Radio galaxies and their environments

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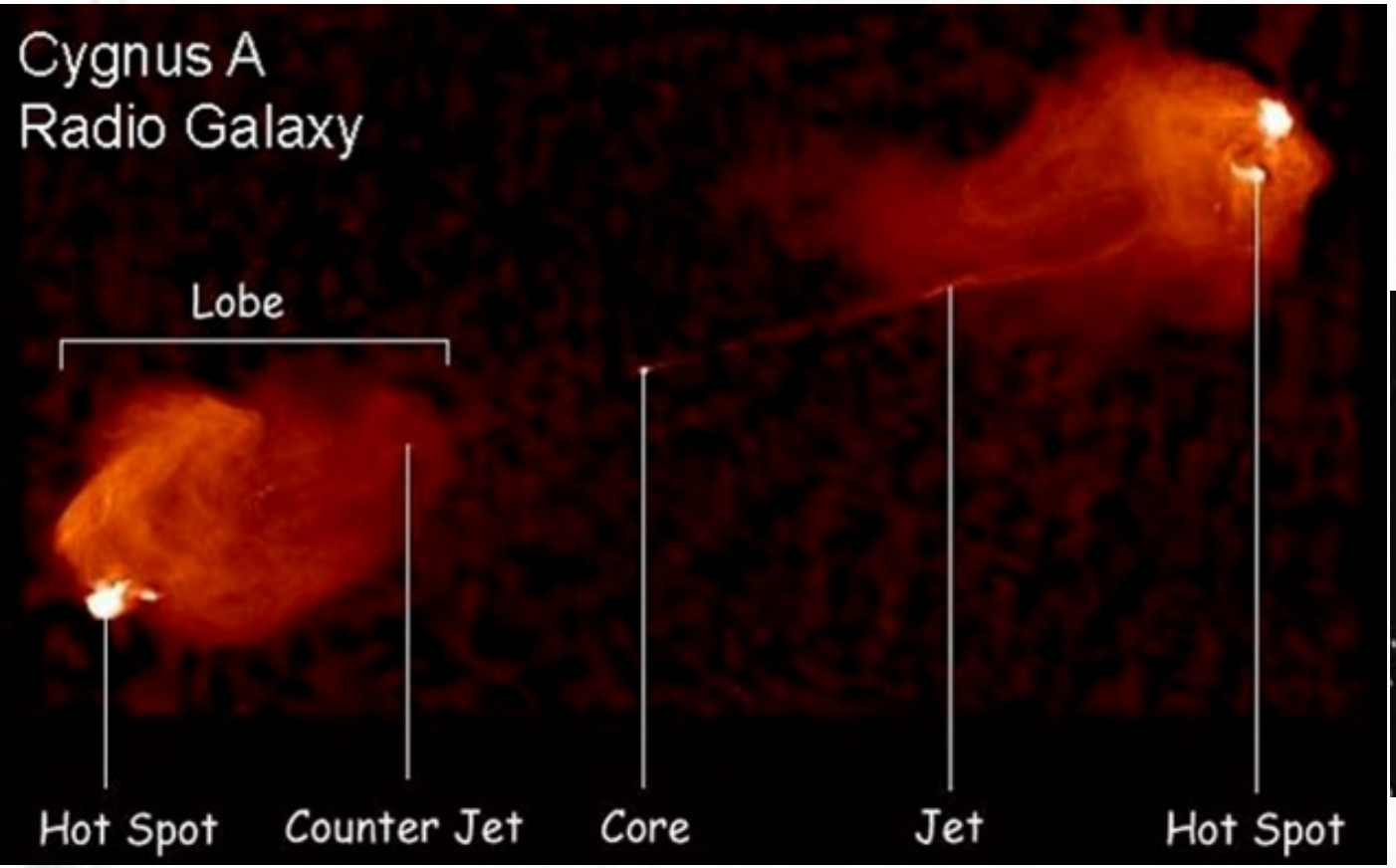
Outline

- Radio galaxies
- Search for high-z radio galaxies
- 325 MHz GMRT and 1.4 GHz VLA surveys
- Ultra steep spectrum (USS) radio sources as the tracer of HzRGs
- Optical, near-IR, mid-IR identification of USS sources
- Redshift distributions
- Environments of HzRGs

Radio galaxies



Radio powerful AGN ($L_{1.4\ GHz} > 10^{24}$ W Hz^{-1})

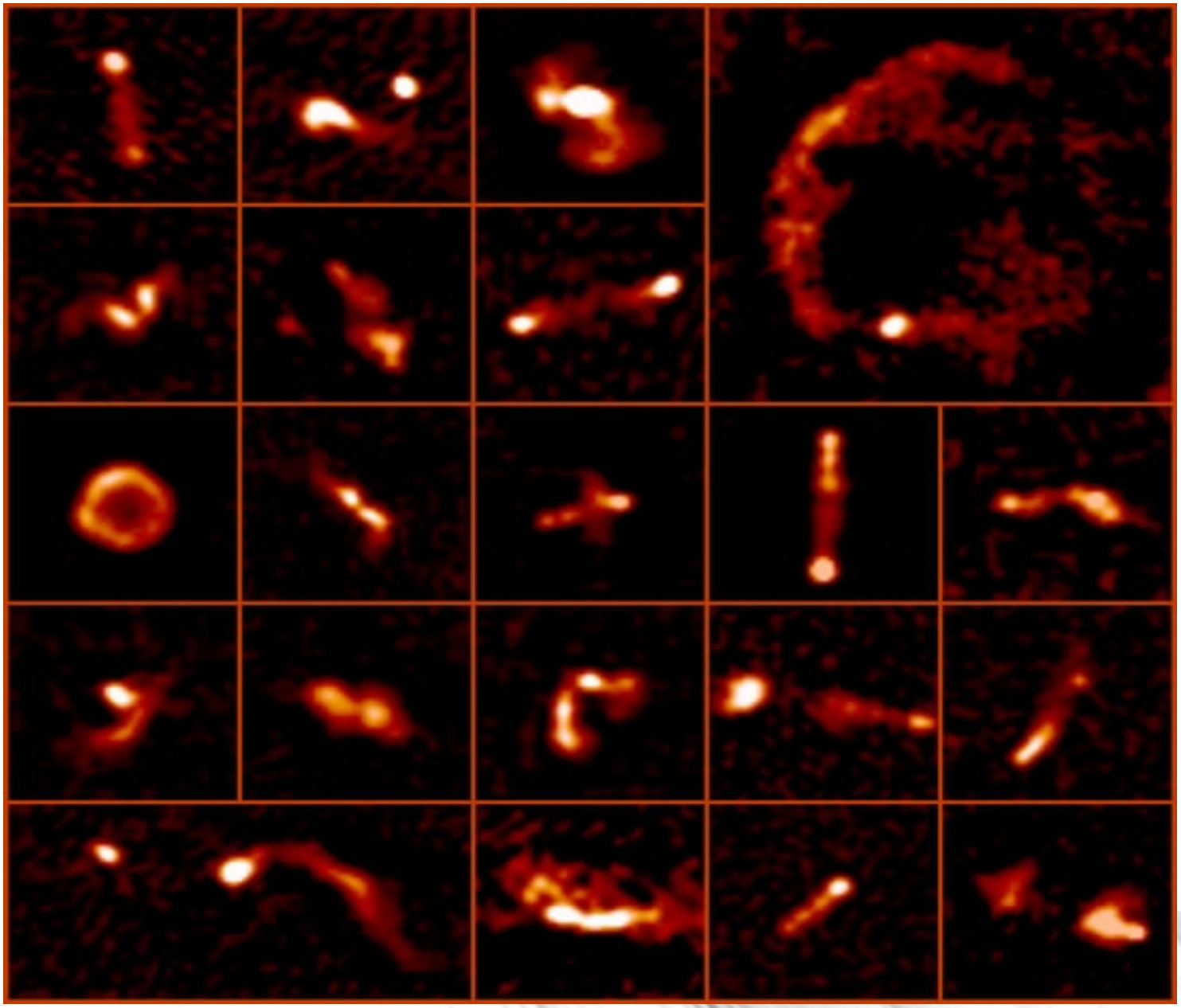
Radio size : Few 100s kpc to ~ Mpc

Radio morphology : typically pair of symmetrically opposite jets and lobes

Radio emission : synchrotron process

Variety of radio morphologies

Factors : viewing angle, evolutionary stage (young, old), AGN parameters (AGN power, mass, spin of SMBH), Host galaxy, Environment (field, group, cluster)



Credit: VLSS

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)

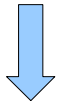
- Likely to be progenitor of massive elliptical galaxies in local universe
  (Best et al. 1998; McLure et al. 2004)

- Often associated with over-densities i.e., proto-clusters and clusters
  (Stevens et al. 2003; Venemans et al. 2007); Galametz et al. 2012)

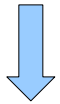
HzRGs are important to understand the formation and evolution of galaxies at higher redshifts and in denser environments.

