# GMRT deep images of legacy fields and new efforts using uGMRT

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# DEEP fields

Deep Optical/IR/X-ray observations of several small regions of sky carried out with different science goals, publicly available

CANDLES, CDF, DEEP2, EGS, ELIAS-N1/S1, HDF, LOCKMAN HOLE, VIRMOS-VLT, VLACOSMOS, XMM-LSS, + + , and ultra-deep variants

Most of the fields lack radio observations <1 GHz

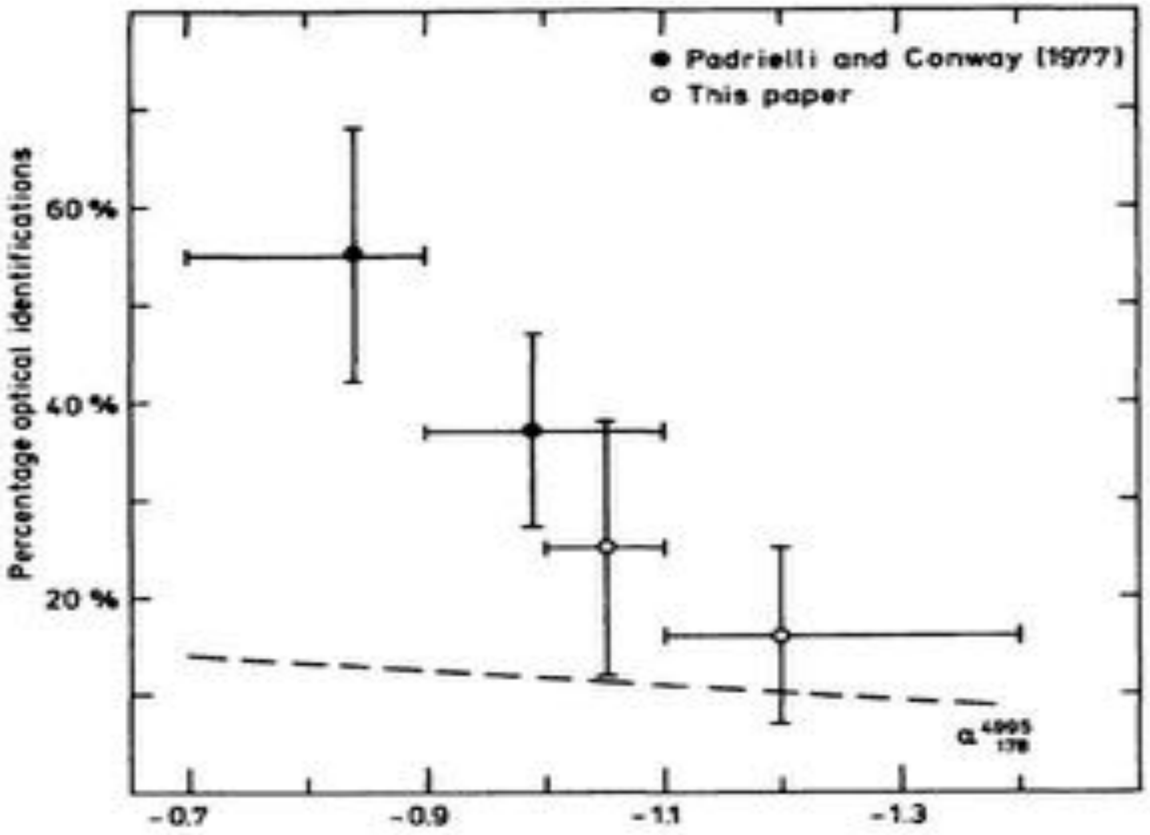
– ***advantage GMRT ; different science goals***

Advantage starting from radio (dust) ; double advantage low freq (stronger)

# Optical identification of RGs

**Lessons from 3C Sources:** Steep spectrum sources are more distant as compared to the sources with normal spectra

Most of the High-z (z > 3) radio galaxies known today (~ 50) are discovered using this correlation.




*Blumenthal and Miley (1979);*

*Miley & de-Breuck (2008; review);*

*Ishwara-Chandra et al. 2010 ;*

*Ker et al. 2012*

# Radio: The most efficient band to find high-redshift radio galaxies (HzRGs).

- Radio spectral-index – redshift correlation is most efficient to find HzRGs.
- Samples selected at low frequencies like 150 MHz have significantly higher fraction of HzRGs as against at 1.4 GHz (Ker et al. 2012)
- Method: Shortlist USS **---** get accurate radio positions, **---** discard nearby objects using known optical surveys, **---** get K-band imaging (*K-z relation*) and last, spectroscopy (the major limitation).. ***(or the reverse)***
- **Till date, there is <u>only one</u> radio galaxy known with z > 5 (*discovered in 1999*)!!**

# Our Work using GMRT

We have started a programme with GMRT to search for HzRGs

***taking advantage of***

Radio is the most efficient band to discover HzRGS

***and***

Low frequency is best ! (*Ker et al 2012*)

*Contributed to TMT(-India)  and SKA(-India) science case.*

*Miley and de breuck, 2008; Ishwara-Chandra et al, 2010*

# Known Objects at z > 5

In SDSS alone, several hundreds of quasars at z > 5…

LBGs – Large number of Lyman Break Galaxies known at z > 5
(*eg: Tilvi et al. 2013, McLure et al. 2010*)

***Only one radio galaxy at z > 5! (****van Breugel, et al. 1999****)***

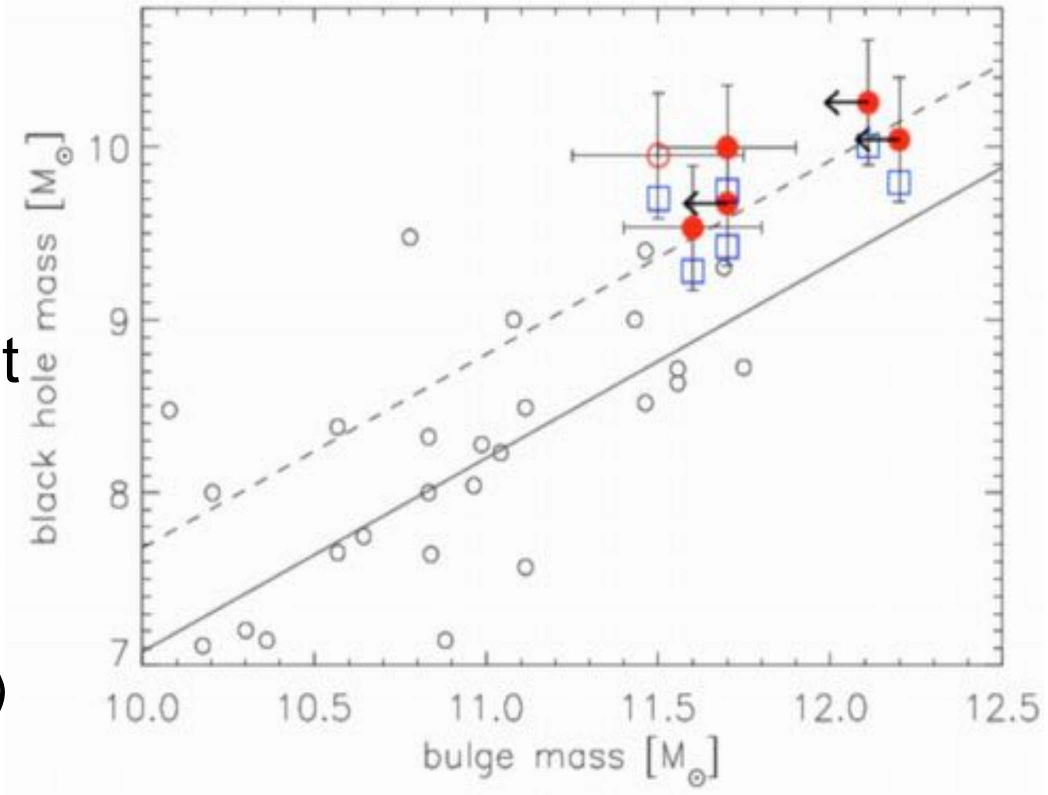
# Why high-redshift radio galaxies?

