Radio Halos in ACT Galaxy Clusters

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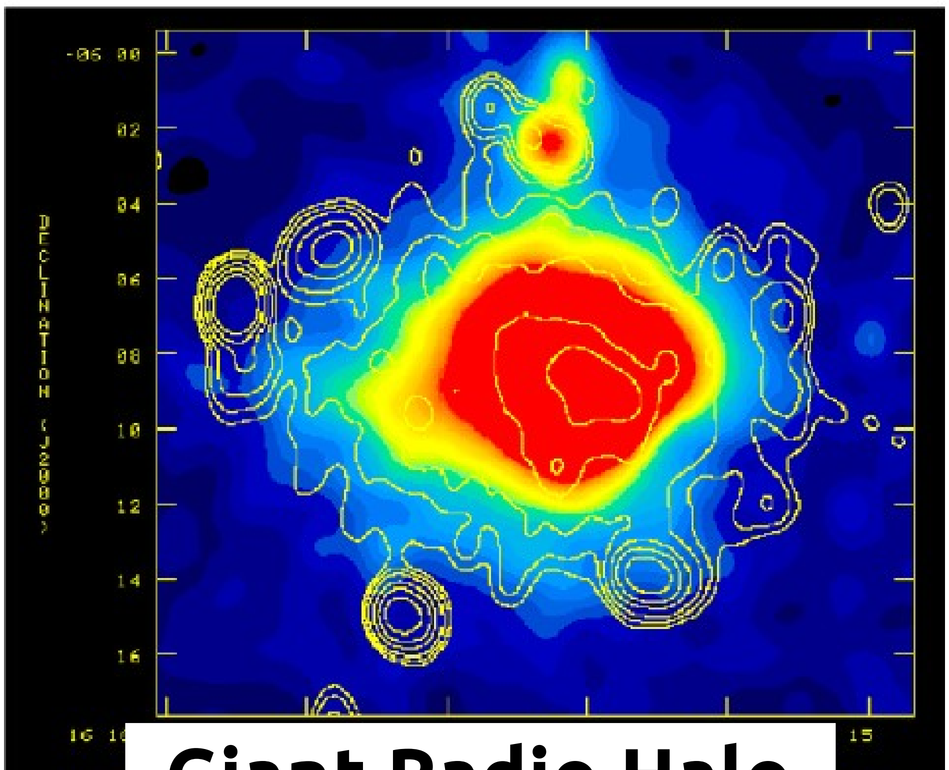
Cosmology on Safari, Bonamanzi
28 January 2015

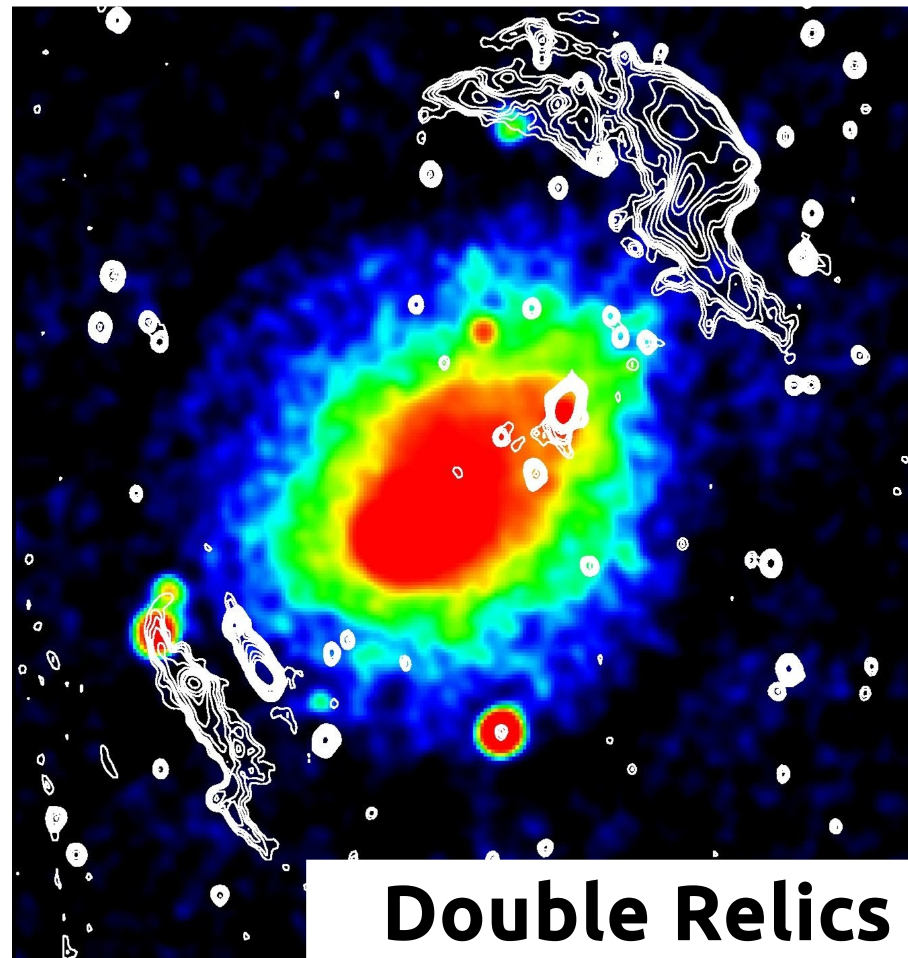
Kavilan Moodley, Huib Intema, et al

Giant Radio Halos & Radio Relics: What Are They?

- ~Mpc scale, faint, diffuse synchrotron emission; not linked to individual galaxies; exhibit steep spectra → electron cooling



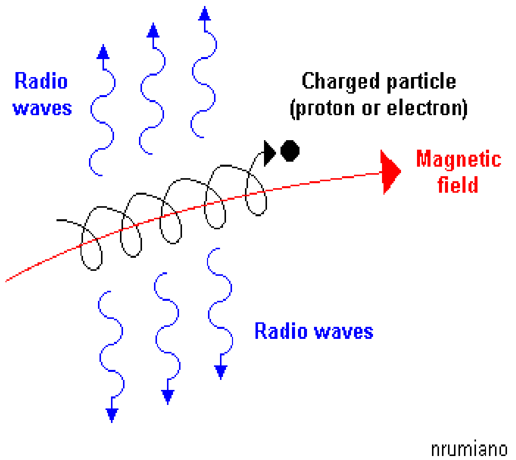
Giant Radio Halo
A2163, Feretti+ 2001



Double Relics
A3667, Rötgerring+ 1997

What do we know about GRH?

- Synchrotron emission associated with non-thermal ICM



- **In-situ particle acceleration needed!**
  - radiative lifetime of cosmic ray electrons (CRe) << than diffusion time necessary to cover cluster-scale volumes

- Can give us a better understanding of the cluster environment
  - Constrain strength of B-fields
  - Physics of the ICM

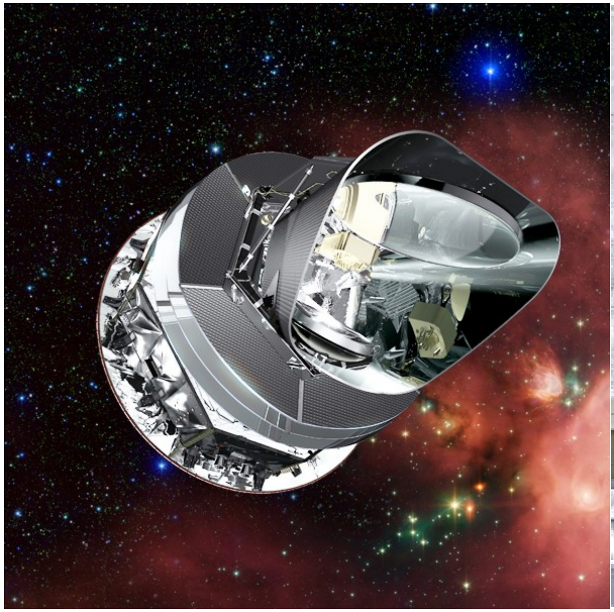
Formation Models

- Two competing theories for the in-situ CRe acceleration
- Hadronic / Secondary Electron
  - CRe created from p-p collisions in ICM
  - Predictions:
    - γ-ray emission
    - Spectral index α independent of position
- Turbulent Reacceleration / Primary Electron
  - Existing CRe re-accelerated by merger-driven turbulence
  - Predictions:
    - population of Ultra-Steep Spectrum radio halos (USSRH)
    - bimodality in Radio-Xray plane related to cluster dynamical state