How to search radio galaxies

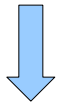
Step 1: Deep and wide low-frequency radio surveys



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



Step 3: Identify optical, IR counterparts

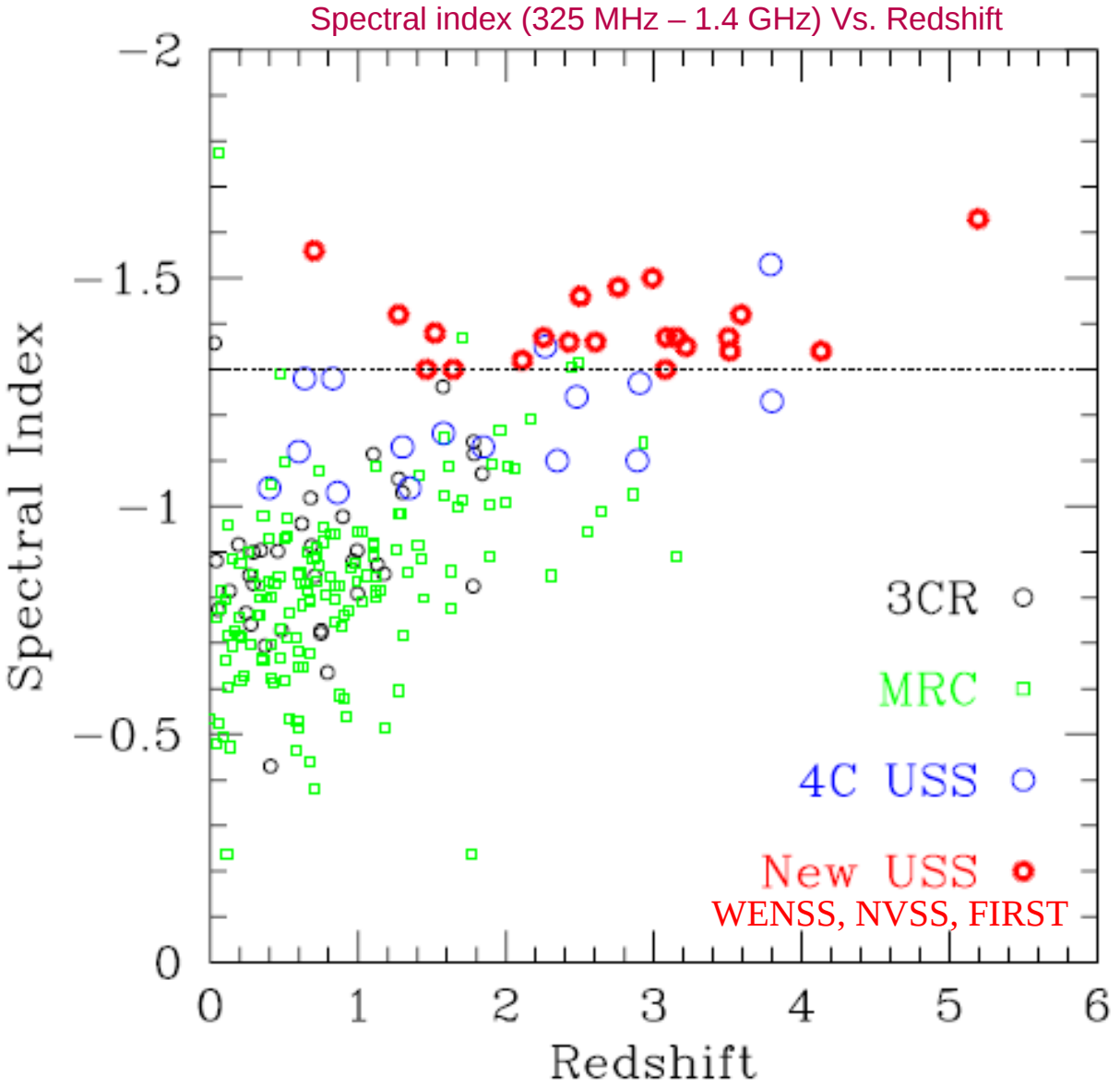


Step 4: Redshifts from spectroscopic observations

(Röttgering et al. 1994, Blundell et al. 1998, De Breuck et al. 2000, De Breuck et al. 2004, Jarvis et al. 2004, Cruz et al. 2006, Bornancini et al. 2007, Ishwara-Chandra et al. 2010, Ker 2012)

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

z - α correlation is one of the successful tracers



De Breuck et al. 2000

Most of the radio galaxies known at z > 3.5 are searched using z – α correlation
(Jarvis et al. 2004; Cruz et al. 2006; Miley & De Breuck 2008)

However, an USS can not be guaranteed as a high redshift source and vice-versa
(e.g., Waddington et al. 1999; Jarvis et al. (2009)

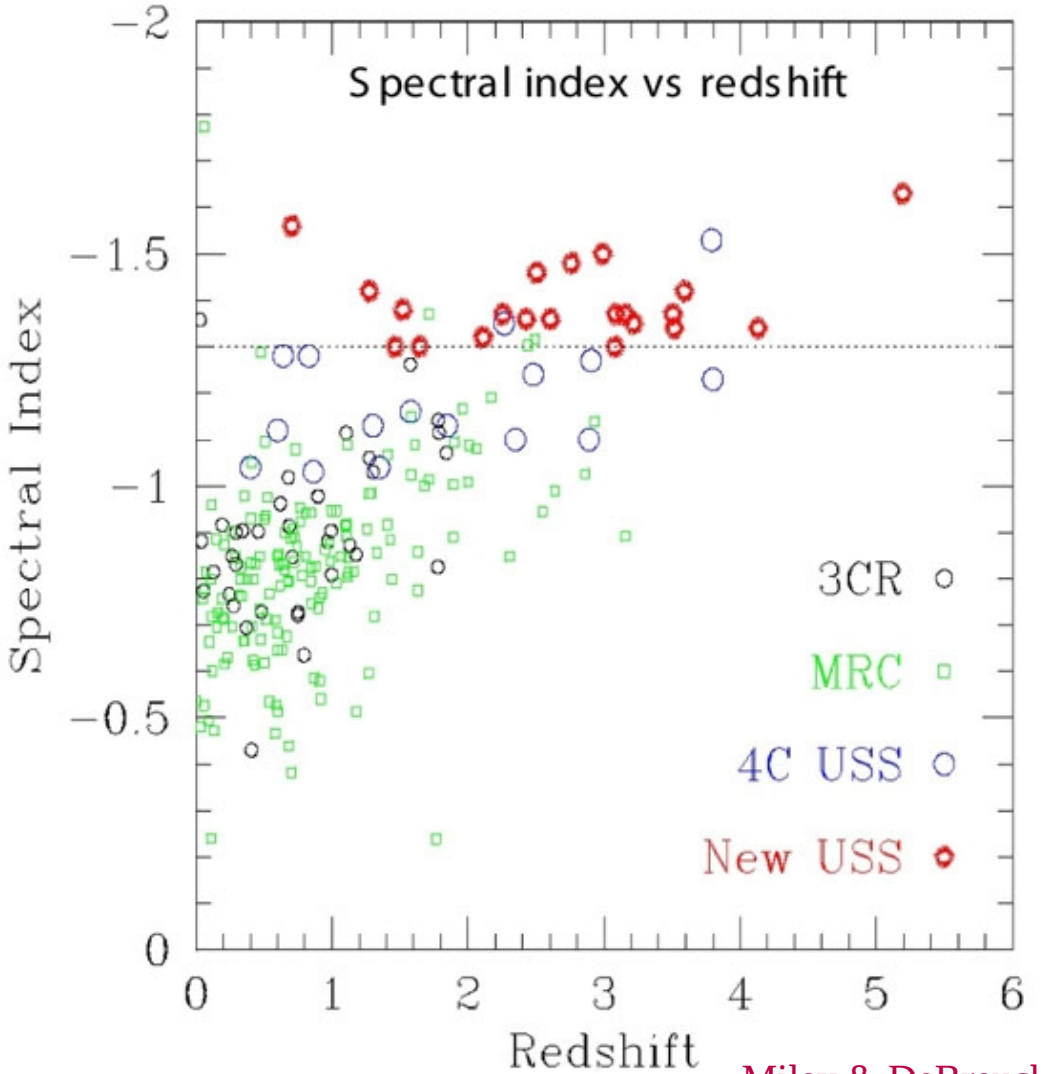
USS radio sources: HzRG candidates

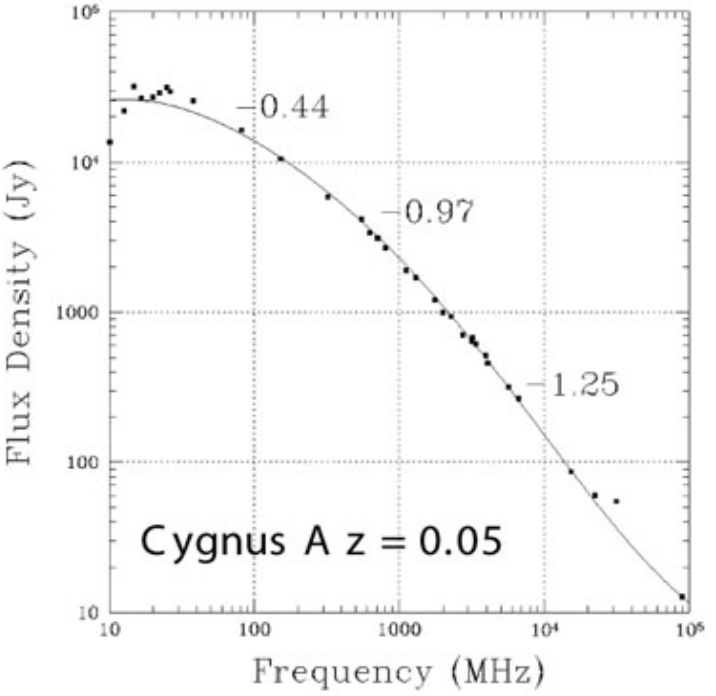
The conventional explanation

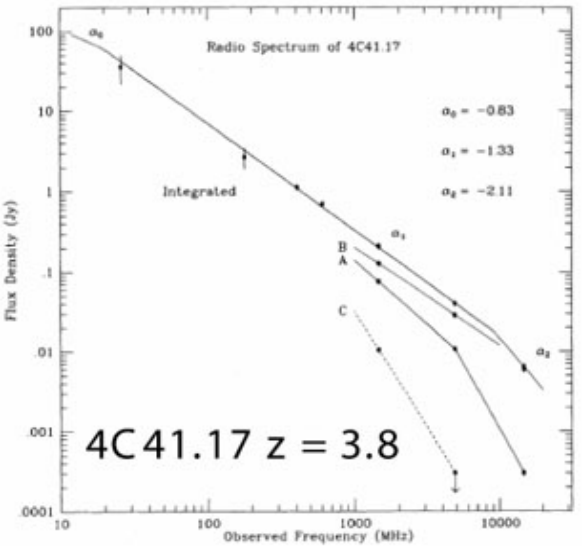
- a concave radio spectrum coupled with a radio K-correction

