Radio sources in MaDCoWS

(Massive and Distant Clusters of WISE Survey)
(Wide-field Infrared Survey Explorer)

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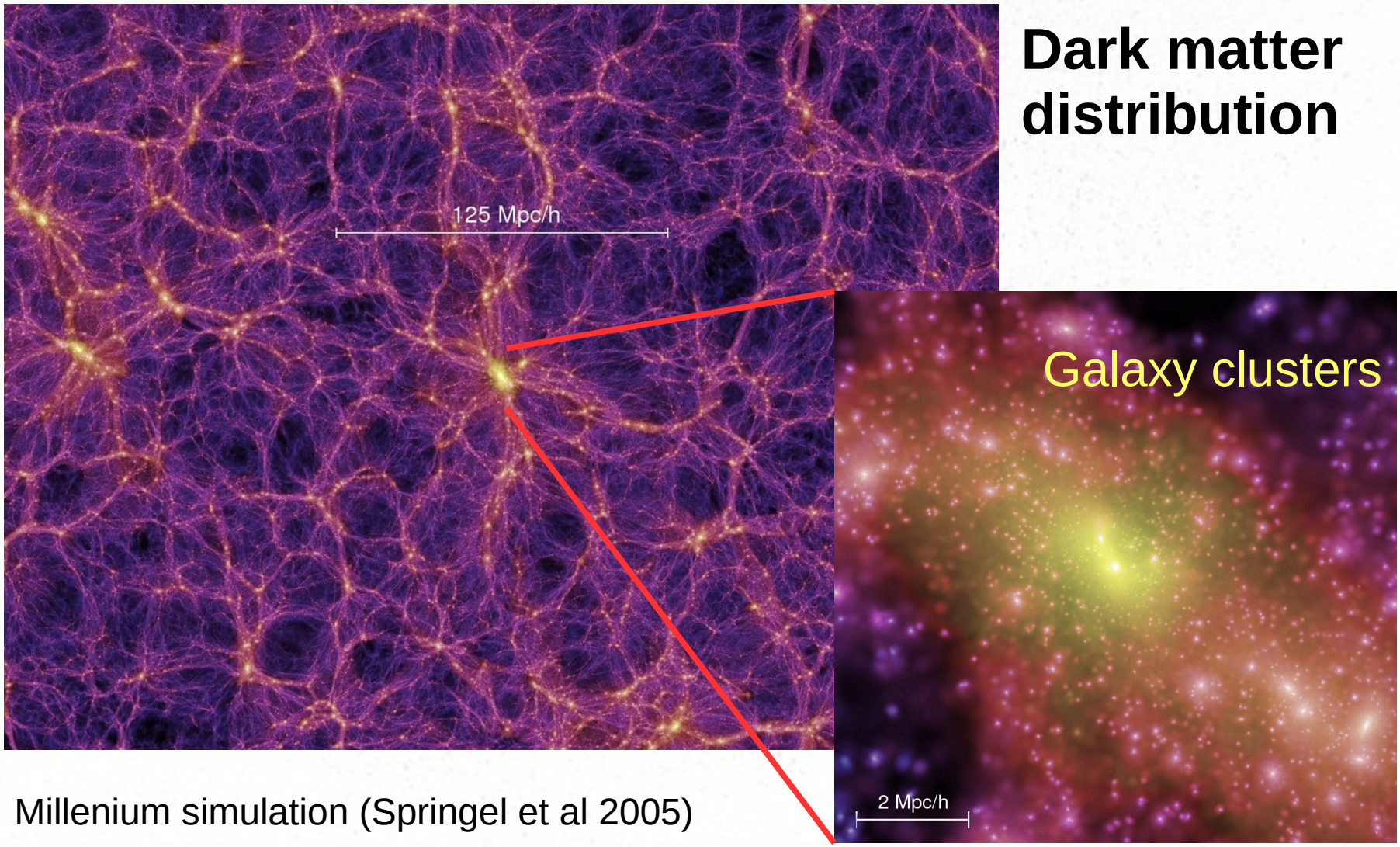
Outline

- Radio sources in galaxy clusters
- Feedback
- MaDCoWS sample
- Radio sources at low frequencies
- GMRT observations and preliminary results
- Summary

SKA Pathfinder

Large-scale structure formation



Dark matter distribution

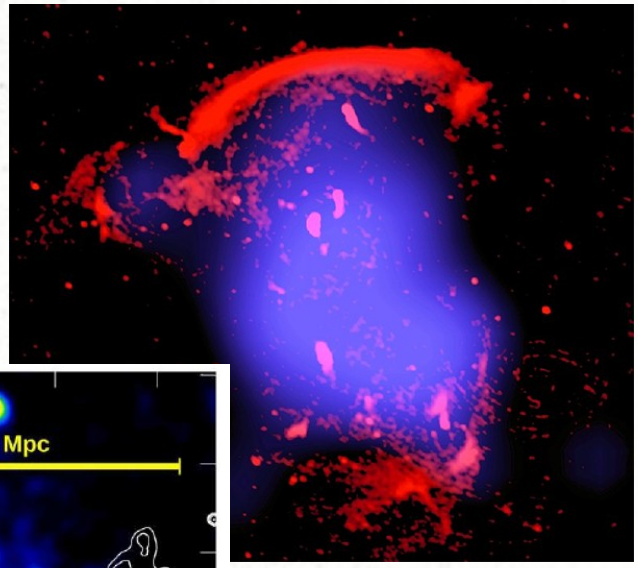
Millenium simulation (Springel et al 2005)

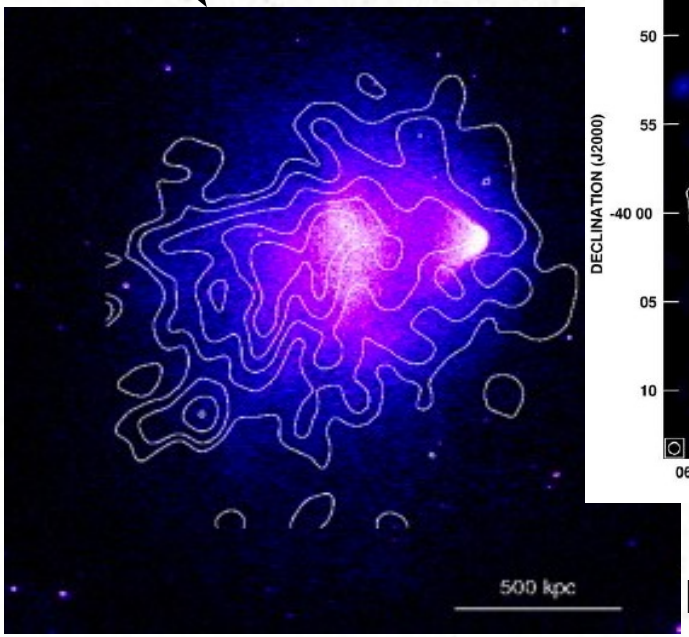
Cluster radio sources (~ Mpc)

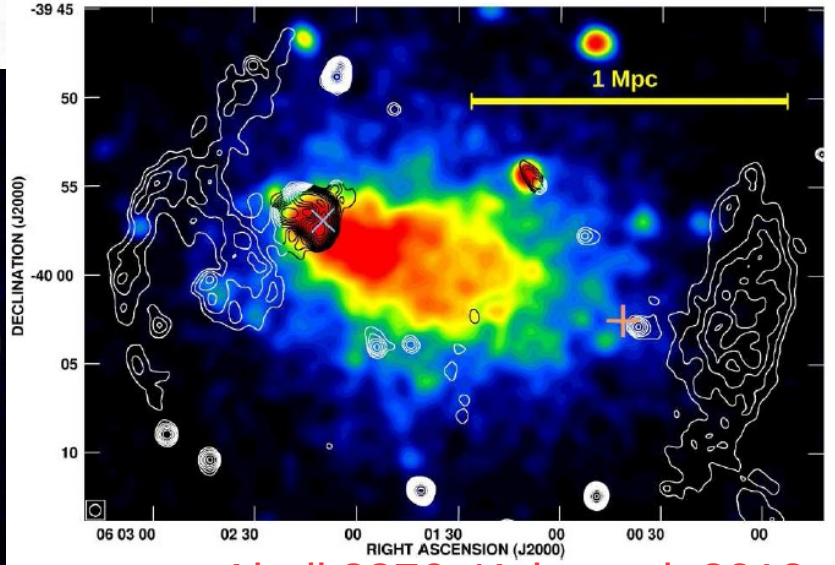
Shocks and turbulence in the intra-cluster medium: Particle acceleration+ magnetic fields ~ 0.1 – a few microGauss

Lead to diffuse synchrotron sources detected at low frequencies:

Radio halos and relics







"Sausage relic" Van Weeren et al 2010

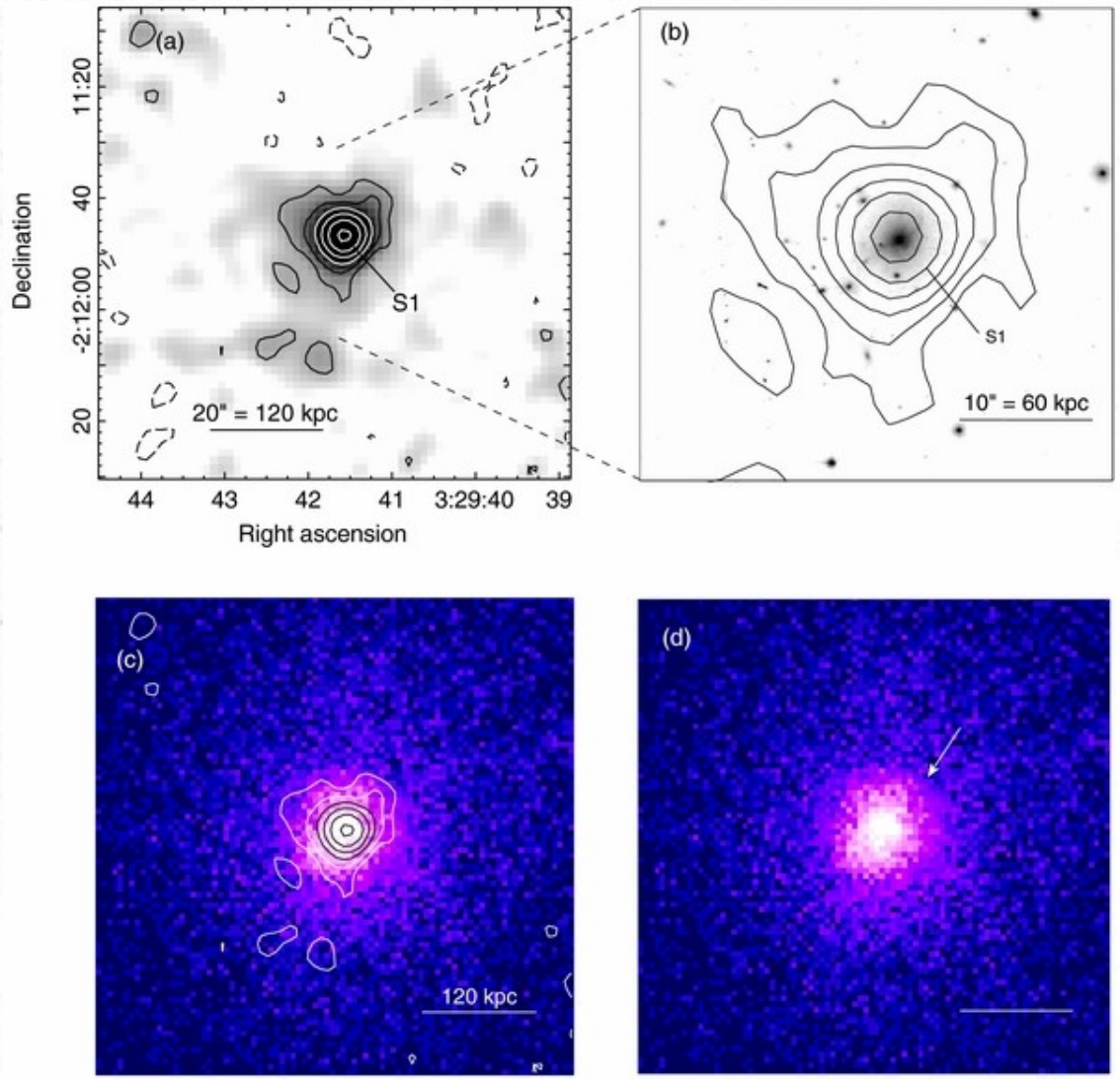
Abell 3376, Kale et al. 2012, Bagchi et al 2006

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

Mini-halos in cool-core clusters

Diffuse radio sources of 100 – 500 kpc sizes found surrounding the central galaxy in cool-core (relaxed) clusters.

M. Gitti's talk (next !)



MACS J0329.6–0214, Giacintucci et al. 2014.