Cluster selection: X-ray vs SZ

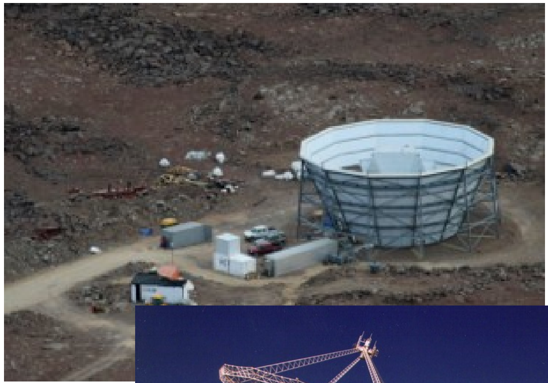
- Majority of GRH studies done on X-ray selected samples → biases?

- **SZ effect** → an efficient way to search for massive galaxy clusters



Radio Program for ACT Clusters

- Investigate radio properties of the ACT-E sample (68 clusters)



- Pilot study (PI: Knowles)
  - 4 targets @ 610 MHz on GMRT
- High-z study (PI: Knowles)
  - 4 targets @ 610 MHz on GMRT
- VLA S82 (PI: Jarvis)
  - 1-2 GHz detections & stacking on ACT-E positions

Radio Program for ACT Clusters

- Investigate radio properties of the ACT-E sample (68 clusters)

- Pilot study (PI: Knowles)
  - 4 targets @ 610 MHz on GMRT

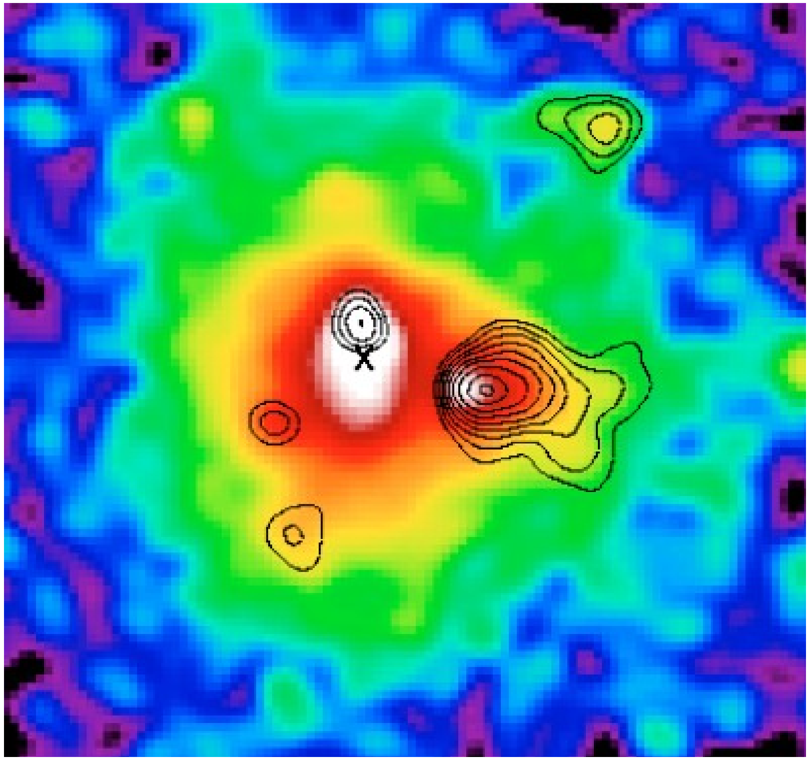
A giant radio halo in a low-mass SZ-selected galaxy cluster: ACT-CL J0256.5+0006

in preparation...

K. Knowles,[1] et al.

[1] *Astrophysics & Cosmology Research Unit, School of Mathematical Sciences, University of KwaZulu-Natal, Durban 4041, South Africa*

ACT-CL J0256.5+0006



XMM-Newton

Majerowicz+ 2004

- Major Merger (1:3)
- $z = 0.363$
- Low Mass:
  $M_{SZ,500} = 3.8 \times 10^{14}\ M_{sol}$
- $L_{X,500} = 1.49 \times 10^{45}$ erg/s
- $Y_{500} = 3.7 \times 10^{-4}$ arcmin^{-2}
- GMRT: 10 hrs @ 610 MHz
  + 8 hrs DDT @ 325 MHz

- Radio reduction with AIPS, SPAM (Intema et al.) & CASA

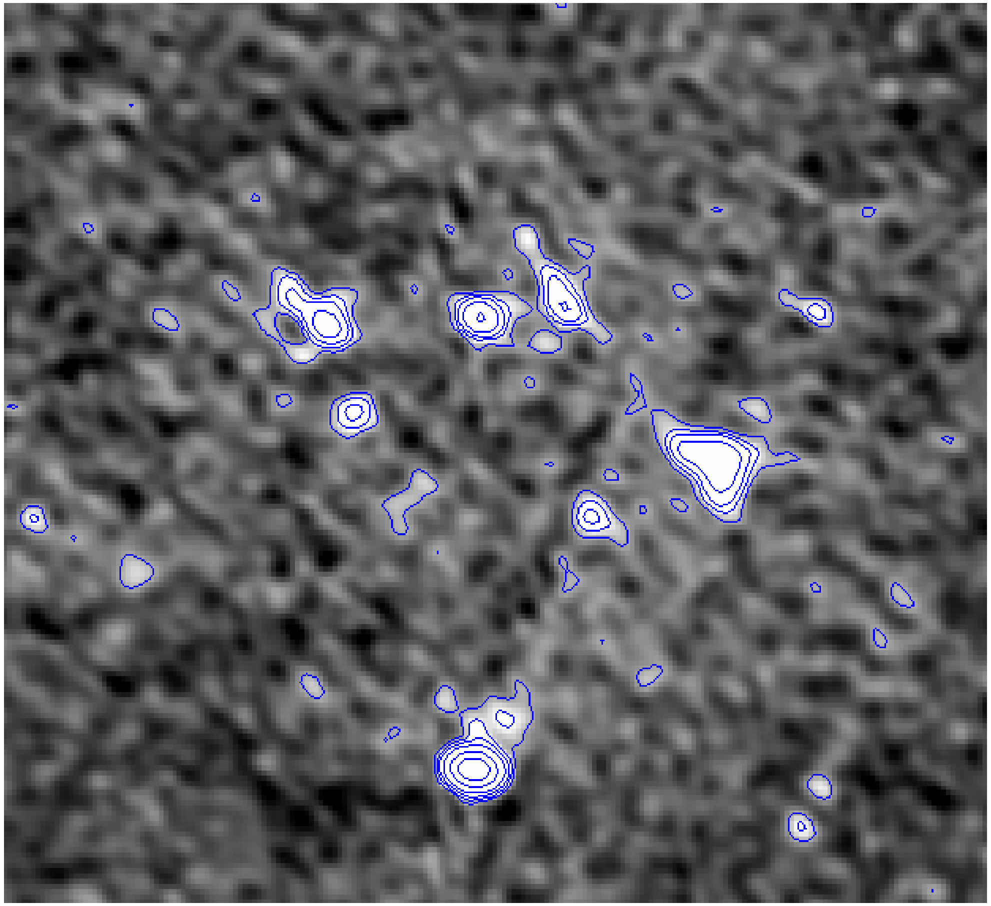
- Ionospheric & direction-dependent calibration via SPAM pipeline