- 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)







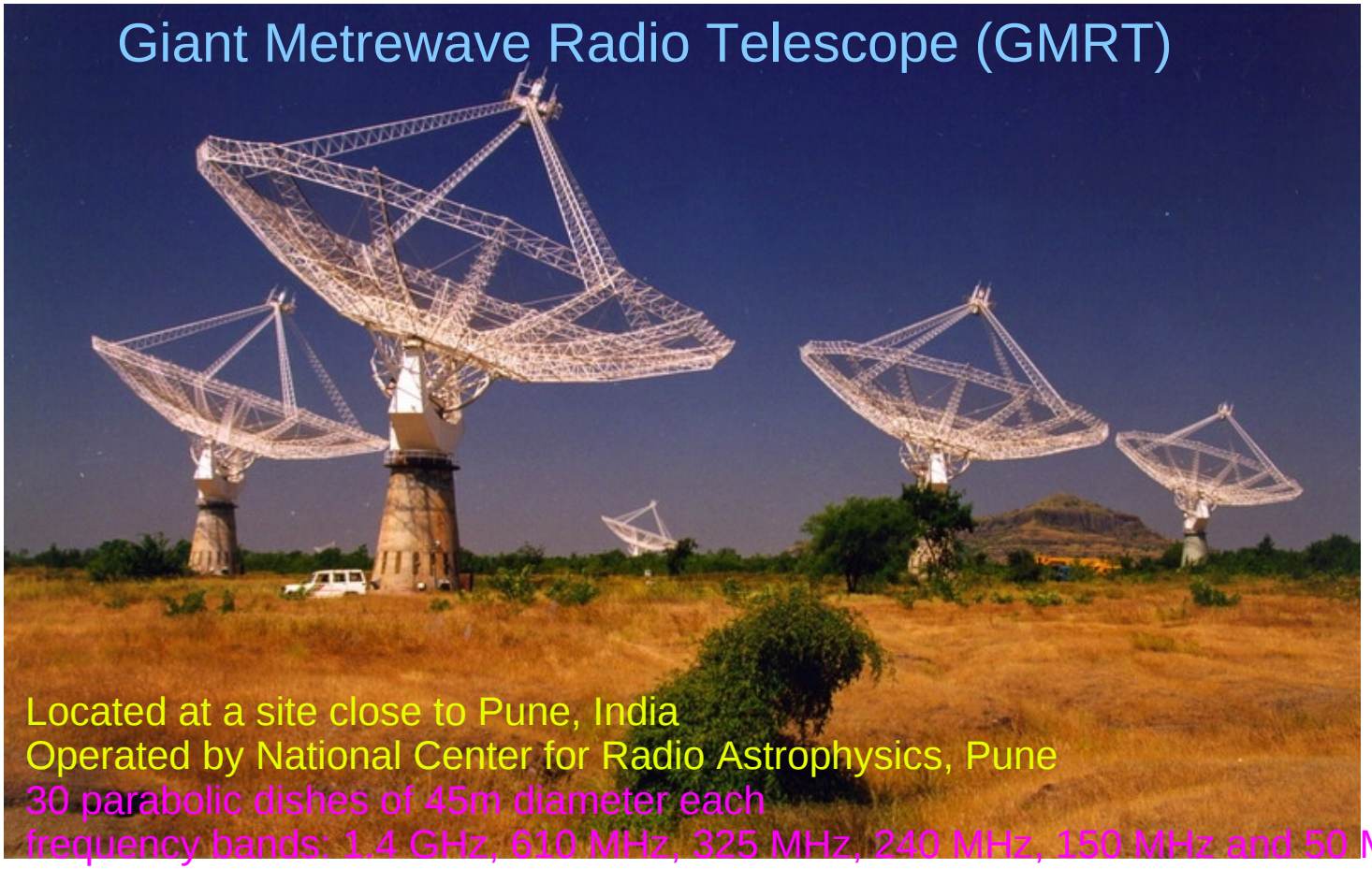
Miley & DeBreuck 2008

325 MHz GMRT radio observations of Herschel fields

advantage at low-frequency: large collecting area, large foV and adequate resolution (~ 9")

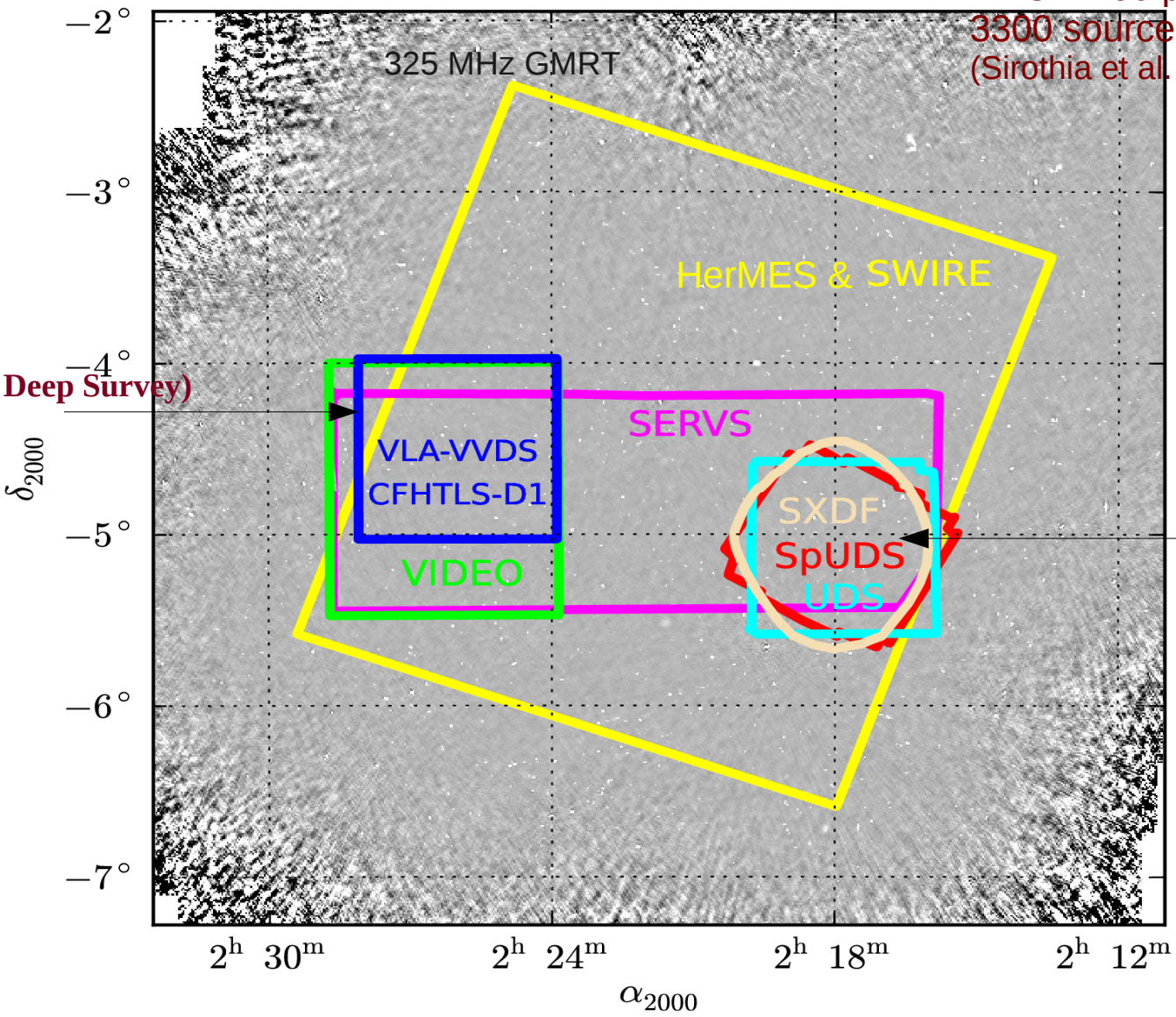
Field	Area	Total Time	Rms	No. of sources (≥ 5σ)
XMM-LSS	9 deg^2	40 h	160 μJy/b	3300
Lockman hole	18 deg^2	200 h	40 μJy/b	
ELAIS-N1	9 deg^2	100 h	40 μJy/b	

Deepest low frequency wide radio survey in XMM-LSS field (Sirothia et al. In preparation)



Multiwavelengths observations in XMM-LSS

325 MHz GMRT
9 deg^{-2}
Rms ~ 160 µJy
3300 sources
(Sirothia et al. 2014, in preparation)



VVDS (VIMOS VLT Deep Survey)

