

From GMRT to uGMRT and beyond: Prospects for studying diffuse extended sources



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Outline

- Galaxy clusters: diffuse large-scale radio sources
- Extended GMRT Radio Halo Survey: Precursor to future cluster surveys
- Ongoing projects: Filling the gaps in sky and redshift
- Spectral index mapping: wide band implications
- uGMRT :early images from the 16 antenna system
- Summary

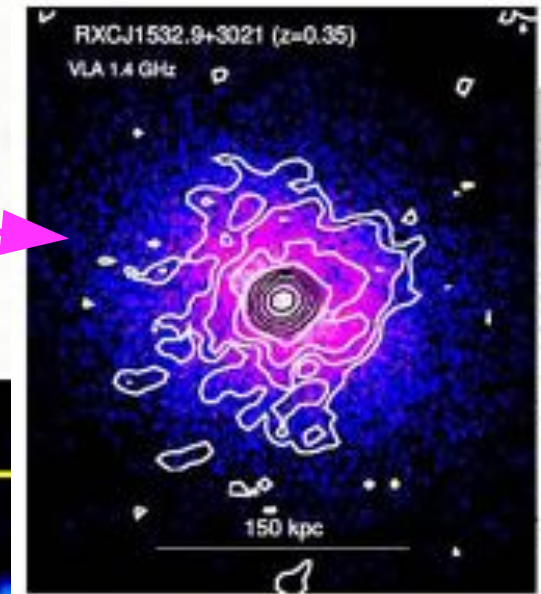
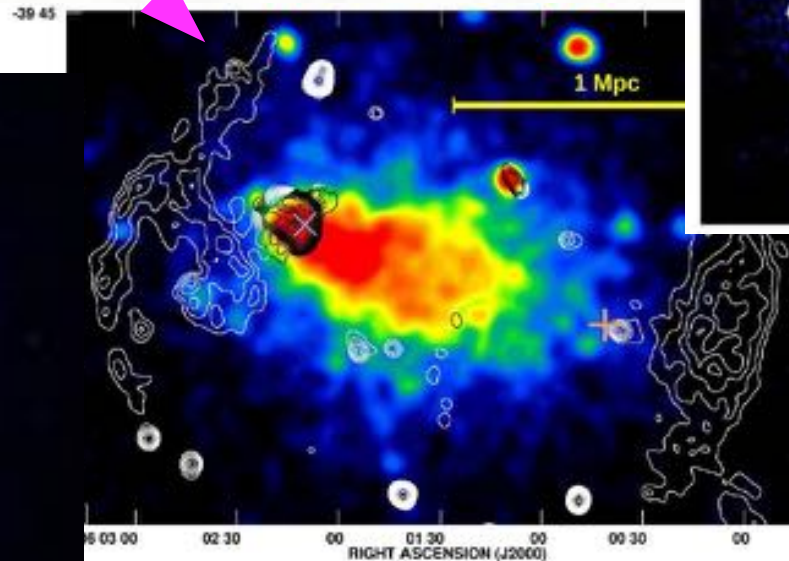
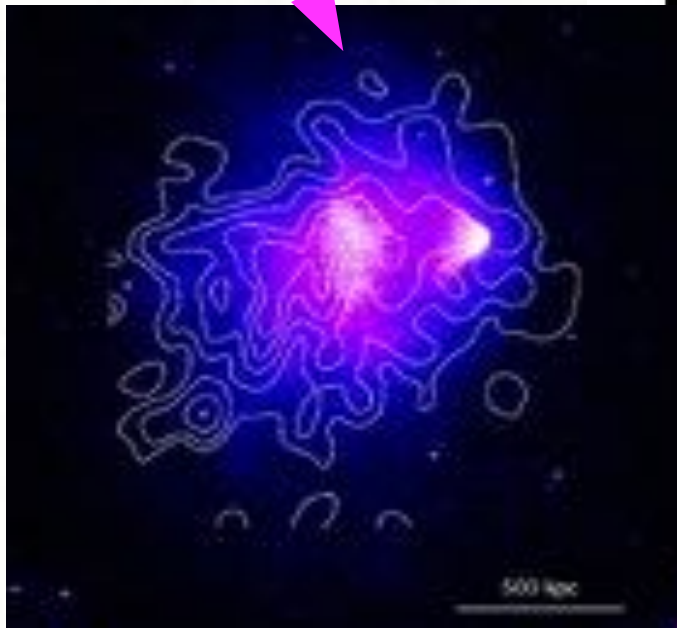
Cluster radio sources (~ 100 s kpc)

Diffuse synchrotron sources
100s kpc to Mpc scales

Hlavacek-Larrondo 2013;
Kale et al 2013

Radio halos, relics and mini-halos

Review: Brunetti & Jones
2014



Abell 3376, Kale et al. 2012, Bagchi et al 2006

Bullet cluster, Liang et al 2000, Markevitch et al 2005

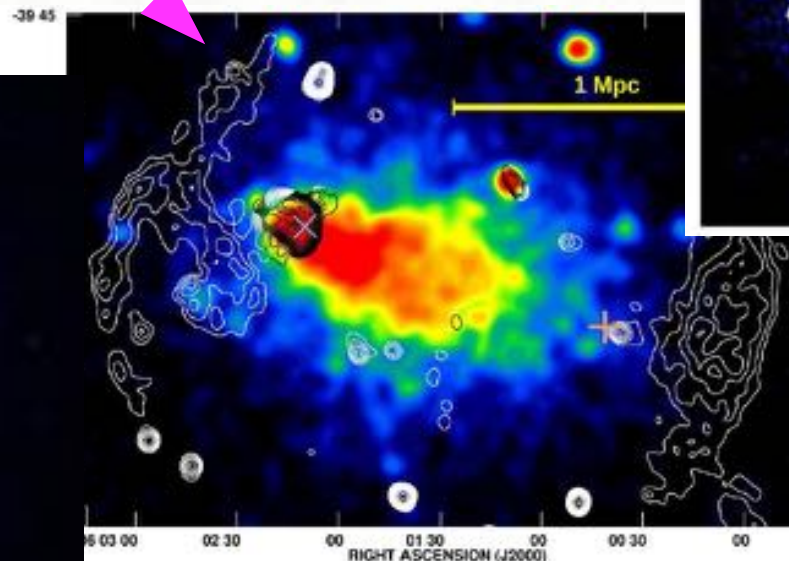
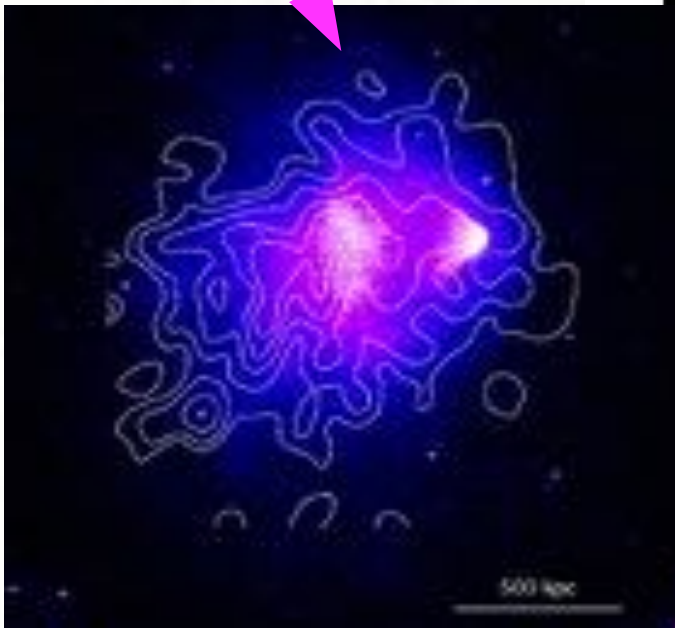
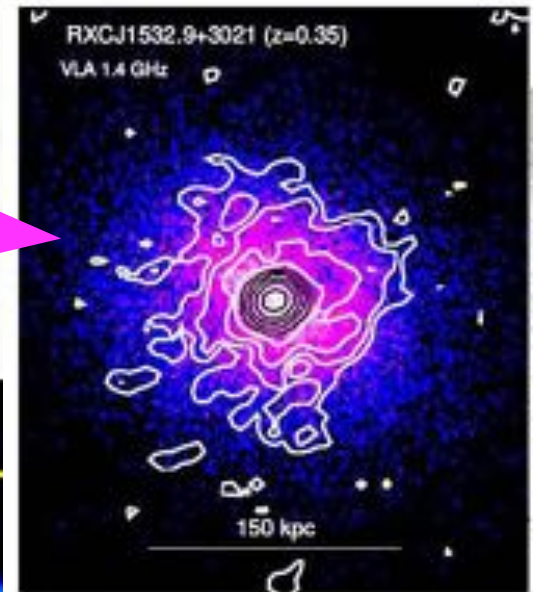
Cluster radio sources (~ 100 s kpc)

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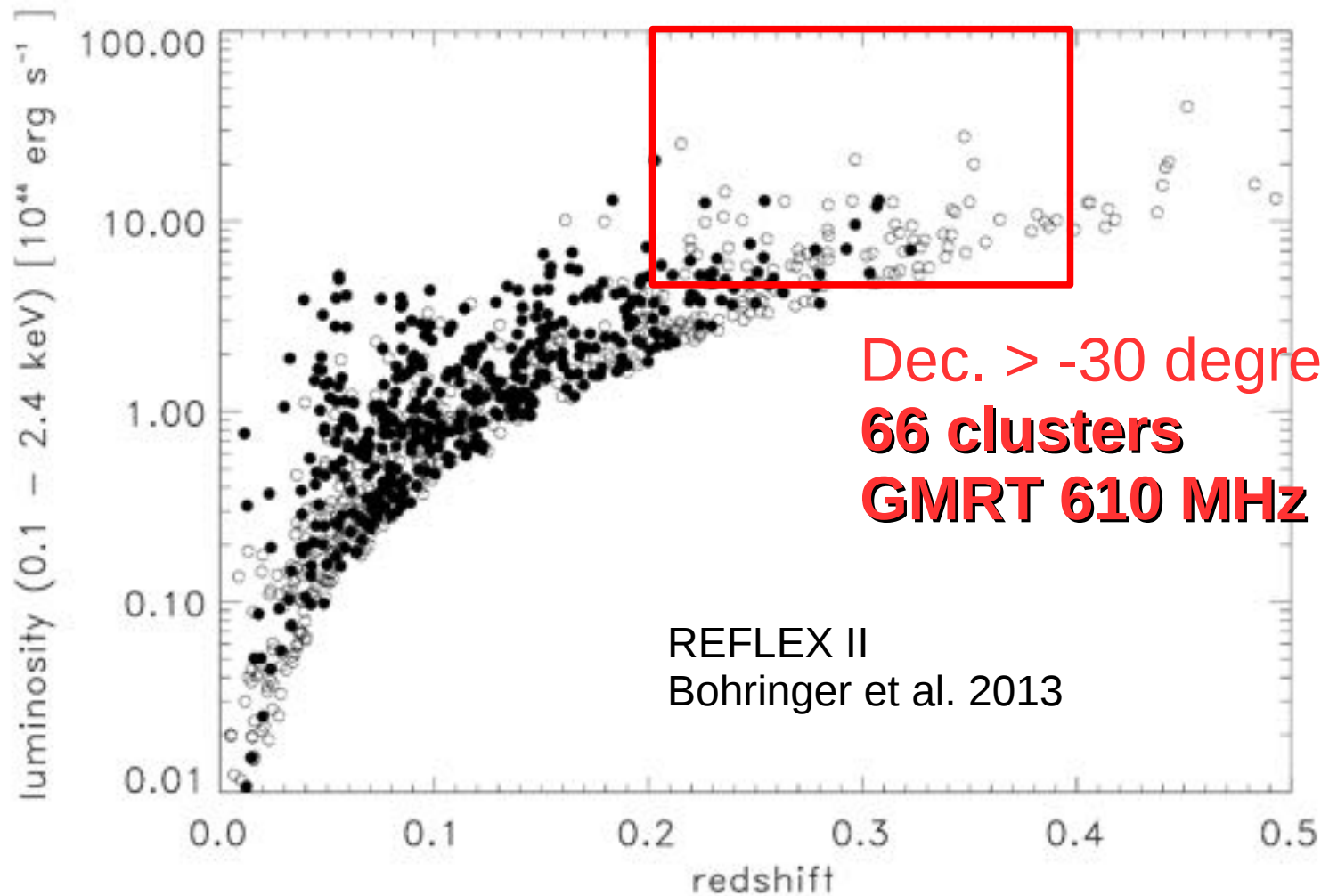
RARE ?