- Imaging process:
  - Make PTSRC image (uv > 5 klambda)
  - FT PTSRC model into uv-plane & subtract from data
  - Re-image at full res to check if removal was successful
  - Image @ low-res to bring GRH emission to the fore (uv < 5 klambda, 4 klambda taper)

- Full resolution image

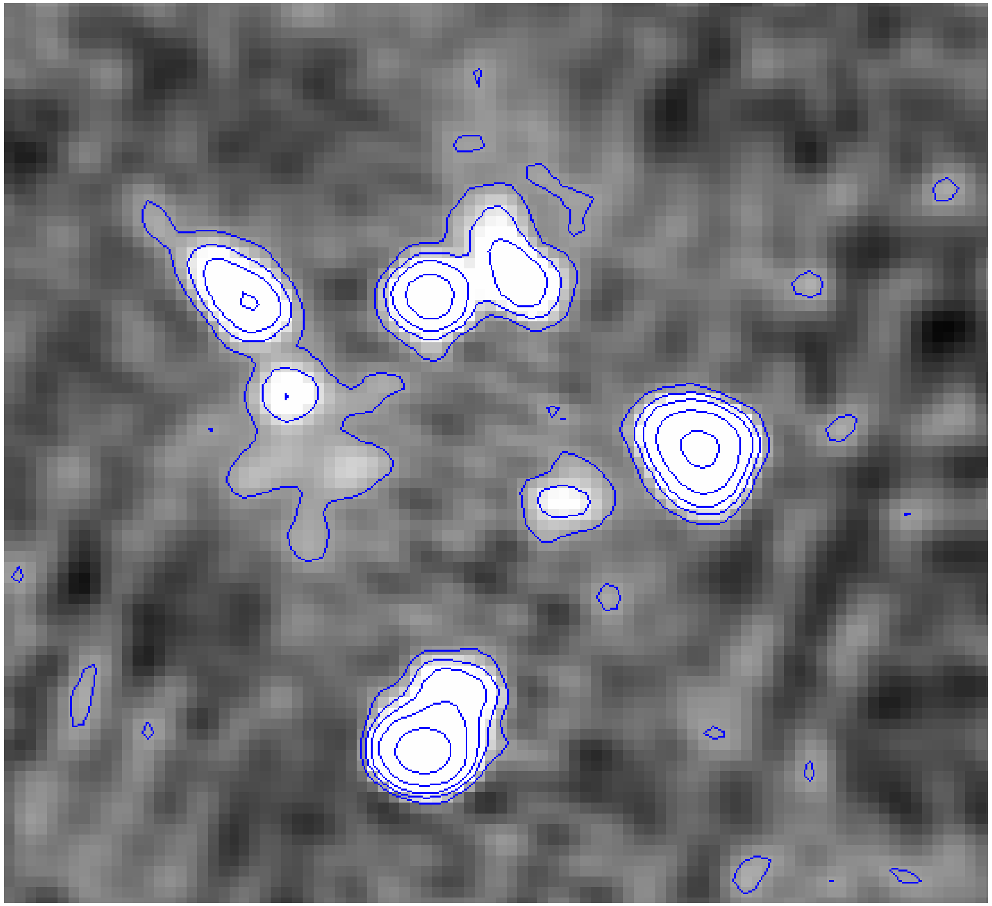
610 MHz

33 μJy/b
(6.0'' x 4.5'', 70°)



325 MHz

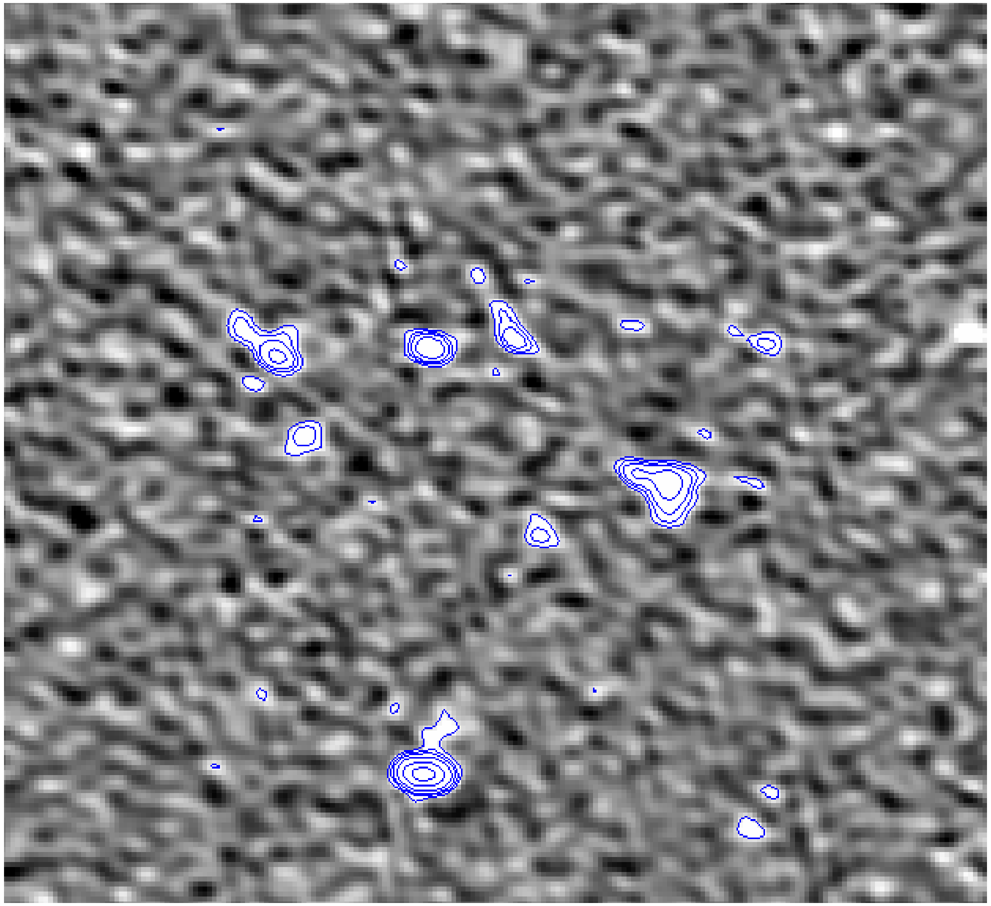
110 μJy/b
(10.1'' x 8.7'', -77°)