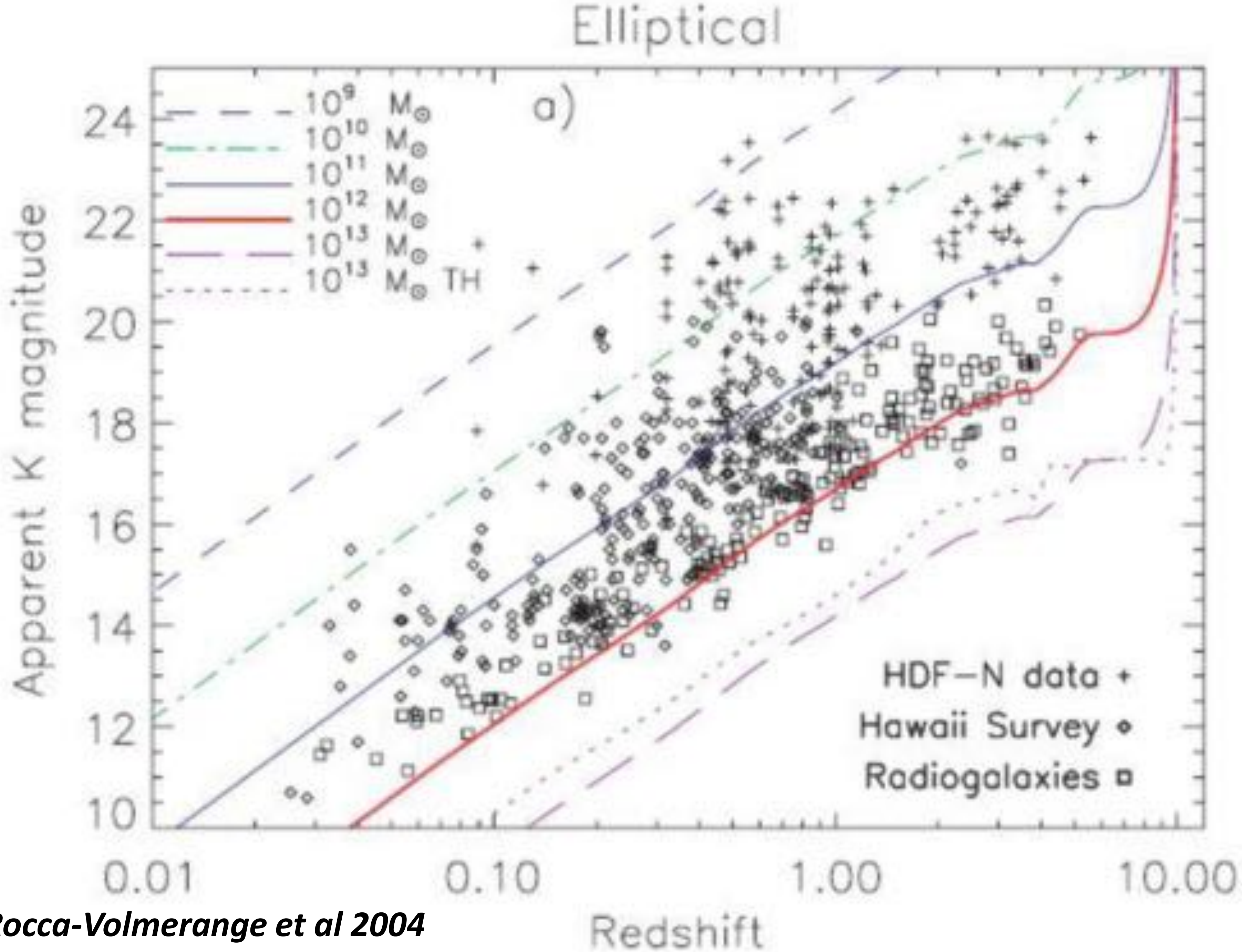
- **They trace most massive galaxies!**

**Formation and Evolution of Galaxies:** Host galaxies are the most massive and at the top end of mass function. High star formation up to 1500 $M_{\Theta}$ per year (eg: *Rocca-Volmerange et al, 2013; Dey 1997*)

Hosts most massive BH (eg: *Nesvadba et al, 2011*)

Radio Advantage: Unbiased from dust extinction (problem in optical) guaranteed massive systems; 3 mag brighter in K, easy to get redshifts. *(Kerr et al, 2012; Miley and de Breuck, 2008)*






***Rocca-Volmerange et al 2004***

# Why high-redshift radio galaxies?

## Evolution of Radio Galaxies and Quasars

- Does HzRG population decrease beyond redshift of 4?
- Evidence for redshift cutoff (1990) not valid anymore (2009) ?

## Supermassive BH formation at these epochs

*Relationship between SMBH and host galaxy is a key problem*

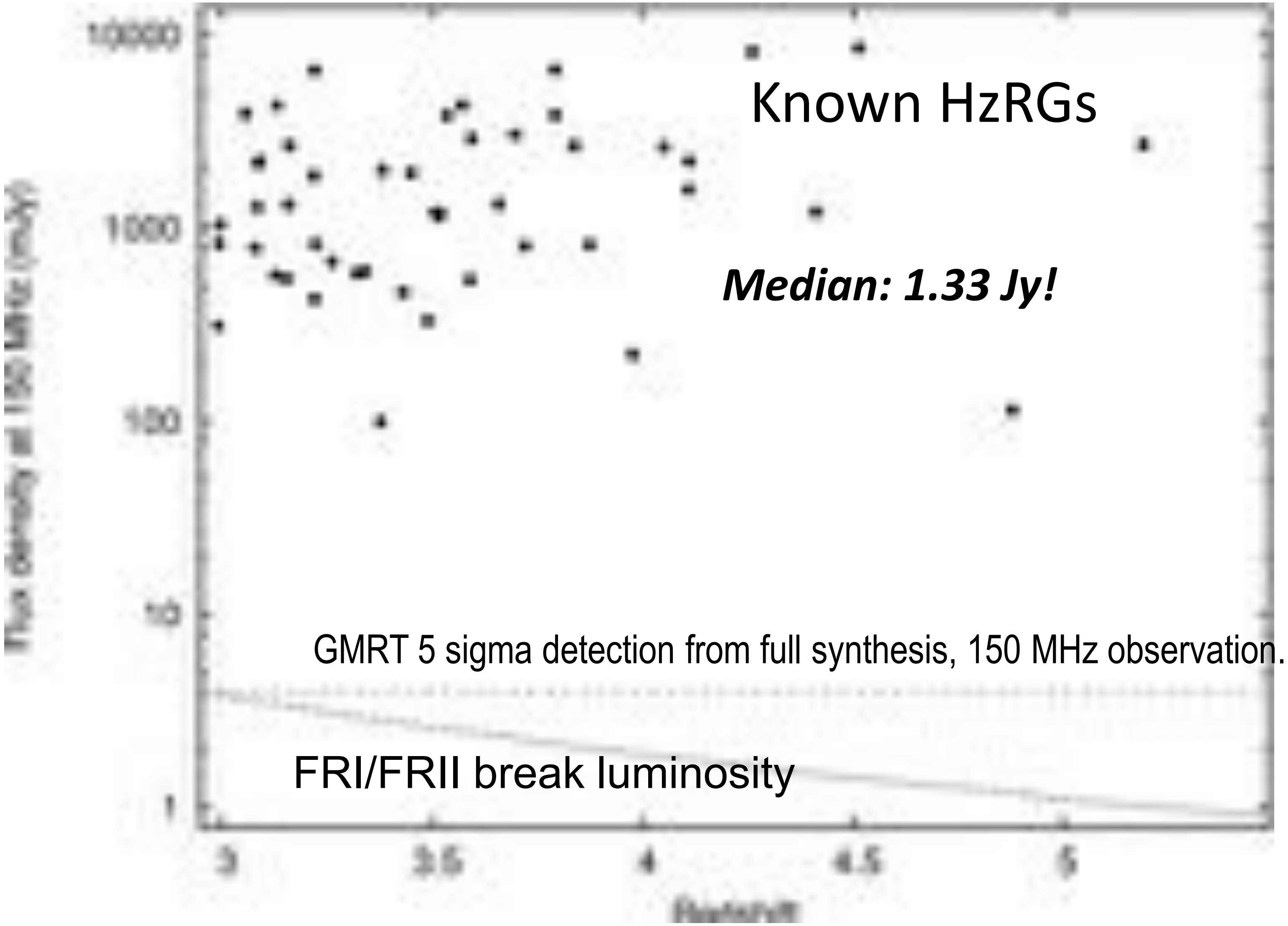
## As proxy to discover protoclusters

HzRGs mark the locations of galaxy overdense regions.