Radio sources associated with galaxies in clusters

Star formation

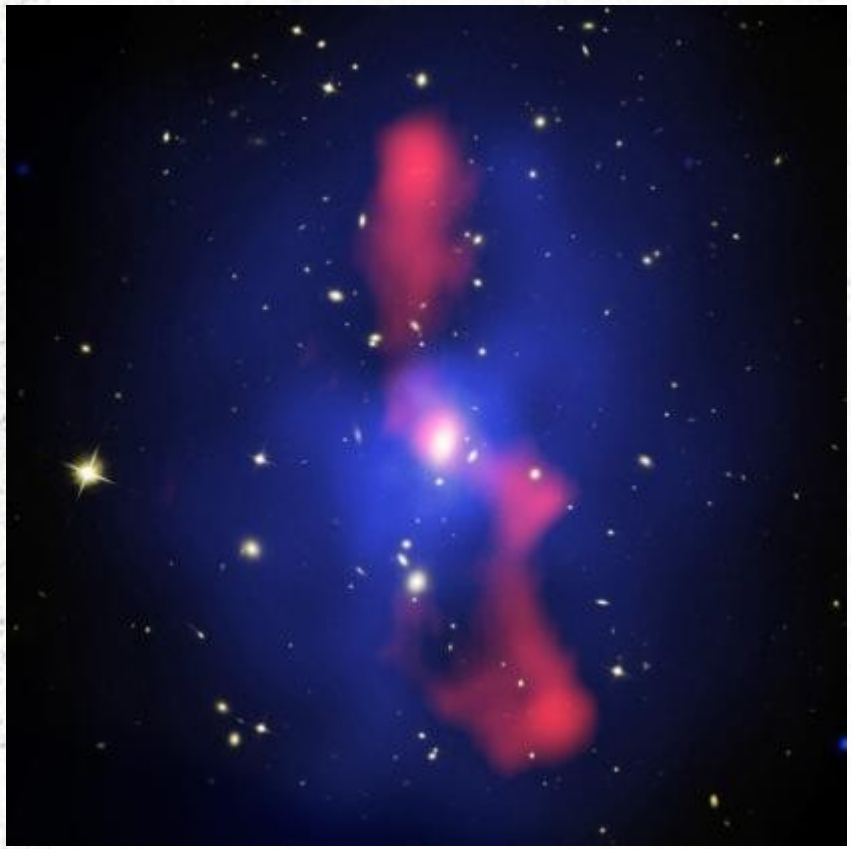
Quasars, AGN, Radio galaxies

Dying radio galaxies

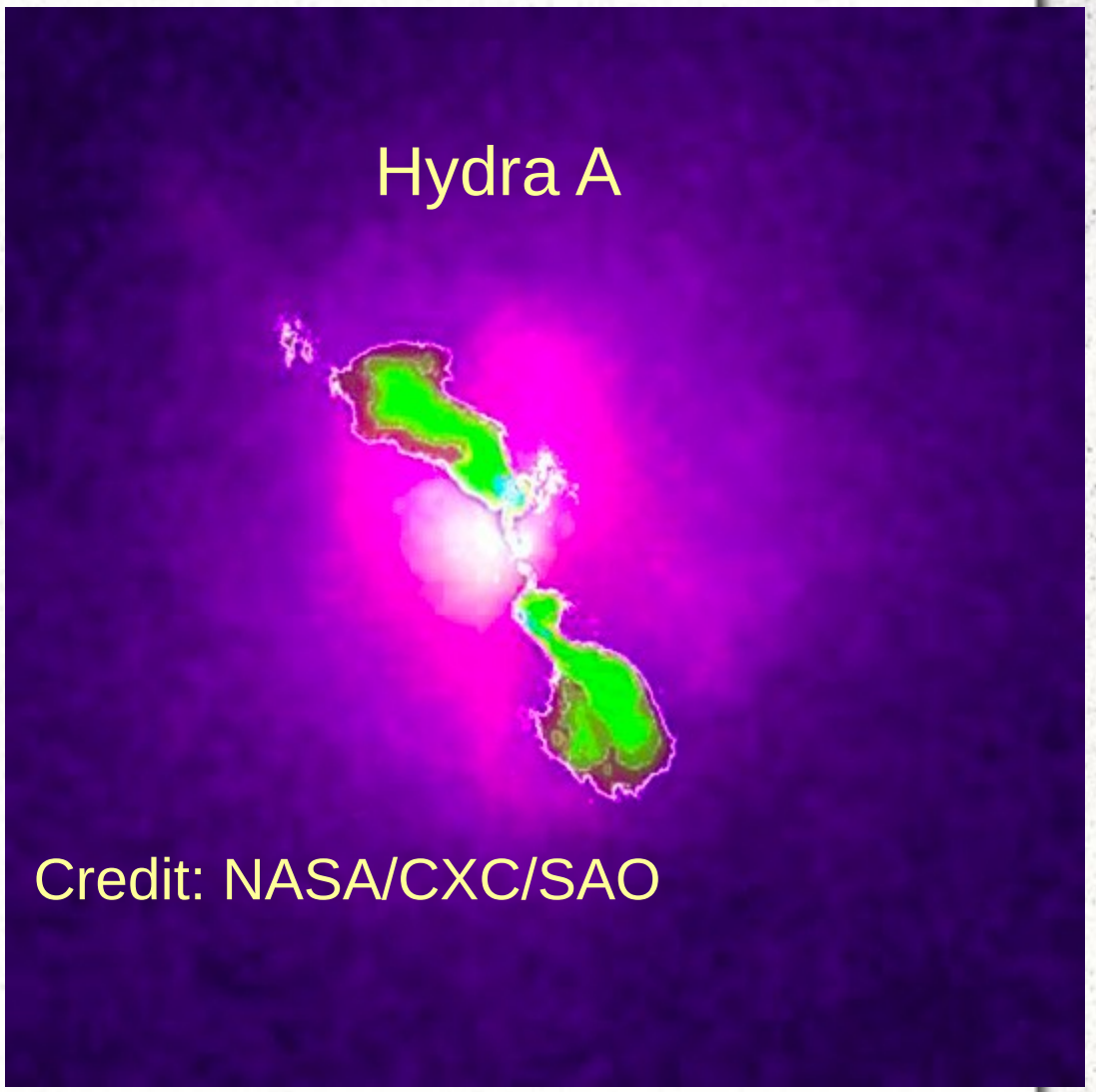
Revived radio galaxies

Feedback

AGNs affect the cluster and cluster affects the galaxies



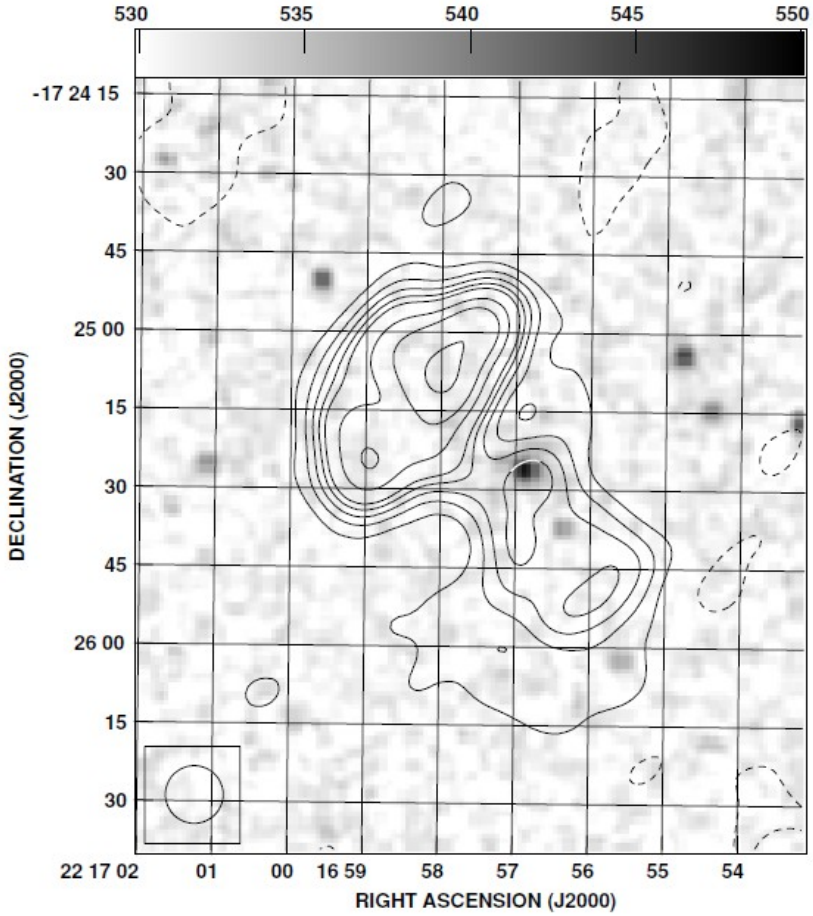
Credit: X-ray: NASA/CXC/Univ. Waterloo/B.McNamara; Optical: NASA/ESA/STScI/Univ. Waterloo/B.McNamara; Radio: NRAO/Ohio Univ./L.Birzan et al.



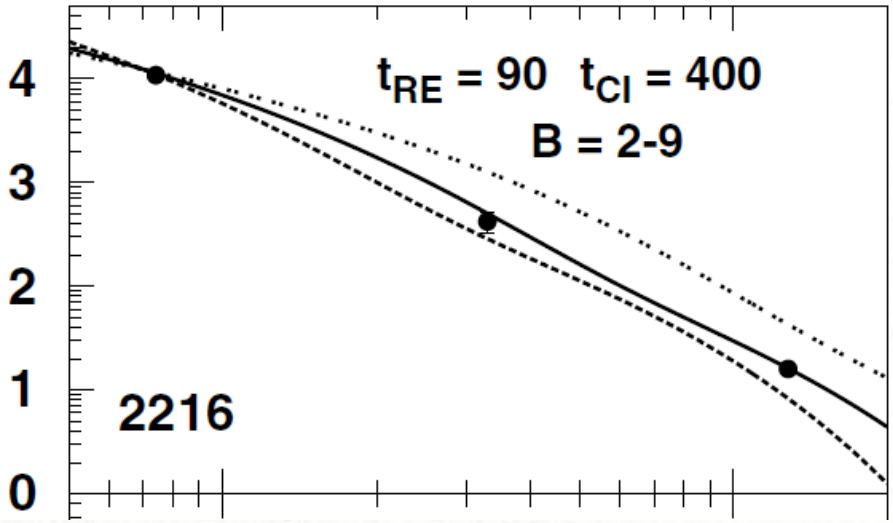
Review: McNamara and Nulsen 2007

Dying radio sources: steep spectrum

E.g. Dwarakanath and Kale 2009



Spectral index -2.2 over 74 – 1400 MHz

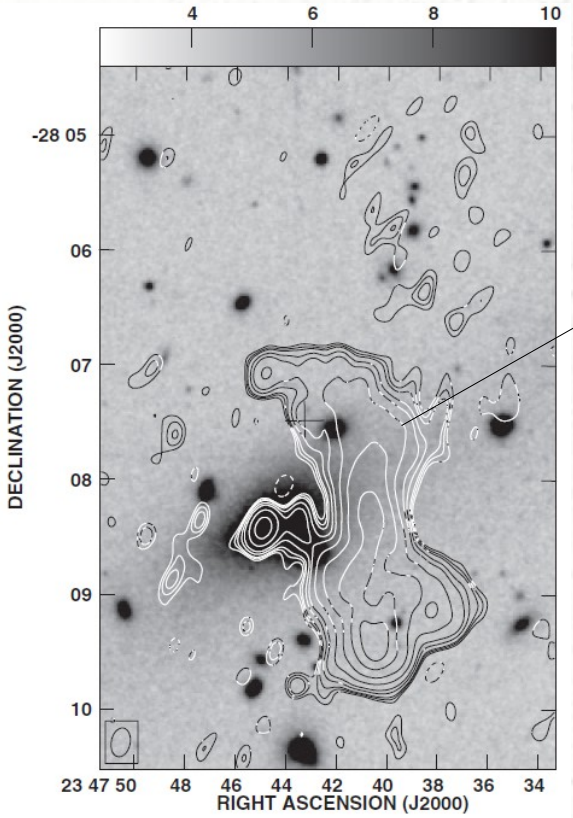


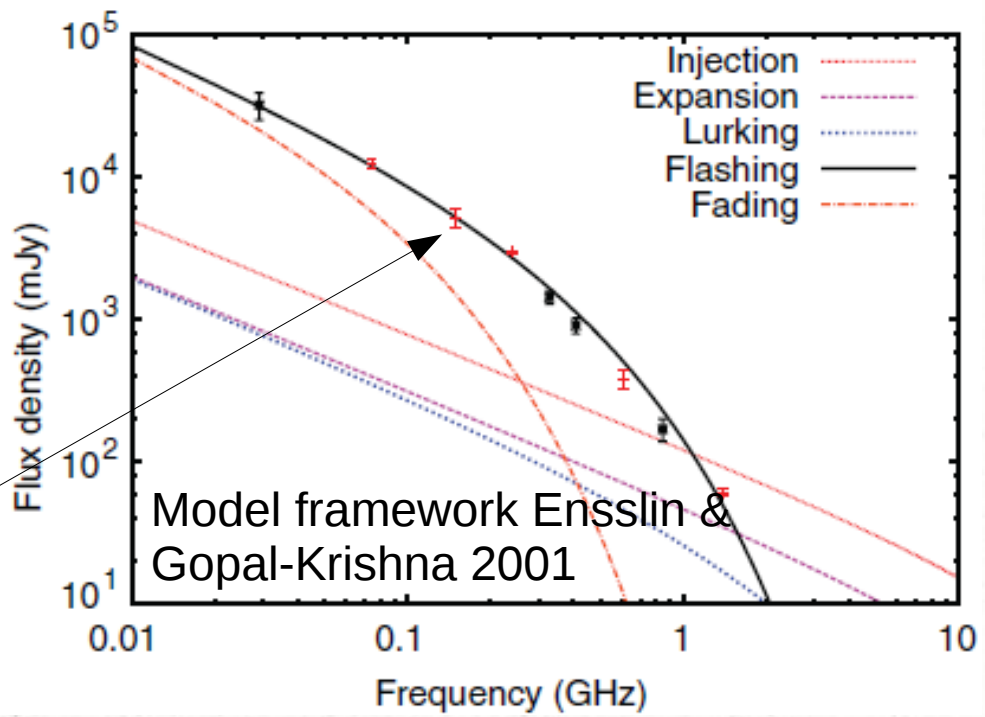
Model fit based on Ensslin and Gopal-Krishna 2001

E.g. Slee et al. 2001;
ZwCl 0735.7+7421, Cohen et al. 2005;
A2256, van Weeren et al. 2009;...

