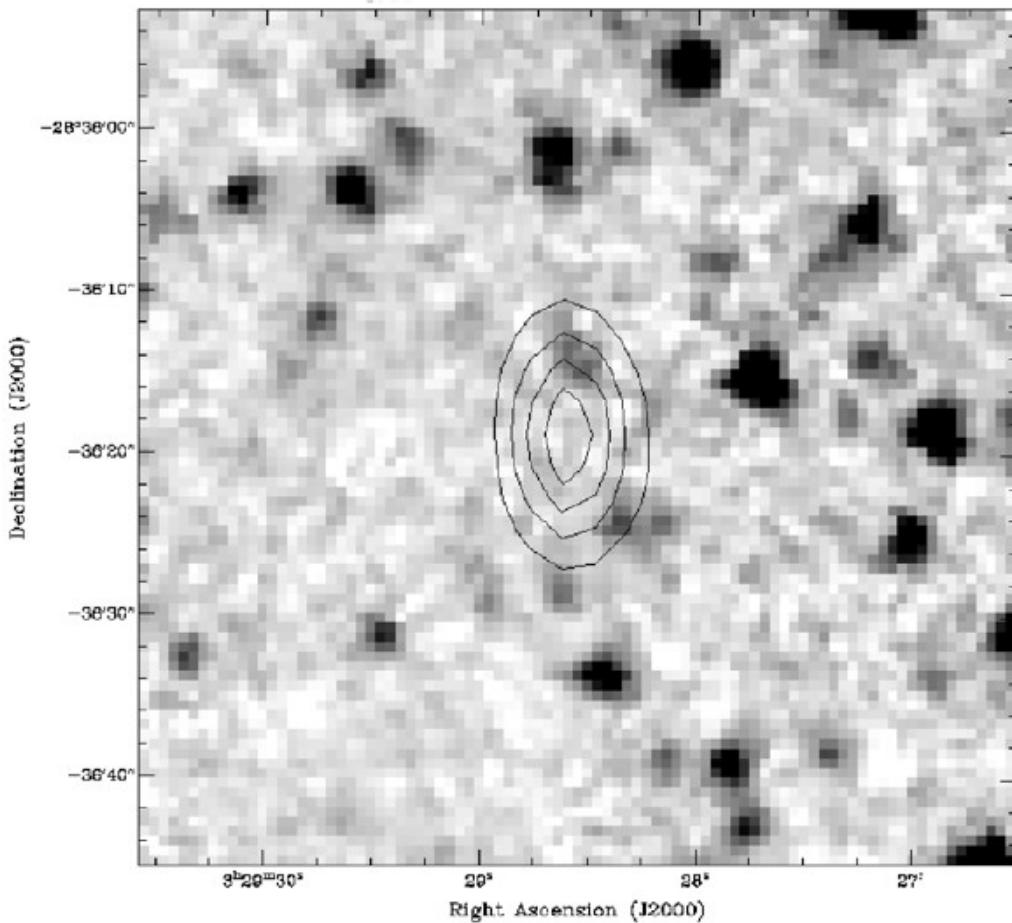
HzRGs: Population of dusty AGN



- ◆ A large fraction of USS sources falling in SMGs, LIRGs / ULIRGs regions
- ◆ Radio AGN hosted in SMG-like dusty obscured intensely Star forming galaxies at moderate redshifts

Infrared-faint radio sources (IFRS)

- ◆ First reported by Norris et al. 2006
- ◆ 22 radio sources in ATLAS with no IR counterpart
- ◆ No detection in 3.6 μm stacked image
(median $S_{3.6 \mu\text{m}}$ gives upper limit 0.2 μJy)