## What triggers Radio Jets?

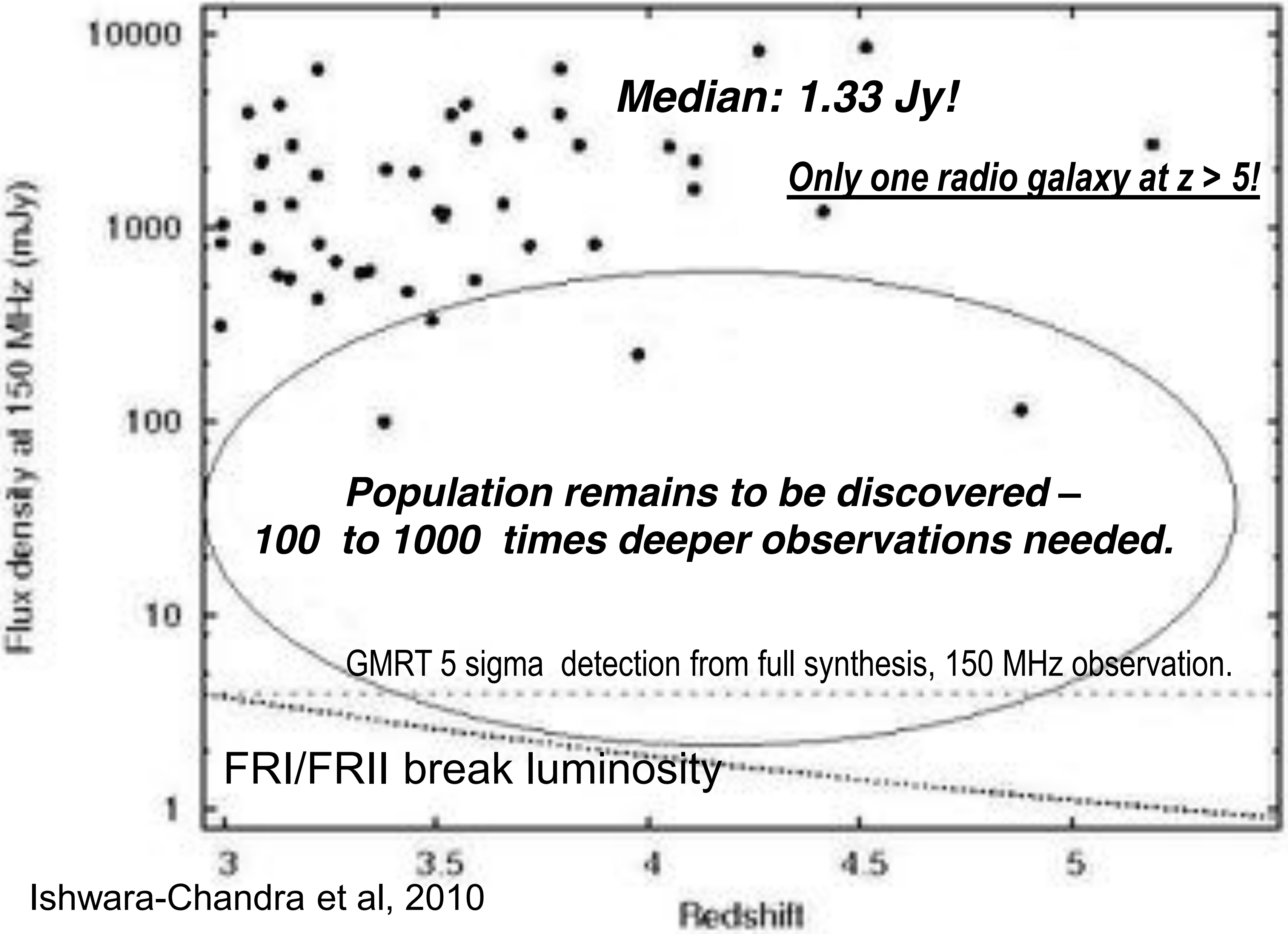
*Jarvis et al. 2001; Donoso, Best and Kauffmann, 2009, Ker et. al 2012, Afonso et al 2015 – SKA Science Chapter*