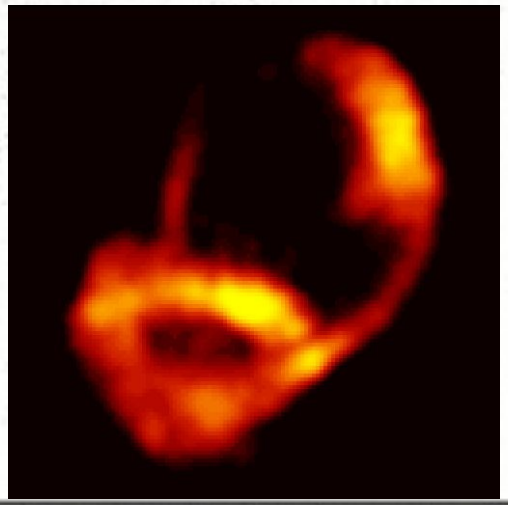
Revived radio galaxies

E.g. Abell 4038:
Kale and Dwarakanath 2012





E.g Abell 85
Slee et al. 2001;
Ensslin & Gopal-Krishna 2001



Radio sources in high redshift clusters

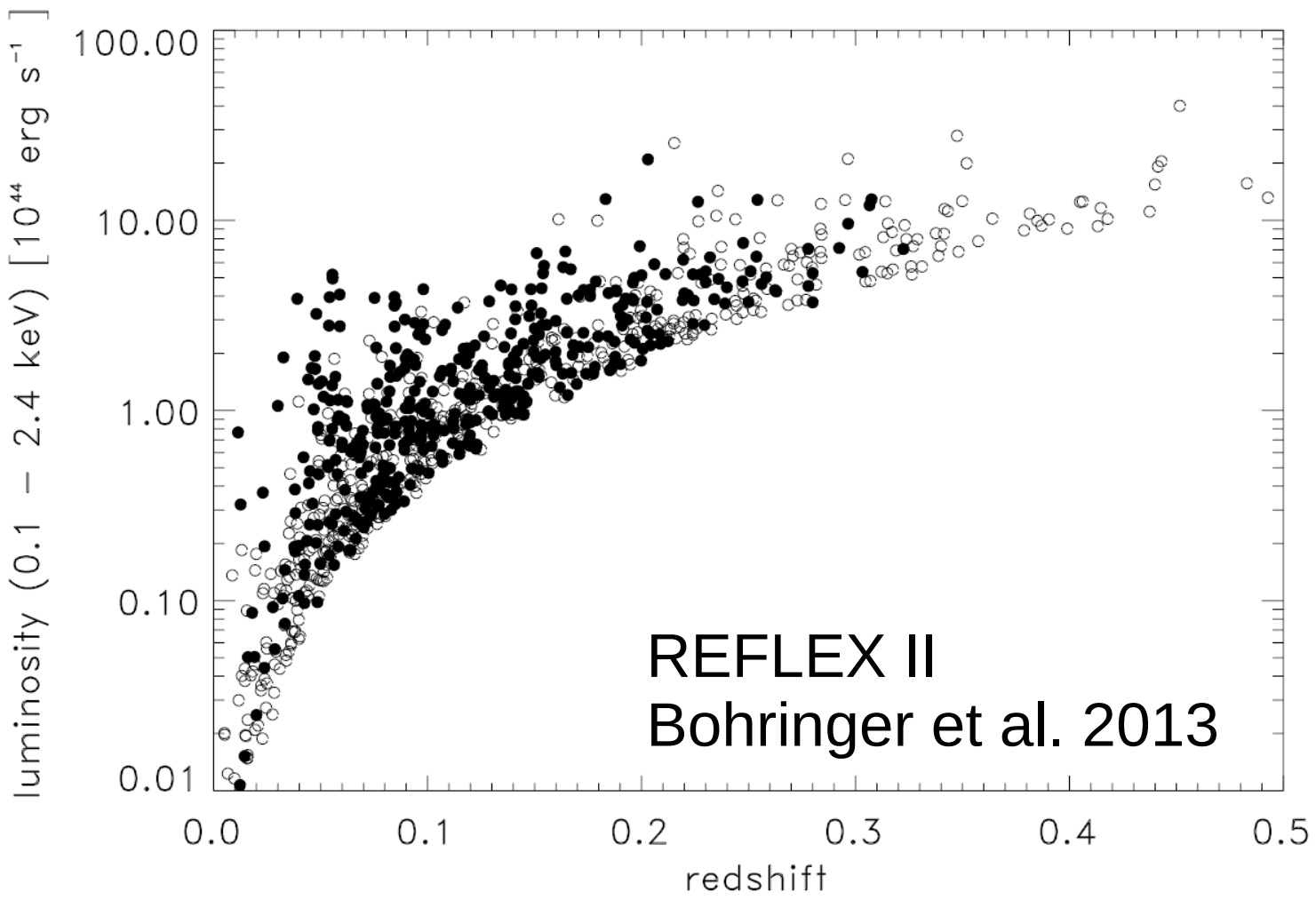
Radio sources such as bent sources are themselves tracers of high density cluster like environment.
(Earlier talks in this meeting!)

Steeper spectra
(E.g. Ishwar's poster)

A number of studies have probed properties of galaxies in high redshift clusters:

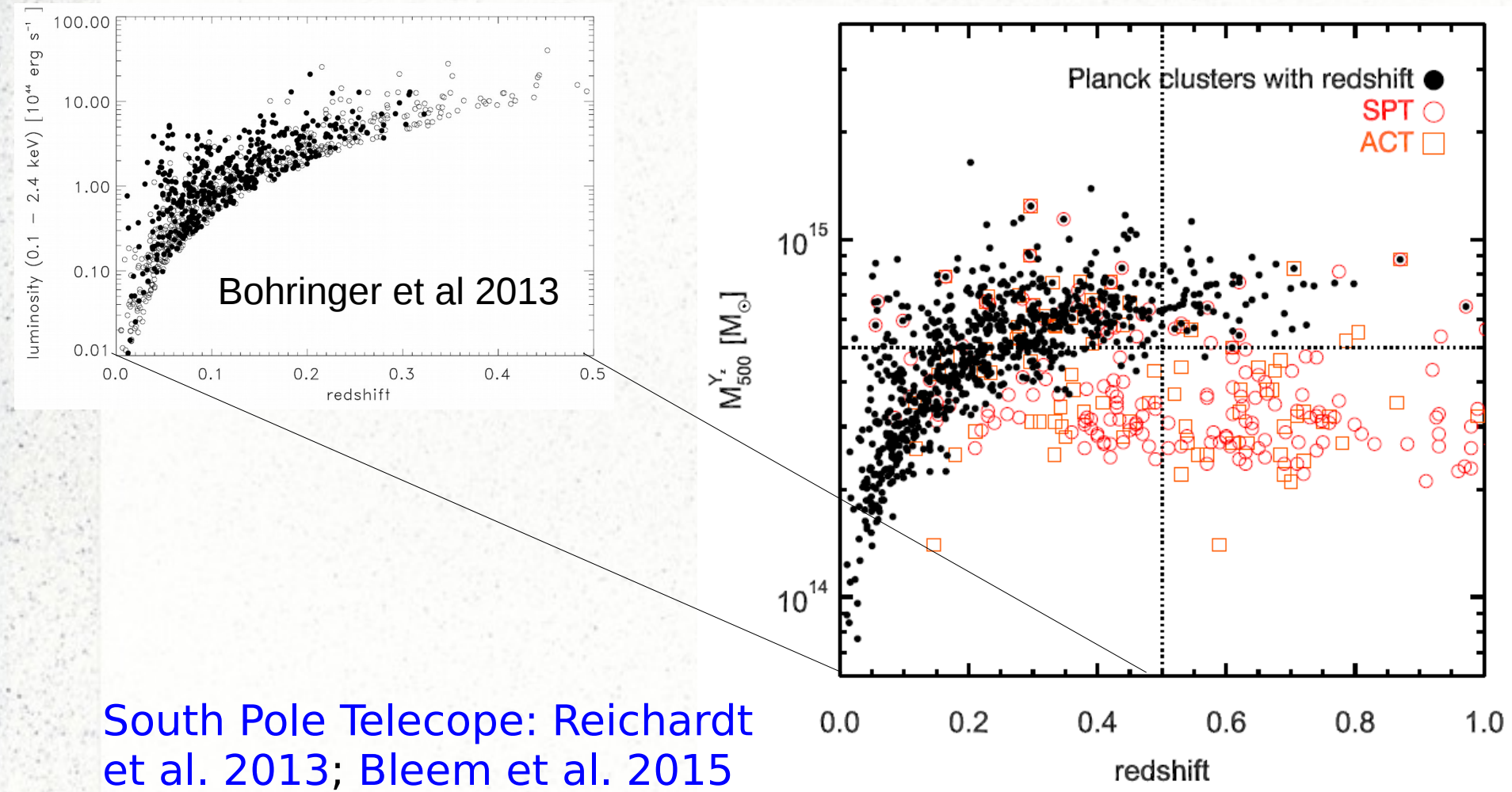
(e.g., Bassett et al. 2013; McIntosh et al. 2014; Zeimann et al. 2012, 2013; Santos et al. 2013; Strazzullo et al. 2013; Gobat et al. 2013; Casasola et al. 2013; Brodwin et al. 2013; Alberts et al. 2014; Castignani et al 2014; Lin & Mohr 2007...)

Cluster surveys: X-rays



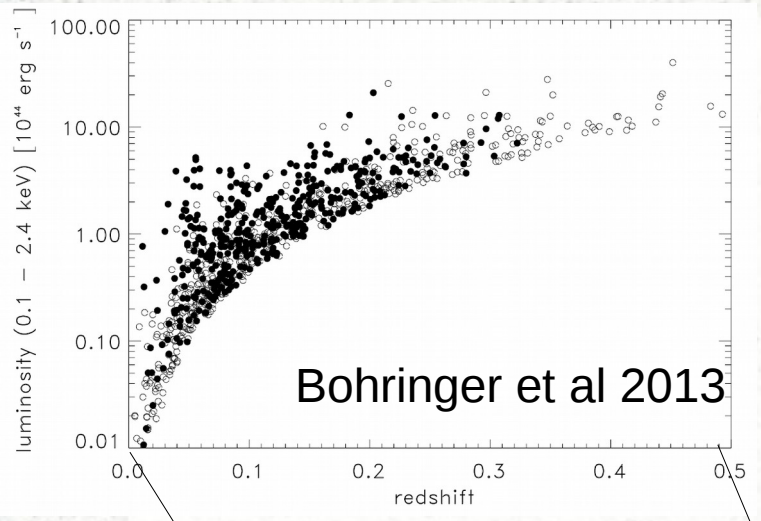
Clusters from SZ surveys: Planck, SPT, ACT