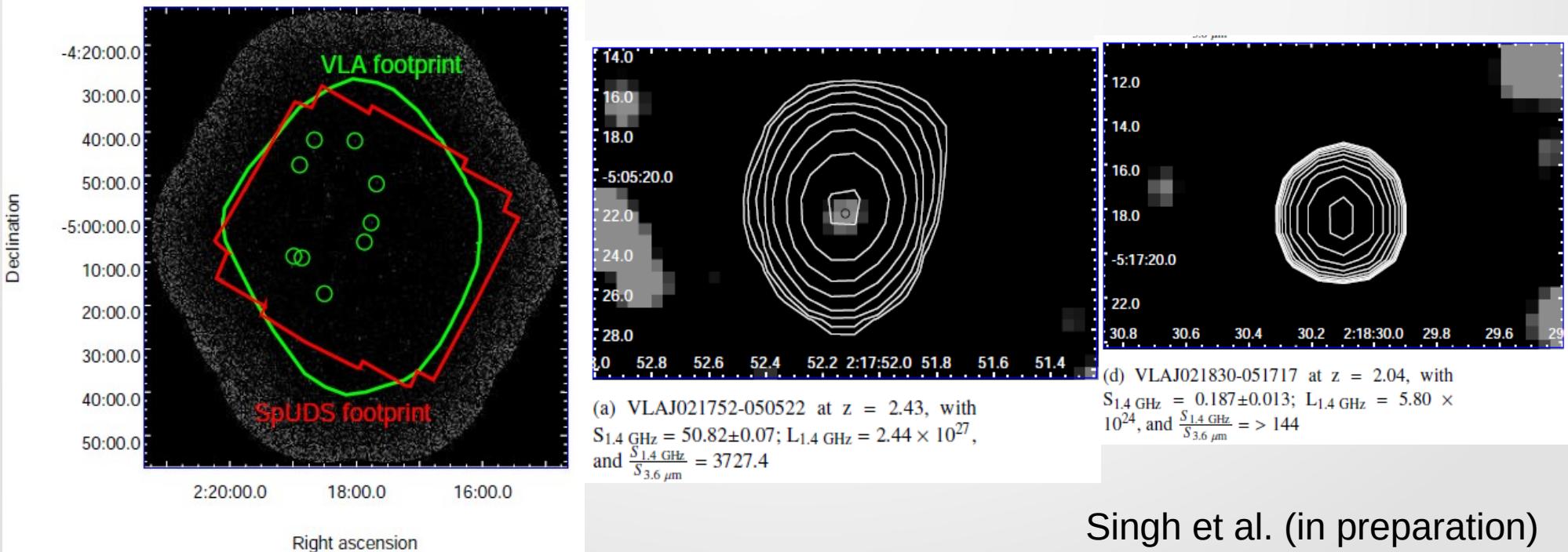


Infrared Faint Radio Sources (IFRS)