# The 150-MHz flux densities of known HzRGs,




*Ishwara-Chandra C. H et al. 2010*

# Known HzRGs:- Tip of the iceberg?

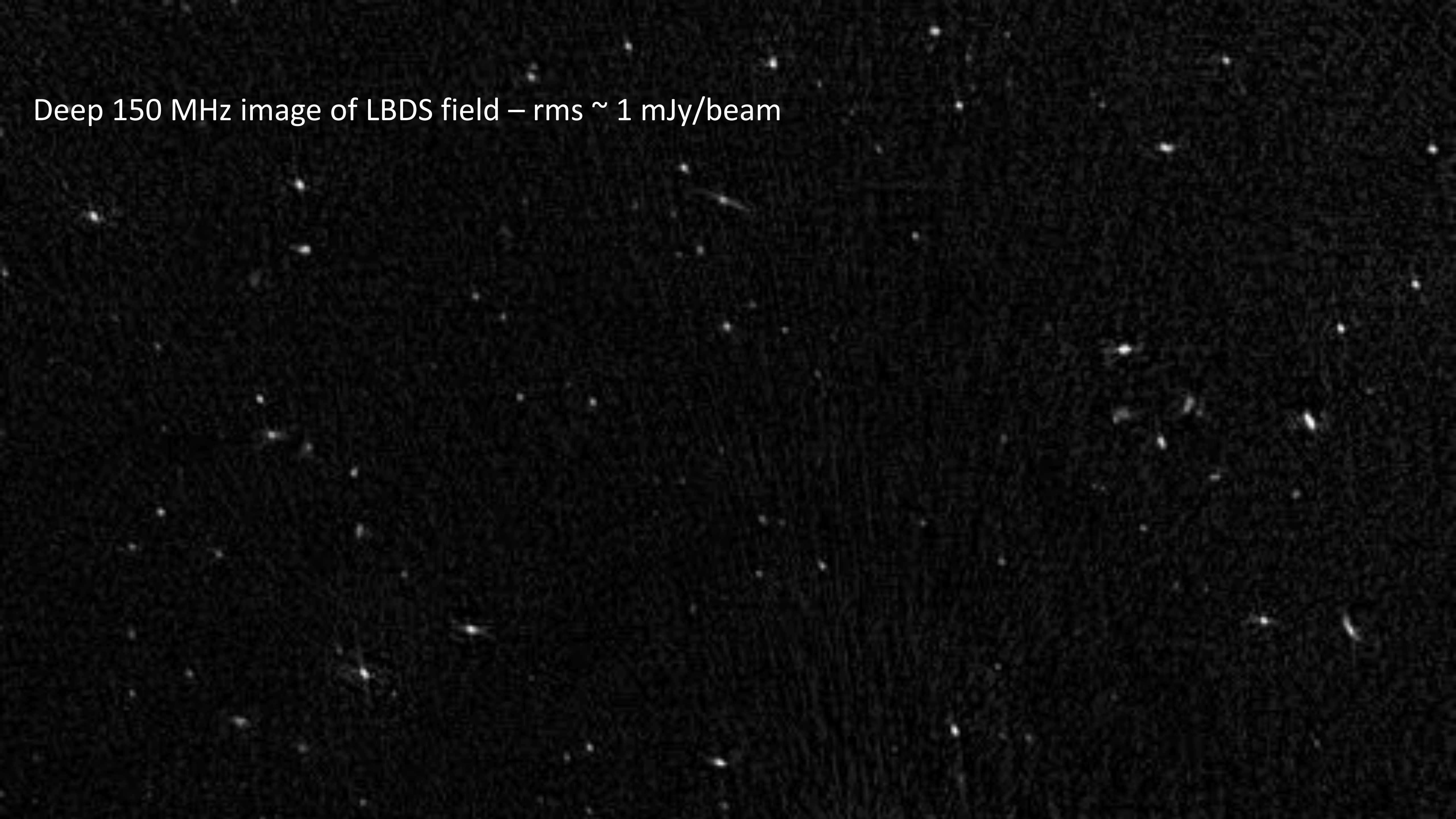



Ishwara-Chandra et al, 2010

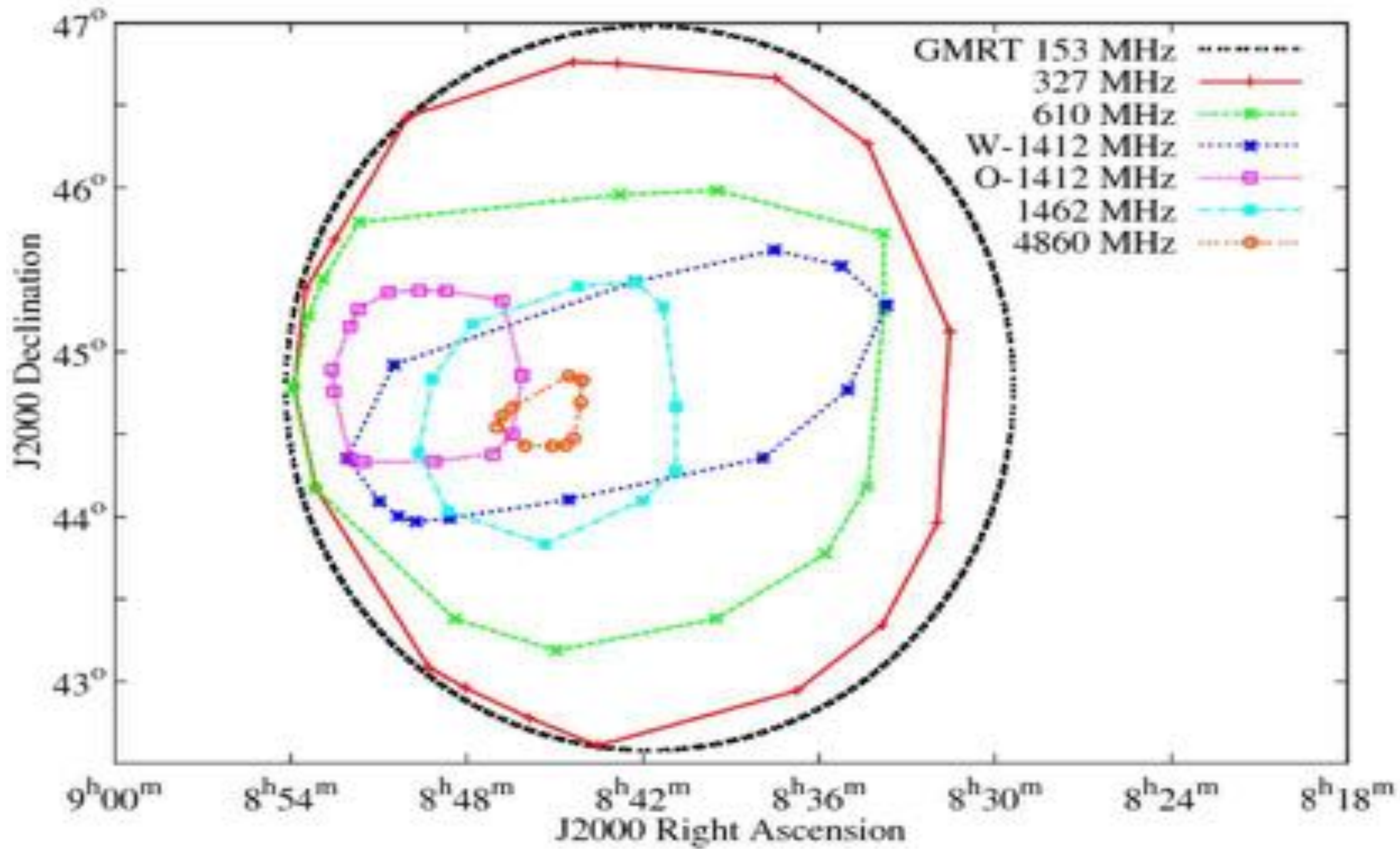
# The GMRT Programme....

- To optmize the search, 'well known deep fields' are chosen for observing ***at 150 MHz*, **which don't have radio data below 1.4 GHz ***(in 'reverse' direction)***
- **LBDS** – ***Ishwara-Chandra et al, 2010, MNRAS, 405, 436***
- **DEEP-II-1,2,3** (~2 deg X 0.5 deg/field & 50,000 spectra)
- **VIRMOS-VLT** – (~ 4 degree$^2$ and 10,000 spectra)
- **VLA-COSMOS** - (~ 2 degree$^2$ and 40,000 spectra)
- **HDF/GOODS-N** – small field of view, but wealth of data .
- **Deep Fields from HerMES (***Wadadekar, Veeresh***)**

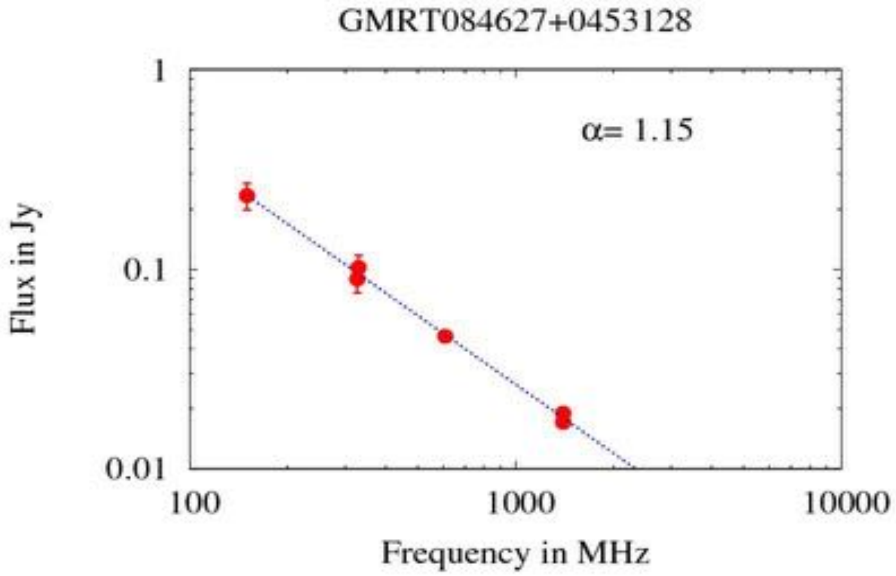
Deep 150 MHz image of LBDS field – rms ~ 1 mJy/beam

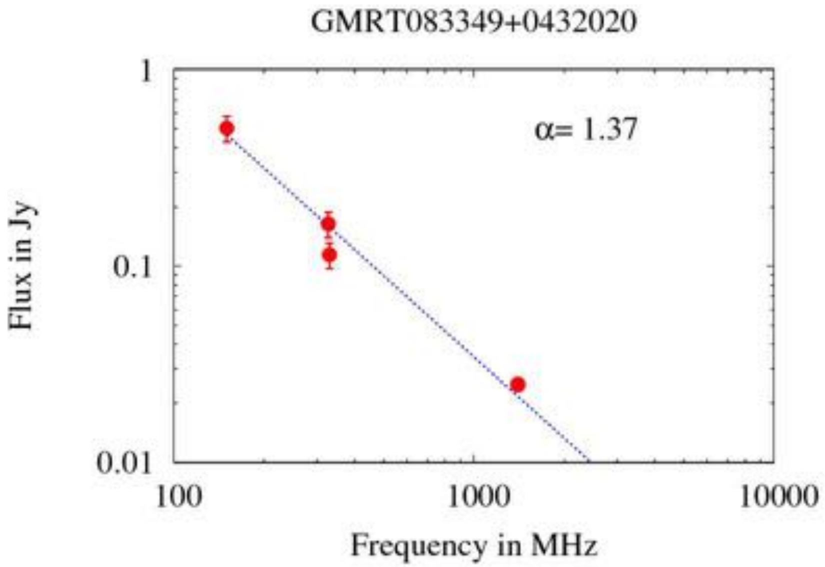


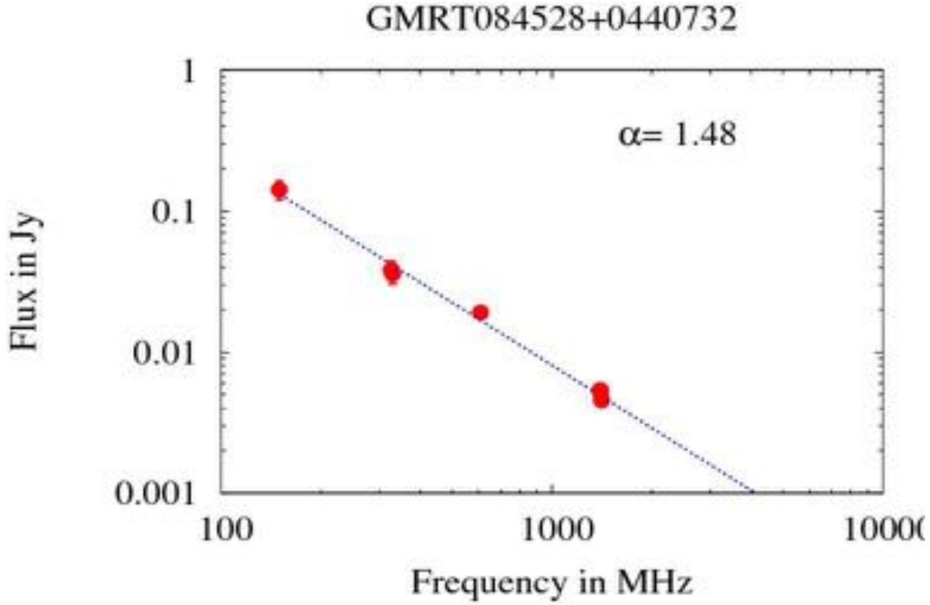
# Other available radio data...