1.4 GHz VLA
1.0 deg^{-2}
rms ~ 16 µJy
1054 sources
(Bondi et al. 2003)

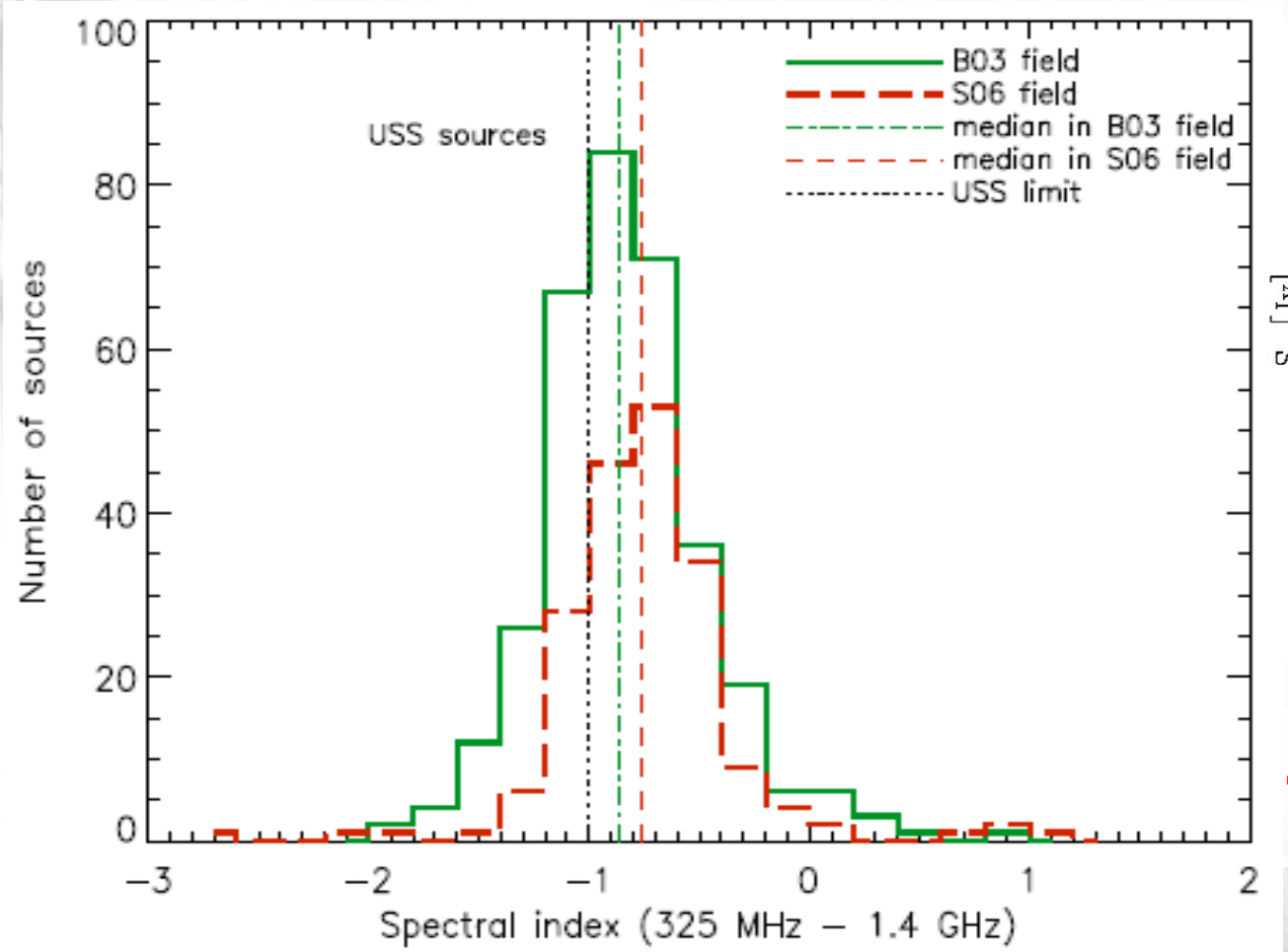
SXDF
(Subaru XMM-N Deep Field)

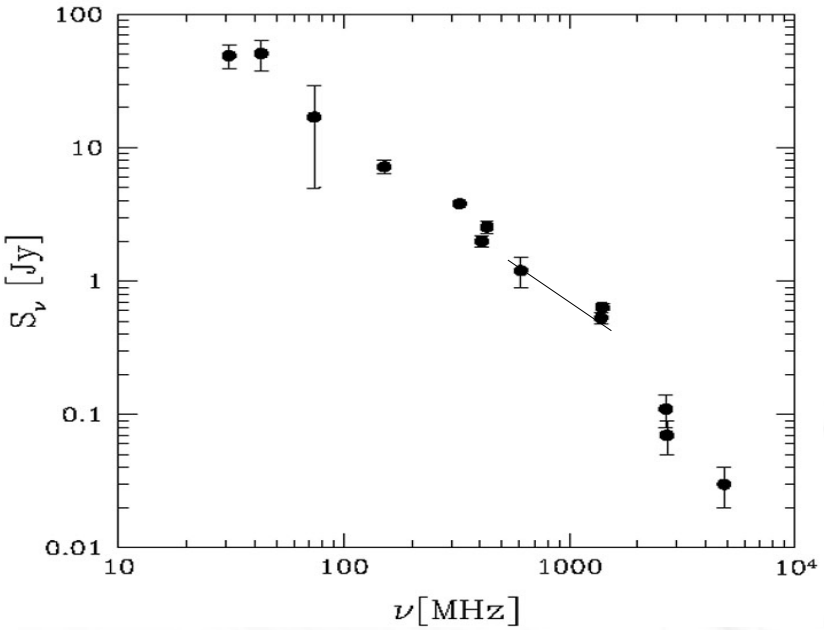
1.4 GHz VLA
0.8 deg^{-2}
rms ~ 20 µJy
512 sources
(Simpson et al. 2006)

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 (α ≤ -1.0)	116	44





USS sample :

325 MHz – 1.4 GHz spectral index (α) ≤ -1.0

Total 160 USS sources

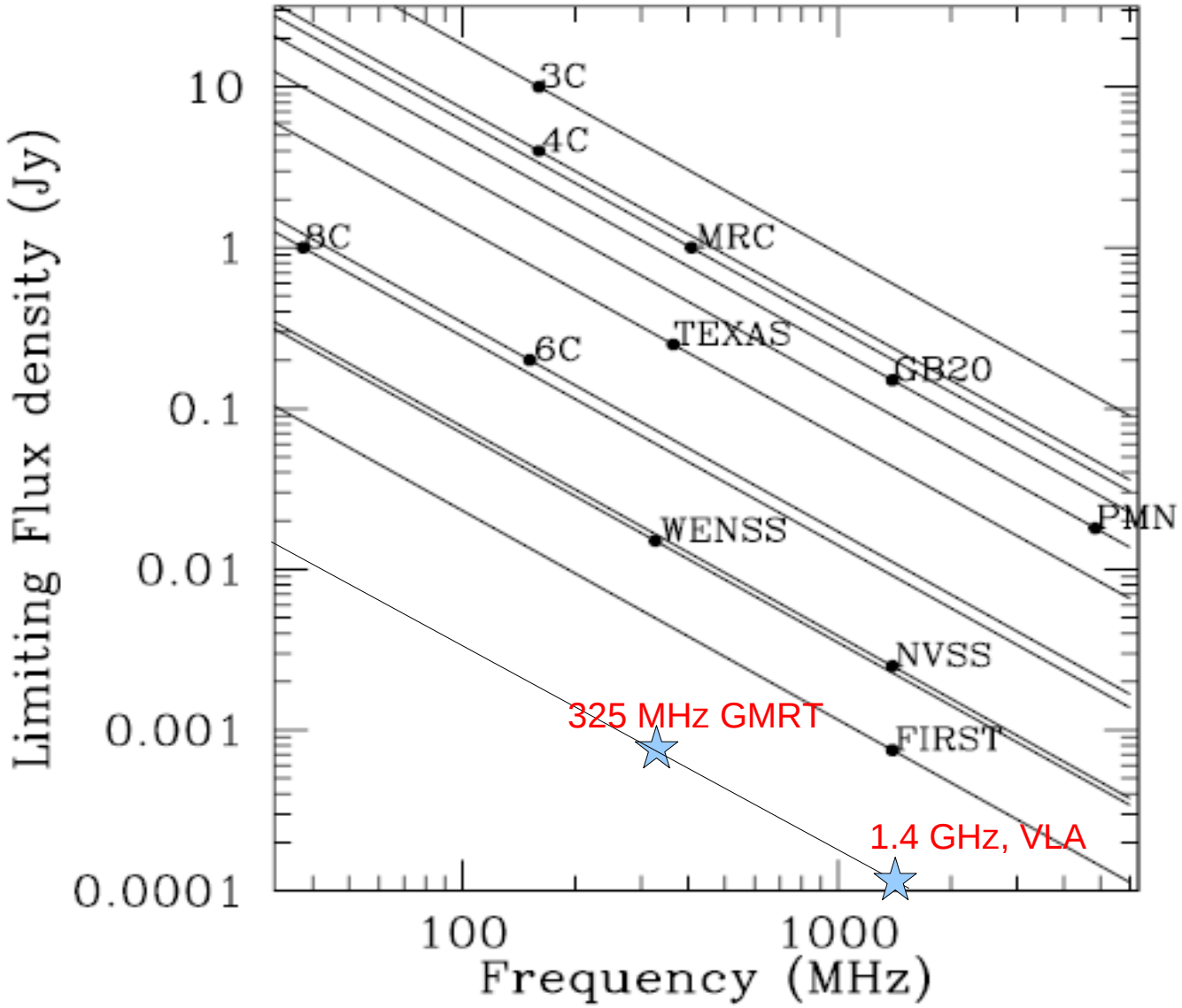
Singh et al. 2014 A&A

Comparison with previous USS samples (HzRGs candidates)

HzRGs serach limited to bright USS sample based on shallow or moderately deep radio surveys (e.g., De Breuck et al. 2002a, 2004; Broderick et al. 2007, Bryant et al. (2009); Bornancini et al. (2010)).

we are probing ~10 times deeper ($S_{1.4\ GHz} \geq 0.1$ mJy) : a different flux density regime

Relatively faint and High-z sources in our sample



Nature of USS at faint (submJy) flux densities?