- Point source image to create model

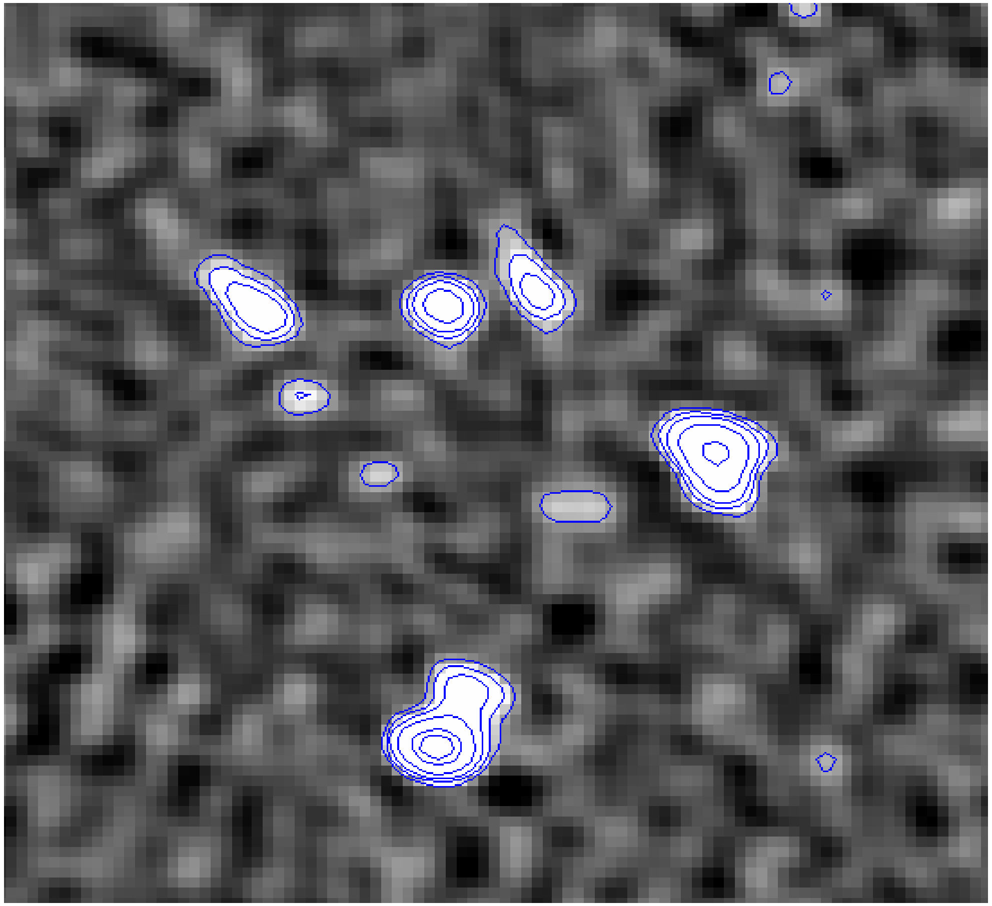
610 MHz

37 μJy/b
(5.3'' x 3.7'', 75°)

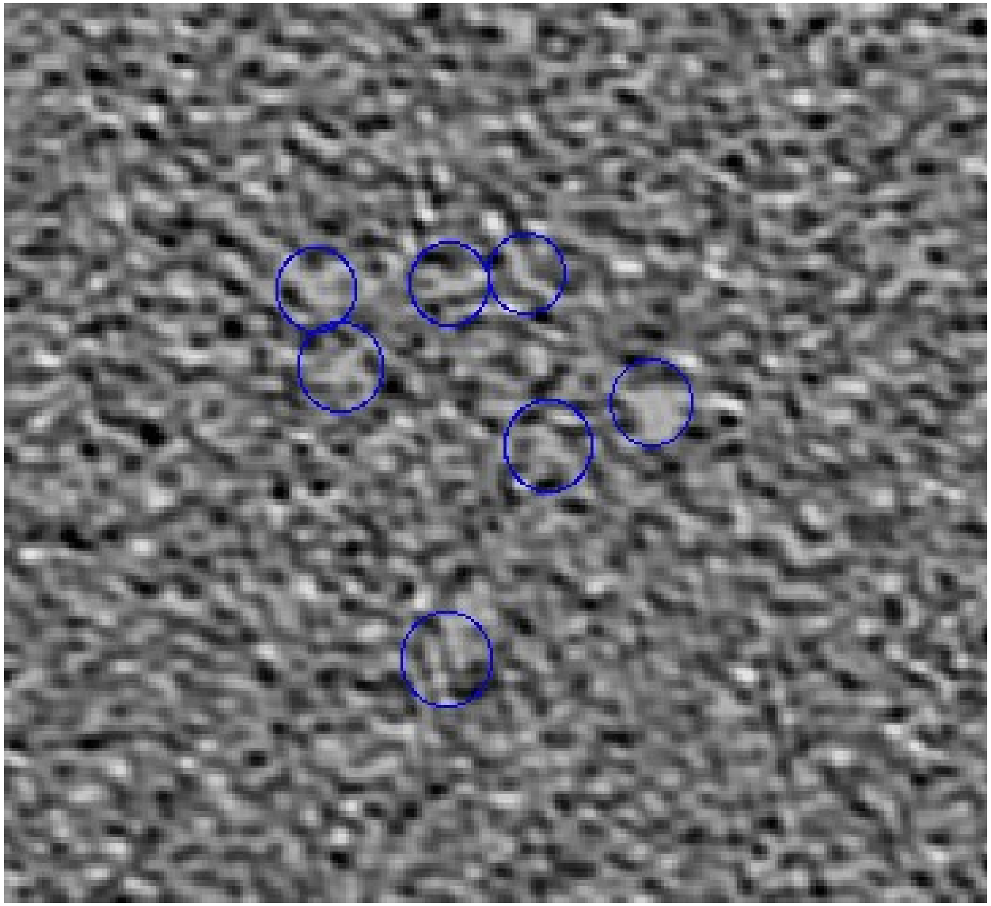


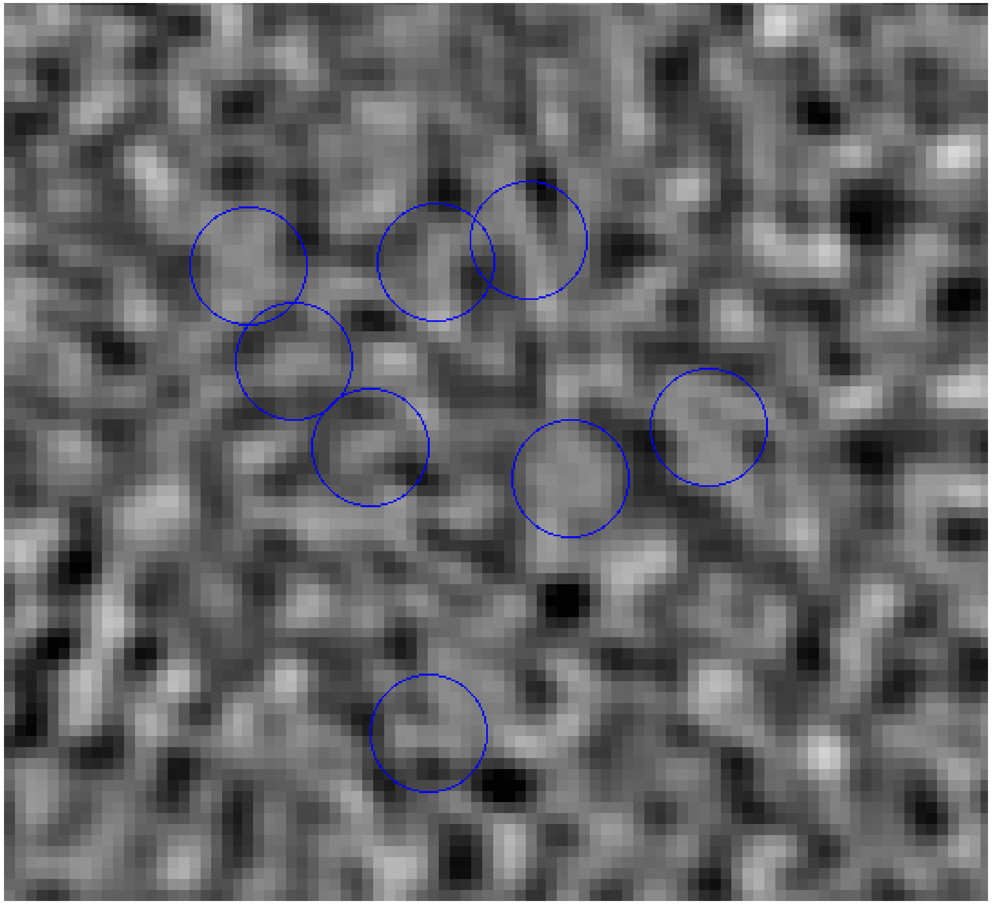
325 MHz

99 μJy/b
(8.7'' x 6.6'', 73°)



- Point source residual
  - have we cleaned to the level of the noise?