Abell 3376, Kale et al. 2012, Bagchi et al 2006

Bullet cluster, Liang et al 2000, Markevitch et al 2005

Clusters surveys

Extended GMRT Radio Halo Survey (GRHS + EGRHS)

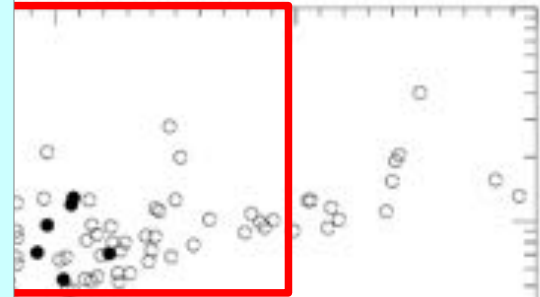


GRHS : Venturi et al 2007, 2008; EGRHS: Kale et al 2013, 2015a

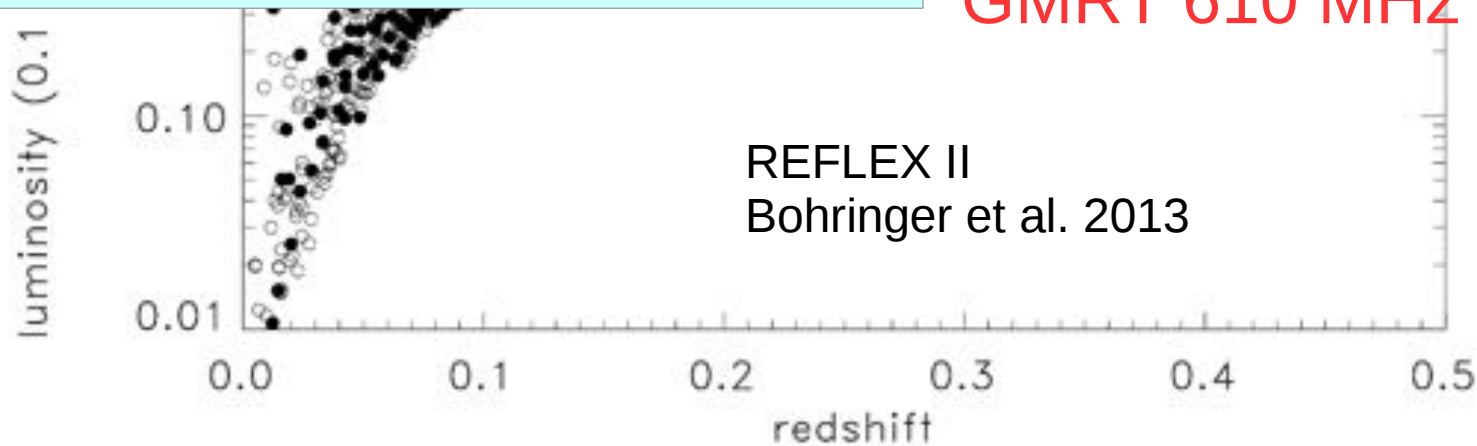
Clusters surveys

Extended GMRT Radio Halo Survey (GRHS + EGRHS)

GMRT imaging ~ - 53 degrees!
Southern declinations still unexplored

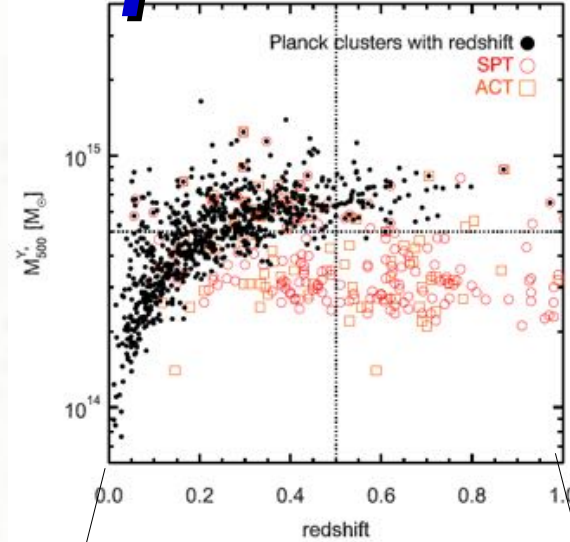
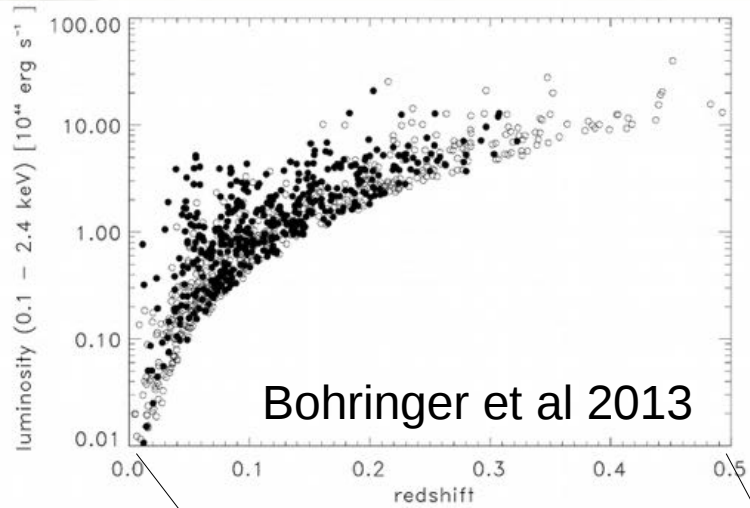


Dec. > -30 degrees
66 clusters
GMRT 610 MHz



GRHS : Venturi et al 2007, 2008; EGRHS: Kale et al 2013, 2015a

Clusters near and far: Planck, SPT



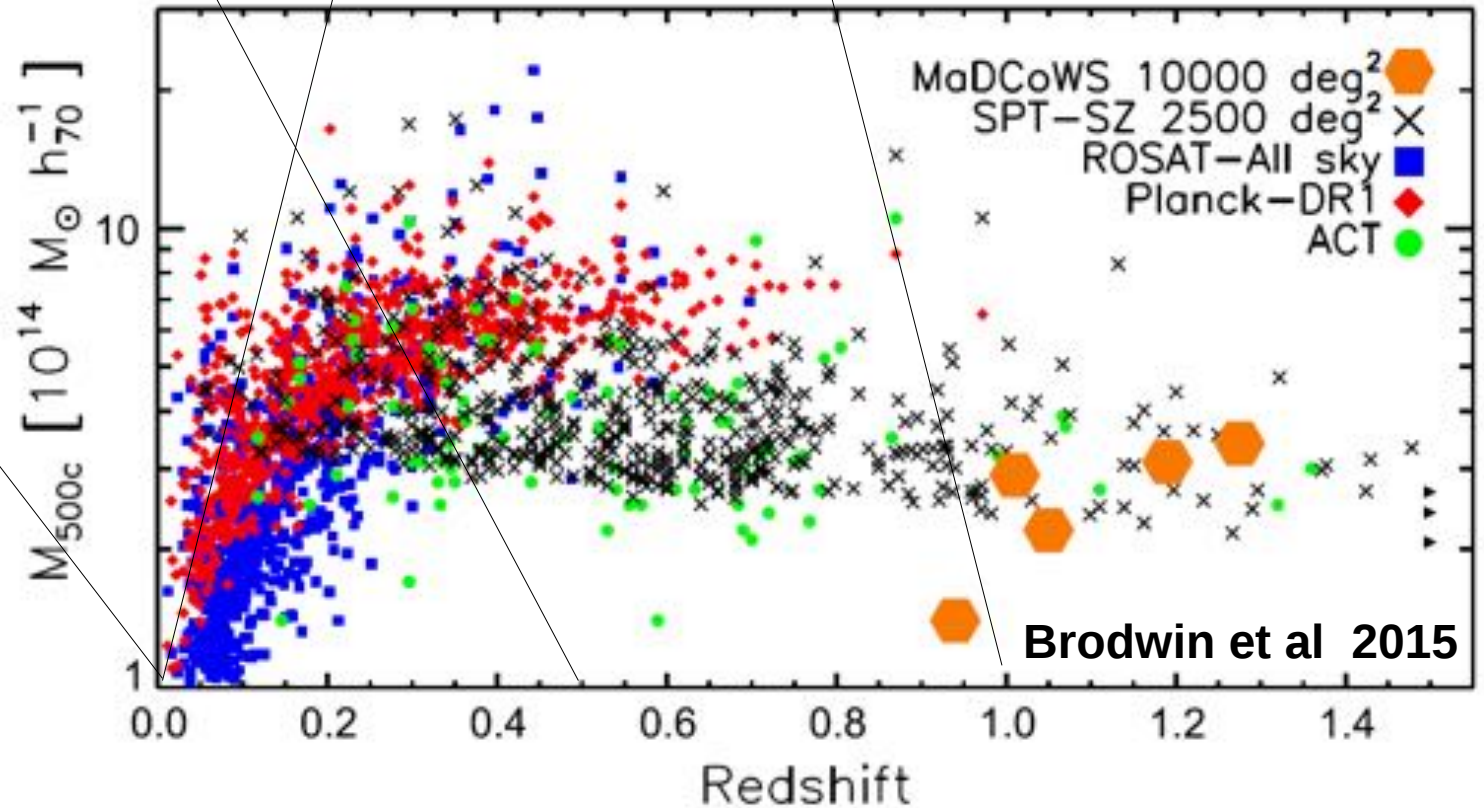
Planck collaboration
2014

SPT Reichardt
et al. 2013; Bleem et
al. 2015
ACT: Marriage et al.
2011; Hasselfield et al.
2013