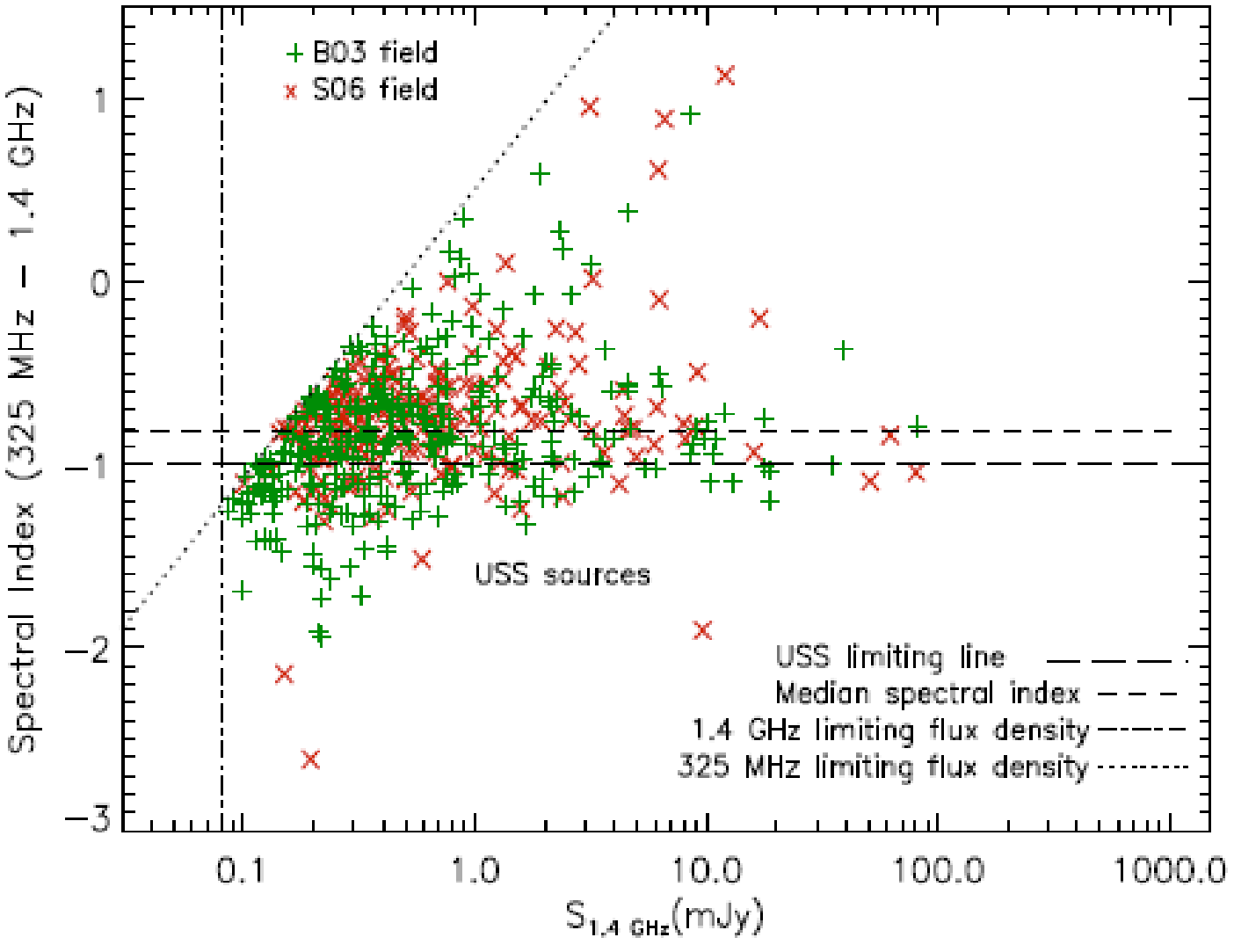
- Powerful radio galaxies at higher redshifts

  or

- Population of low-power AGNs at moderate redshifts

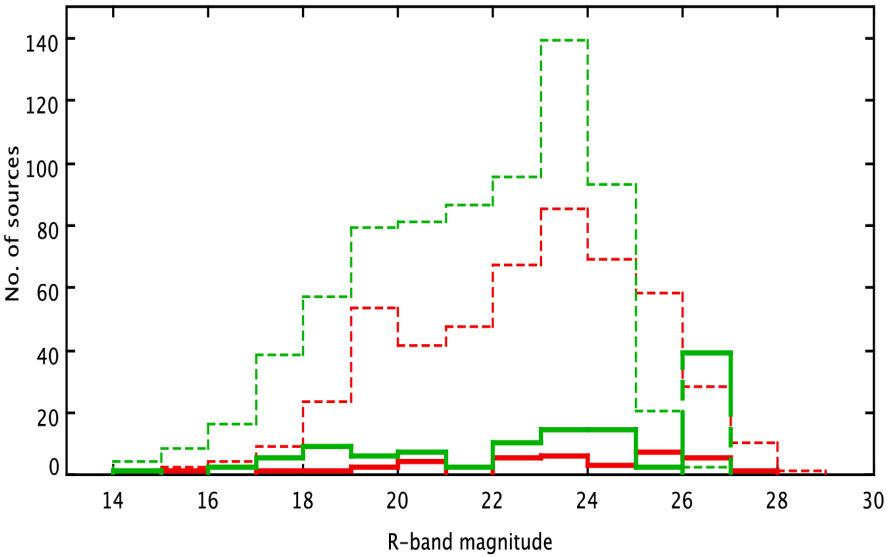
  or

- Mixed population



Optical, near-IR Identification of USS sources

	VLA-VVDS	SXDF
	AB mags limits	AB mags limits
B	26.5	28.4
V	26.2	27.8
R	25.9	27.7
I	25.0	27.7
Y	25.7	
Z	24.6	
J	24.5	23.7
H	24.0	23.5
K	23.5	23.7



VVDS : optical data limited to I_{AB} ~ 25.0 identify only 65 % USS sources

Oprtical near-IR identifcation rates of USS are lower than that for non-USS source

SXDF : Deeper optical data (I_{AB} ~ 27.7) identify nearly all USS sources

USS sources are systematically fainter.

Redshifts of USS radio sources

Photo-z of 1.4 GHz radio population

VVDS field : Optical CFHTLS + near-IR VIDEO data
VIMOS VLT Deep Survey (VVDS) spectroscopic survey
McAlpine (2013).

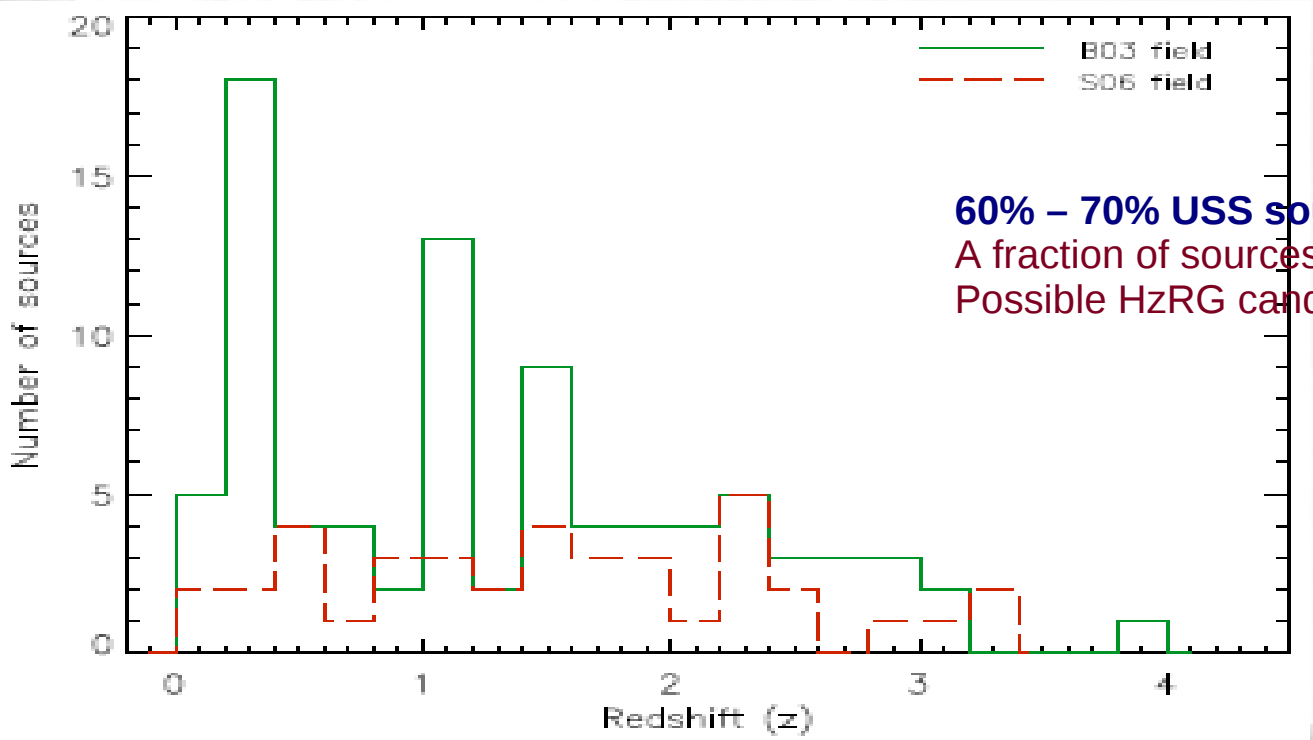
SXDF : 11 band photo-z (u, B, V, R, i, z, J, H, K plus IRAC bands 1 and 2)
Visible Multi-Object Spectrograph (VIMOS)
Simpson et al. (2012).