Planck collaboration 2014

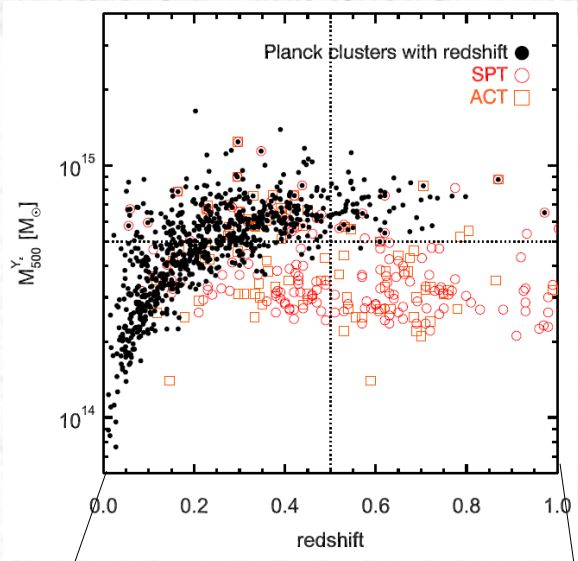


South Pole Telecope: Reichardt et al. 2013; Bleem et al. 2015

Atacama Cosmology Telescope: Marriage et al. 2011; Hasselfield et al. 2013

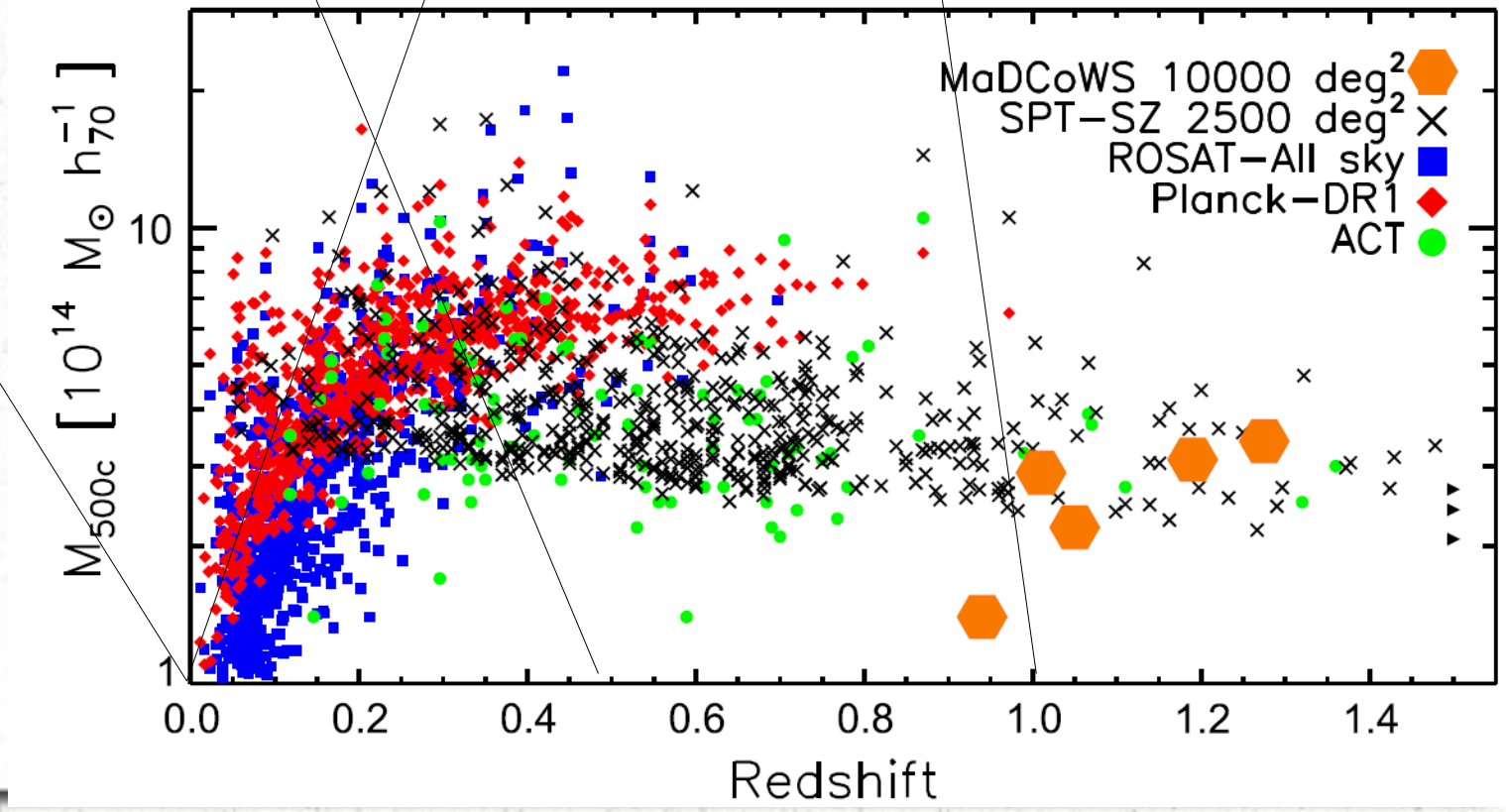


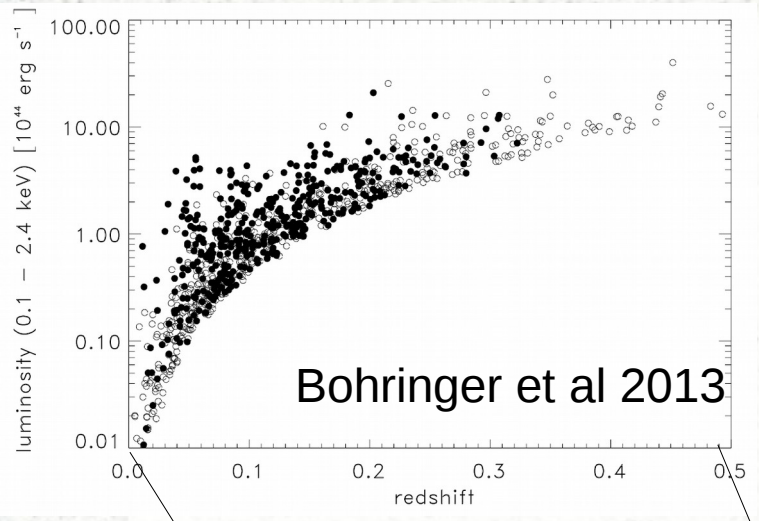
Bohringer et al 2013



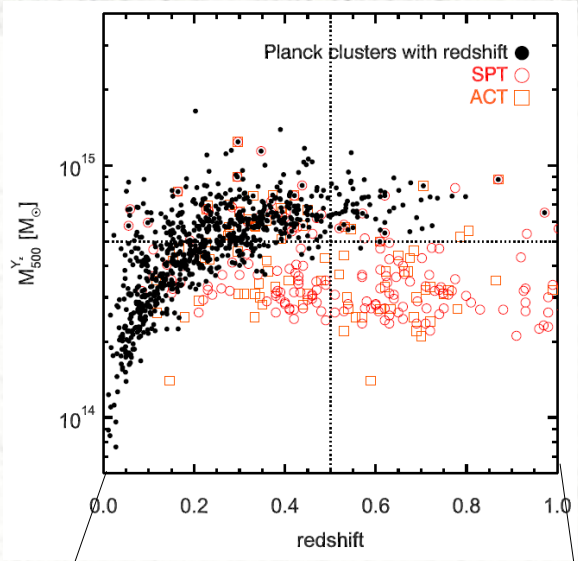
Planck collaboration 2014

Brodwin et al 2015



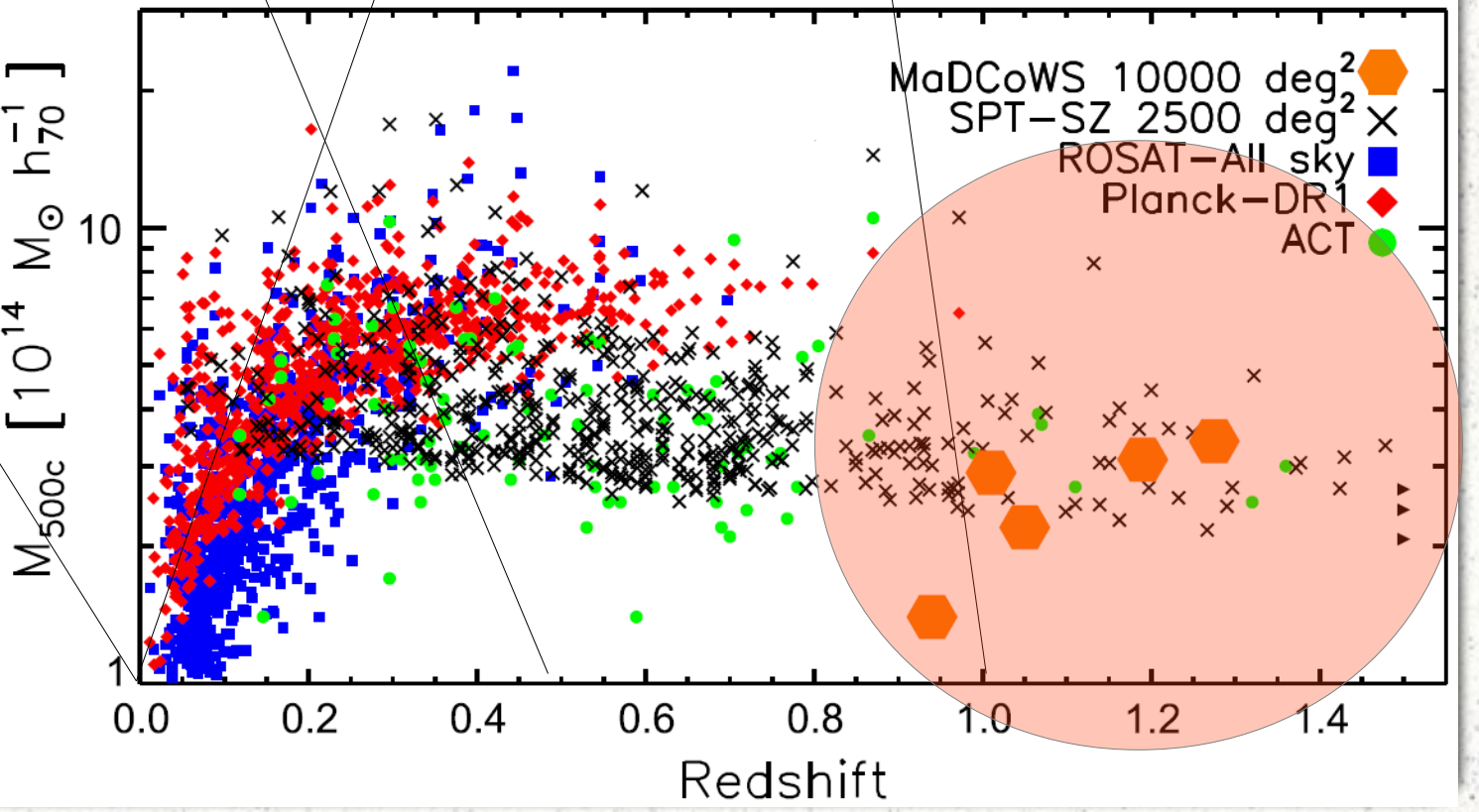


Bohringer et al 2013



Planck collaboration 2014

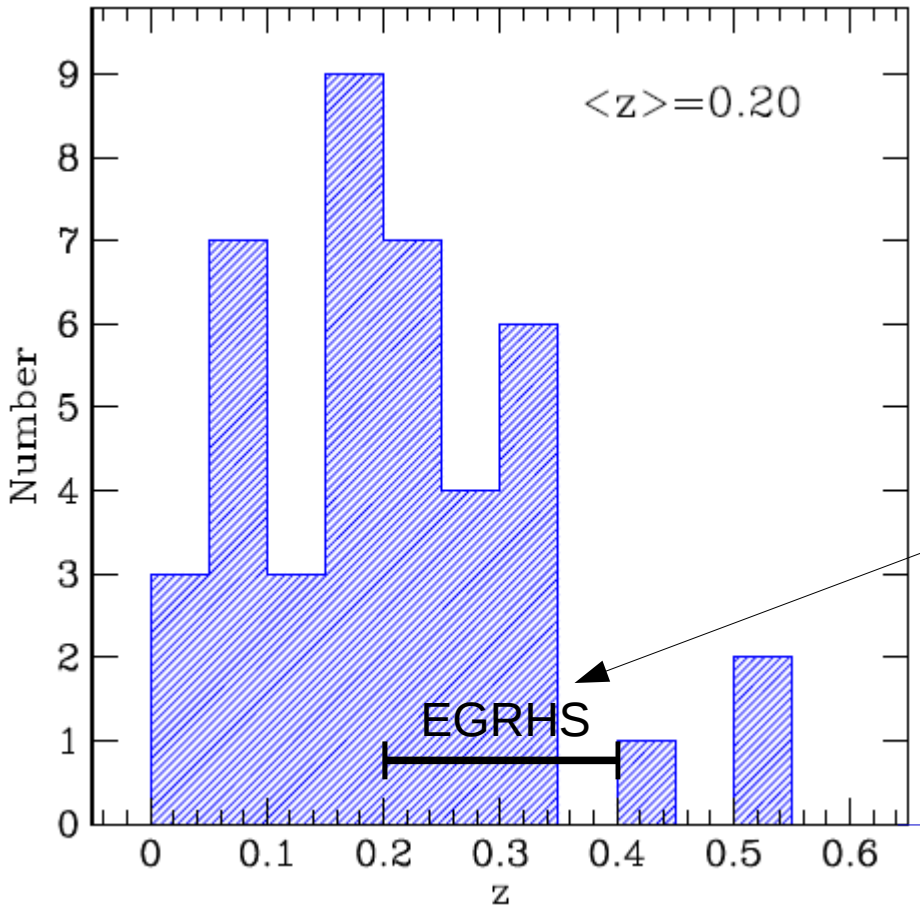
Brodwin et al 2015



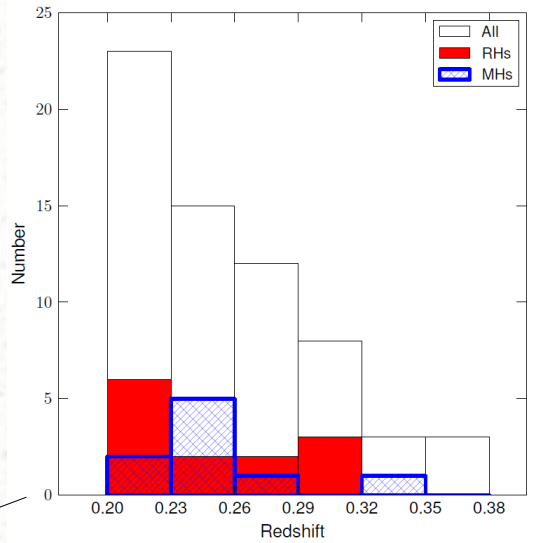
Cluster radio halos: redshift distribution ?

Not known due to lack of deep systematic surveys...(ongoing surveys)

Feretti and Giovannini 2012



Kale et al. 2015a



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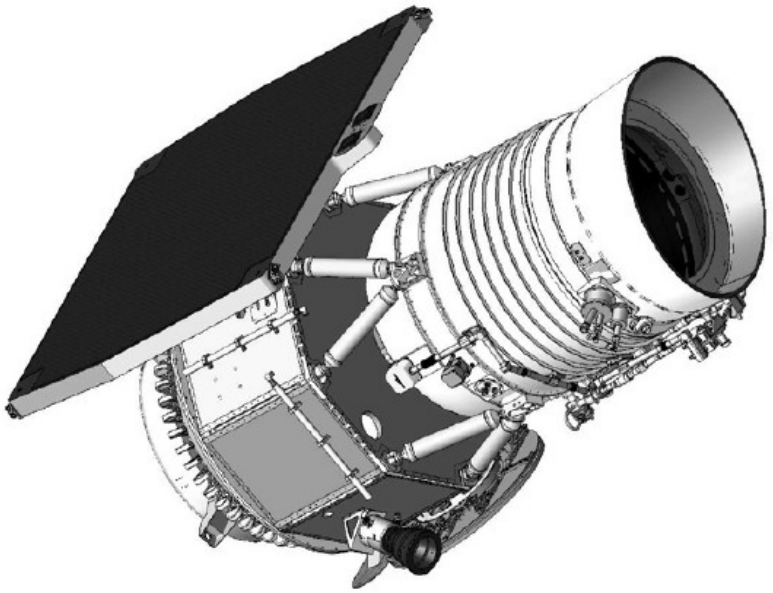
0.87

Lindner et al. 2014

El Gordo

Wide-field Infrared Survey Explorer

- 16-inch aperture
- 3.4, 4.6, 12, 22 microns
- FoV 47 arcminutes
- 6" resolution at 3.4, 4.6 and 12 microns
- 12" resolution at 22 microns
- Surveys of full sky at the four bands

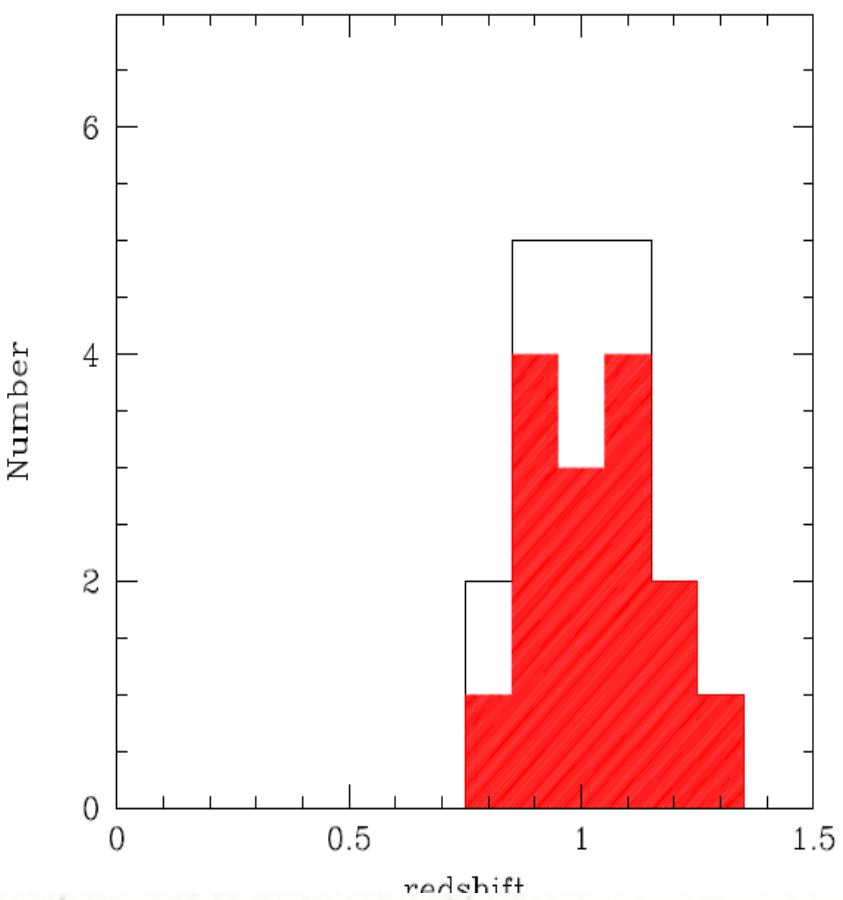


MaDCoWS clusters

Stanford et al. 2014

Magnitude and colour cuts in WISE and optical bands.
WISE and SDSS DR8 match.
W1(3.4 micron) -W2(4.6 micron) < 0.2 and i<21 rejected to remove foreground galaxy population.
Wavelet search to find overdensities on scales of 3' (1.4 Mpc at z~1).
Most significant density peaks are MaDCoWS candidates.