X-ray flux limited
samples

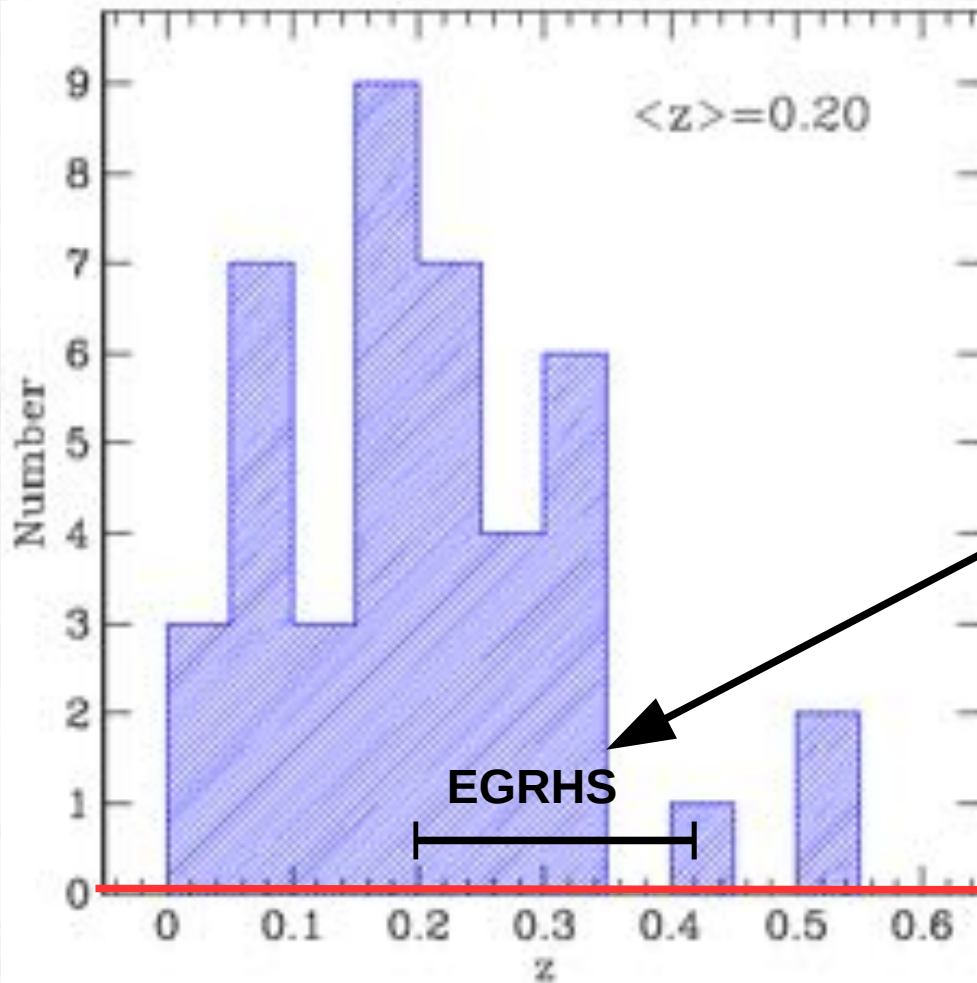
To

SZ-selected
nearly mass
limited samples

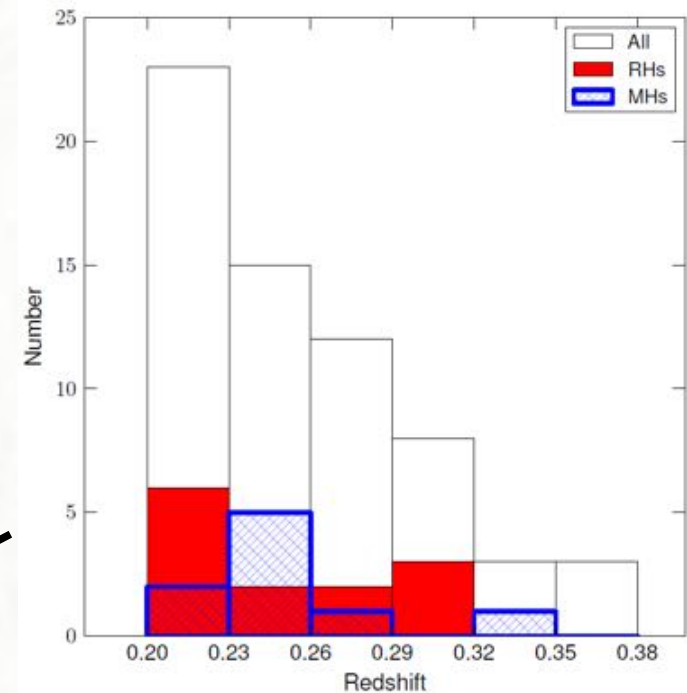


Clusters near and far

Feretti and Giovannini 2012



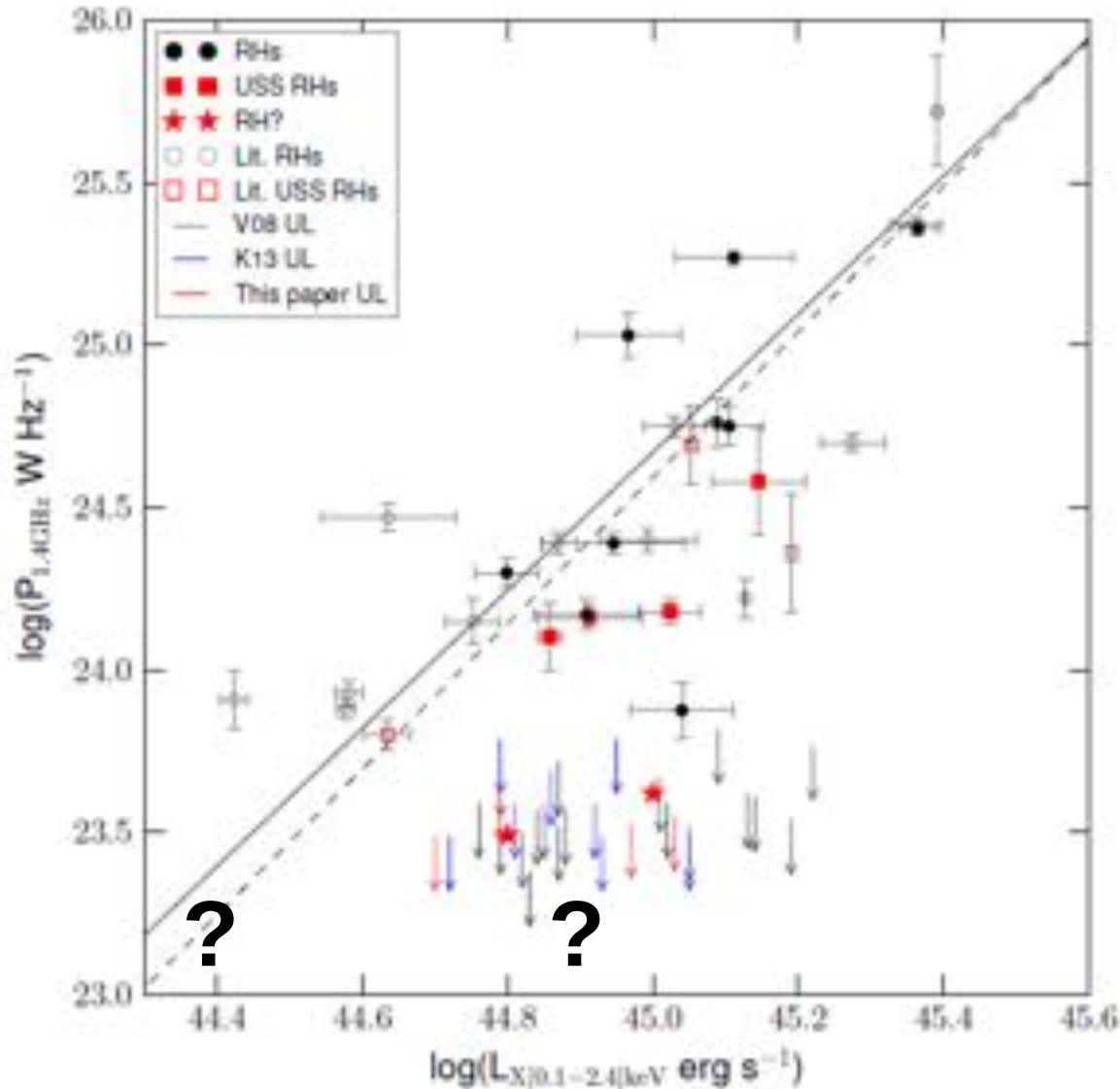
Kale et al. 2015a



???

0.87
Lindner et al. 2014
El Gordo

Extended GMRT Radio Halo Survey



GRHS : Venturi et al 2007,
2008;
EGRHS: Kale et al 2013,
2015a

Non-detections:
Upper limits using model
radio halo injections

Ongoing projects

- Southern Cluster Scale Extended Source Survey (SUCCESS): low and high mass; near and far

GMRT 325 and 610 MHz observations scheduled for first set of targets.

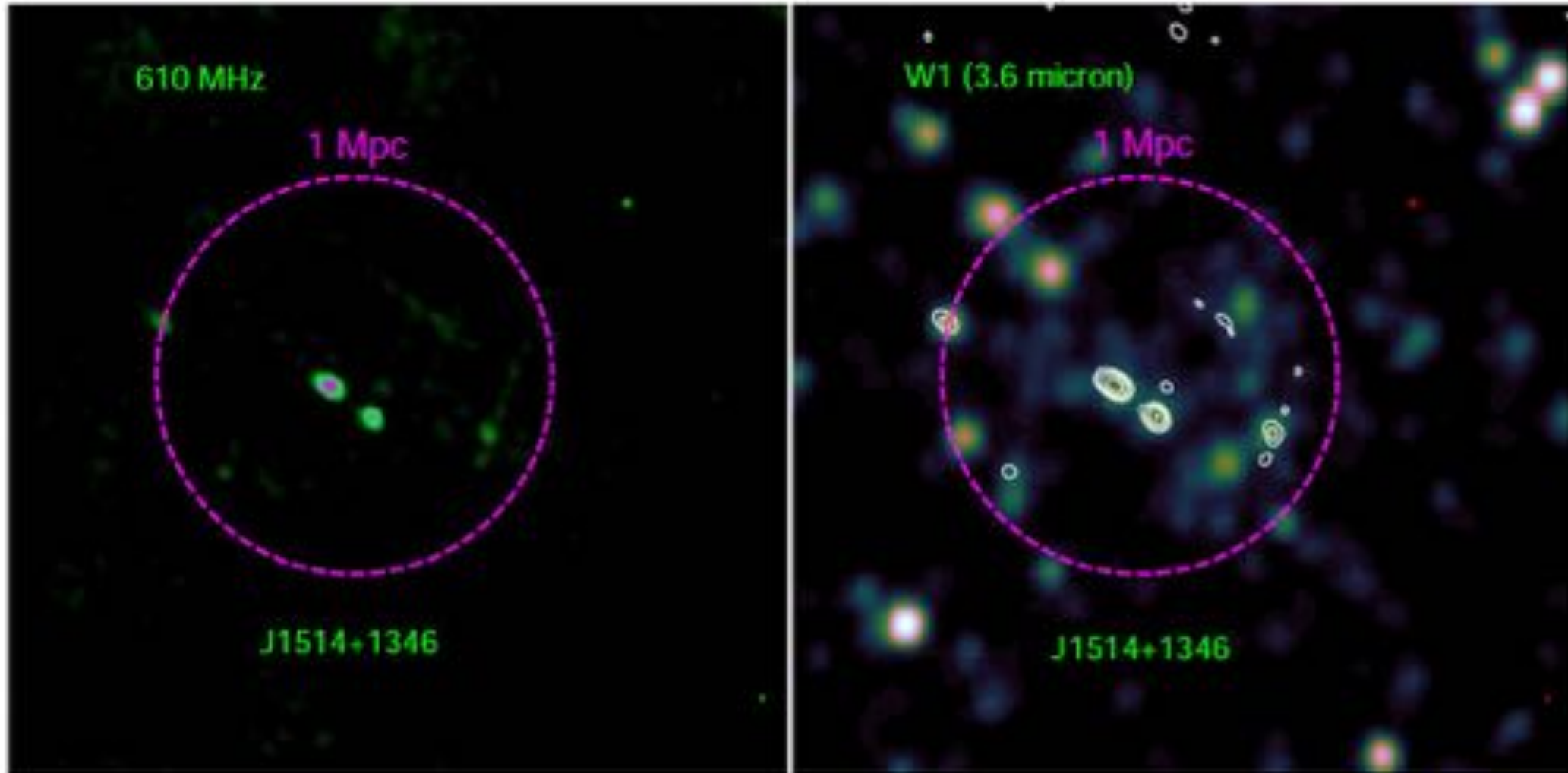
Ongoing projects

- Radio follow up of Massive and Distant Clusters from the WISE Survey (MADCoWS)
 $z > 0.8$
- GMRT 1280 and 610 MHz analysis of 4 clusters completed.

Cluster MOO_	RA_{J2000}	DEC_{J2000}	V_{obs} MHz	rms $mJy\ b^{-1}$	Beam "×", p. a.
J0012+1602	00 12 13.0	+16 02 16	1280	0.045	$2.6 \times 2.0, 63.4^\circ$
J0133-1057	01 33 55.6	-10 57 44	610	0.051	$5.1 \times 4.9, 31.5^\circ$
J1155+3901	11 55 45.4	+39 01 06	610	0.04	$5.4 \times 4.1, 43.2^\circ$
J1514+1346	15 14 43.8	+13 46 32	610	0.06	$5 \times 4, p. a. 42.7^\circ$