VVDS field
86/111 (77%) photo-z
11/86 Spec-z

$0.09 \leq z \leq 3.86$, median z ~ 1.18
53/86 ~ 61.5/% are at $z \geq 1.0$

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

$0.03 \leq z \leq 3.34$, median z ~ 1.57
26/32 ~ 72 /% are at $z \geq 1.0$

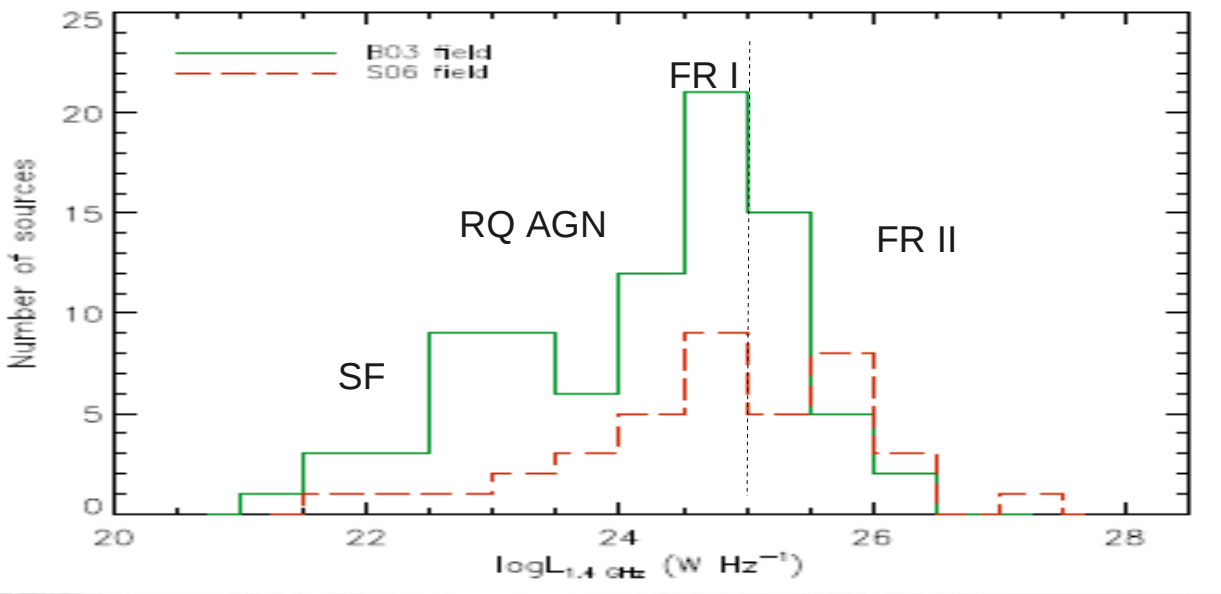


60% – 70% USS sources are at z > 1.0
A fraction of sources without redshift estimates.
Possible HzRG candidates

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

Radio Luminosities

1.4 GHz



VVDS field :

$2.88 \times 10^{21} \leq L_{1.4GHz,} \leq 1.2 \times 10^{26}$ W Hz^{-1}

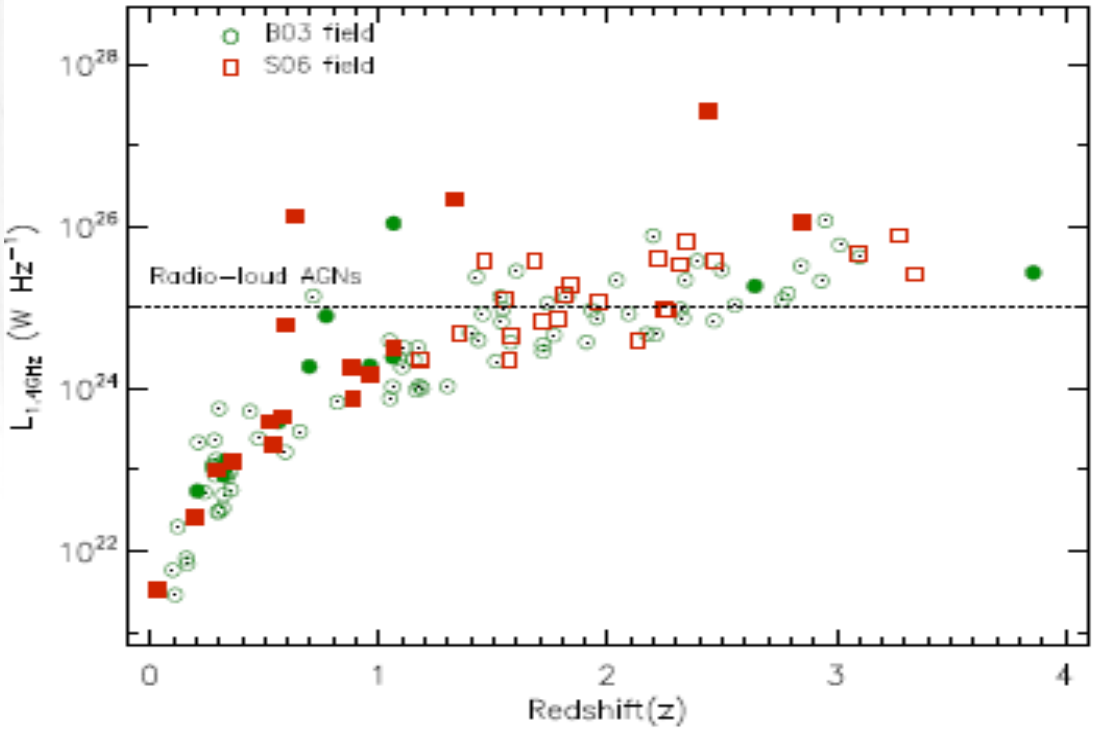
$L_{1.4GHz, median} \sim 3.16 \times 10^{25}$ W Hz^{-1}

SXDF :

$3.31 \times 10^{21} \leq L_{1.4GHz,} \leq 2.69 \times 10^{27}$ W Hz^{-1}

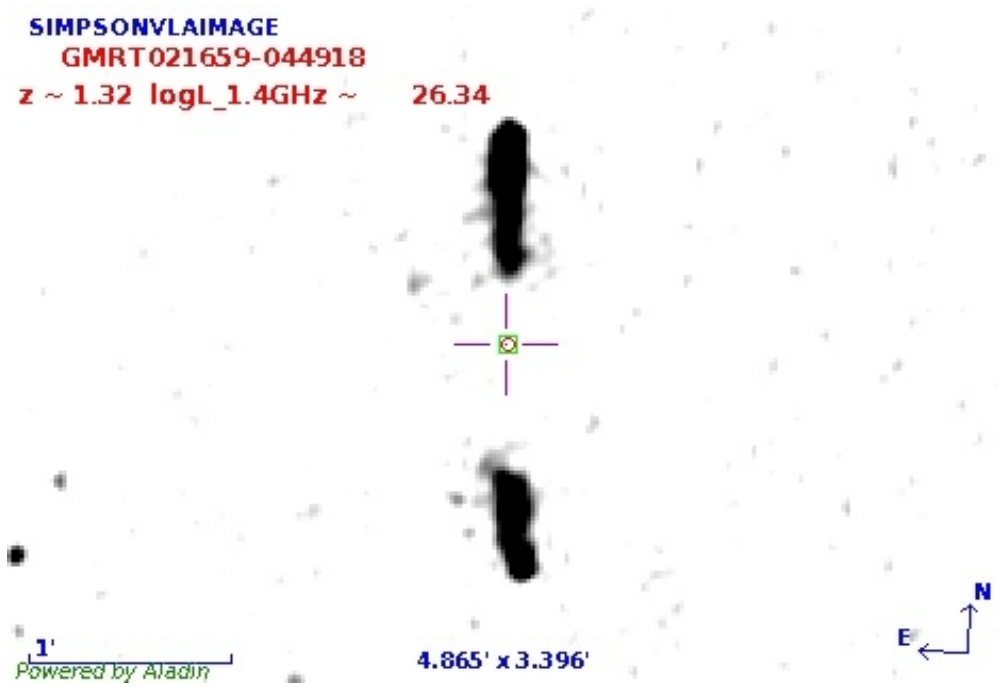
$L_{1.4GHz, median} \sim 7.24 \times 10^{24}$ W Hz^{-1}

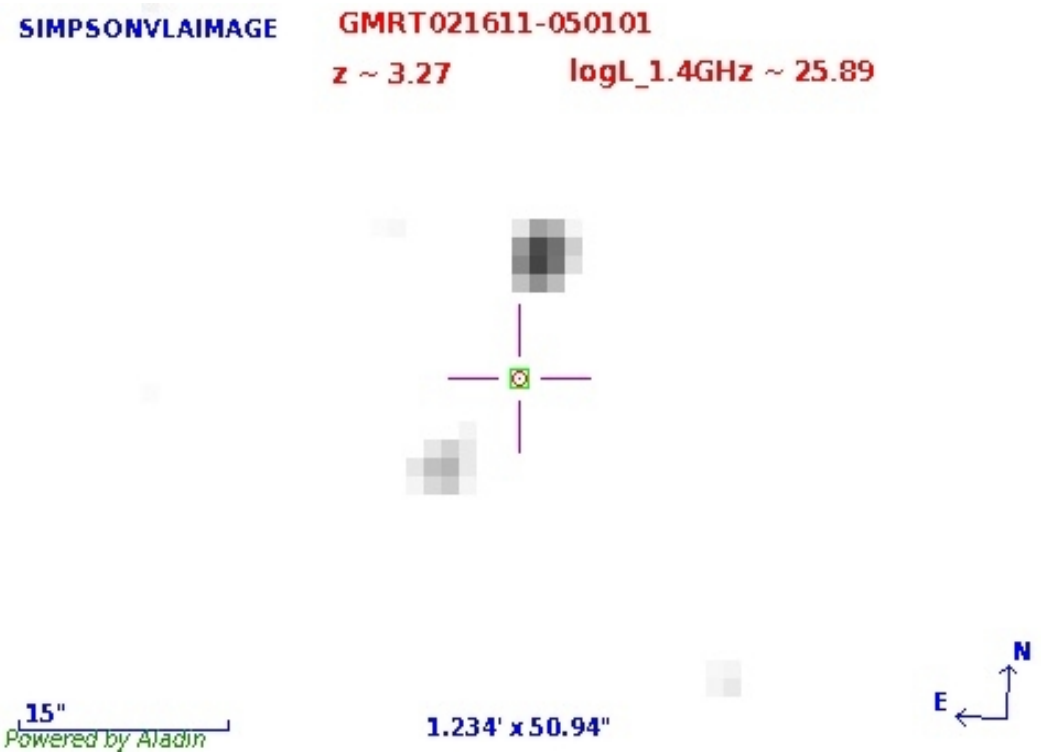
FR I $< P_{178\ MHz} \sim 10^{25}$ W Hz^{-1} < FR II