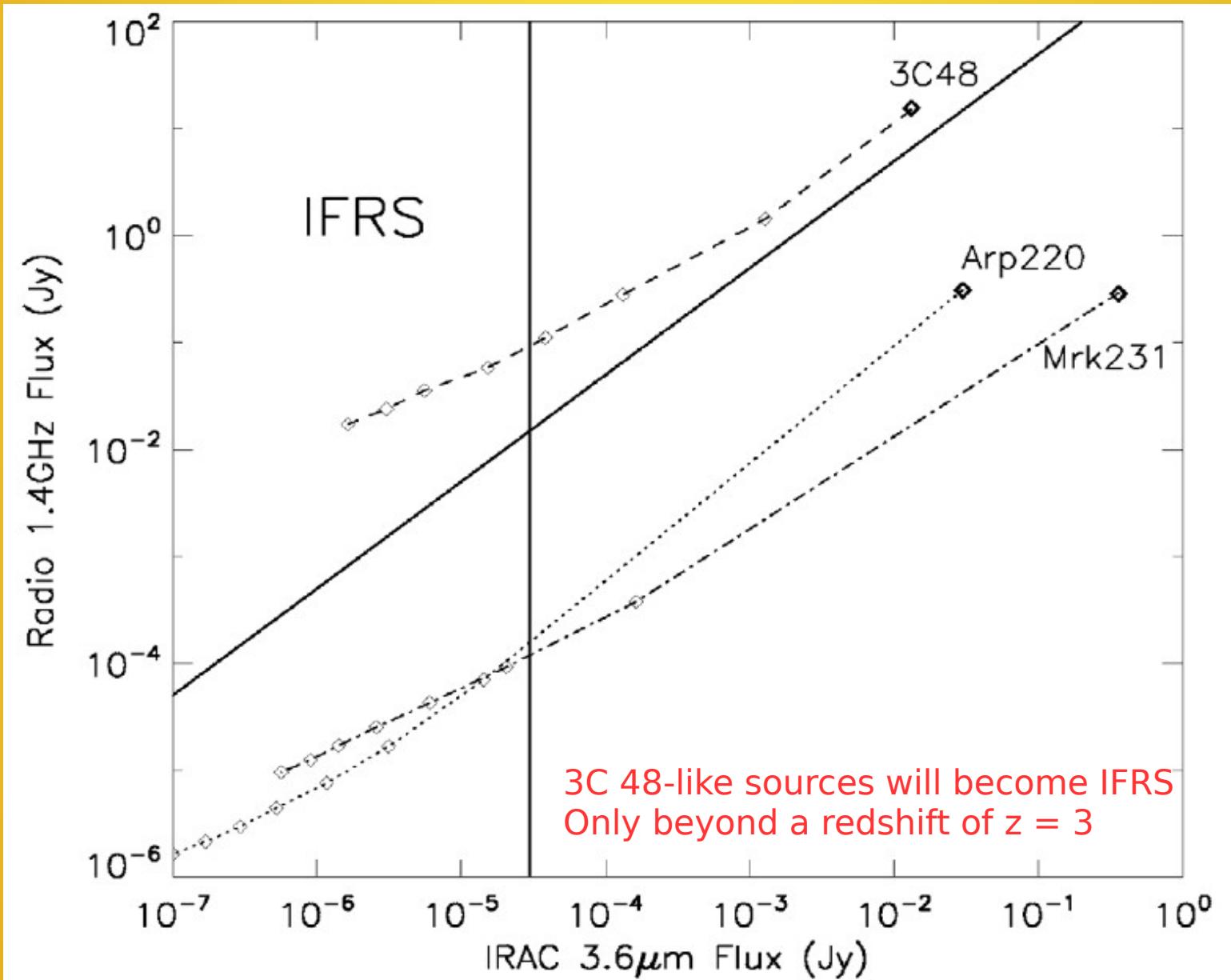
- (i) Radio sources with no IR counterpart
- (ii) $S_{1.4 \text{ GHz}} / S_{3.6 \mu\text{m}} > 500$ (extreme radio to IR flux ratio)
& $S_{3.6 \mu\text{m}} < 30 \mu\text{Jy}$ (eliminate low-redshift radio-loud AGNs)