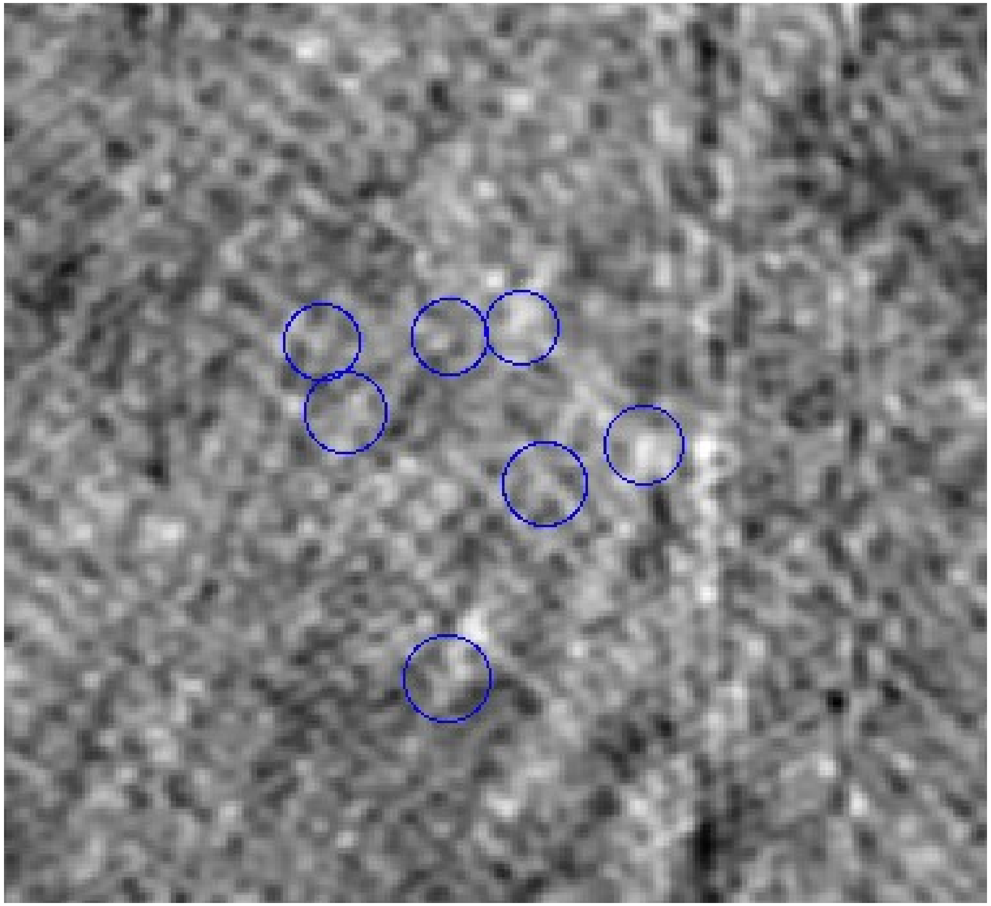




- Full-resolution pt. source subtracted image

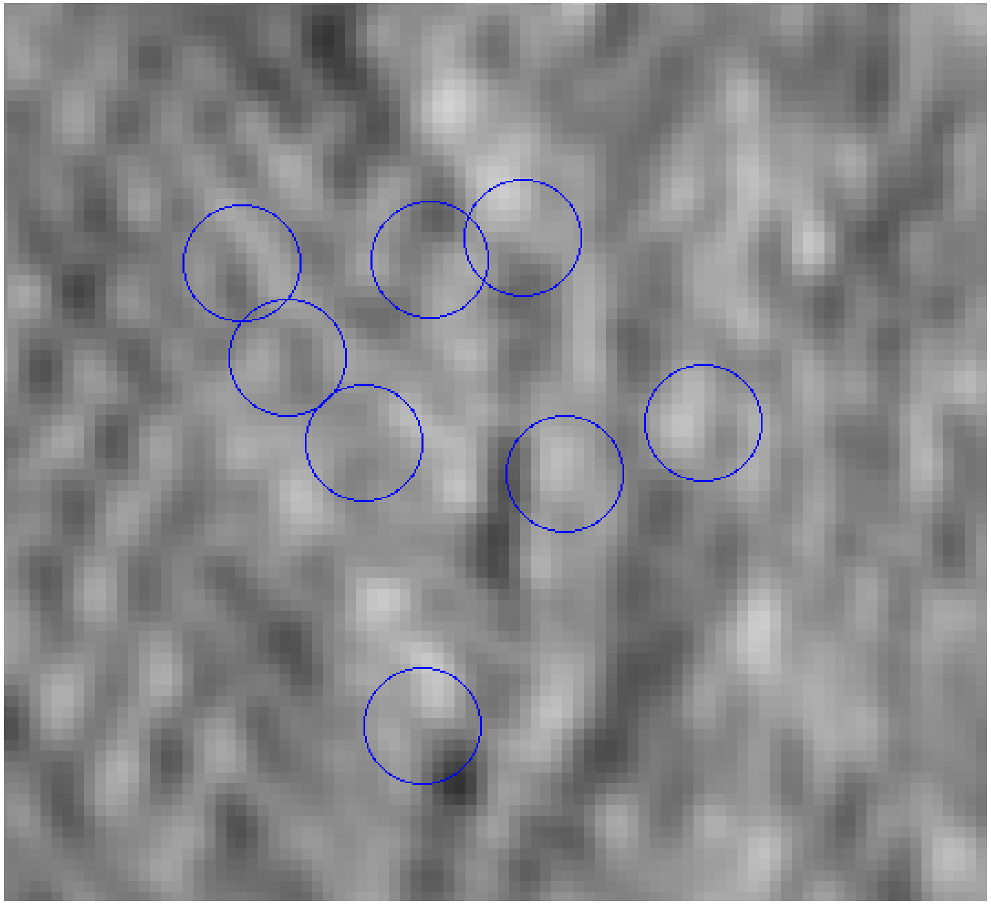
610 MHz

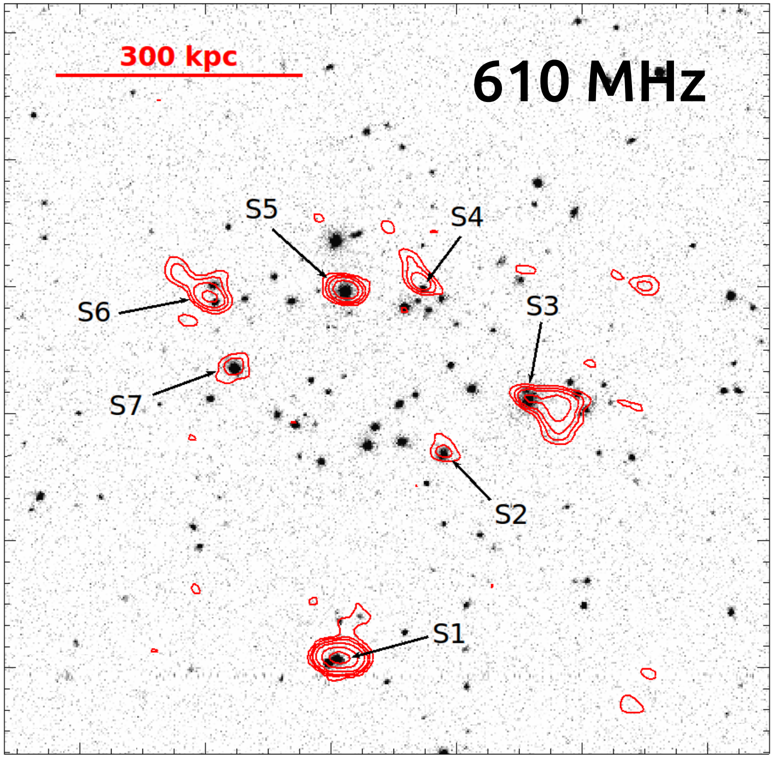
51 μJy/b
(6.0'' x 4.5'', 70°)