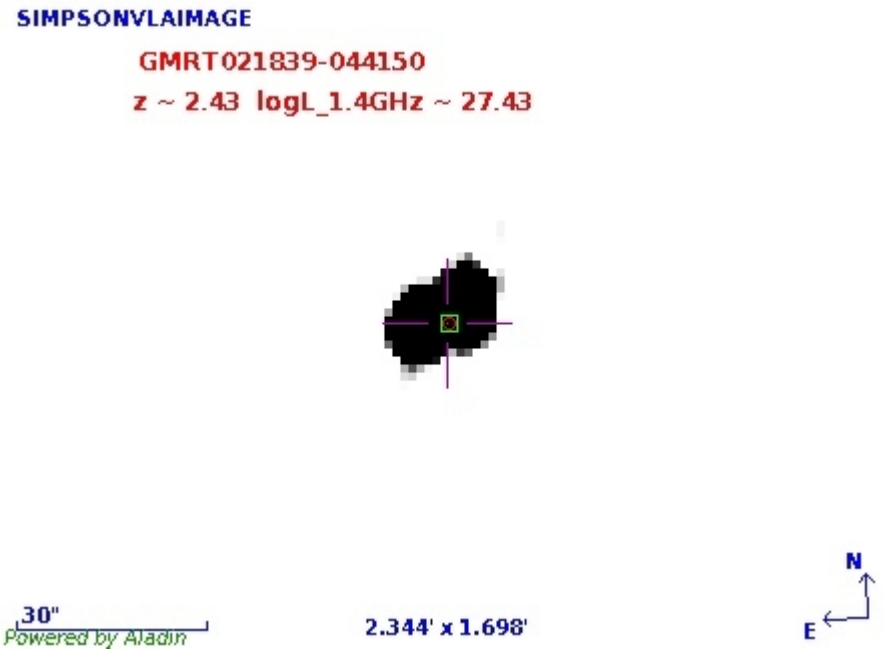
~ 40 % USS have radio luminosities typical of powerful FRII Radio galaxies

HzRGs


SIMPSONVLAIMAGE
GMRT021659-044918
z ~ 1.32 logL_1.4GHz ~ 26.34
1'
Powered by Aladin
4.865' x 3.396'
N
E


SIMPSONVLAIMAGE
GMRT021611-050101
z ~ 3.27
logL_1.4GHz ~ 25.89
15"
Powered by Aladin
1.234' x 50.94"
N
E

SIMPSONVLAIMAGE
GMRT021926-051535
z ~ 1.46 logL_1.4GHz ~ 25.58
15"
Powered by Aladin
1.703' x 50.94"


SIMPSONVLAIMAGE
GMRT021839-044150
z ~ 2.43 logL_1.4GHz ~ 27.43
30"
Powered by Aladin
2.344' x 1.698'
N
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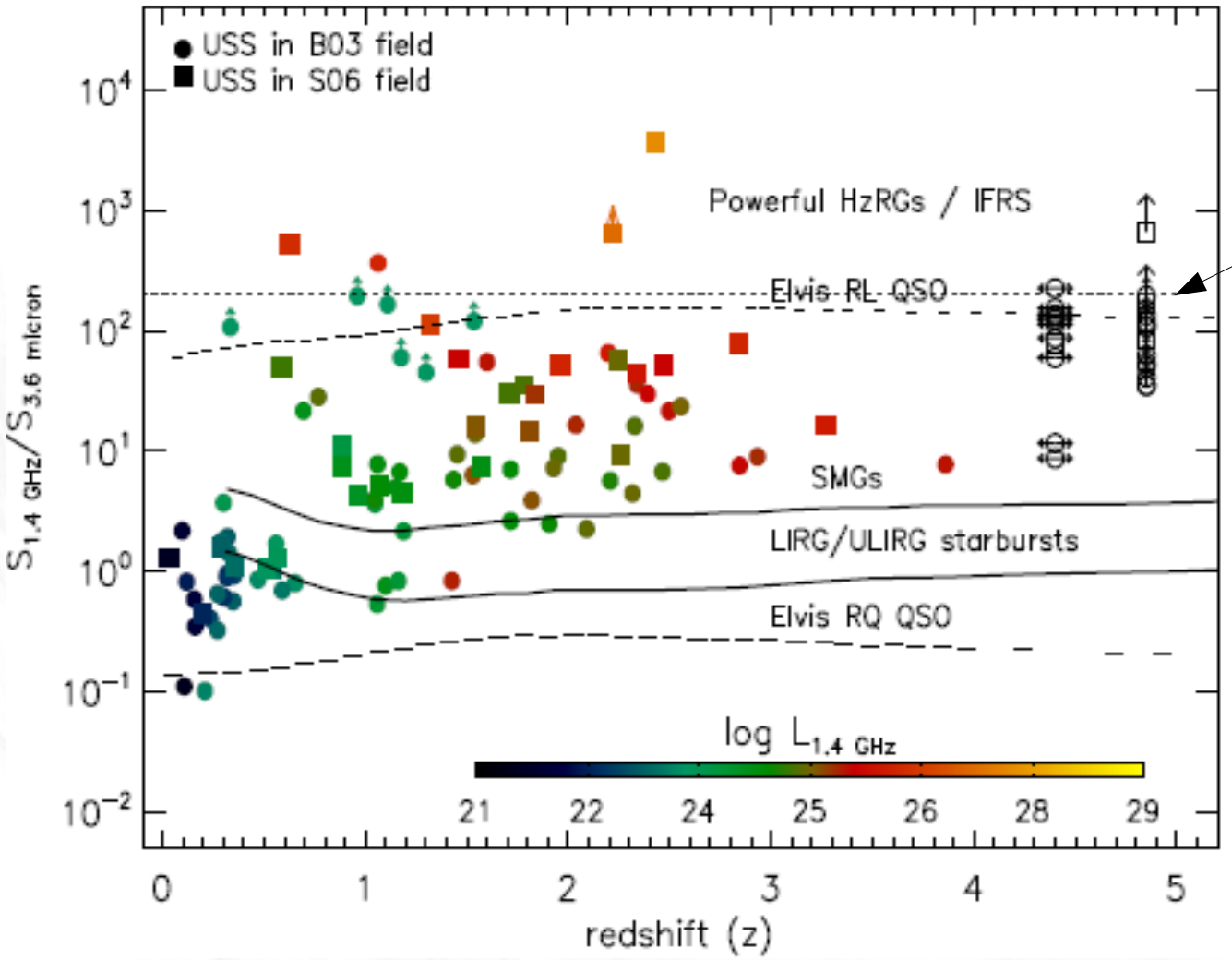
Unveiling the nature of USS radio sources using IR emission

1.4 GHz radio to 3.6 micron flux ratio diagnostic



HzRG candidates

- 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 (e.g., Sajina et al. 2007b).
- Significant fraction of IR Faint Radio Sources (IFRS) => HzRGs (not detected at 3.6 micron) obscured

Singh et al. 2014 A&A

We unveil young radio loud AGN residing in obscured environments.

A significant fraction of our USS sources do have :

- $S_{1.4GHz}/S_{3.6micron}$ similar to SMGs/ULIRGs
- radio loud ($L_{1.4\ GHz} \sim 10^{25} – 10^{26}$ W Hz^{-1})
- unresolved at 1.4 GHz (resolution 6 arcsec)
  (compact steep spectrum or GigaHertz peaked spectrum sources)
  at z ~ 2, 6 arcsec resolution gives size limit < 50 kpc

A possible scenario :

a compact radio-loud AGN surrounded by vigorous starburst activity.
AGN jets of kpc-scale passing through the dense gas and starburst activity that confine them.

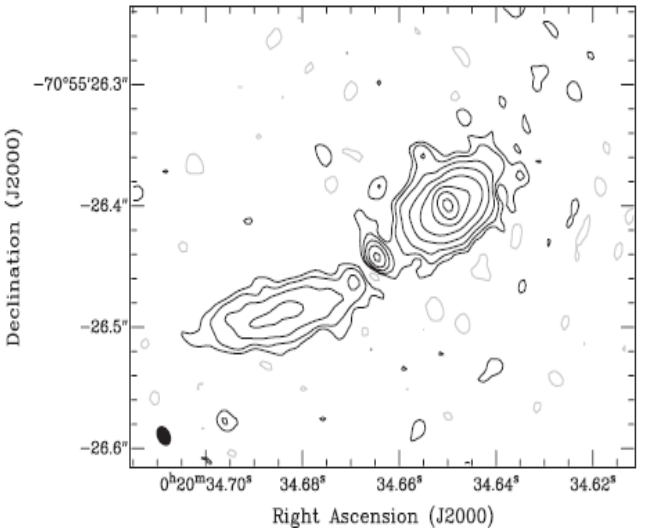
Planned high-resolution radio observations are expected to determine the morphology, physical extent, and brightness temperature of the radio emitting regions

A rare example :

F00183−7111, an ULIRG

$L_{bol} \sim 9x10^{12}\ L_{sun}$
$L_{2.3\ GHz} = 6 \times 10^{25}$ W Hz^{-1})
VLBI observation shows a compact core–jet morphology
With jets spanning only to 1.7 kpc

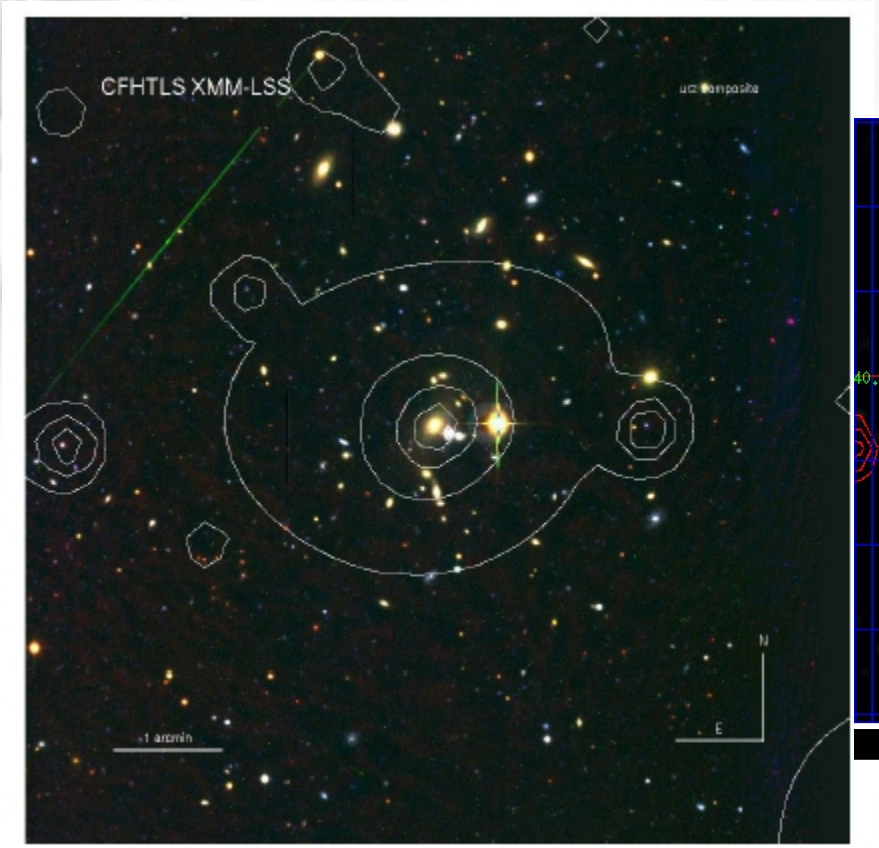
Norris et al. (2012)