17 IFRS 1.8 deg²

5 σ limit : 80 μJy at 1.4 GHz and 1.3 μJy at 3.6 μm with SpUDS



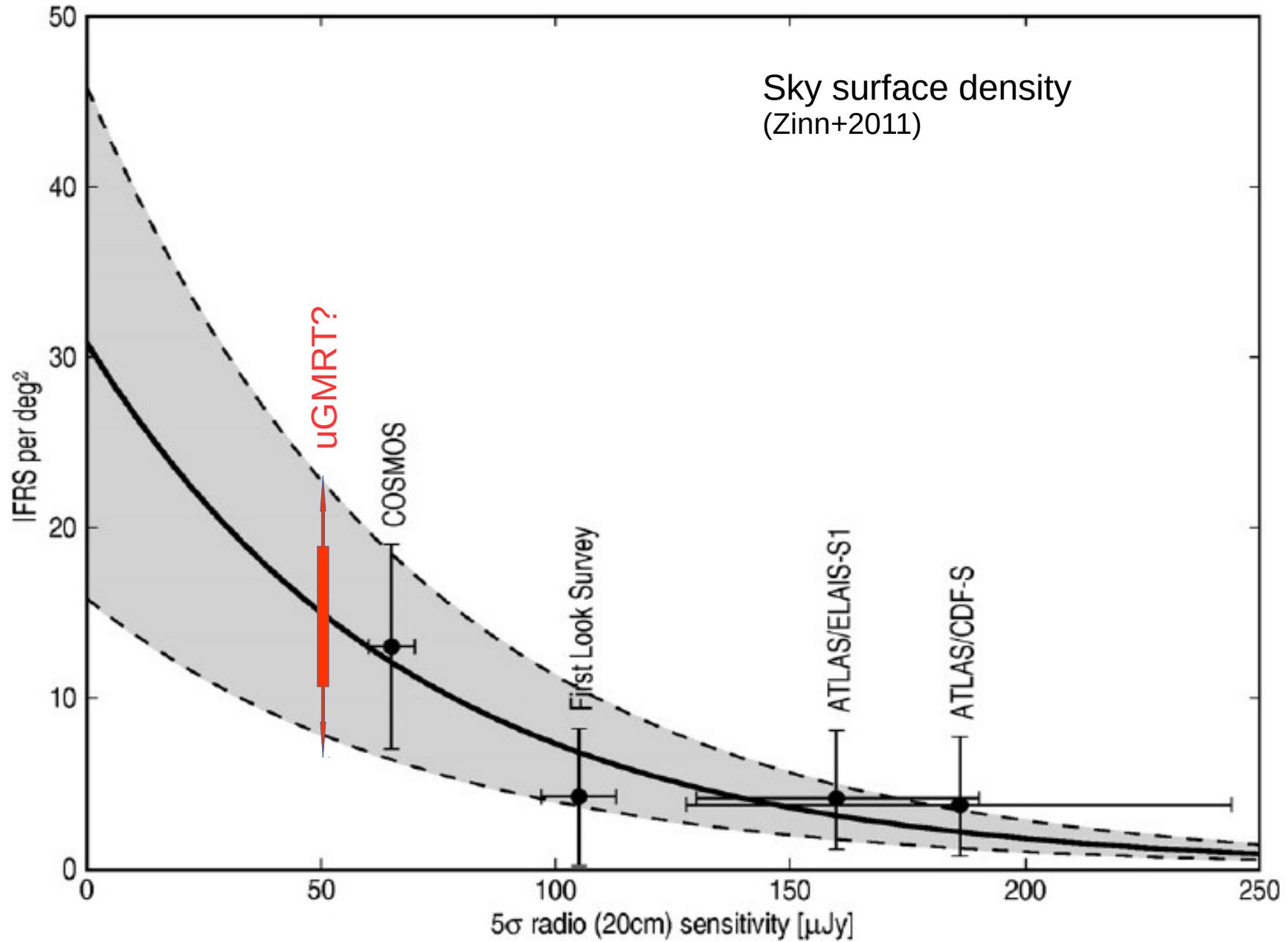
IFRS without redshifts



IFRSs properties

- ✓ Most IFRSs have steep radio spectrum (≤ -1.0)
- ✓ Compact in size (< 40 kpc)
- ✓ Luminosity : (moderate to very powerful) $10^{24} - 10^{27}$ W Hz $^{-1}$
- ✓ Few are clear case of double lobe radio galaxies
- ✓ Redshifts : 1.7 – 4.0
- ✓ Possibly Inhomogeneous population of radio-loud

IFRSs: uGMRT can reveal more



Summary

- ◆ Deep large area radio surveys combined with multiwavelenght data have allowed us to unveil new population of HzRGs.
- ◆ Test-bed for upcoming large area deep surveys.
- ◆ IFRSs samples constitute the radio-loud AGN possibly at different evolutionay stages .
- ◆ Deep large-area multifrequncy uGMRT and ASKAP radio surveys would allow us to carry out detailed study of different types of radio sources belonging to different stages of evolutionary stages.

Thank you