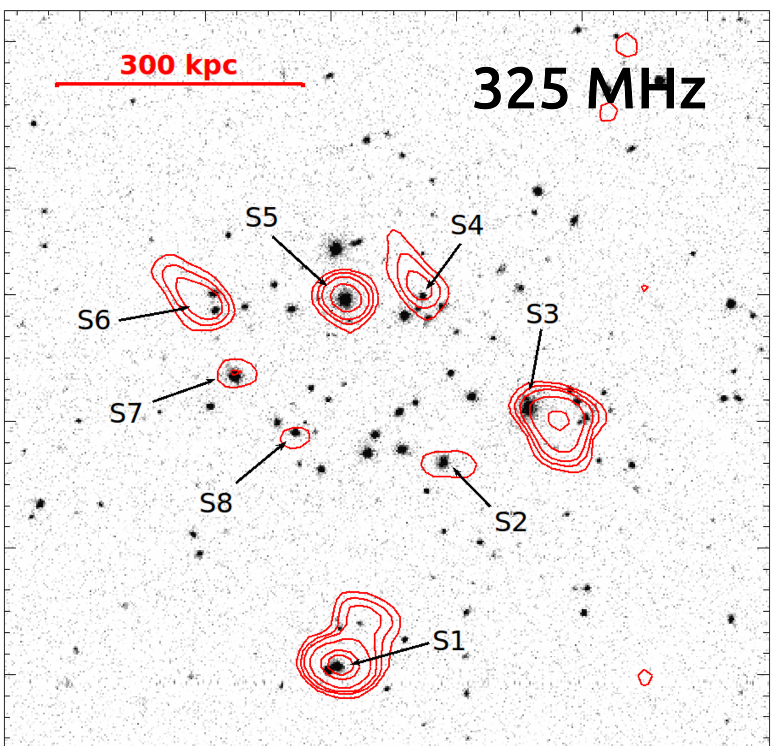


325 MHz

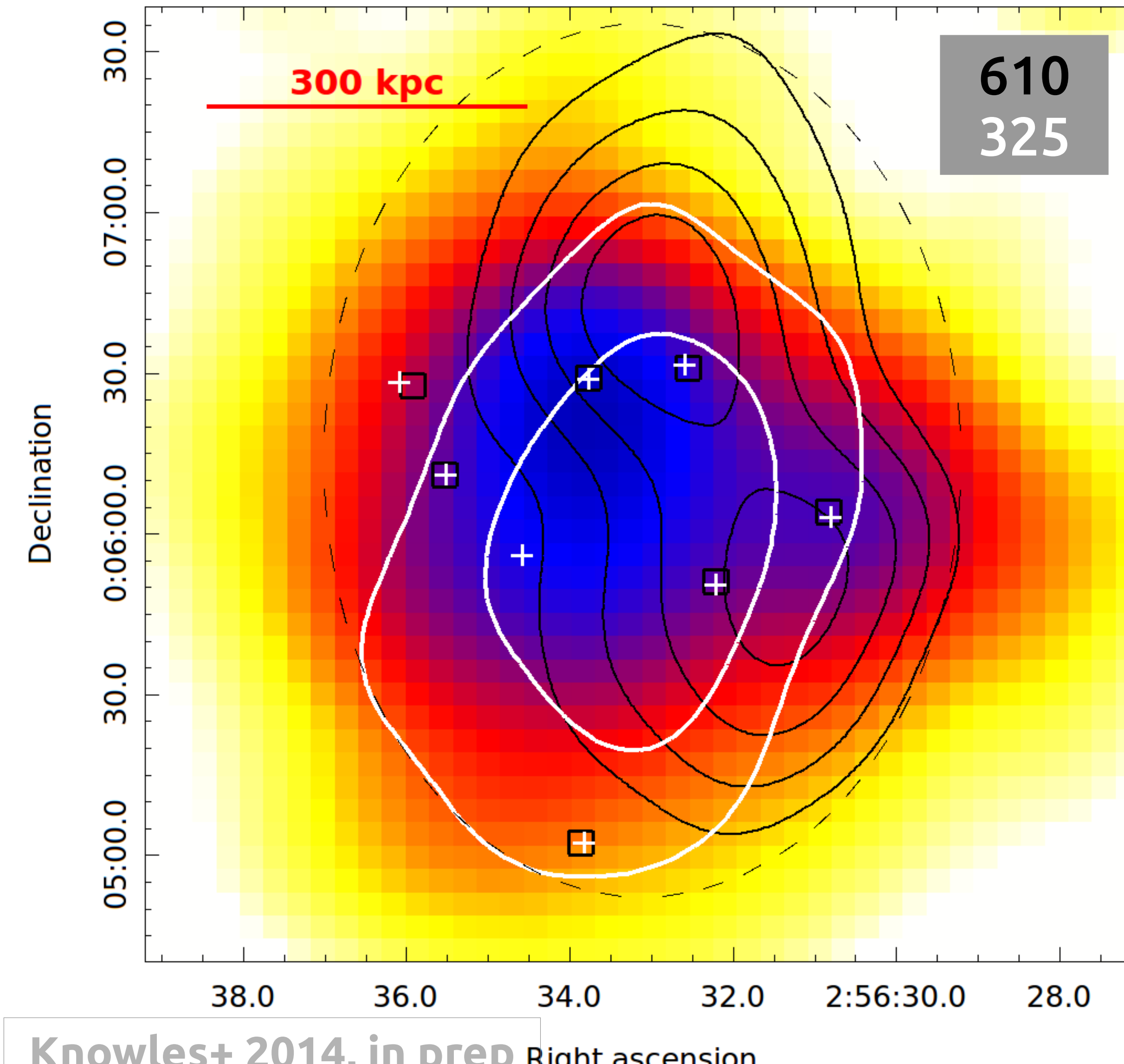
287 μJy/b
(10.1'' x 8.8'', -77°)