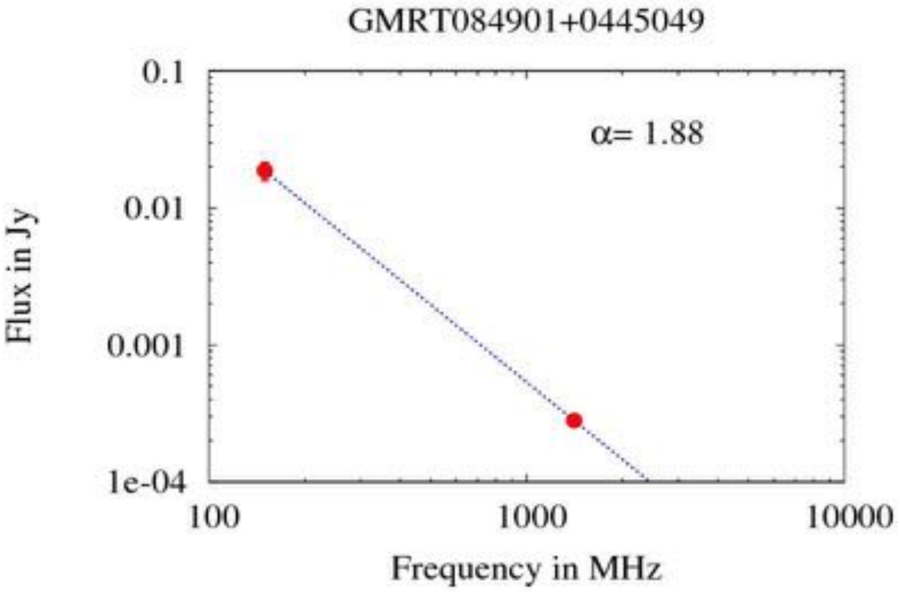


# A few steep spectrum sources



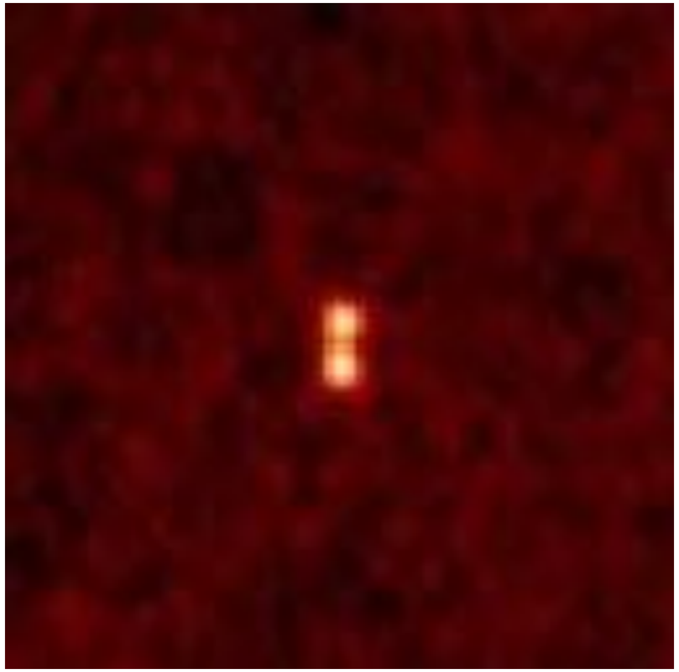



# Results – LBDS

- 98 steep spectrum sources don't have counterparts in SDSS, majority of them unresolved and are strong candidates for HzRGs.
- Further progress on deep K-band imaging and spectroscopy is needed to estimate redshift. Being followed up at MIT..
- One of the object has clear FR-II morphology, based on FRI/FRII luminosity break, its redshift is likely to be > 2



# The GMRT Programme - Extended

- Some 150 MHz observations severely affected by RFI.
- Deep (re-) observations at 325 MHz in 2014
- Resolution of ~ 8 to 10” optimum..
- 100 microJy rms from 1.5 hours on source

- Some more fields observed by collaborators
- 325 MHz is 1400 MHz for redshift 3.3 (*will pickup GPS beyond z=1*)
- Also useful to pickup low power radio sources – IFRS, FR0s
- Other byproducts from these deep observations.

# Results - 325 MHz

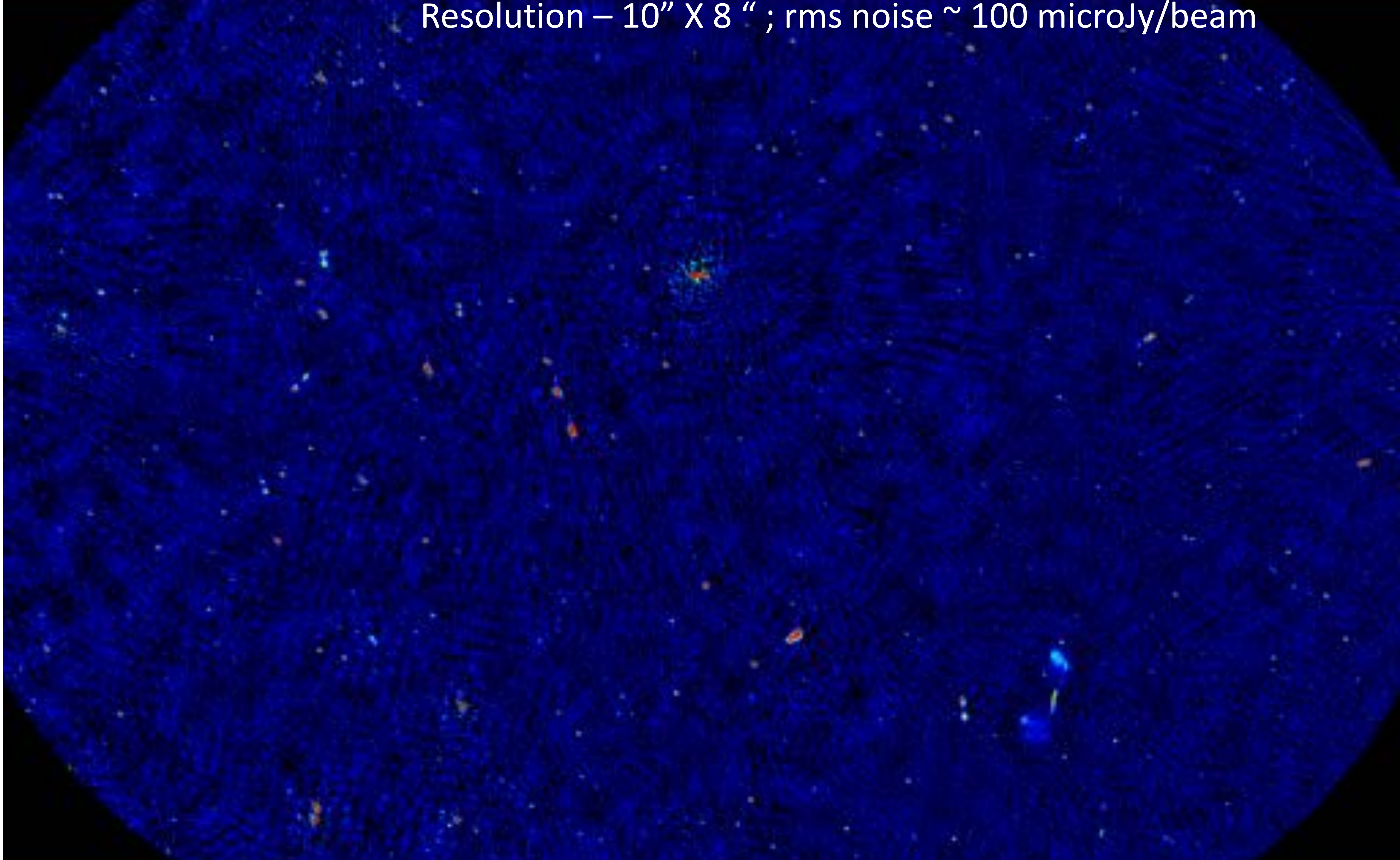
Two of the DEEP2 fields fully analysed at 325 MHz (16h and 02h)

*two pointing each*

Analysis using AIPS; flagging using flagcal, FLGIT and “manual”; 100 microJy from 90 mins ON-Source time (150 microJy in second)