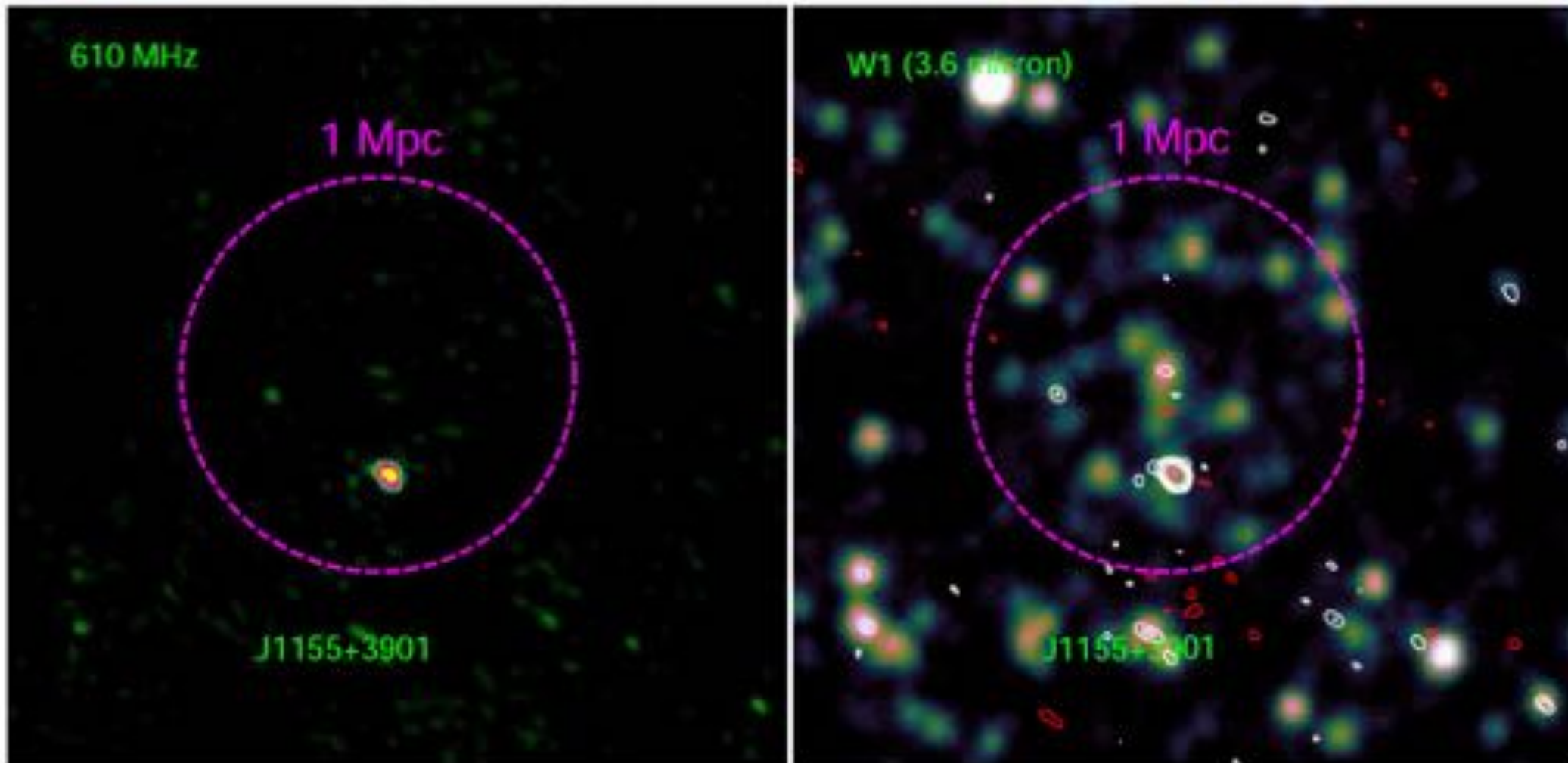
Kale and Parekh, 2015, POS

MOO J1514+1346



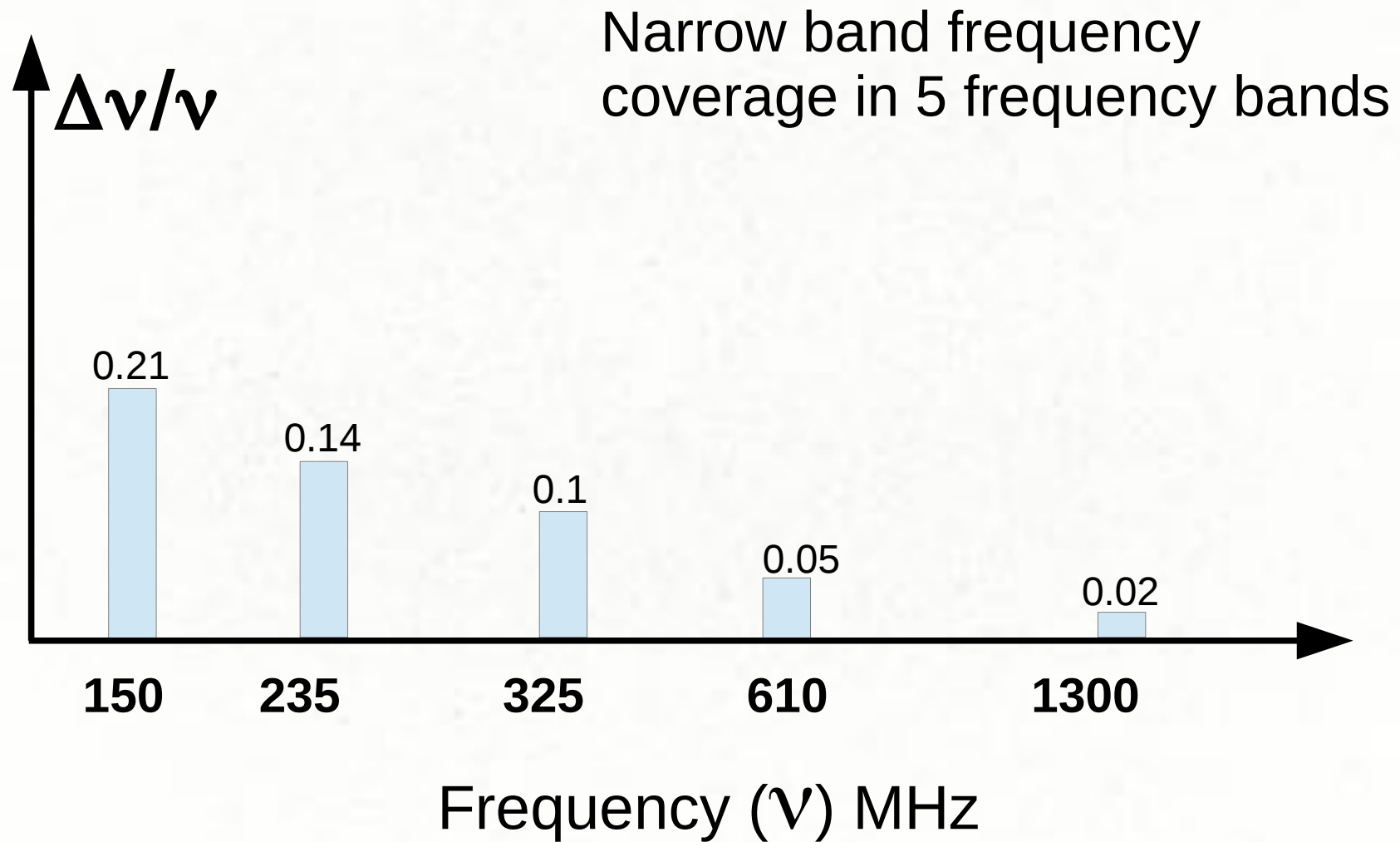
Kale and Parekh, 2015, POS

MOO J1155+3901

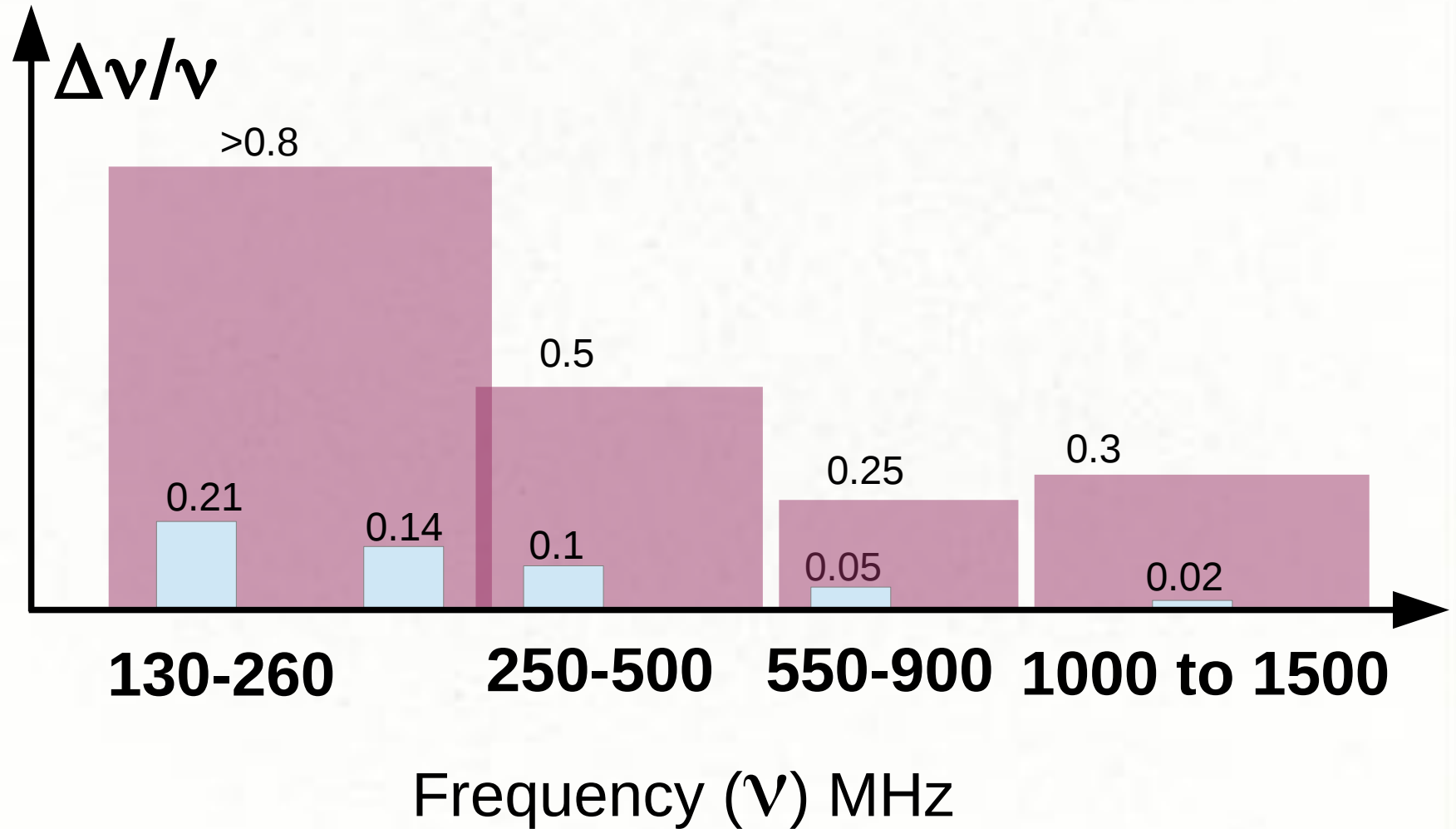


Kale and Parekh, 2015, POS

Current GMRT

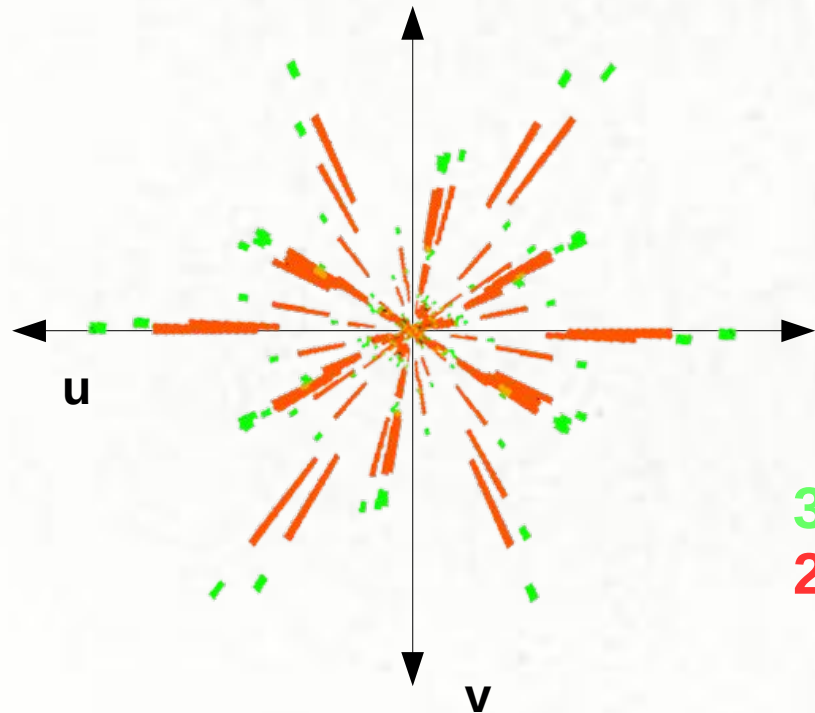


Upgraded GMRT Vs GMRT



uv-coverage: the long and short of it

- Broad bandwidths imply better uv-coverage



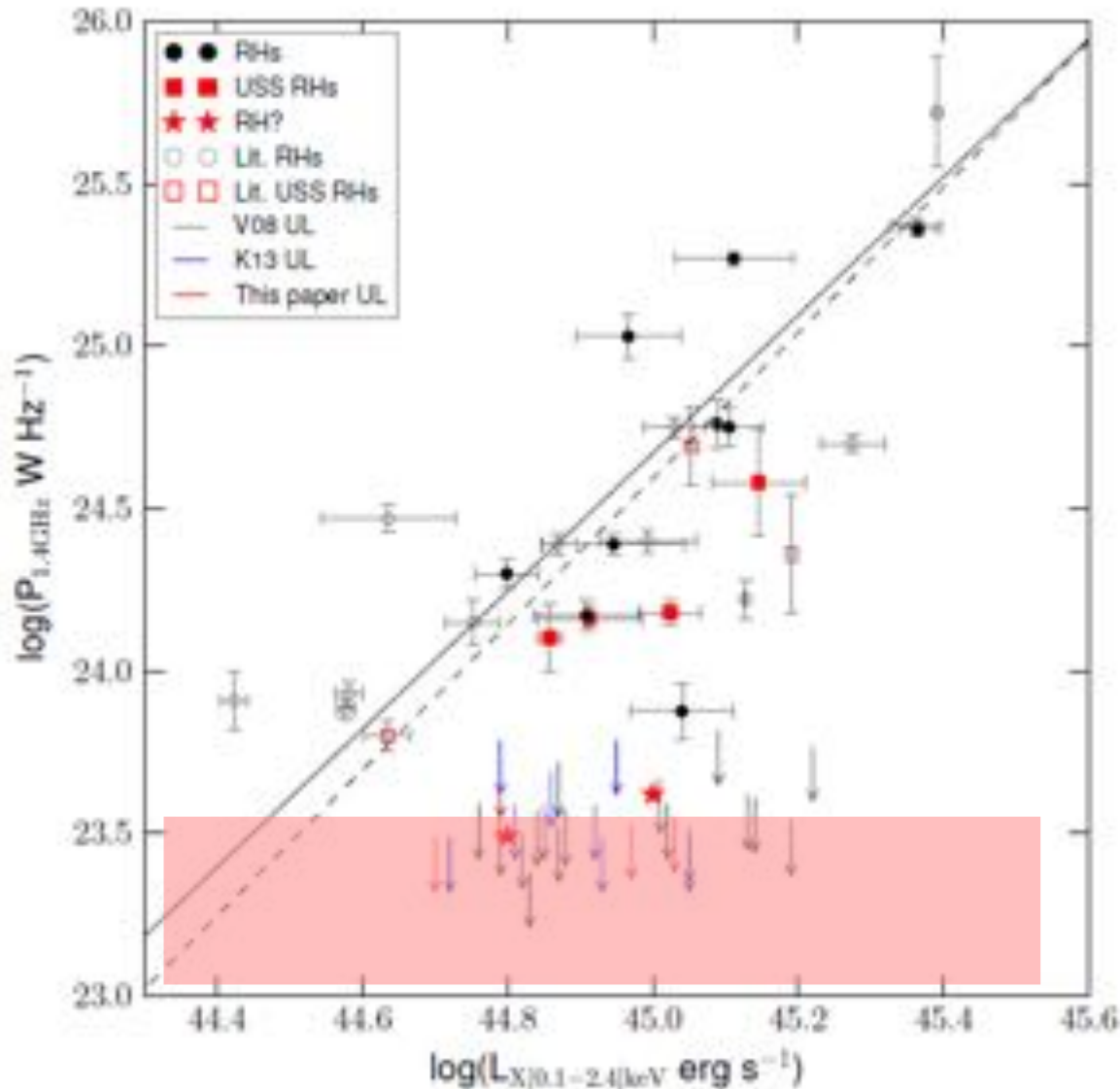
10 minutes uv-coverage
of GMRT and uGMRT

33 MHz GMRT 610 MHz
200 MHz uGMRT 300-500 MHz

uv-coverage: the long and short of it

- Spectral index and spectral curvature mapping for extended synchrotron sources
- Upper-limits on non-detections of extended emission

uv-coverage: upper limits on non-detection of extended sources



Deeper upper limits with increased sensitivity (factors $\sim 2.5 - 3.5$) and uv-coverage.