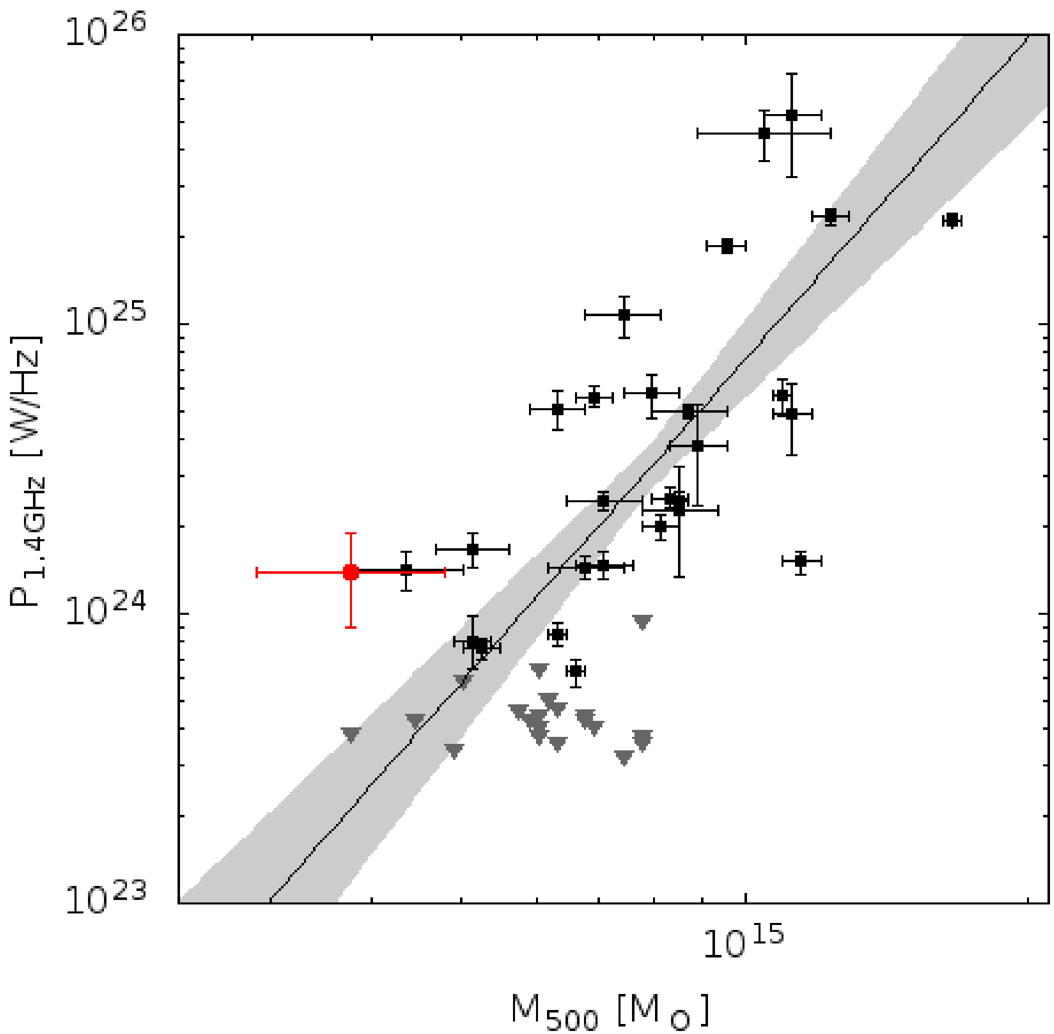


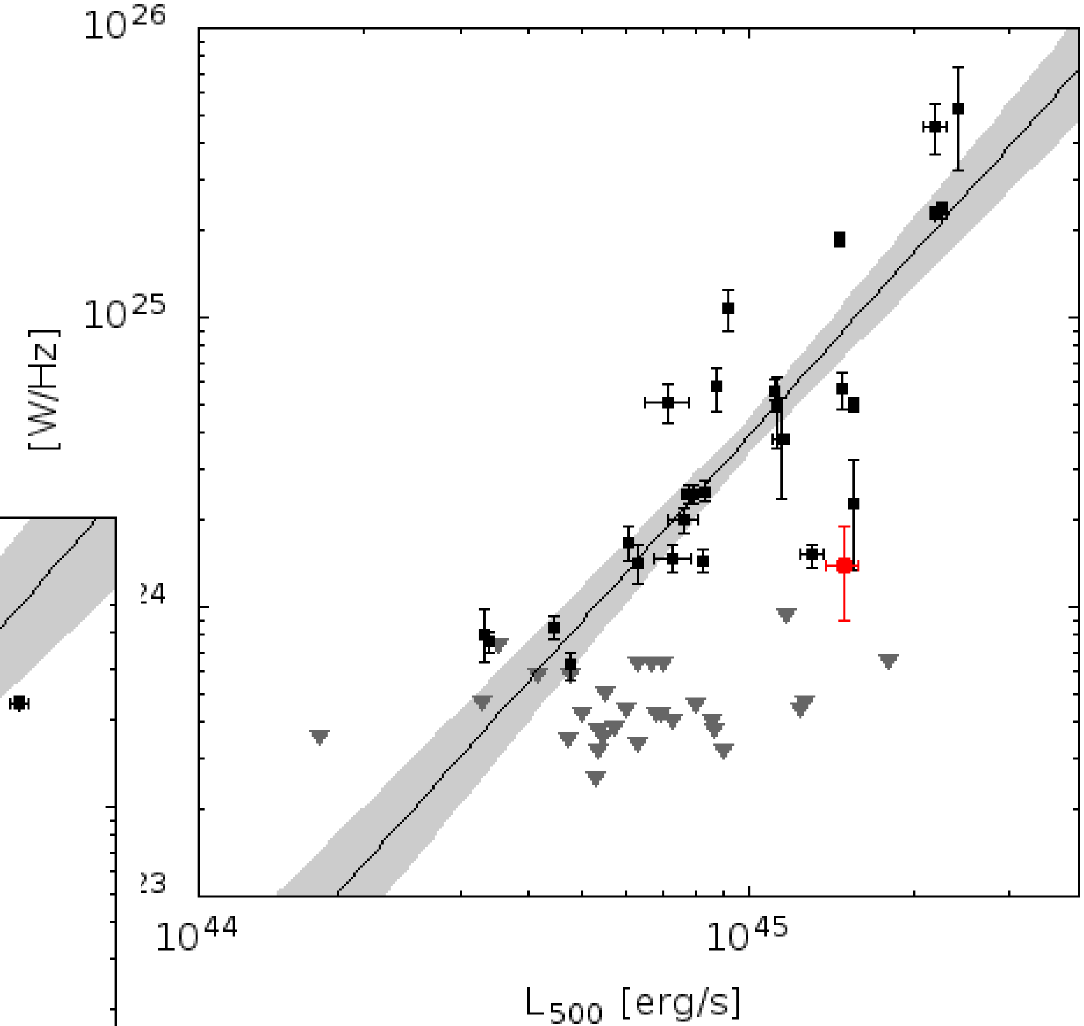
- Low surface brightness halos
- 325: 4σ (1.58 mJy/b, 53.0'' x 49.3'', -88°)
  610: 6σ (368 uJy/b, 54.5'' x 49.0'', -57°)