# One of the DEEP2 field at 325 MHz

Resolution – 10” X 8 “ ; rms noise ~ 100 microJy/beam



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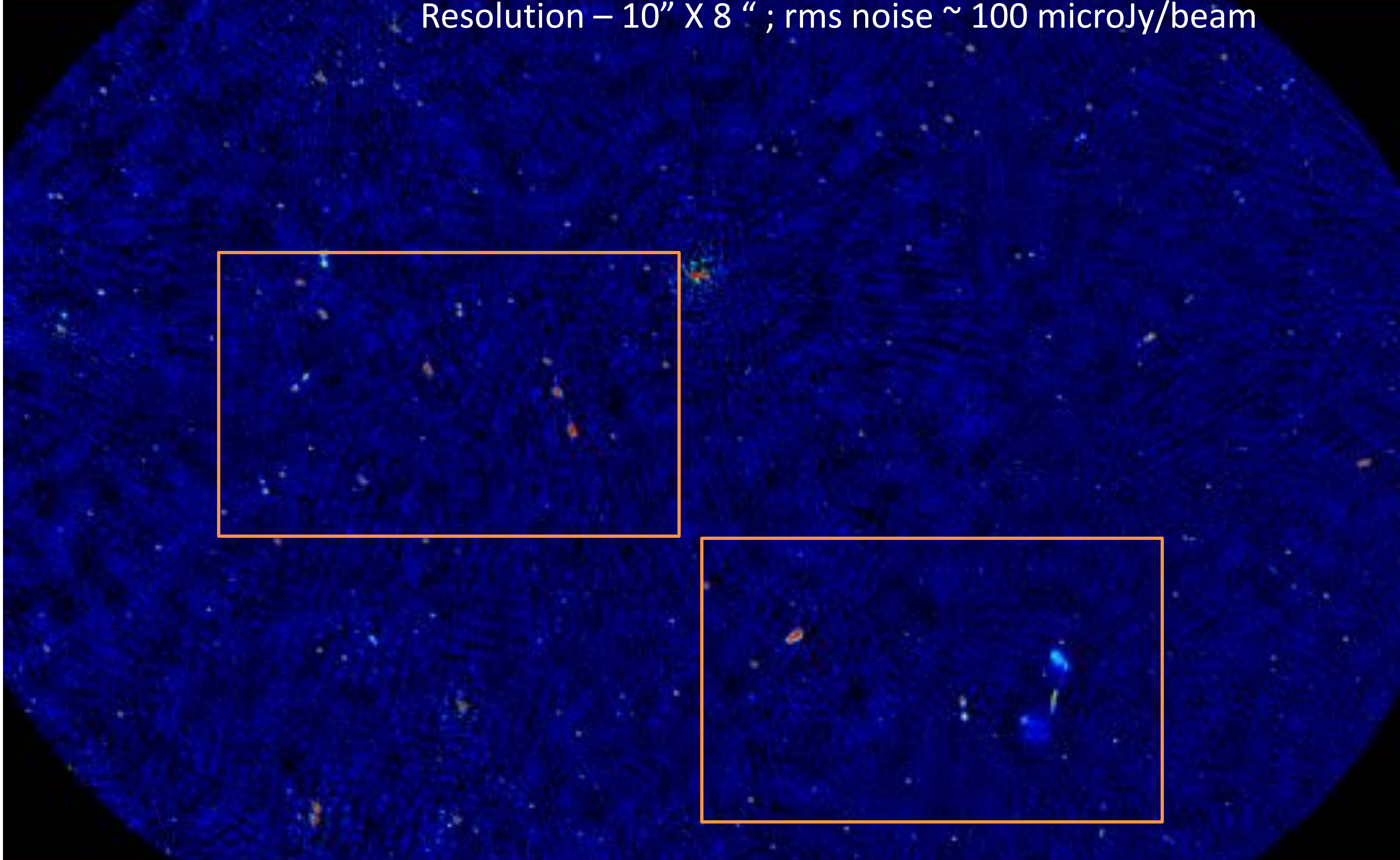
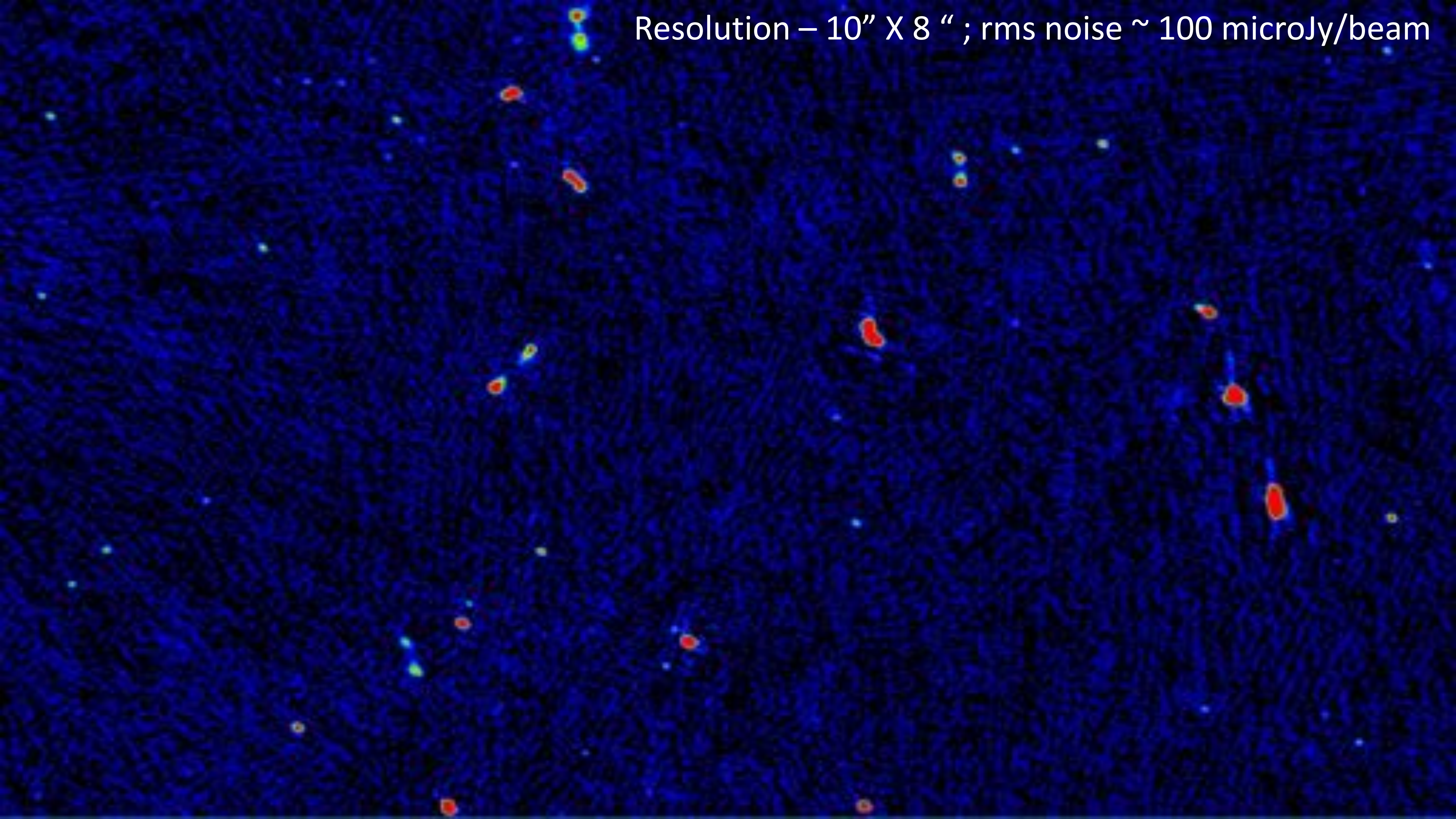