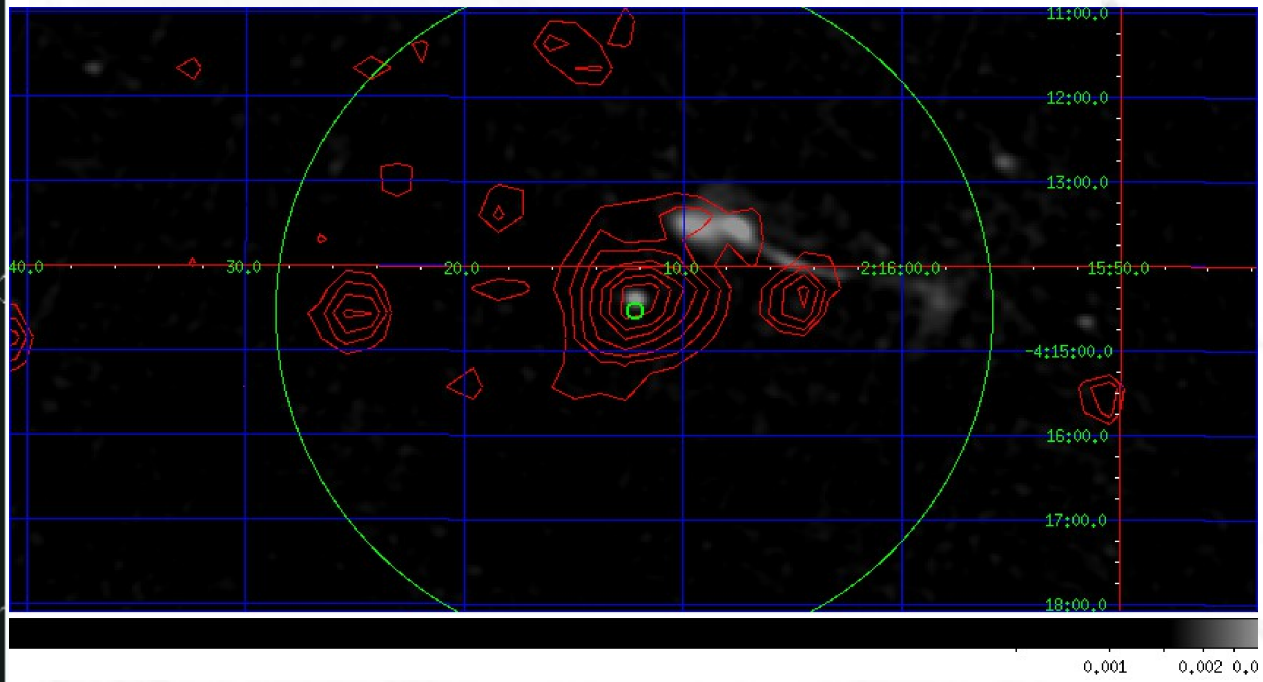


2.3-GHz VLBI image of IRAS F00183−7111

Environments of radio galaxies

- Several radio galaxies of the sample are lying in cluster environments
- Powerful radio galaxies, in particular bent radio galaxies can be used to find high-z clusters





HzRGs as the tracer of (proto)-clusters

Limitations of classical techniques on cluster searches

- X-ray based searches

  The extended X-ray emission associated with the intra-cluster medium is effective up to z ~ 1 (Rosati et al. 2002).

  X-ray surface brightness fades away by $(1+z)^4$

- Cluster searches based on the red sequence

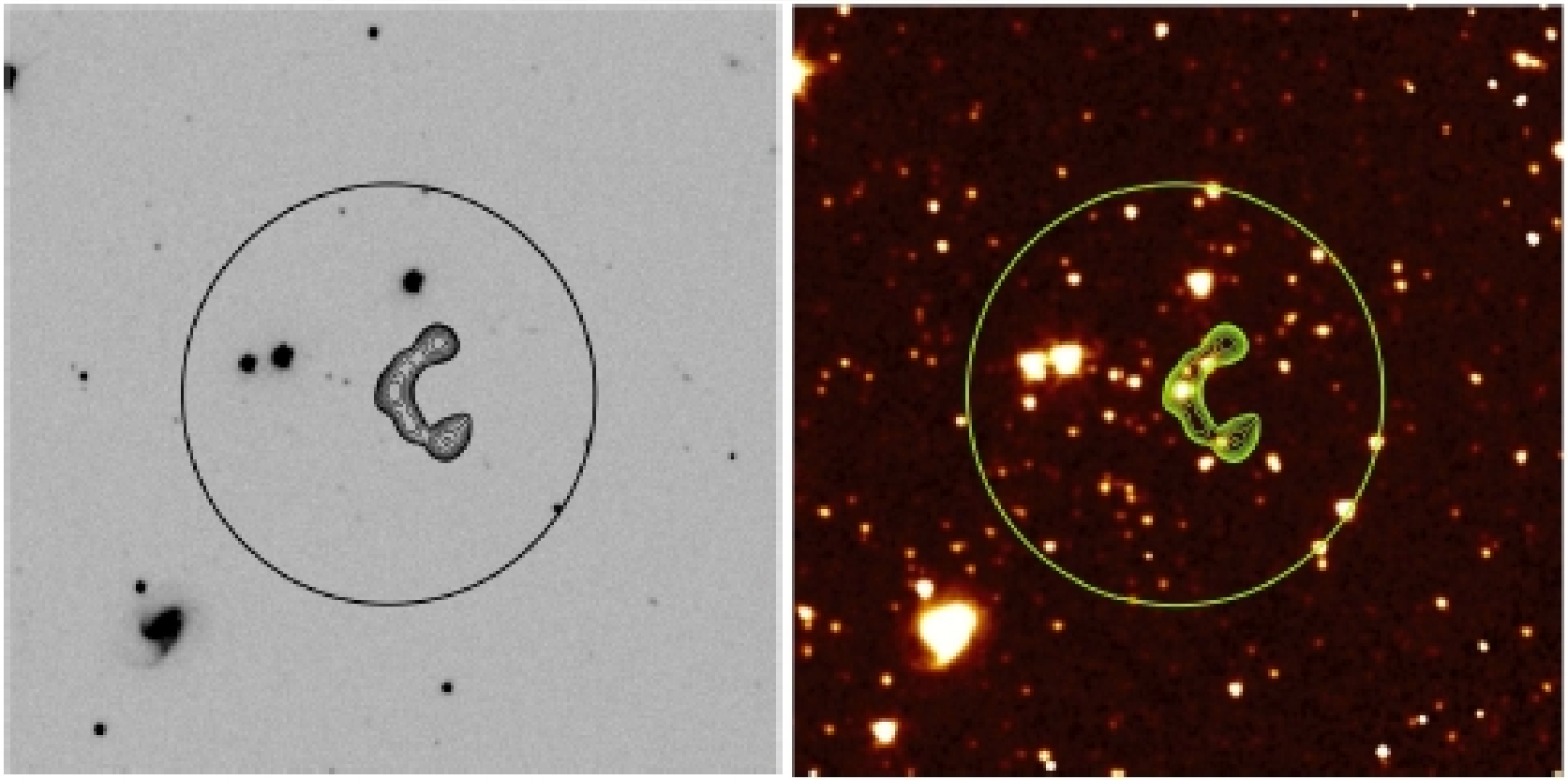
  successful upto z < 1.0

  It requires red sequence galaxies at higher-z

  and such a sequence may not exist at very high-z (Gladders & Yee 2000)

Deep Optical, near-IR observations are required

Redshift ~ 1.1



SDSS r-band

3.6 micron spitzer

Blanton et al. 2014

High-z radio galaxies with MeerKAT and SKA

* Ultra deep radio surveys (rms ~ few microJy at 1.4 GHz)

* Unveil the population of radio galaxies up redshift (z) ~ 5 - 6

* HzRGs Beacon for associated (proto)clusters at high-z

Summary

- We obtain a sufficiently large sample of 160 faint USS sources and investigate their nature using optical, near-IR and mid-IR counterparts from existing deep surveys.
- USS sources are systematically fainter with lower identification rate in optical, near-IR and mid-IR suggesting their high-z and/or obscured nature.
- The radio luminosity distribution infers that substantially high fraction (≥ 40 %) of sample sources have radio luminosities typical FRII radio galaxies.
- A large fraction (~ 50%) of USS have $S_{1.4GHz}$ / $S_{3.6\ micron}$ and redshifts similar to dusty SMGs/ULIRGs. These source are likely to be AGNs hosted in dusty obscured galaxies.
- USS sources without redshifts also do not have detection in deep K-bands and 3.6 micron Images. Flux ratio limits on radio to mid-IR infers these sources to be HzRGs or heavily obscured HzRGs at moderate redshifts (z ~ 2 - 3)
- USS criterion remains an efficient method to select high-z sources even at fainter flux densities.
- Powerful radio galaxies can be used to identify high-z clusters
- MeerKAT, SKA will explore further deeper in distant universe

Thank you for your attention