Kale et al. 2015

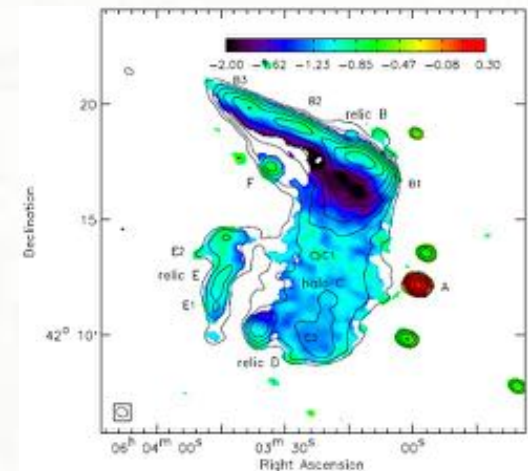
uv-coverage: spectral index mapping

Narrow band observations at two frequencies with different or same telescopes

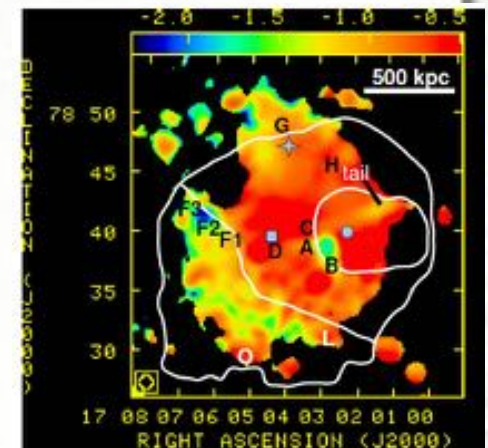
Spectral index mapping:
- restrict uv-distances to that in the overlapping range

BUT:
Even in the overlapping range the coverage is different in detail:
Different telescopes;
flagging; observation for unequal duration

LOFAR+GMRT+JVLA
van Weeren
et al. 2016

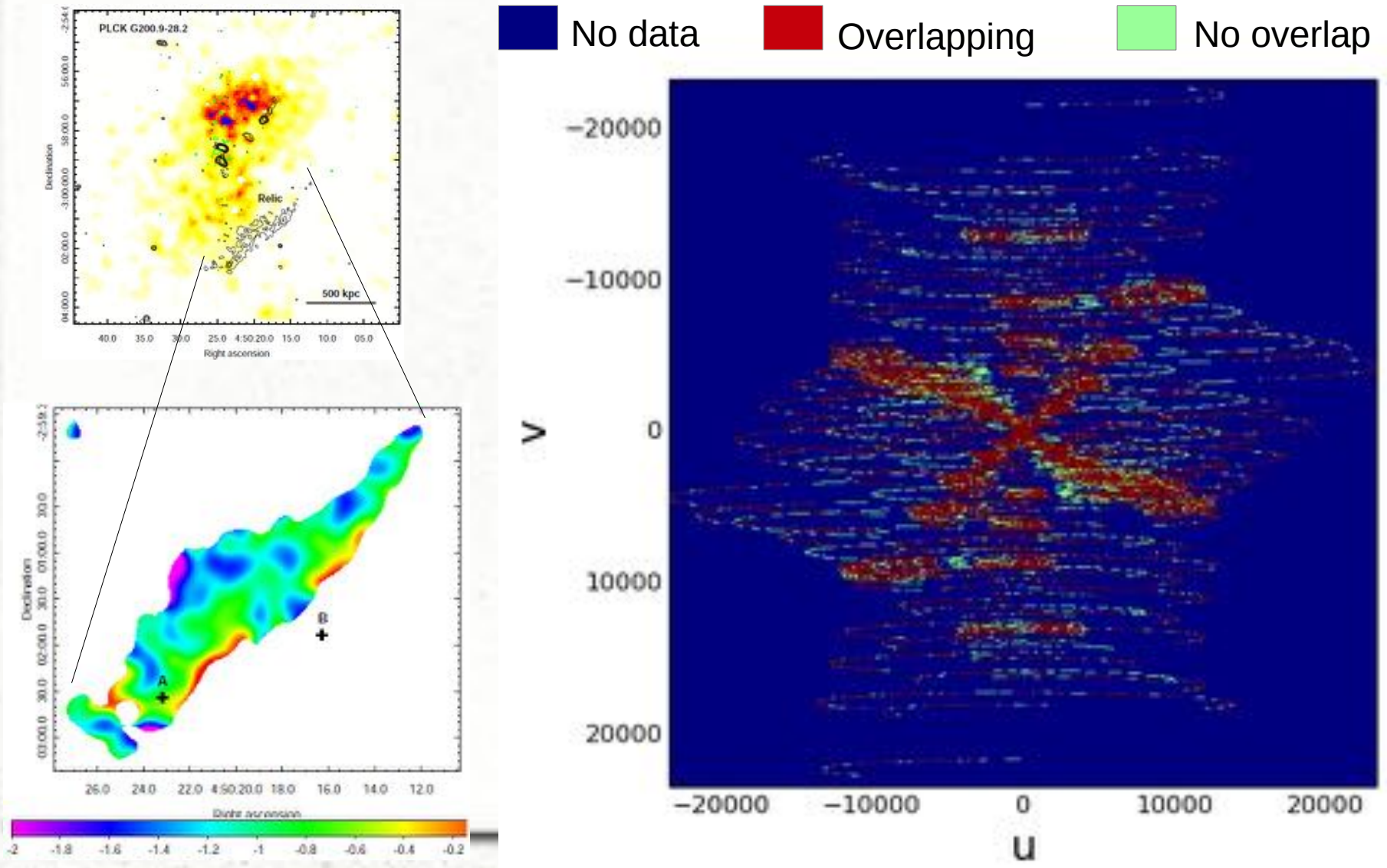


GMRT+VLA
Kale &
Dwarakanath 2010



uv-coverage: spectral index mapping

- Comparison of GMRT 610 and 235 MHz uv-coverages



uv-coverage: spectral index mapping

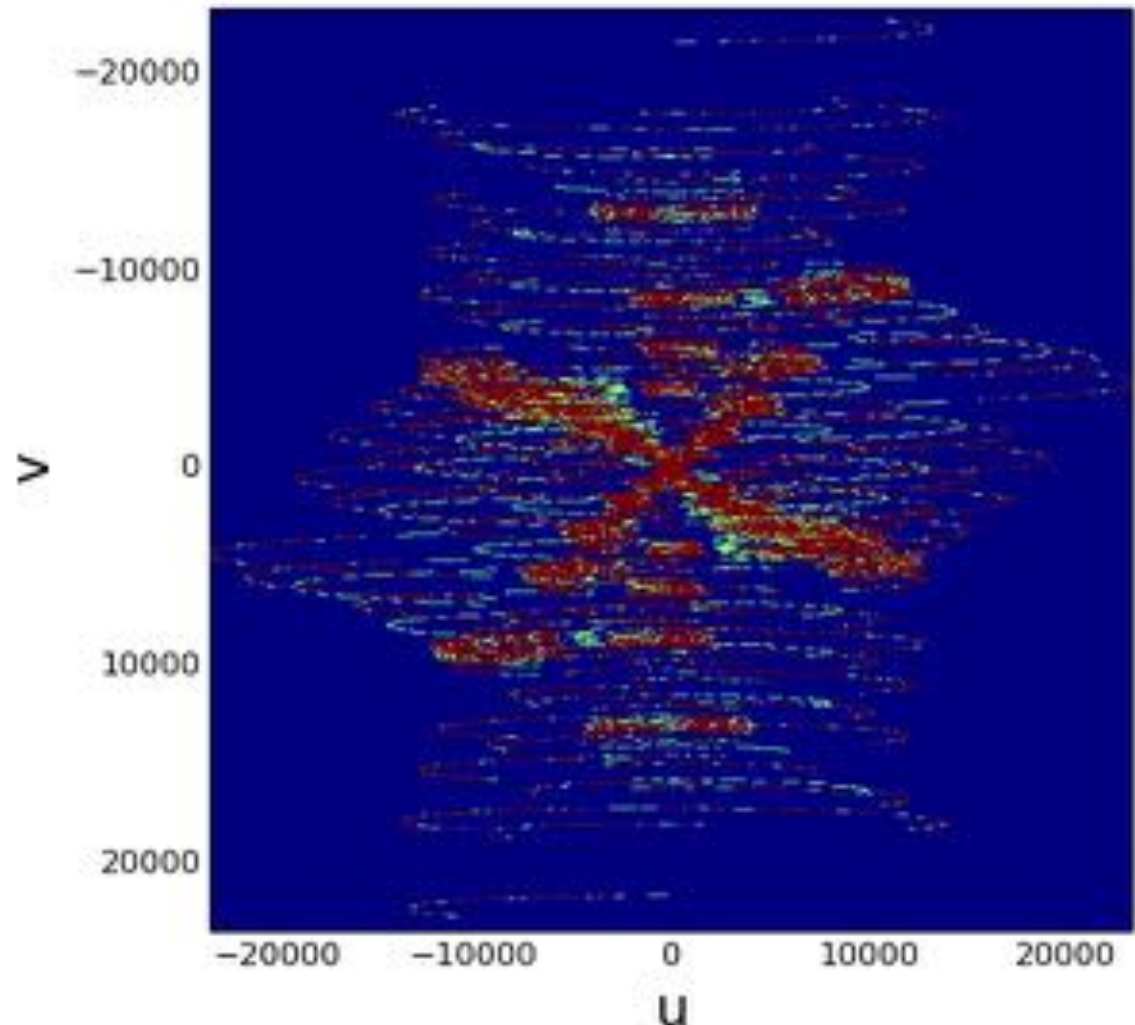
- Comparison of GMRT 610 and 235 MHz uv-coverages

■ No data ■ Overlapping ■ No overlap

Filling fraction
 $= F_{FL} = 11 \%$

Overlap fraction
 $= F_{OL} = 72 \%$

**Wide bandwidth
means implies
factors $\sim 100\%$
overlap and $>50\%$
filling factors**

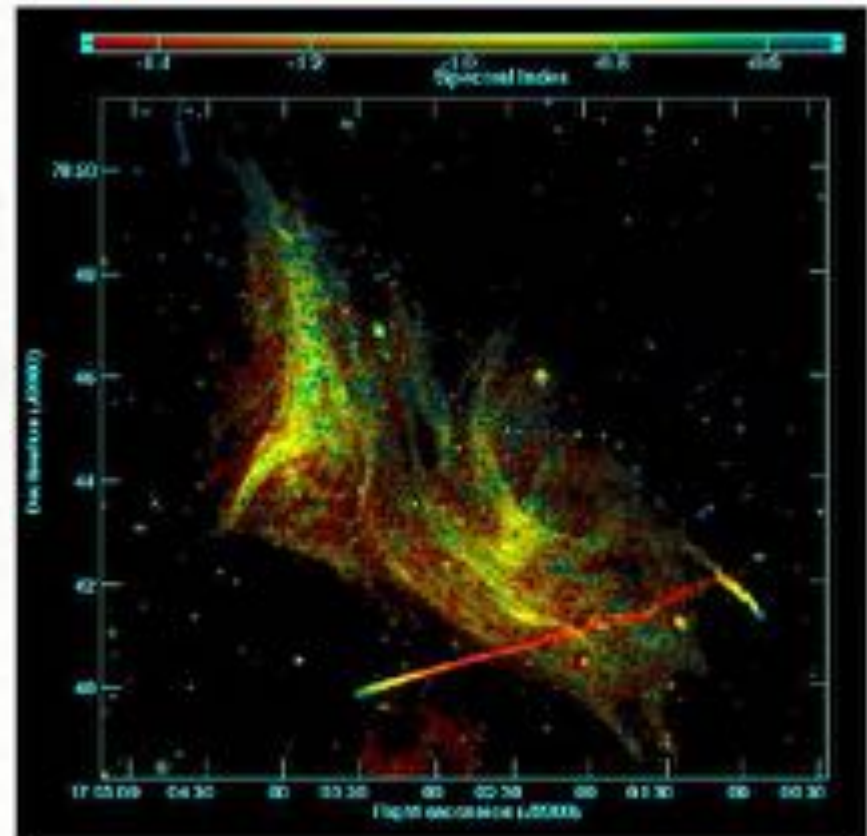


uv-coverage: spectral index mapping

- Wide bandwidth observations will improve spectral index mapping
- MS-MFS clean**
Rau et al. 2011