Resolution – 10” X 8 “ ; rms noise ~ 100 microJy/beam



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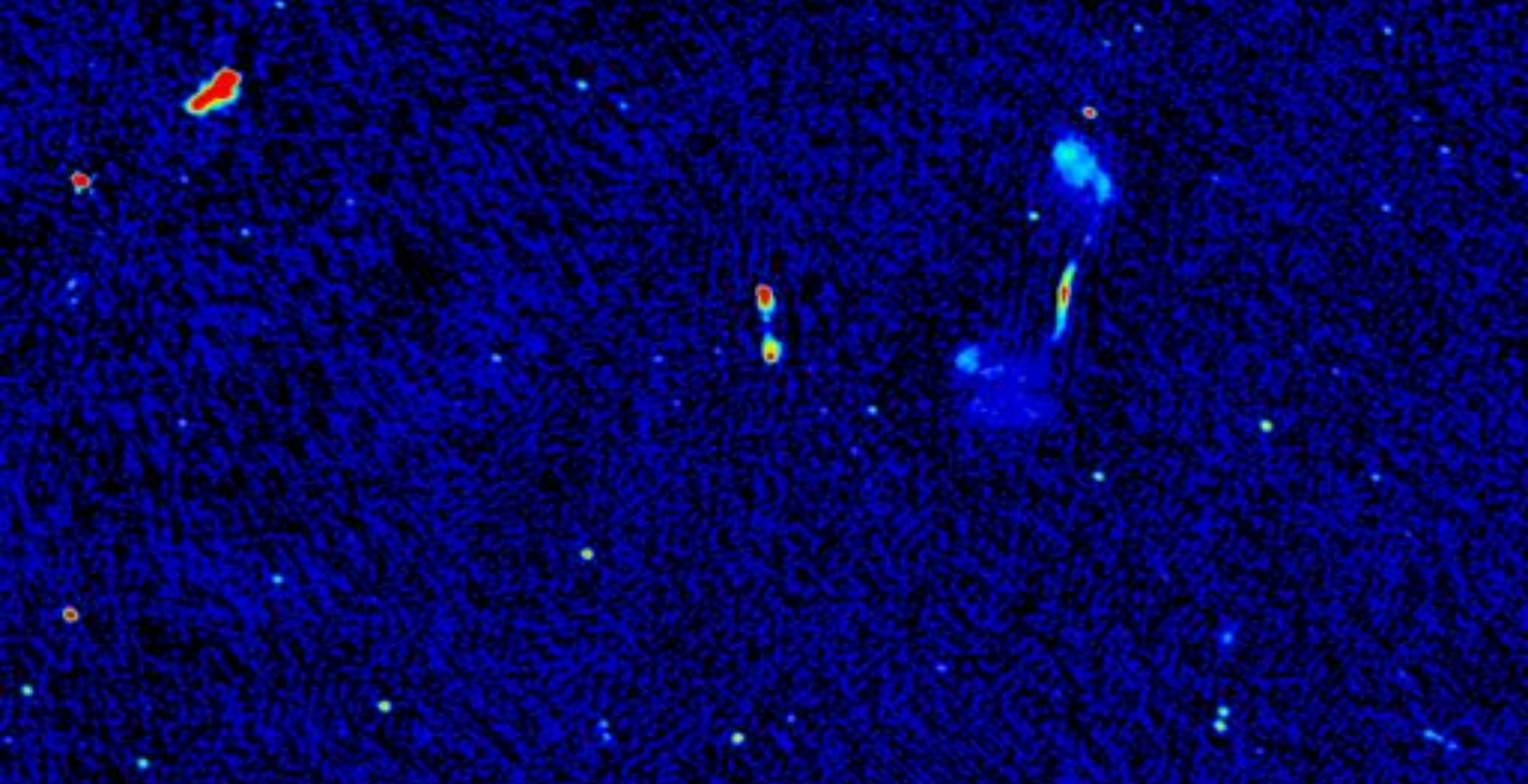


# Results – 325 MHz

Two of the DEEP2 fields fully analysed at 325 MHz (16h and 02h)

*two pointing each*

Analysis using AIPS; flagging using flagcal, FLGIT and "manual"; 100 microJy from 90 mins ON-Source time (150 microJy in second field)

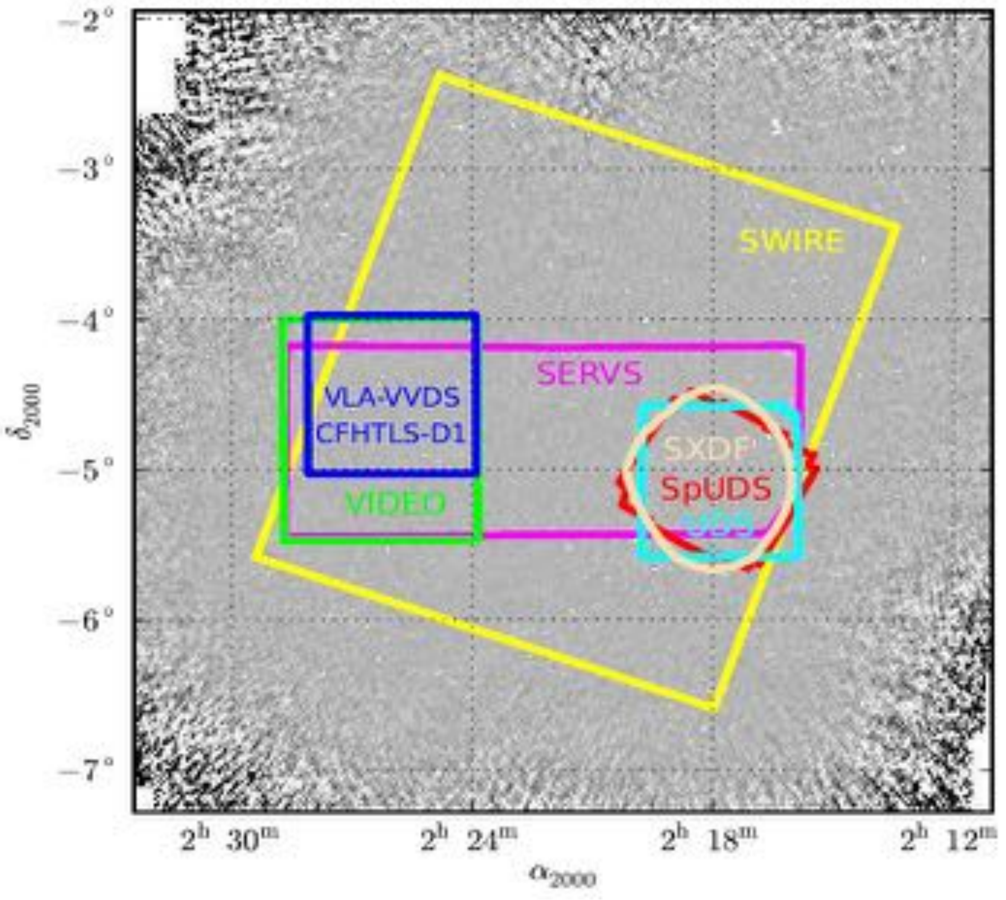
Source catalogue using PyBDSM (for field 1 ; excellent!)

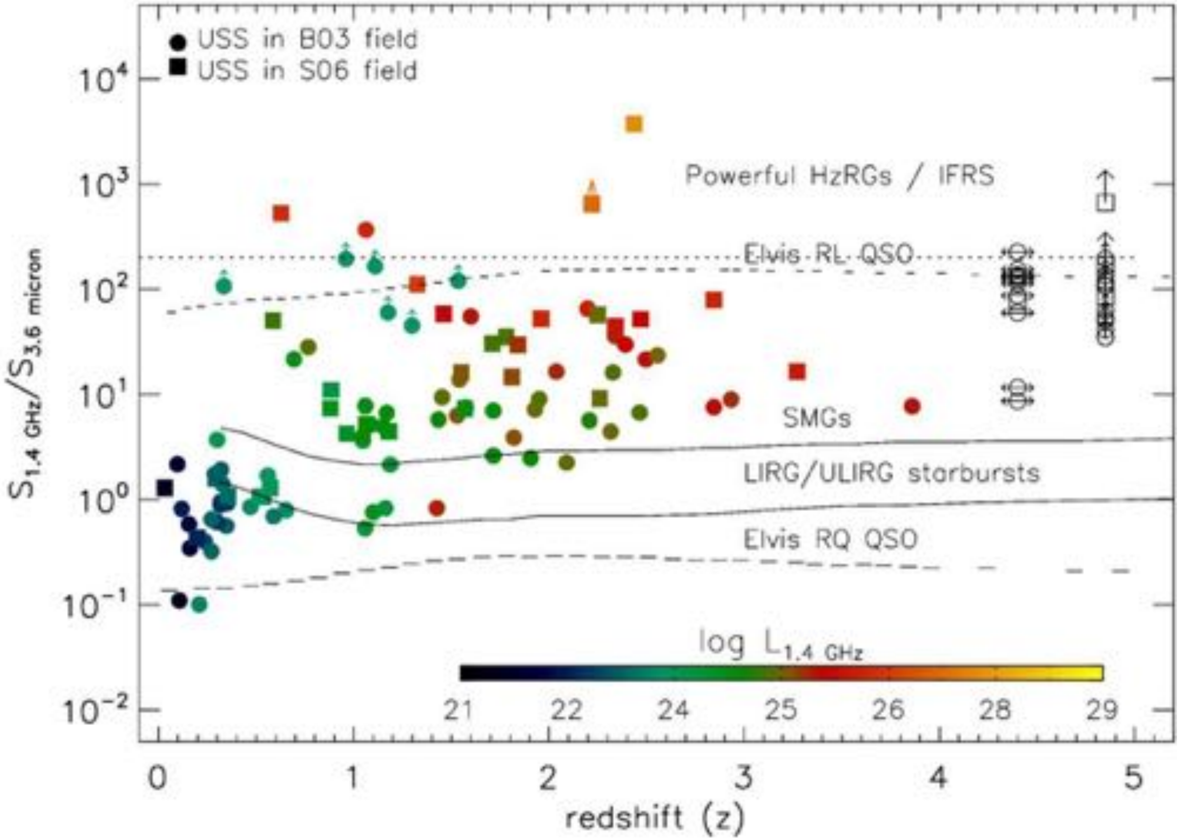
~ 750 sources within 2.5 degree^2

Cross matched with VLA FIRST for spectral index

(*Ishwara-Chandra CH, 2016, PoS*)