Optical follow-up (Gran Telescopio Canarias, Gemini North, IRAC)
- red sequence in color-magnitude diagram
- optical image
- galaxy overdensity in IRAC images.

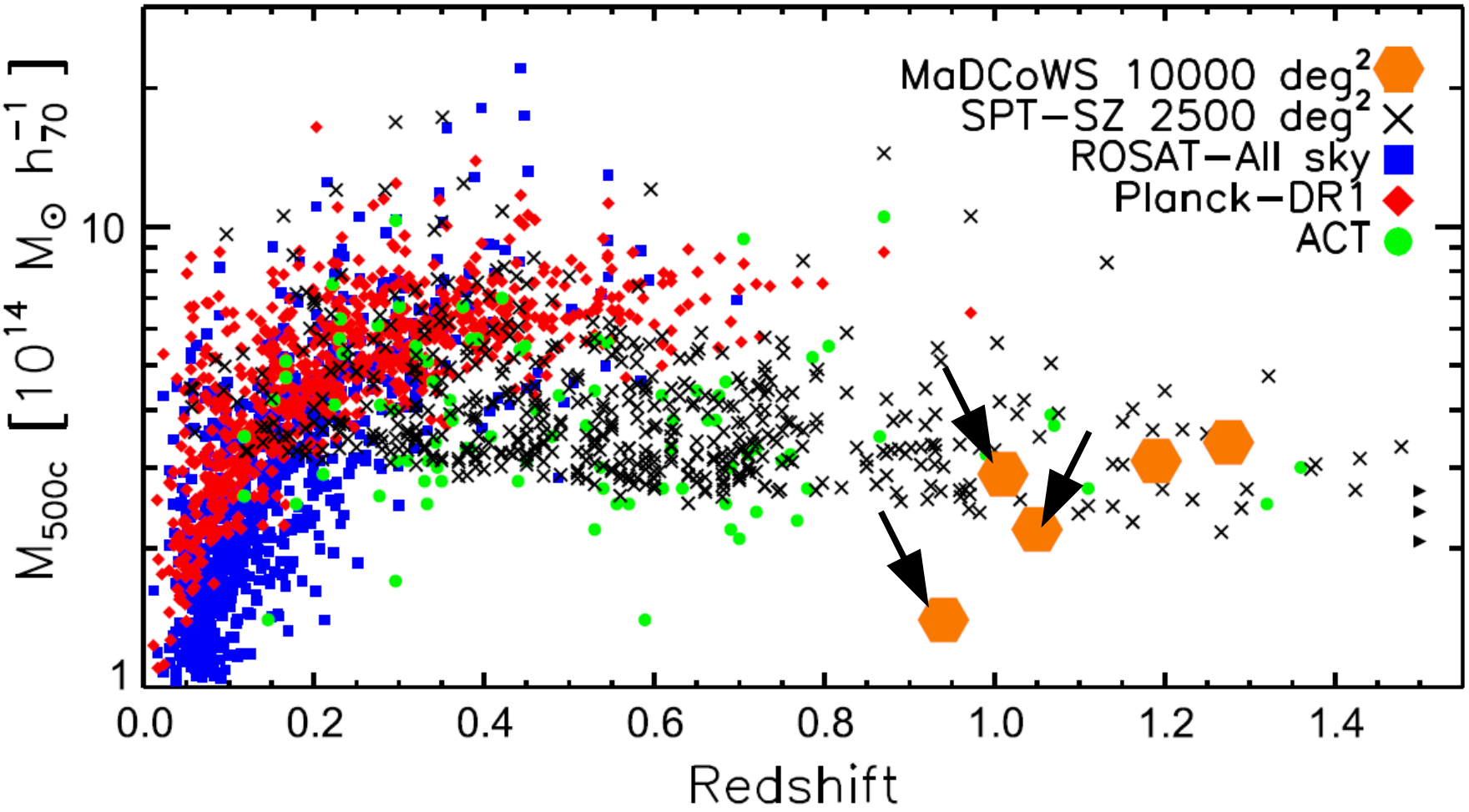


19 new clusters between 0.7 < z < 1.3

Masses between 1.4 – 6 x 10^{14} $M_{\odot}$

CARMA SZ observations

Brodwin et al 2015



Need for new low frequency observations

- Existing surveys:

  NVSS 1.4 GHz, SUMSS 843 MHz, WENSS-WISH 325 MHz, VLSS 74 MHz

  45" – 80" resolution ~ 360 – 640 kpc at z~1

  FIRST 1.4 GHz, 5": does not cover full sky and is shallow.

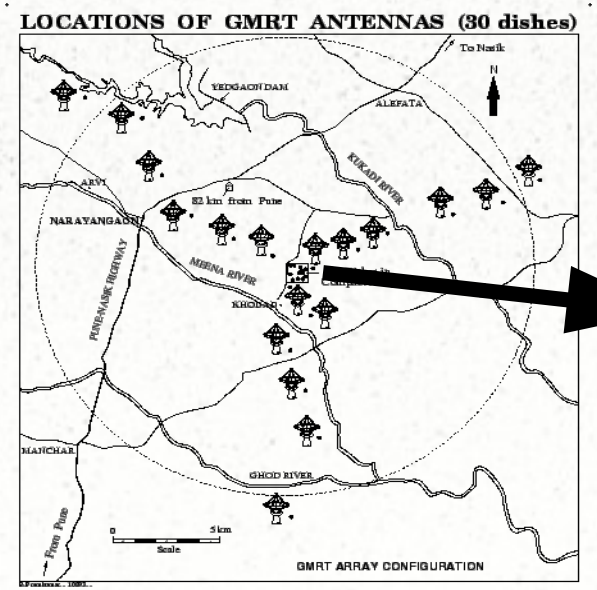
- Deep surveys: limited sky coverage.
- Radio spectra steeper: dominating IC losses

GMRT low frequency observations

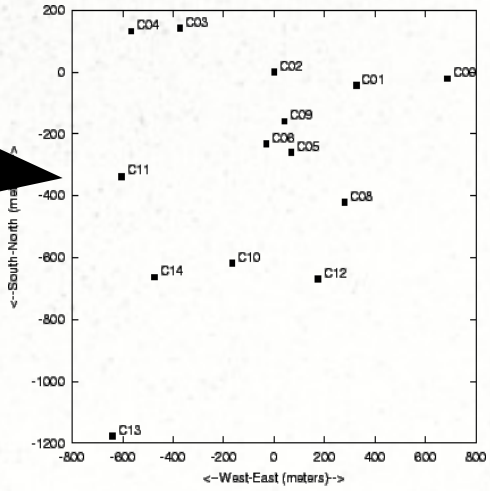
- GMRT at 610 and 1390 MHz: resolutions ~ 5" – 2" which resolves the galaxies at 40 – 16 kpc.
- A few Mpc angular scales easily probed due to short spacings coverage.

~25 km baselines

Rms ~ 30-40 microJy/beam
~ 10-15 microJy/beam with broadband receivers



1 km central compact core



GMRT observations (ongoing)

Cluster	**z**	$\mathbf{M_{500}}$ X 10^{14} $M_{\odot}$
MOO J0012+1602	0.944	1.4 ± 0.5
MOO J0133-1057	0.957	-
MOO J1155+3901	1.009	2.9 ± 0.7
MOO J1514+1346	1.059	2.2 ± 0.6

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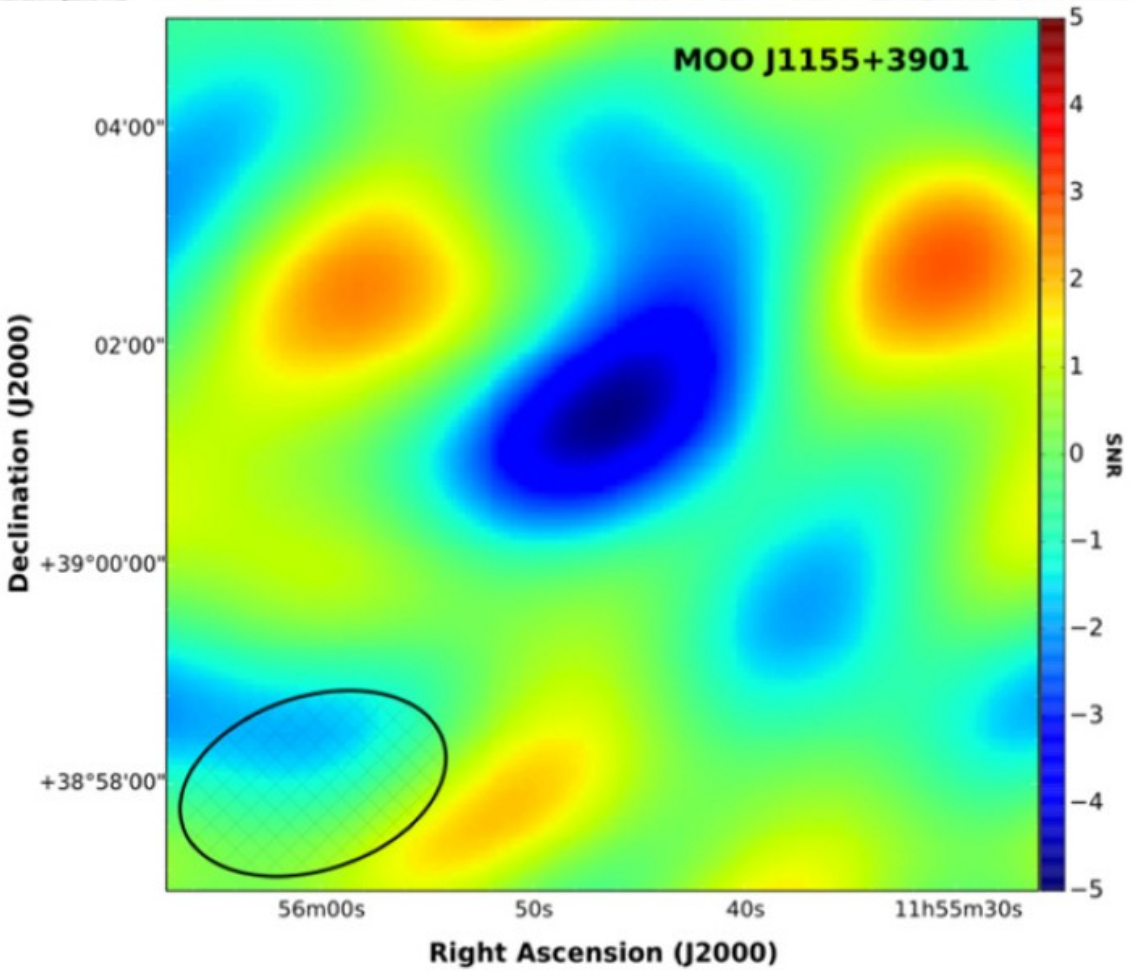
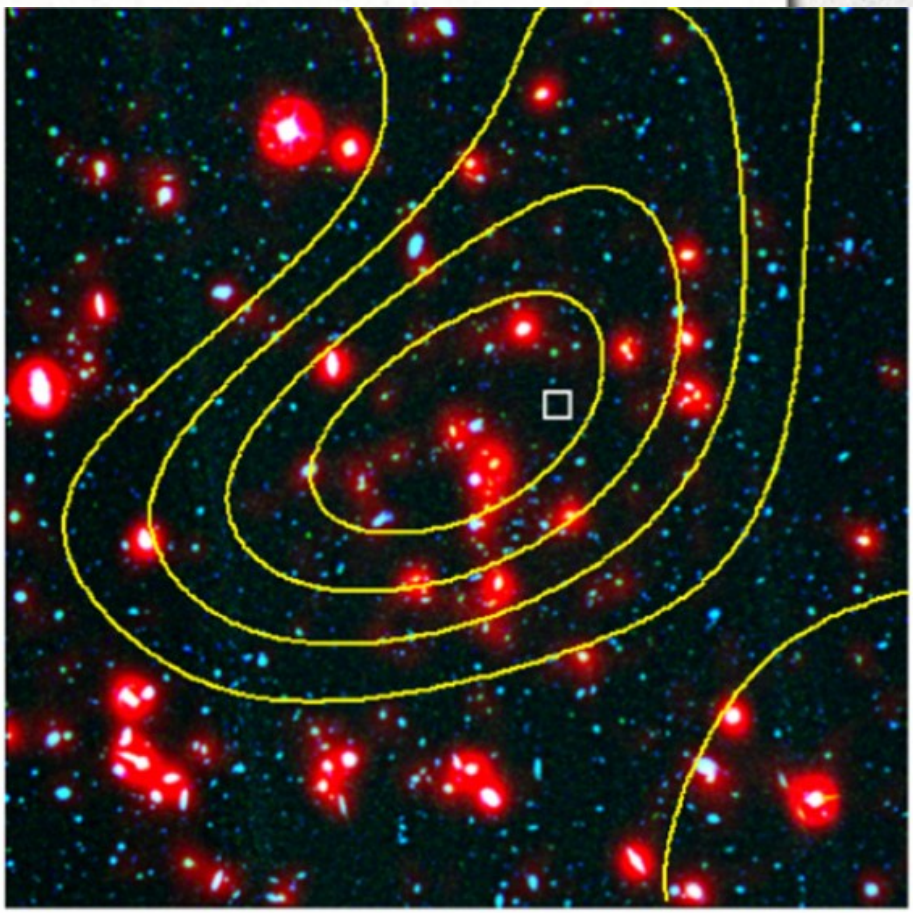
MOO J1155+3901