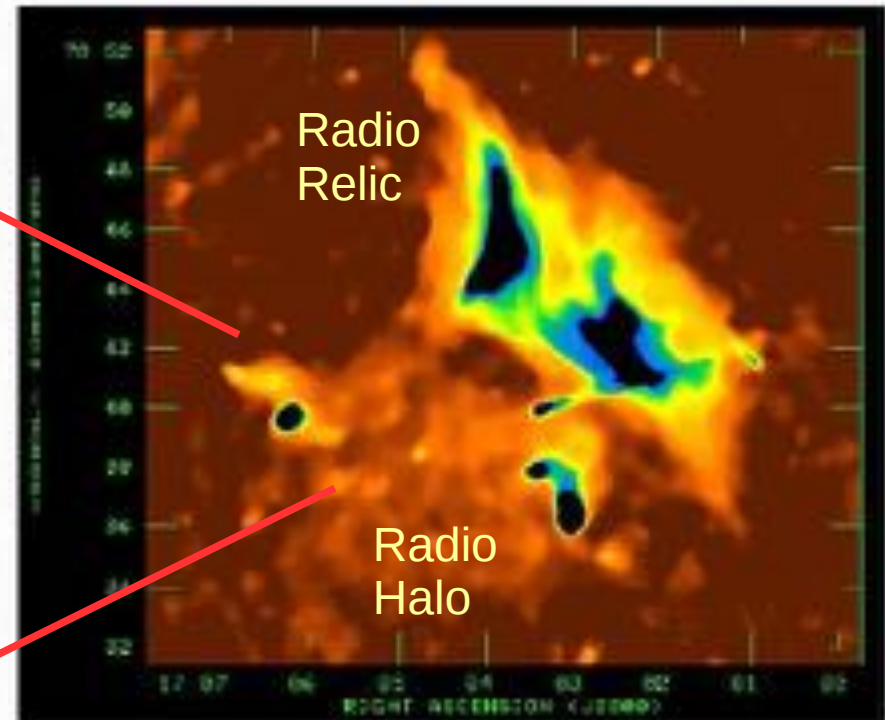
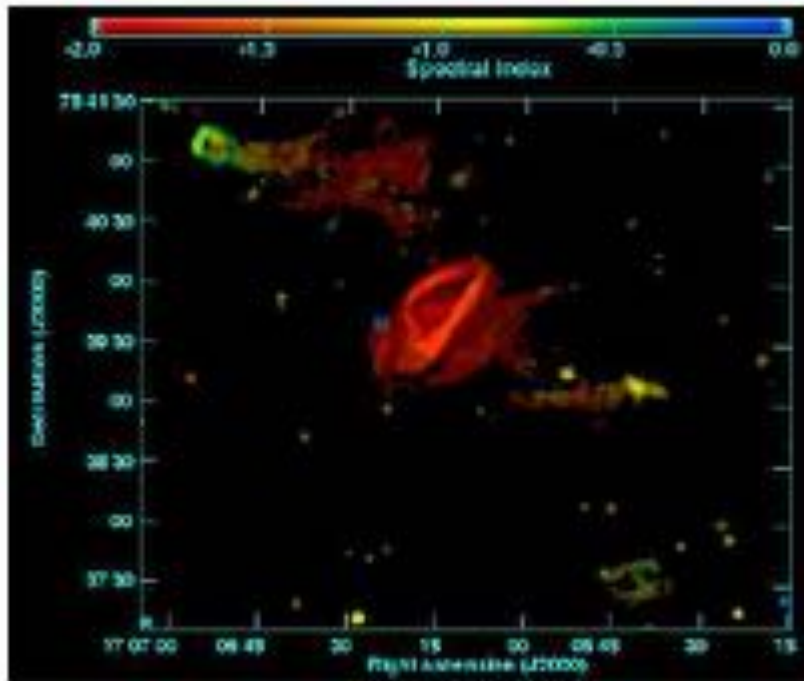
Abell 2256
JVLA 1-2 GHz
Owen et al. 2014

- **uGMRT 300-500 MHz**



**works also for concatenated narrowband data

uGMRT observations of Abell 2256



Owen et al. 2014

Rottgering et al 1997; Carke and Ensslin 2006; Kale and Dwarakanath 2010; van Weeren et al 2009,2013, 2016; Intema et al. 2009.

uGMRT observations of Abell 2256

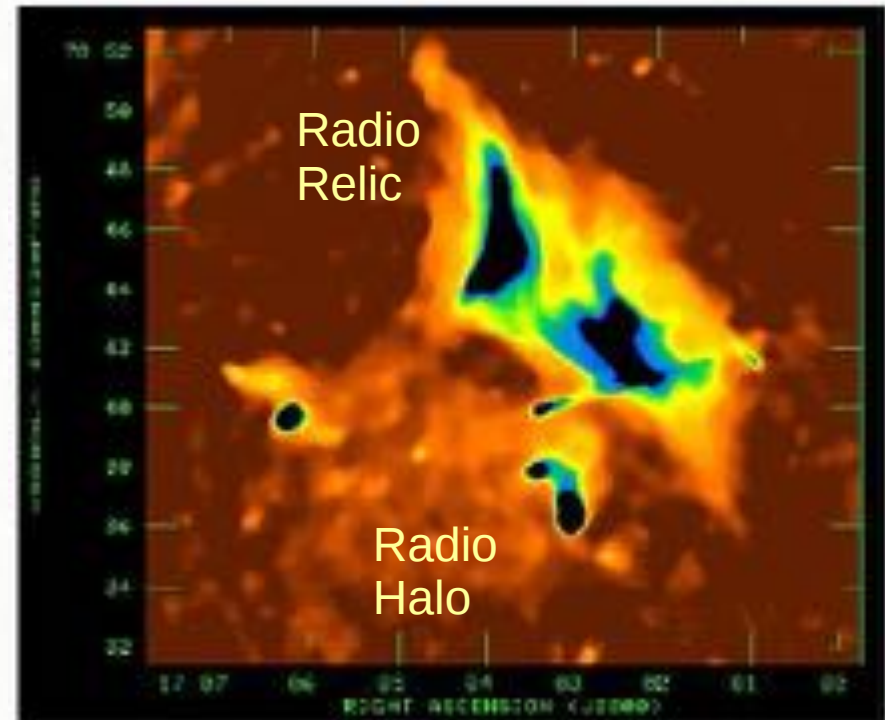
16 antennas (RR, LL)

0.3 – 0.5 GHz

Bandwidth ~ 200 MHz

2048 channels

Time ~ 9 hours



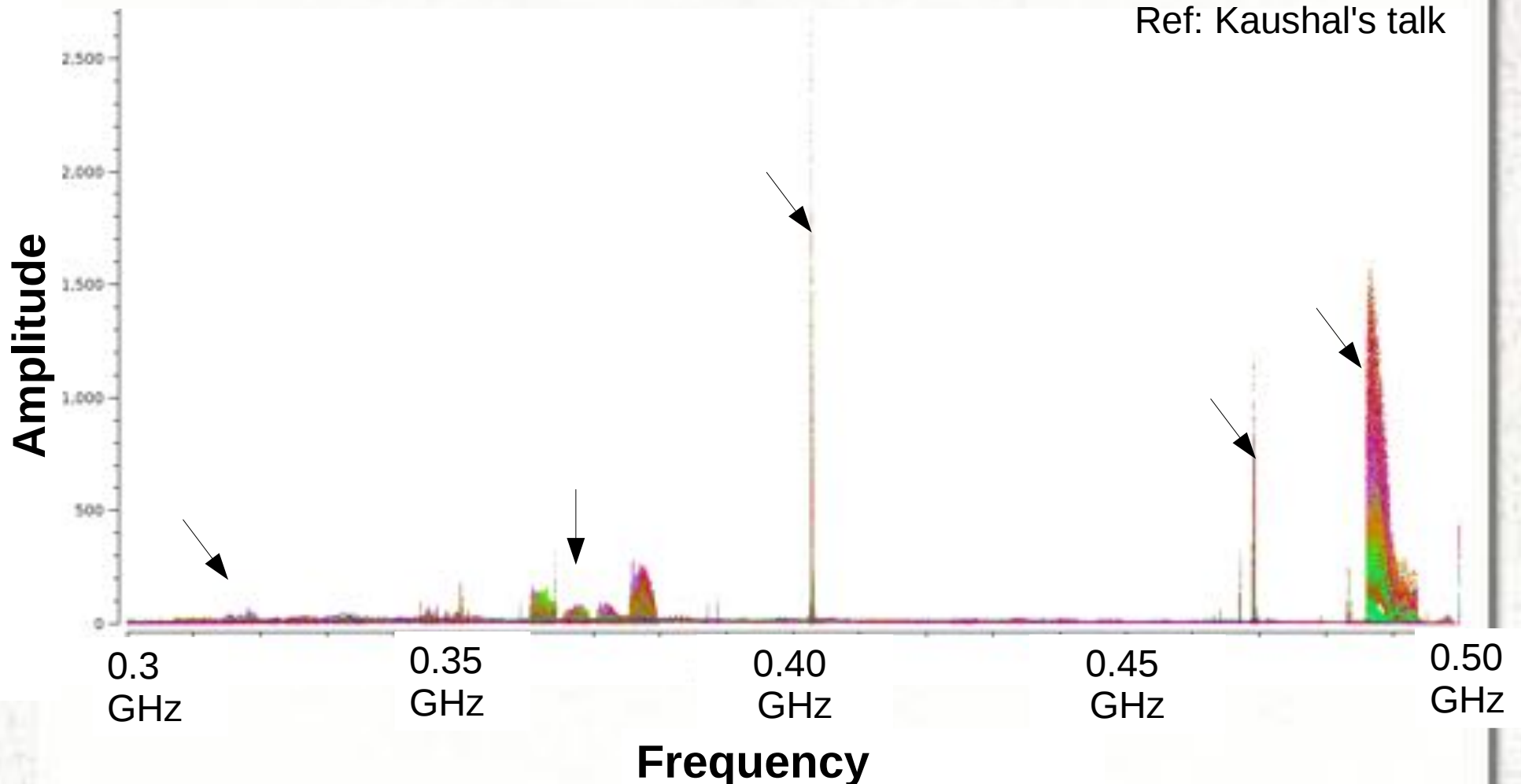
Owen et al. 2014

Rottgering et al 1997; Carke and Ensslin 2006; Kale and Dwarakanath 2010; van Weeren et al 2009,2013, 2016; Intema et al. 2009.

uGMRT observations of Abell 2256

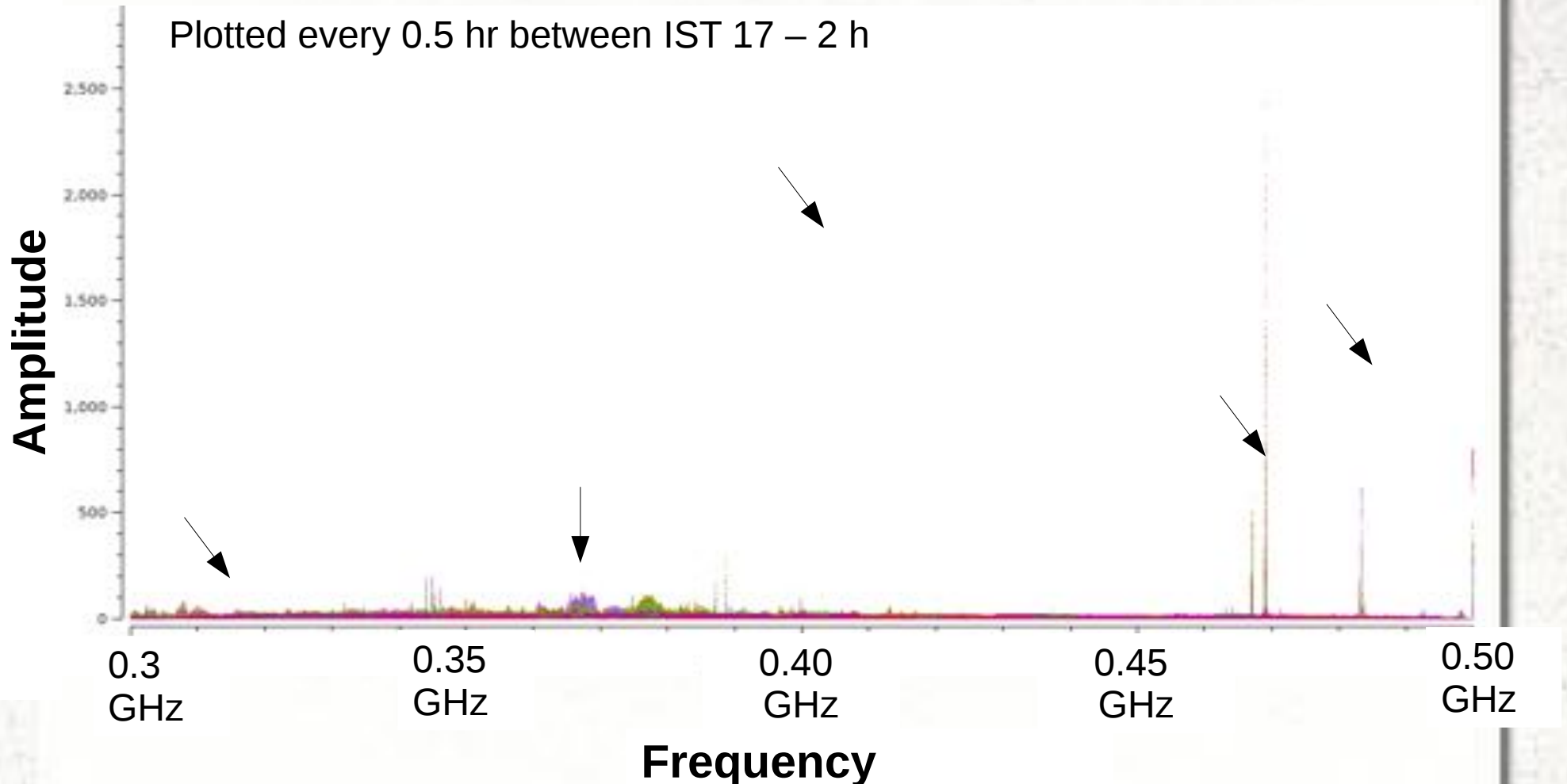
Radio frequency interference: online excision needed !