# XMM-LS at 325 MHz with GMRT




Steep spectrum criteria effective at submJy levels also for detecting high-z sources - ***talk by Veeresh***

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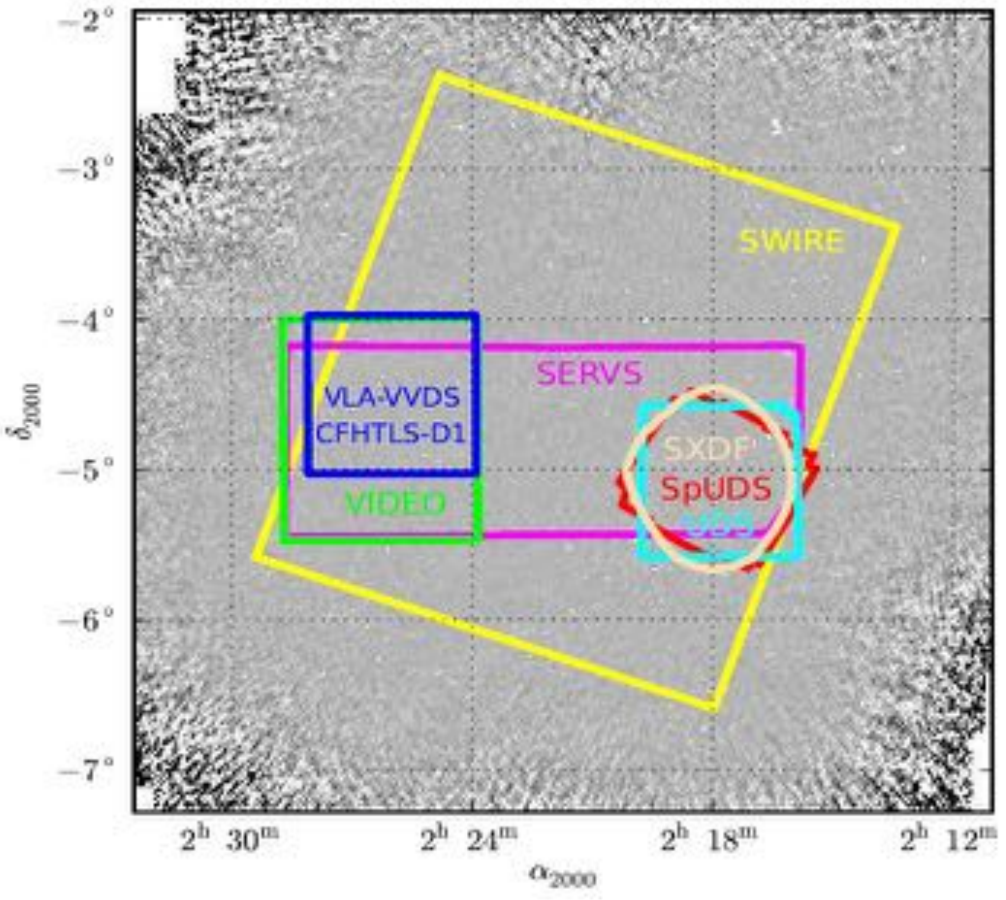


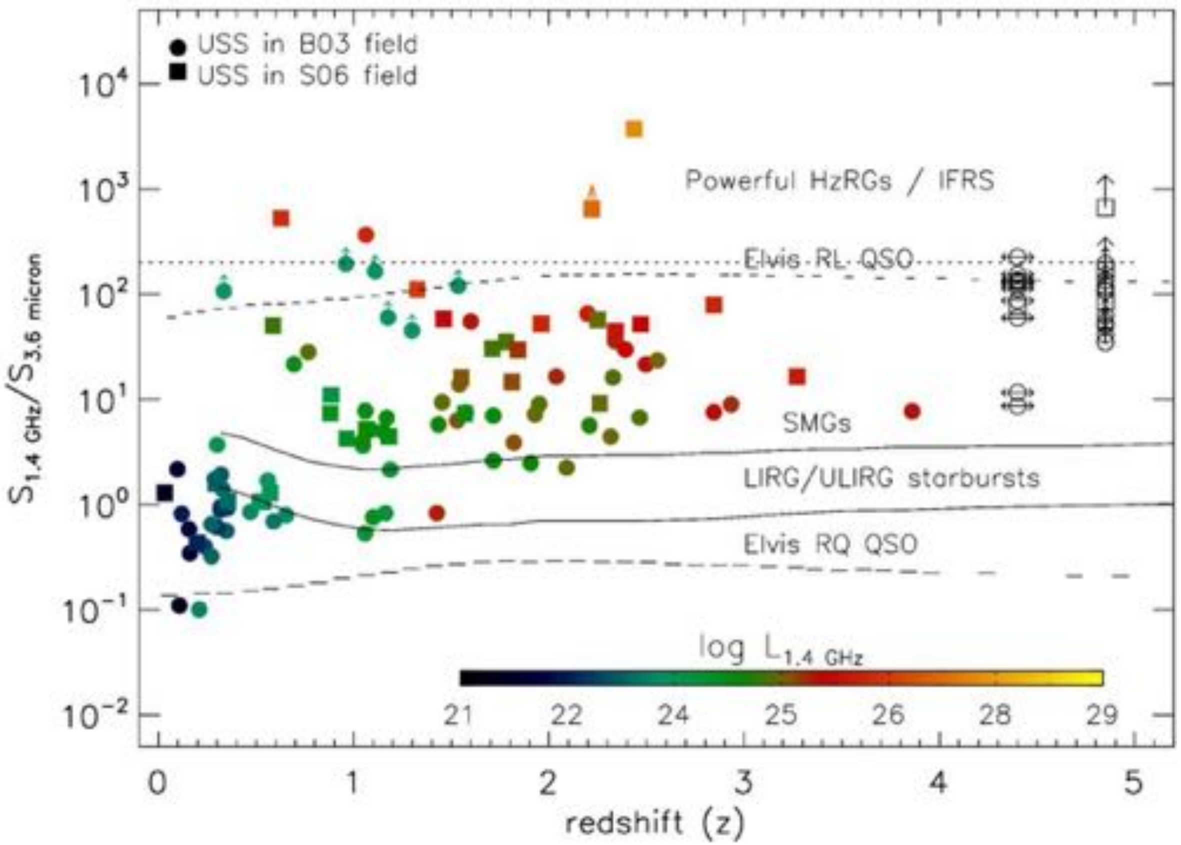


Steep spectrum criteria effective at submJy levels also for detecting high-z sources - ***talk by Veeresh***

***Will be doing uGMRT L-band (400 MHz BW) observation shortly***

# Summary and future…

One of the DEEP2 fields at 325 MHz done; ~ 750 sources over 2.5 deg$^2$ > 0.5 mJy ;
~ 120 sources with alpha steeper than 1 have NO SDSS counterparts

– *strong candidates for HzRGs.*

Study of Faint radio sources – IFRS, FR0 ?

*GPS at z = 3 will peak at 325 MHz*

With 16-antenna *u*GMRT, 25 hour data on single pointing at 610 MHz

– *work in progress to obtain* ***deepest*** *image*

The upgraded 325 MHz band is uniquely positioned and can detect ALL FR-II Radio Sources out to z ≈ 5.

Early SKA science on deep fields with uGMRT (325 MHz; 200 MHz BW) planned;