Brodwin et al 2015

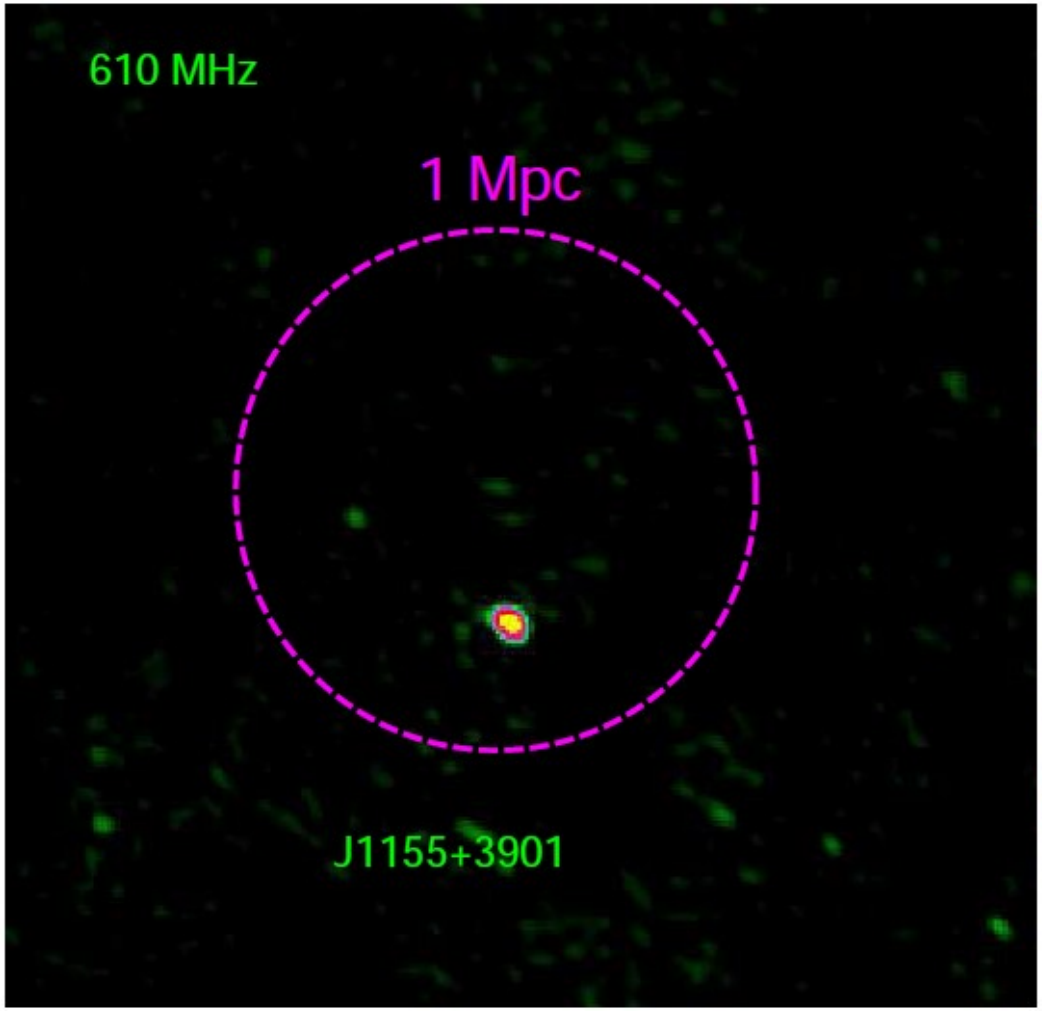


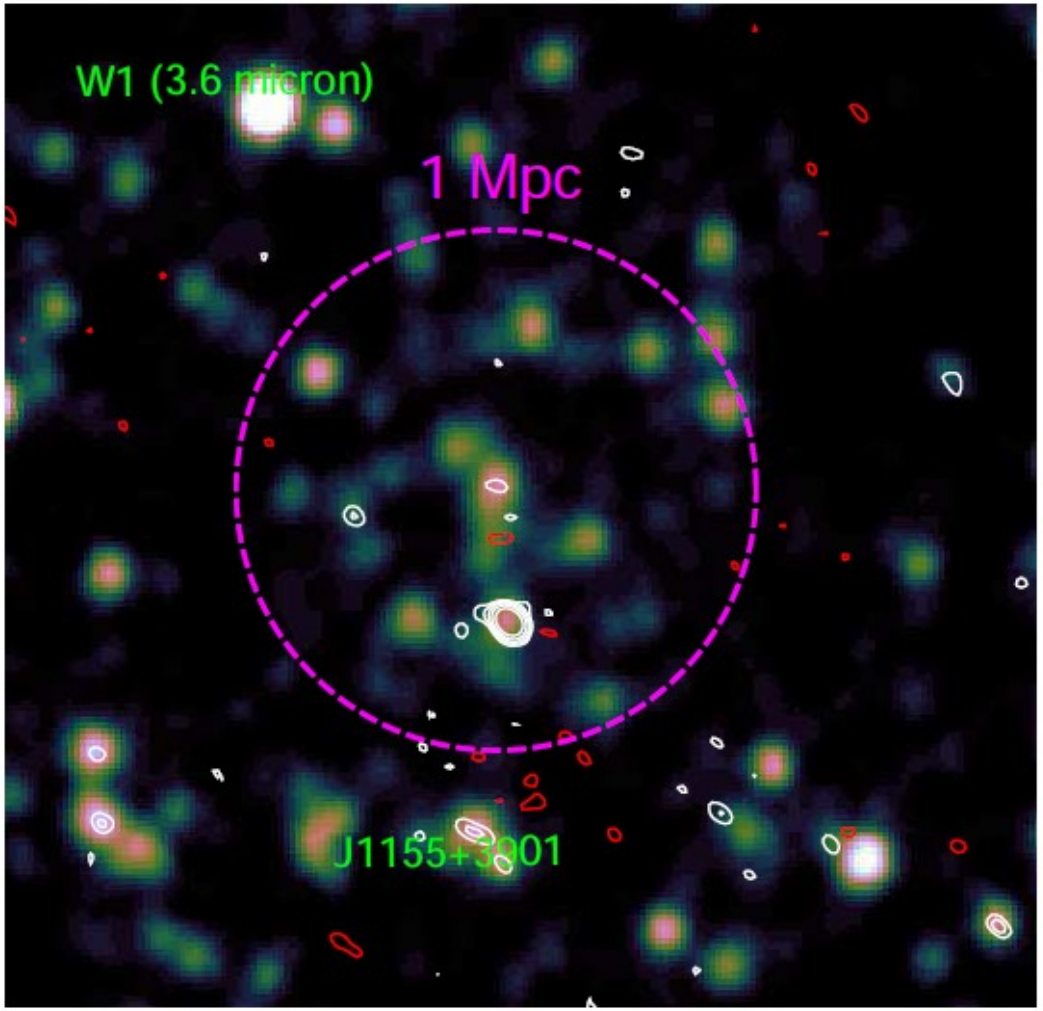


8′ — 8′ CARMA 30 GHz maps

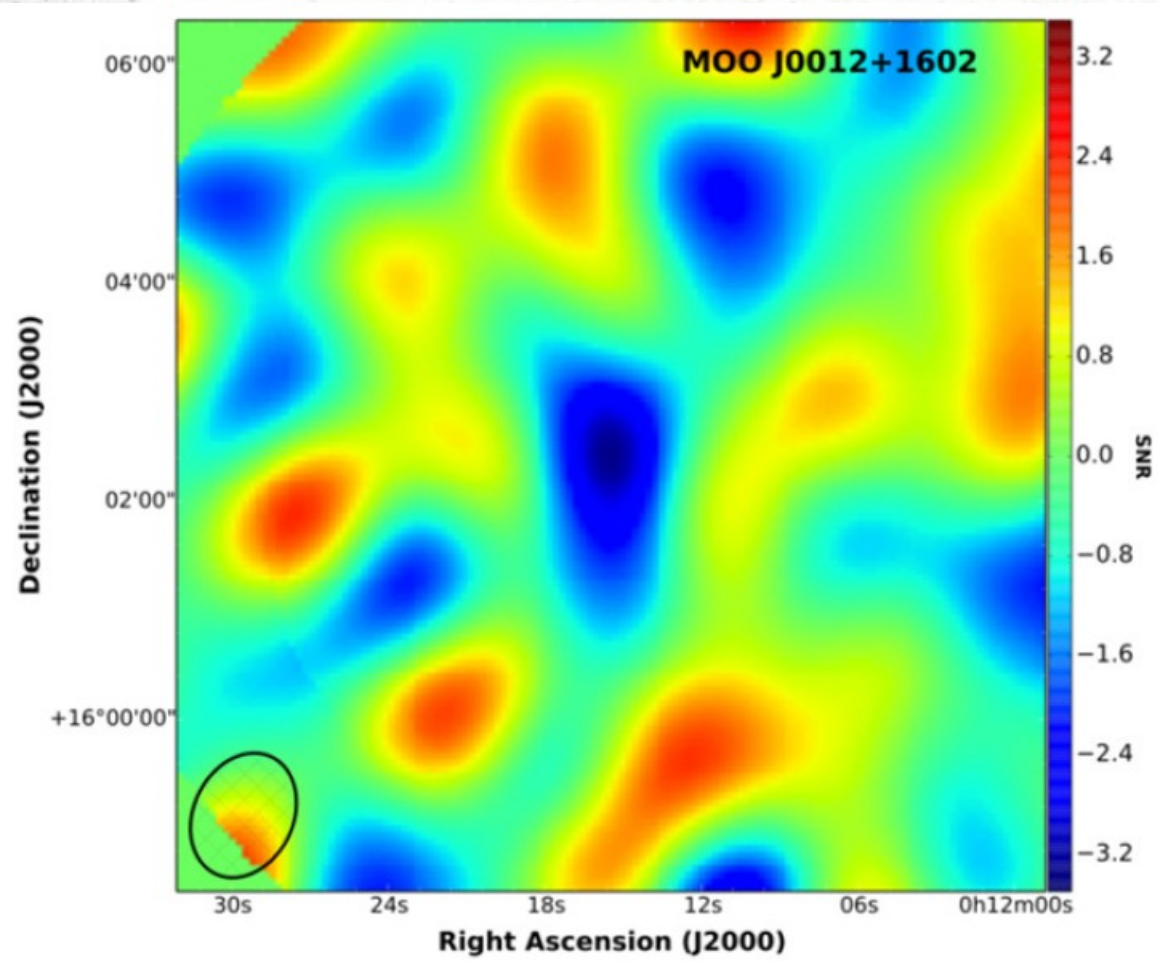
4′ — 4′ optical/IR images

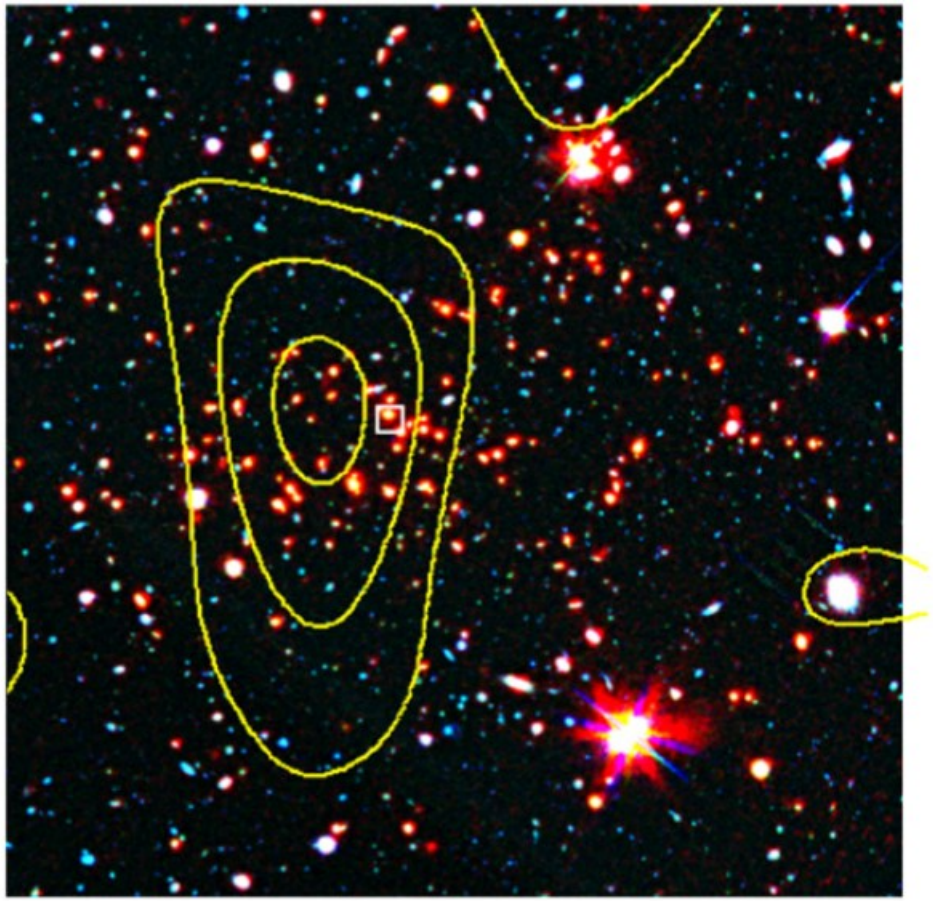
MOO J1155+3901





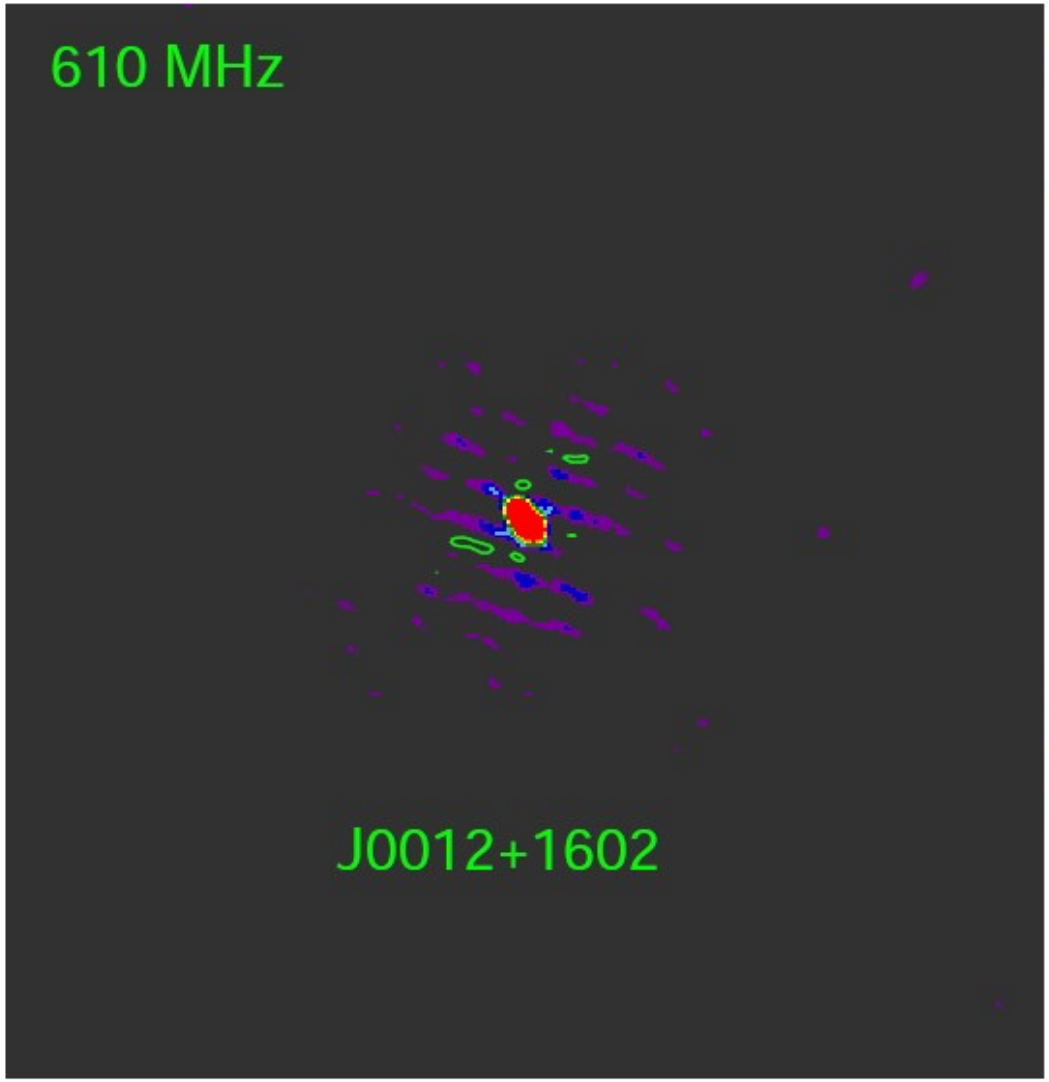
MOO J0012+1602

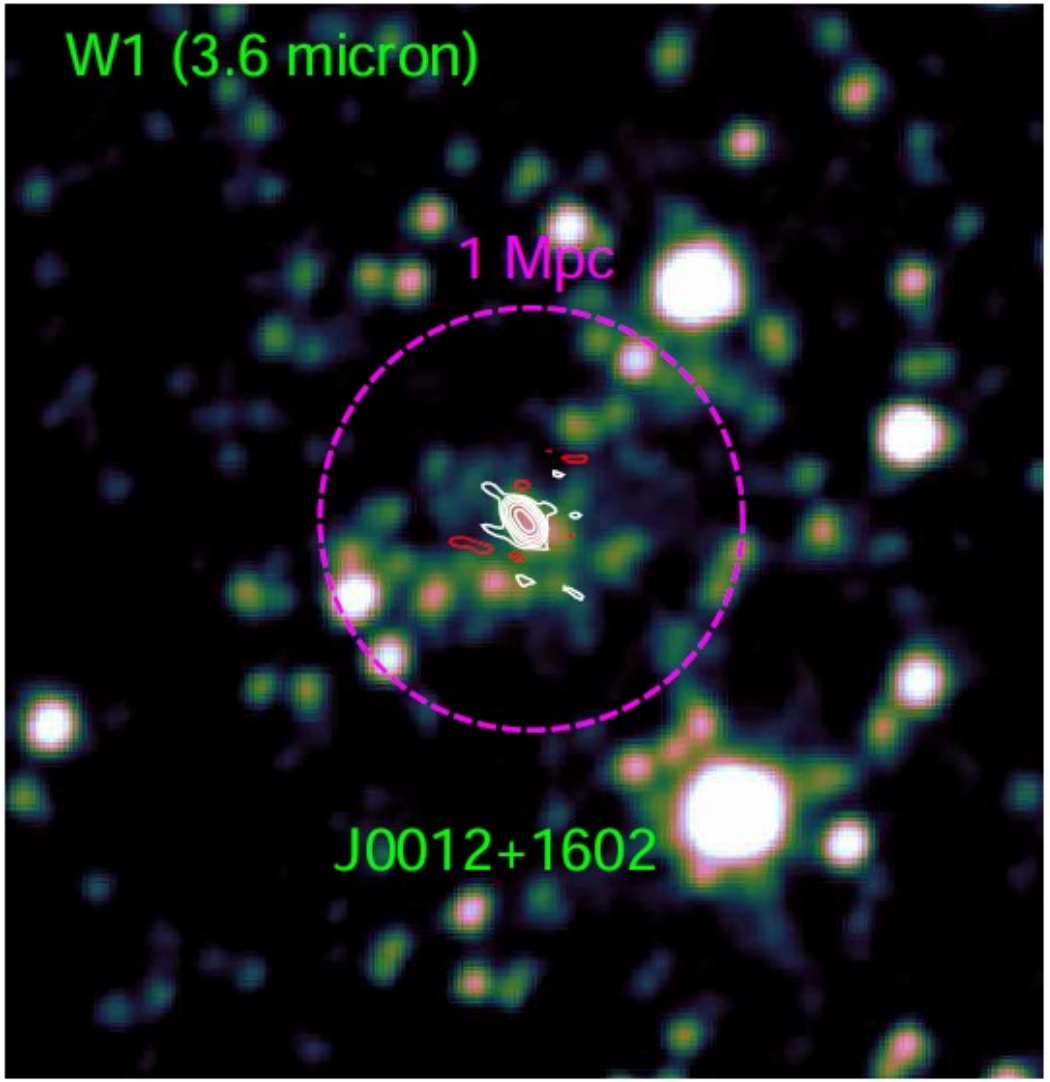




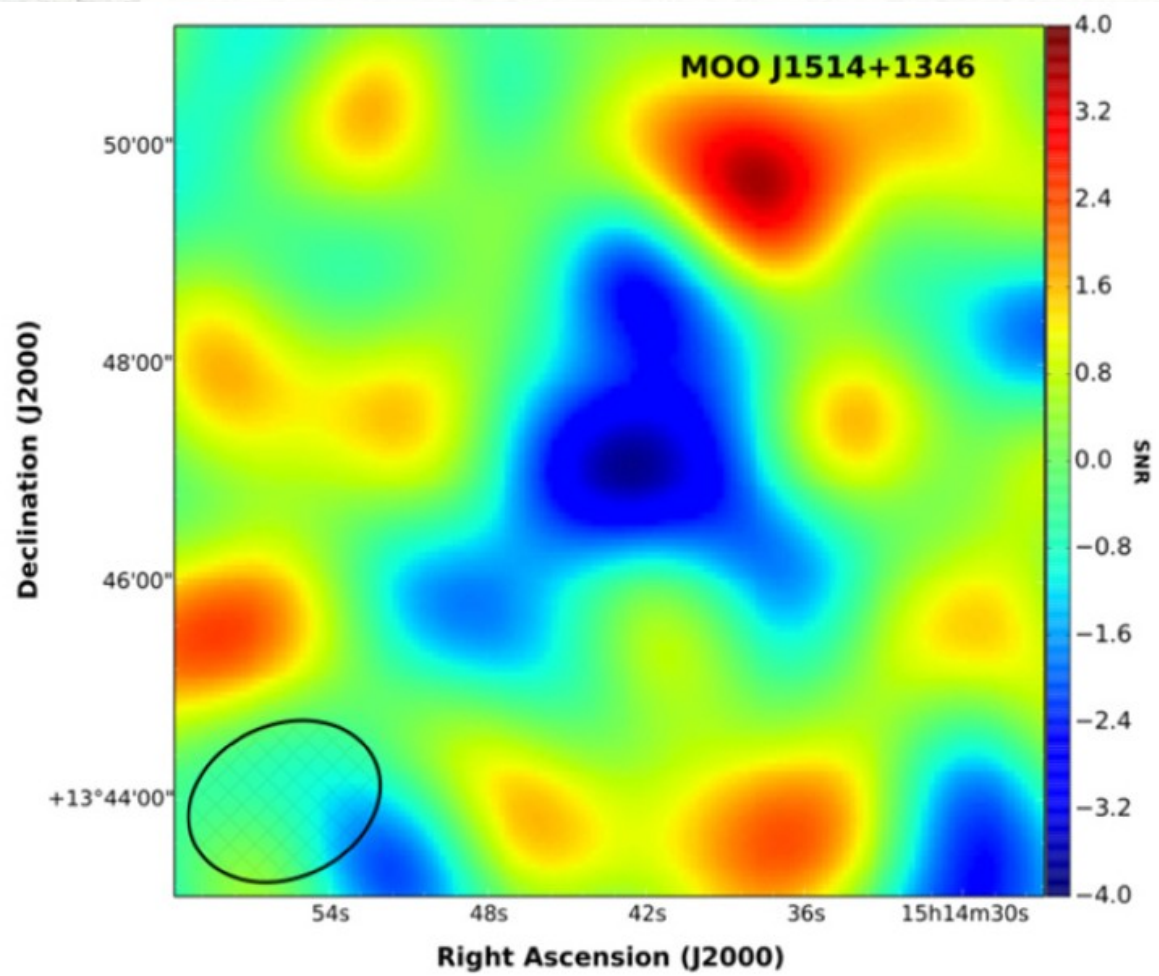