Ref: Kaushal's talk



uGMRT observations of galaxy clusters

Changing RFI environment in the observing session



a2256_split_avg8ch_t1.image.tt0-raster

Abell 2256 uGMRT, 402 MHz

J2000 Declination

80°

79°

78°

77°

17^h30^m 20^m 10^m 00^m 16^h50^m 40^m

J2000 Right Ascension

16 antennas (RR, LL)

402 MHz image

Bandwidth ~ 200 MHz

Time ~ 8 hours

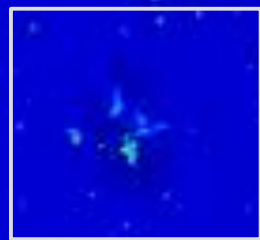
About 40 – 50% data
flagged.

Rms ~ 400 microJy/b

Beam = 17.6" x 8.2"

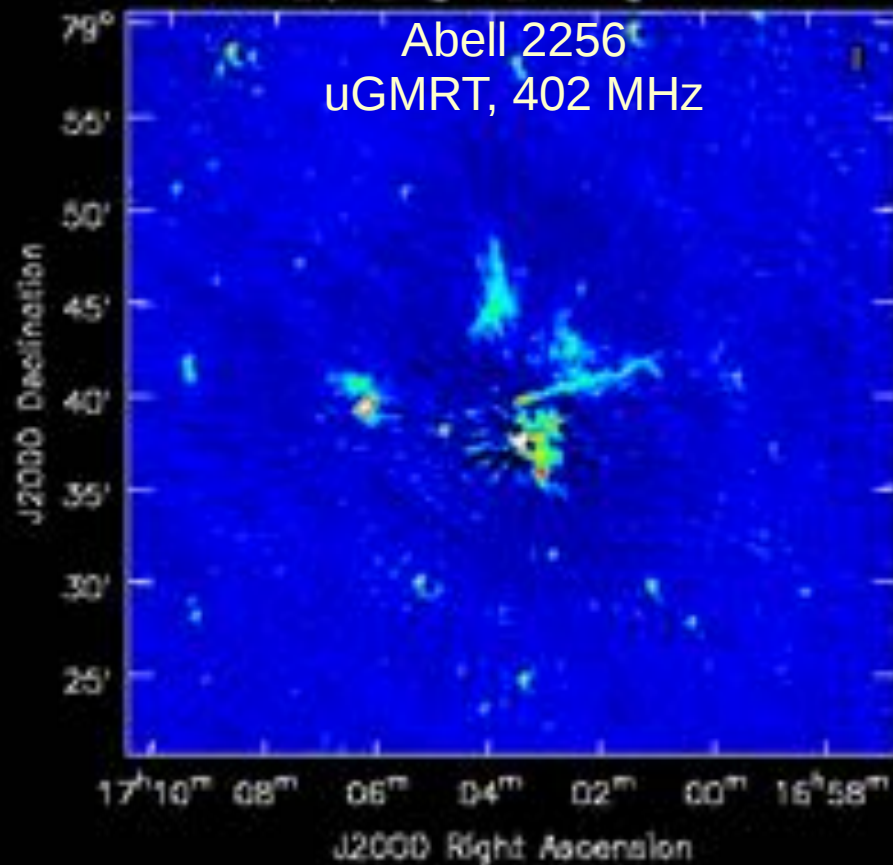
a2256_split_avg8ch_t1.image.tt0-raster

Abell 2256
uGMRT, 402 MHz



a2256_split_avg8ch_t1.image.tt0-raster

Abell 2256
uGMRT, 402 MHz



80°

79°

78°

77°

17^h30^m 20^m 10^m 00^m 16^h50^m 40^m

J2000 Right Ascension

J2000 Declination

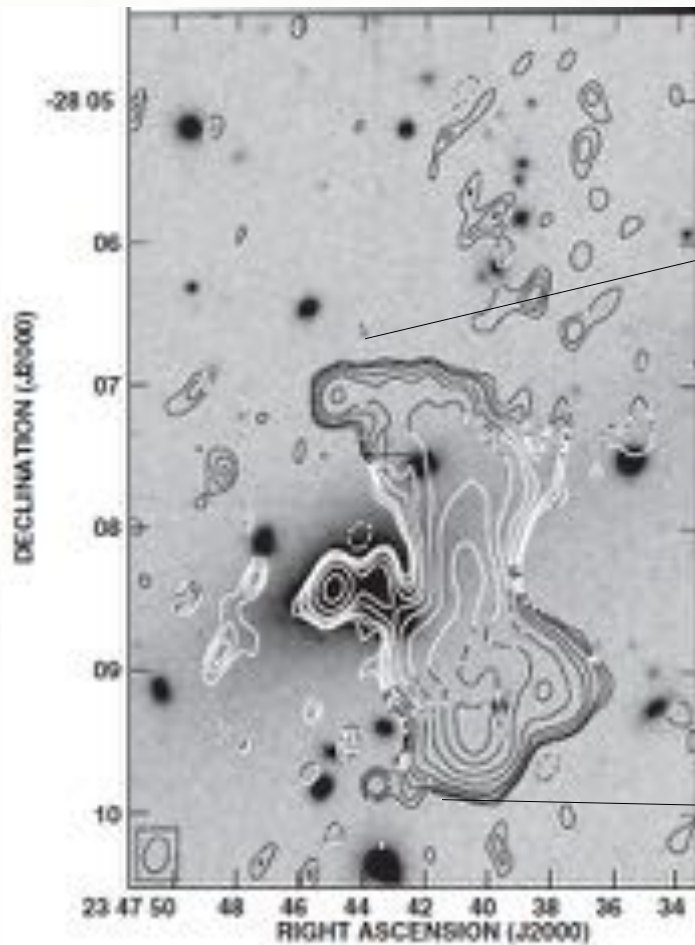
79°
55'
50'
45'
40'
35'
30'
25'

17^h10^m 08^m 06^m 04^m 02^m 00^m 16^h58^m

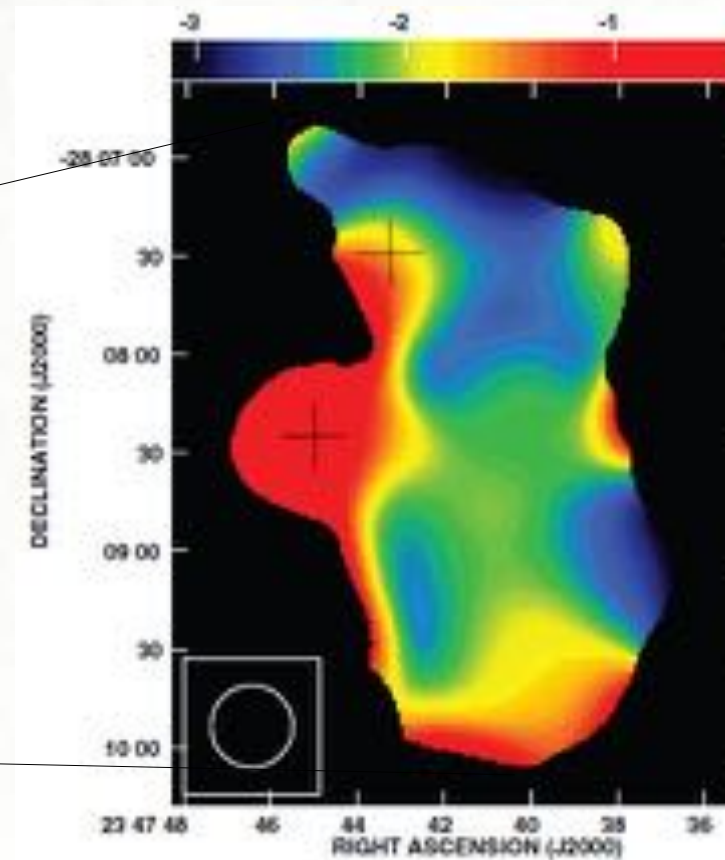
J2000 Right Ascension

uGMRT observations of Abell 4038

GMRT 610 MHz



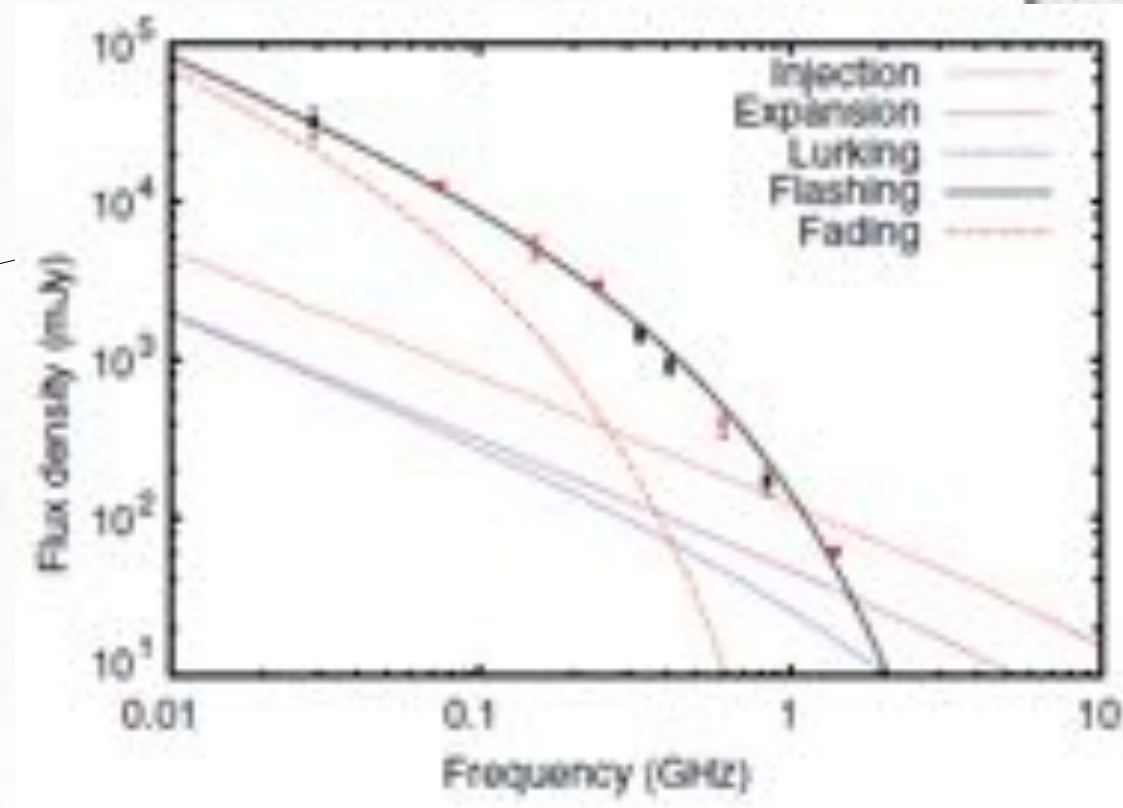
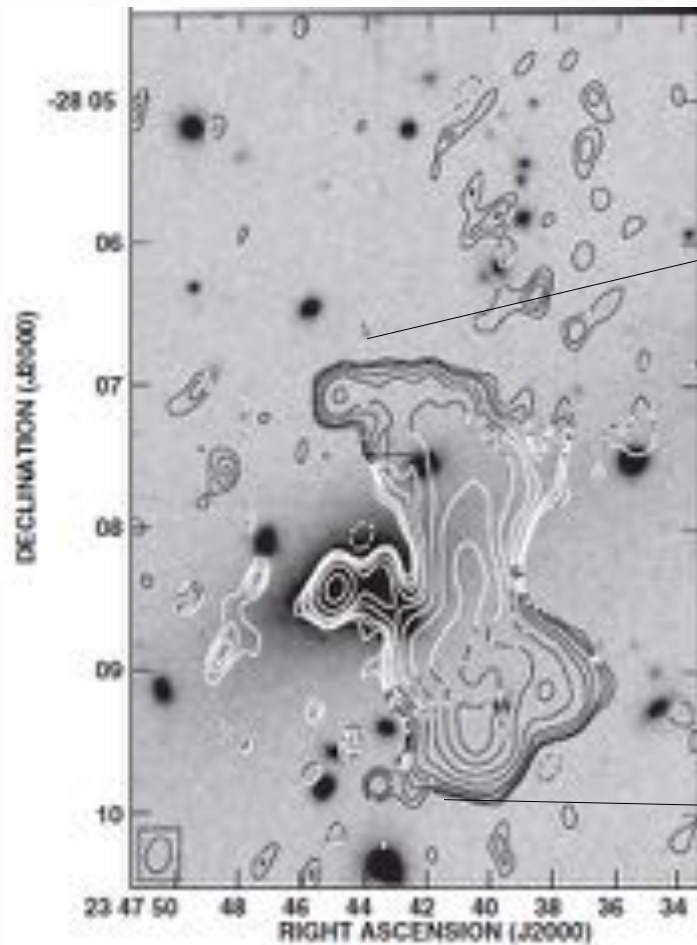
GMRT 610 - 235 MHz spectral index