Brodwin et al 2015

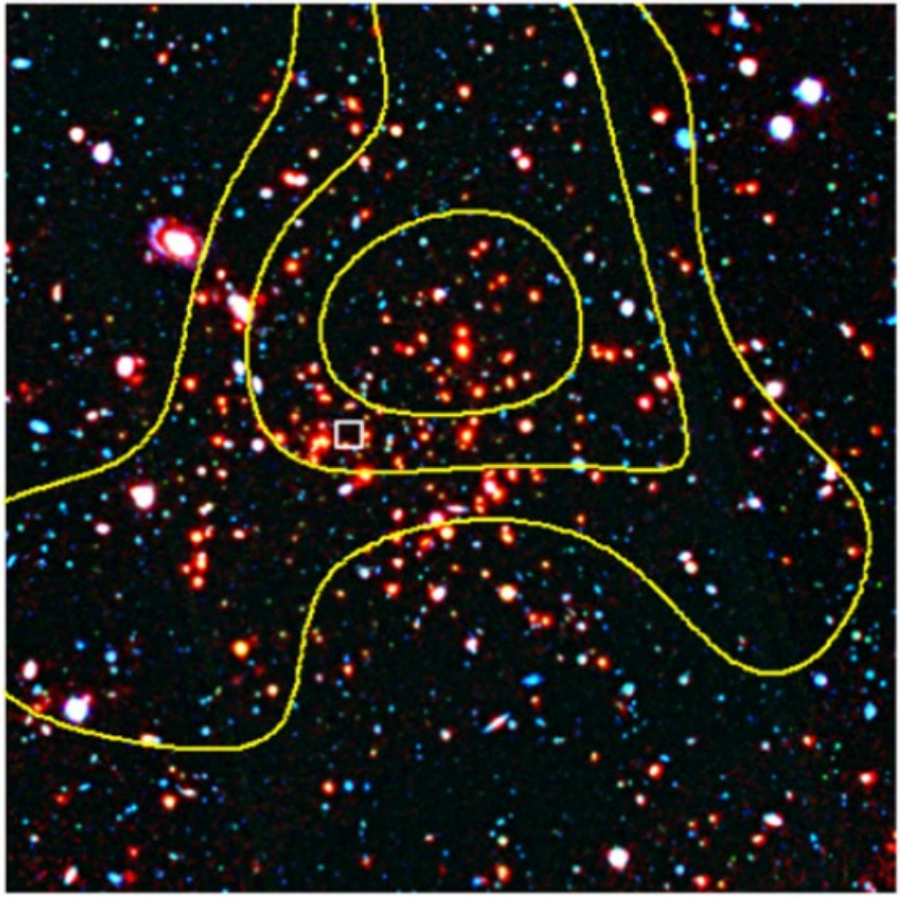
MOO J0012+1602



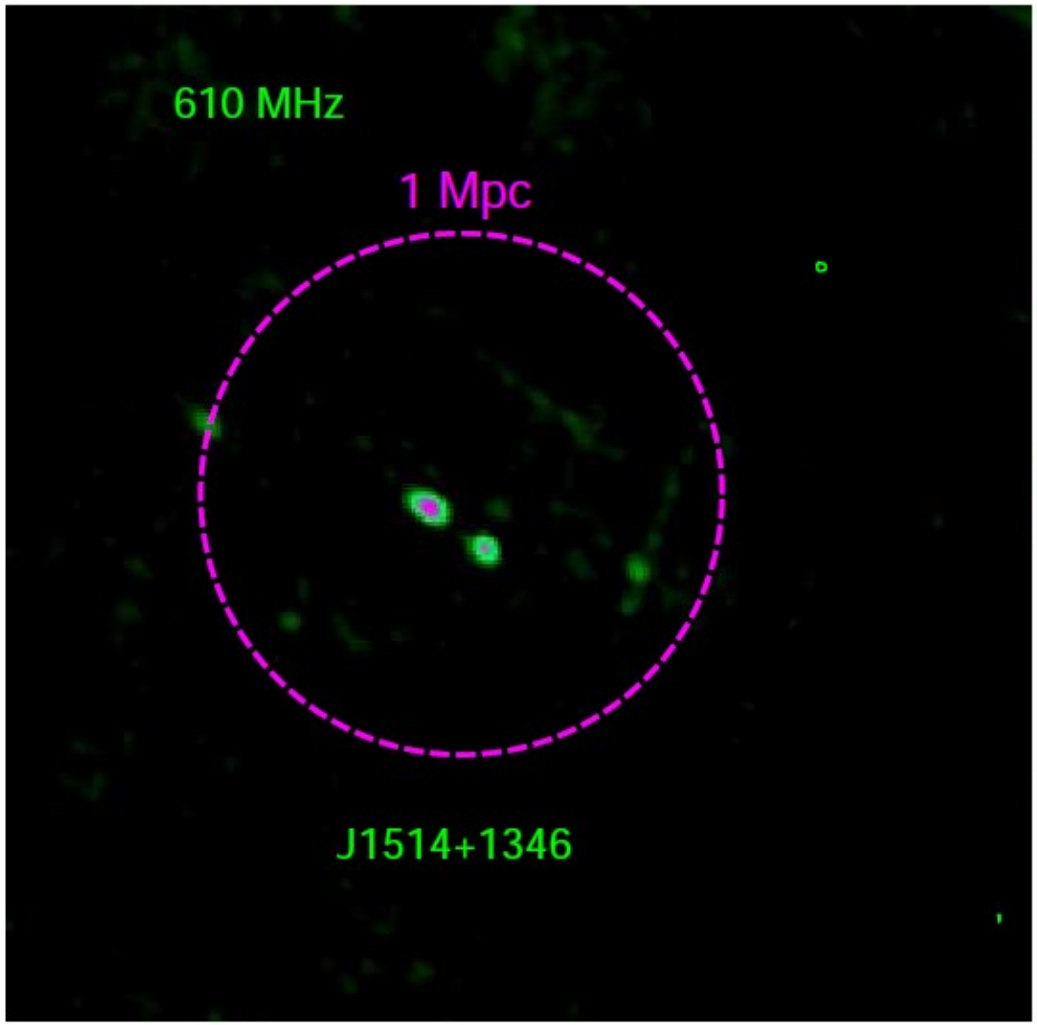


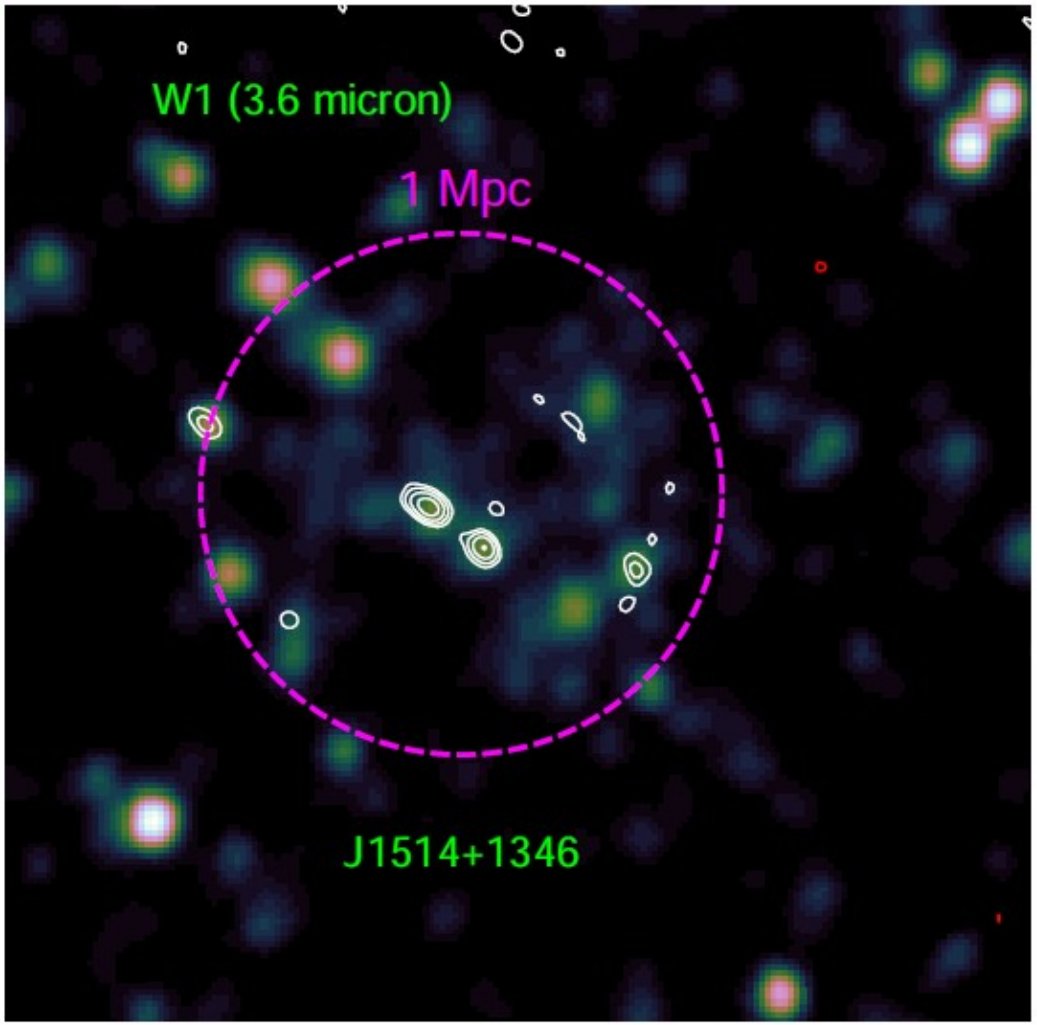
MOO J1514+1346



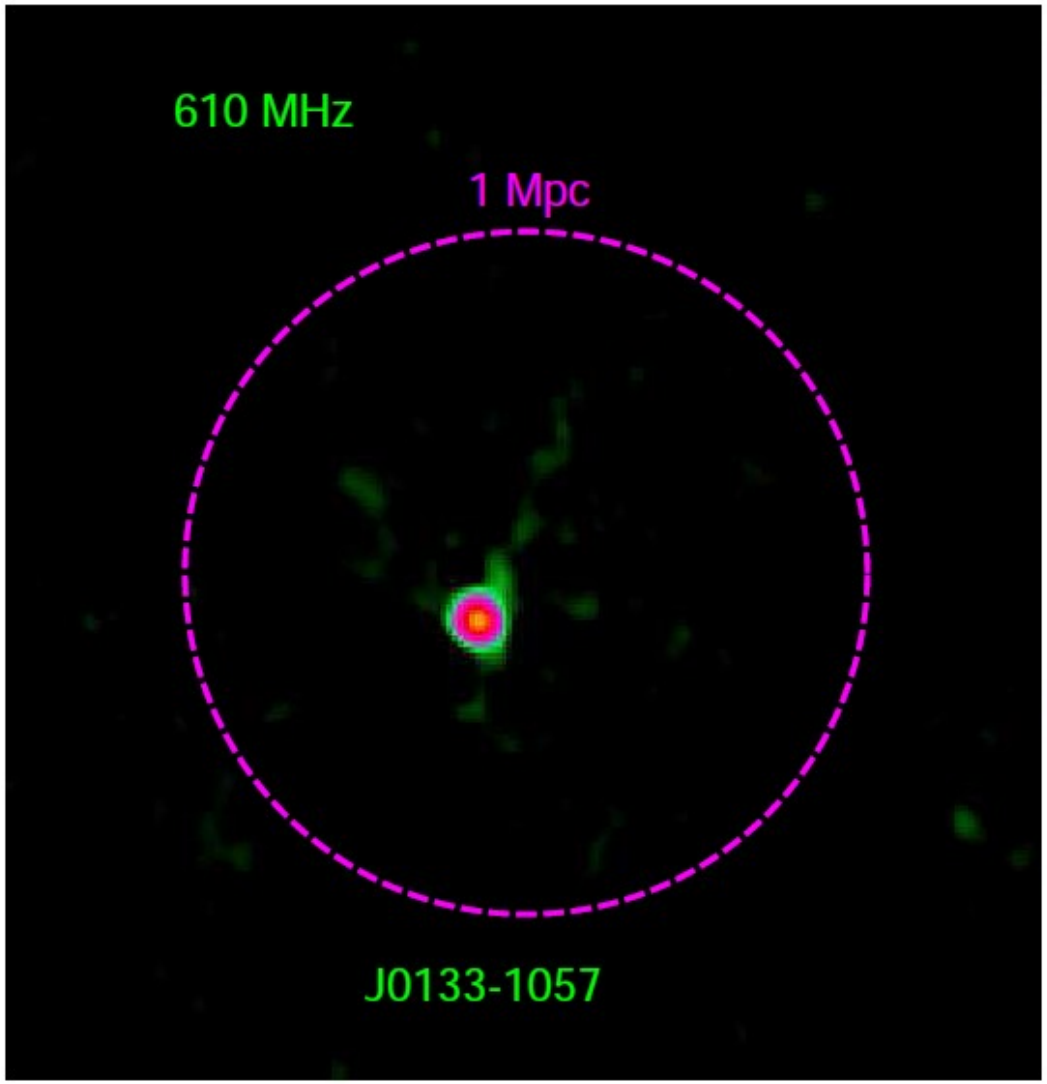


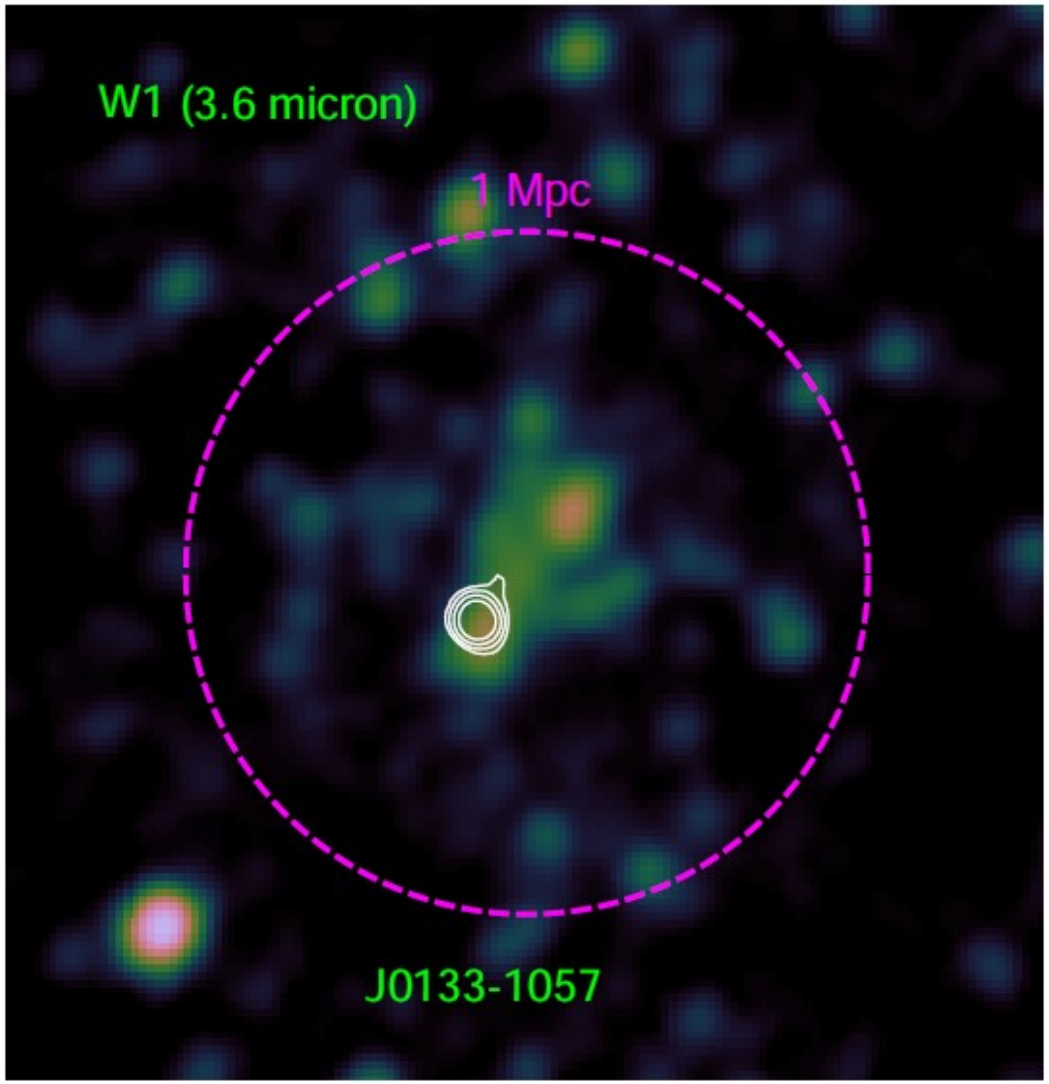
MOO J1514+1346



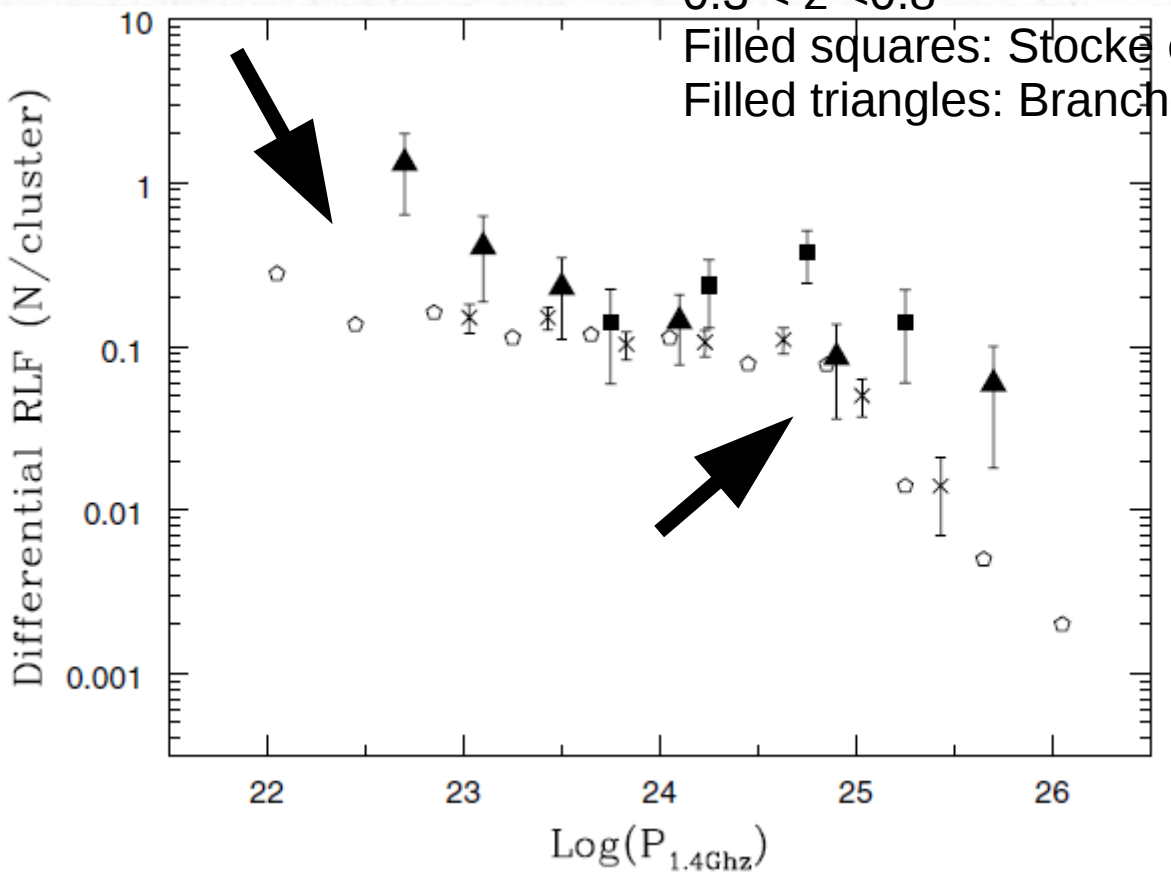


MOO J0133-1057





Comparison of near and far RLF



Nearby clusters
Open pentagons: Fanti et al 1984
Crosses: Lexlow and Owen 1996

Branchesi et al 2006

Summary

- High-z massive galaxy cluster samples are now available and are expanding.
- Ongoing GMRT observations at 610 and 1390 MHz of MaDCoWS clusters.
- Results: Radio sources are detected in the clusters- association with cluster galaxies.
- Future work: Complete the radio survey of the sample and comparison with low redshift clusters.