Kale and Dwarakanath 2012

uGMRT observations of Abell 4038

GMRT 610 MHz



Kale and Dwarakanath 2012

uGMRT observations of Abell 4038

16 antennas (RR, LL)

L band: 1000 – 1400 MHz

Bandwidth = 400 MHz

Time ~ 4 hours

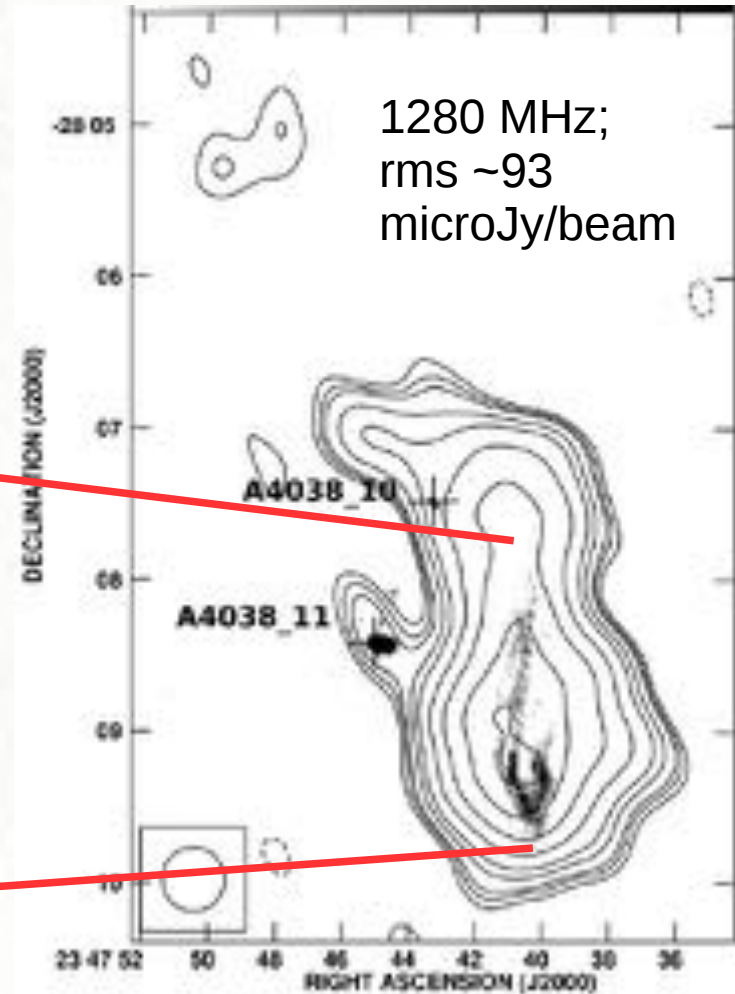
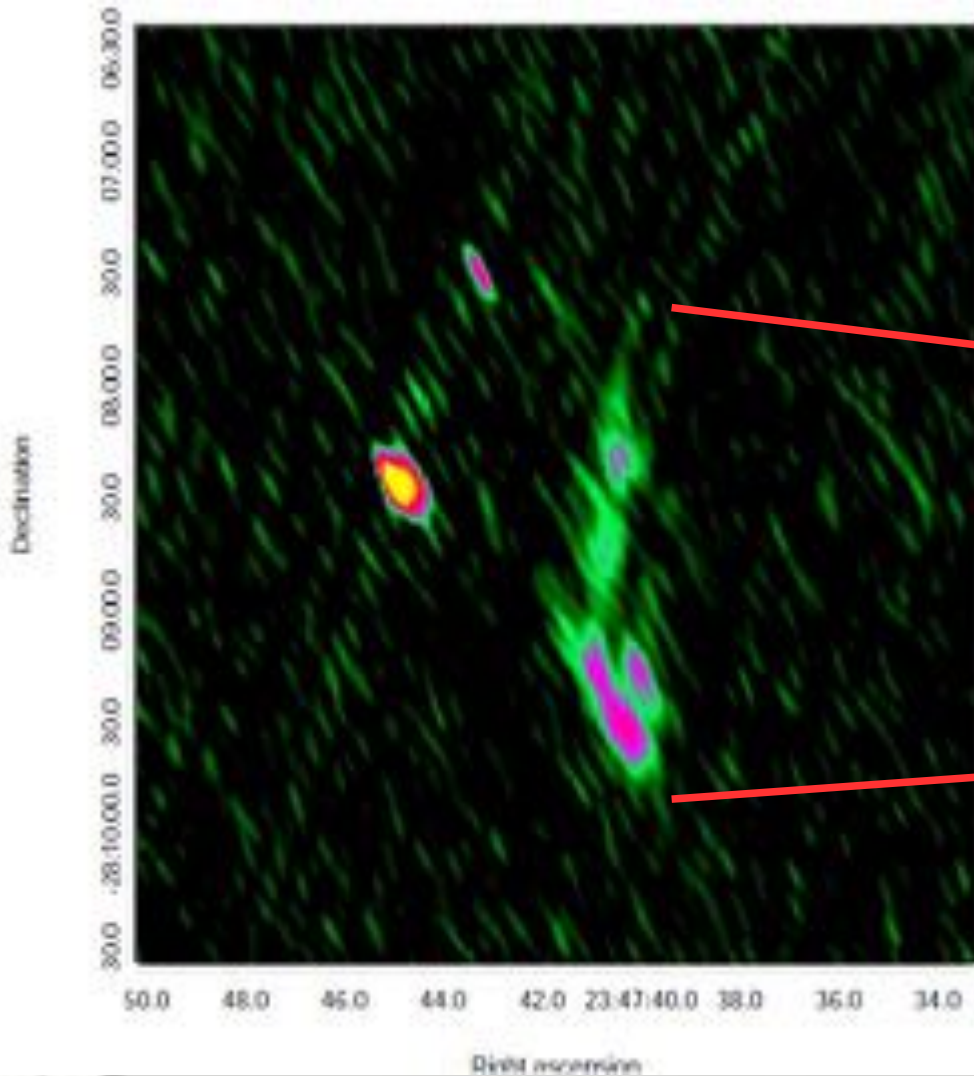
CASA : Each polarization reduced separately**

Self-calibration (only LL shown here)

** CASA flags the entire antenna even if a single pol of that antenna is flagged.

uGMRT observations of Abell 4038

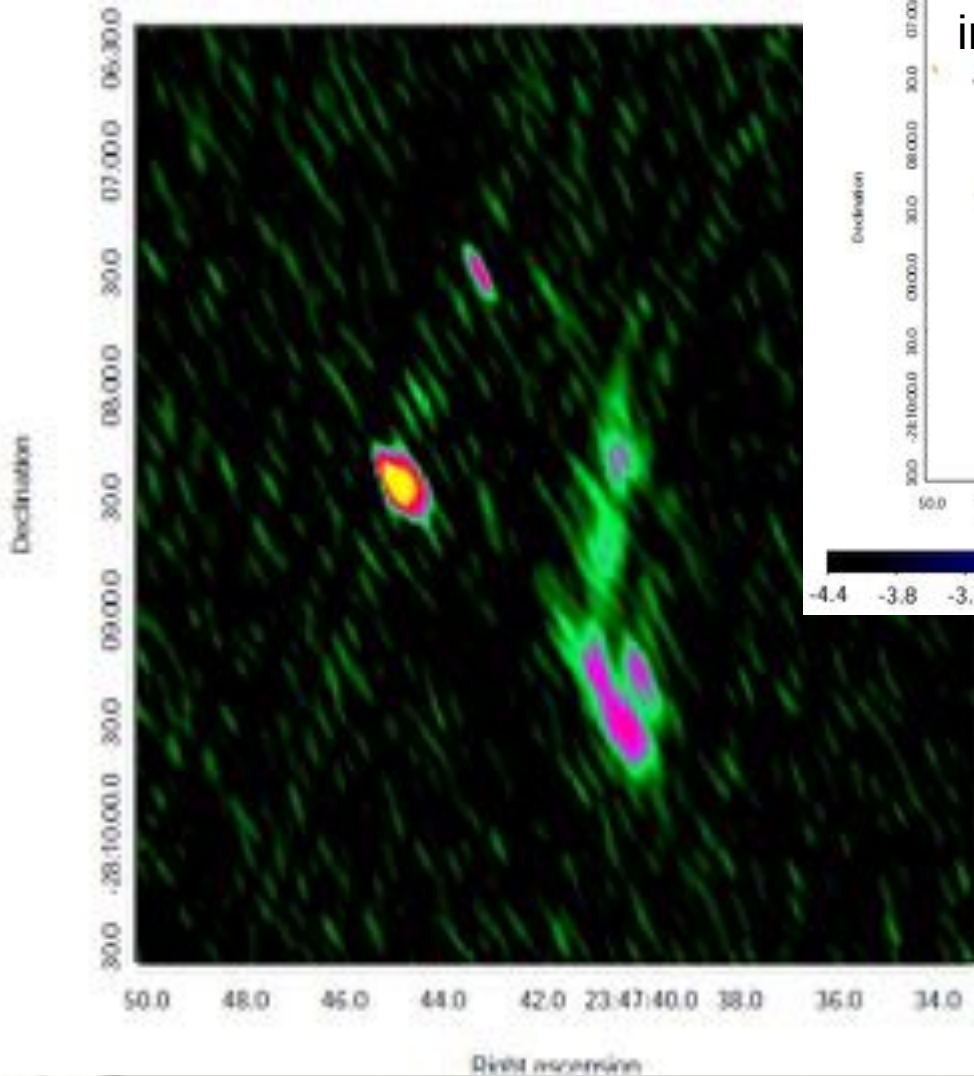
16 antenna, only LL, 2 hours



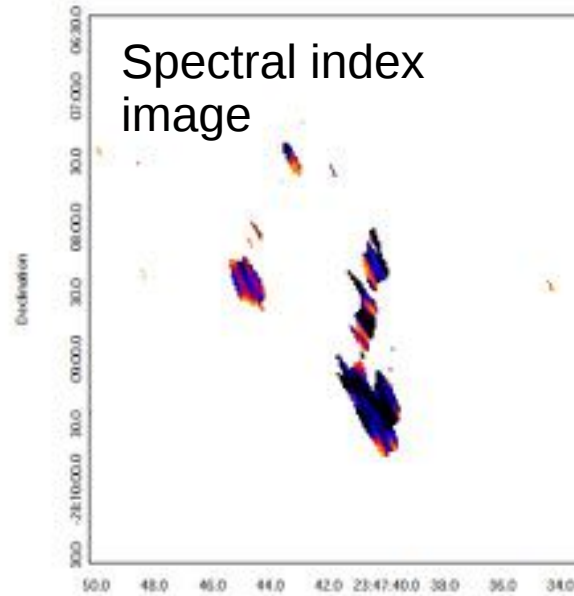
Rms = 60 micro Jy / beam

uGMRT observations of Abell 4038

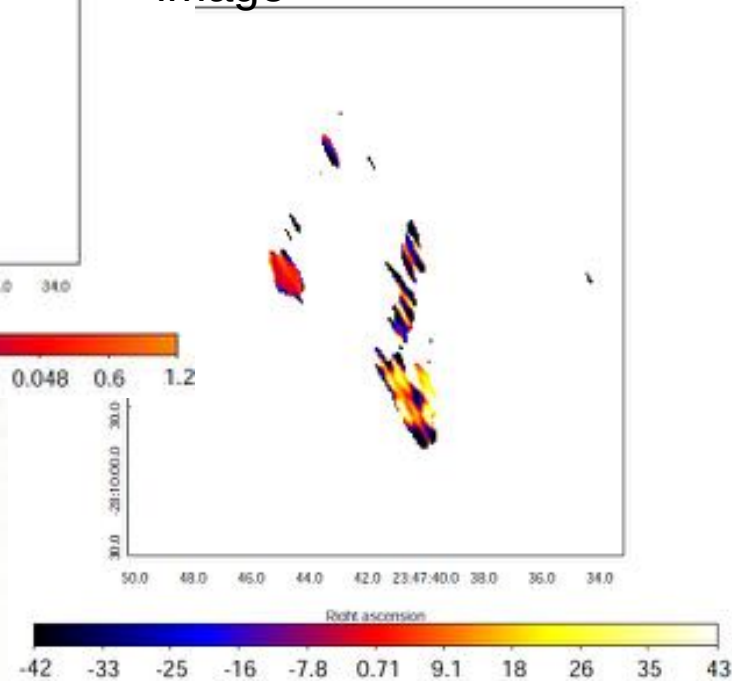
Image



Spectral index image



Spectral curvature image



Rms = 60 micro Jy / beam

uGMRT challenges

- RFI – Online excision (Kaushal's talk)
- Computing challenge
- Wide band primary beam

Summary

- Galaxy clusters surveys: exploration of southern sky, very low and high redshift clusters, low mass clusters
- Ongoing projects with the GMRT: SUCCESS and Radio follow-up of MADCoWS.

uGMRT: 16 antenna system providing the first glimpse of low frequency wide-band images – Abell 2256 and Abell 4038

uGMRT : RFI – online excision, automated flaggers
Computation
Wide band primary beam

uGMRT: Promising prospects for future low-frequency wide-band images