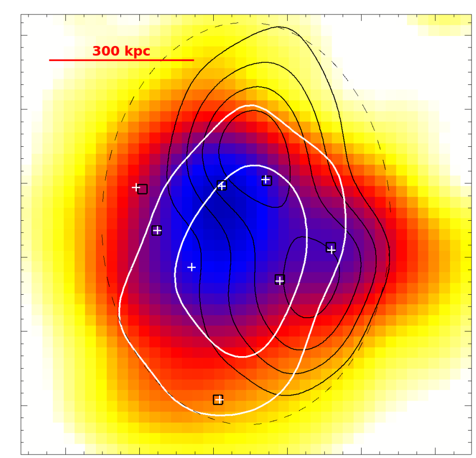


Knowles+ 2014, in prep

- $S_{610} = 6.9 \pm 1.7$ mJy
- $P_{1.4GHz} = 1.4 \times 10^{24}$ W/Hz



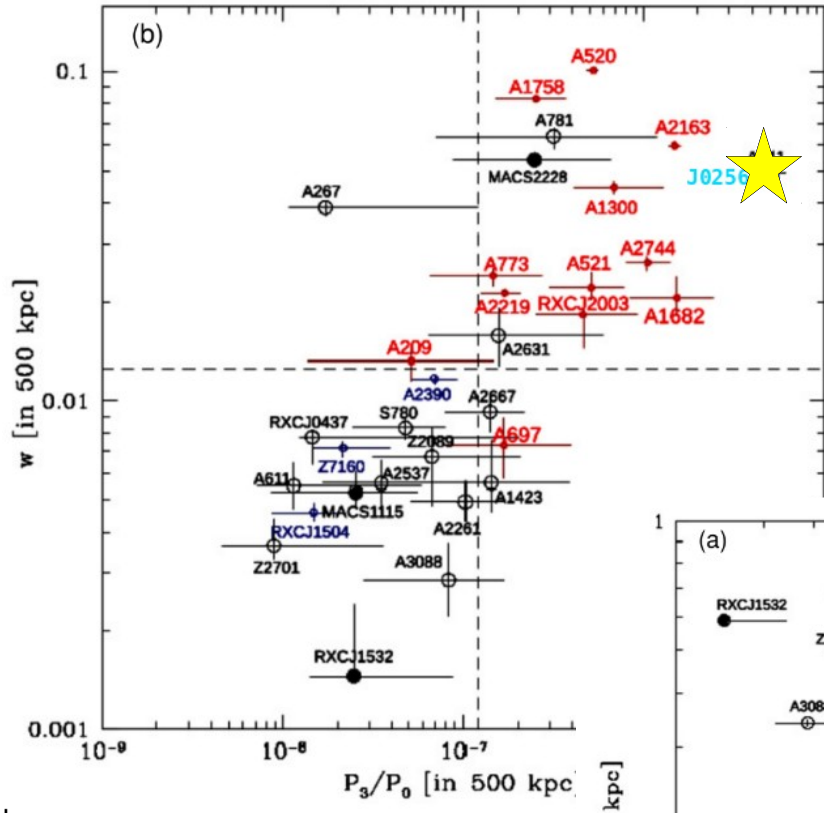




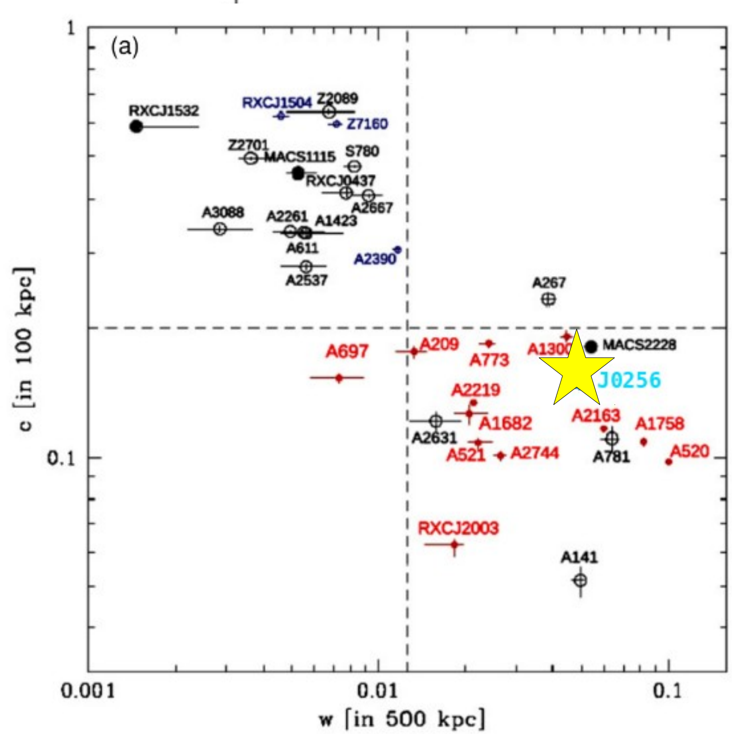
Knowles+ 2015
in prep

J0256 – X-ray Morphology

- Gives indication of spatial structure
- Not sensitive to structure along the line of sight



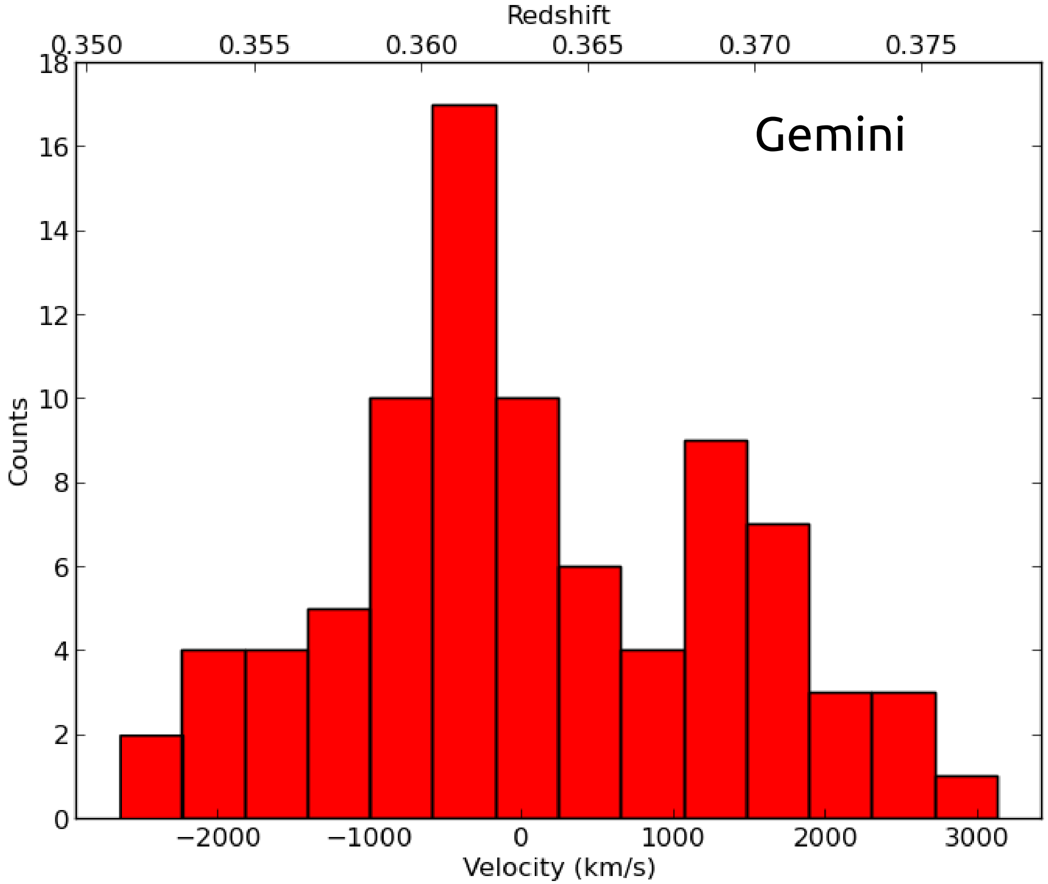
As per Cassano+ 2010



- c – concentration parameter
- w – centroid shift
- P_3/P_0 – power ratio

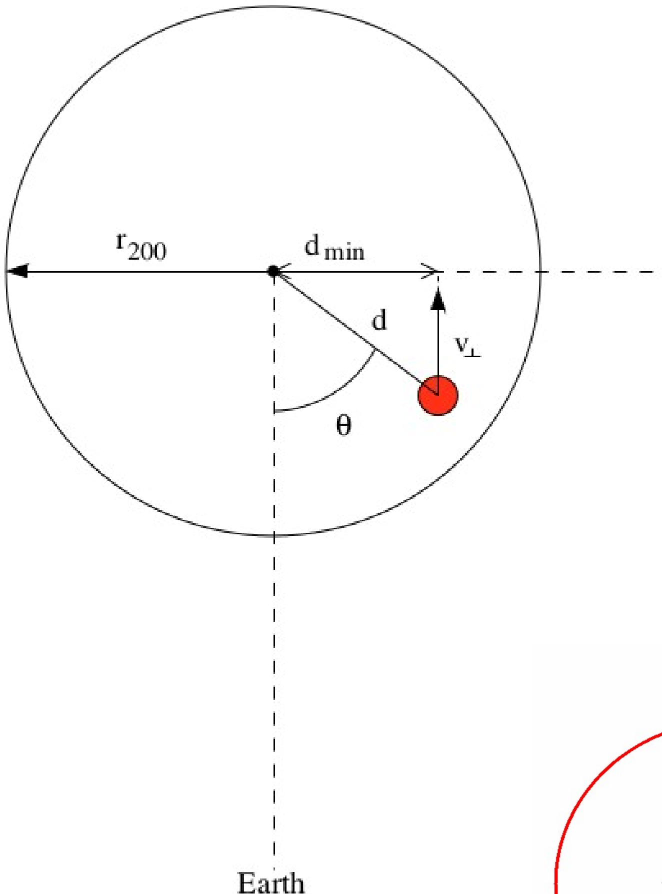
J0256 - Optical

Knowles+ 2015, in prep

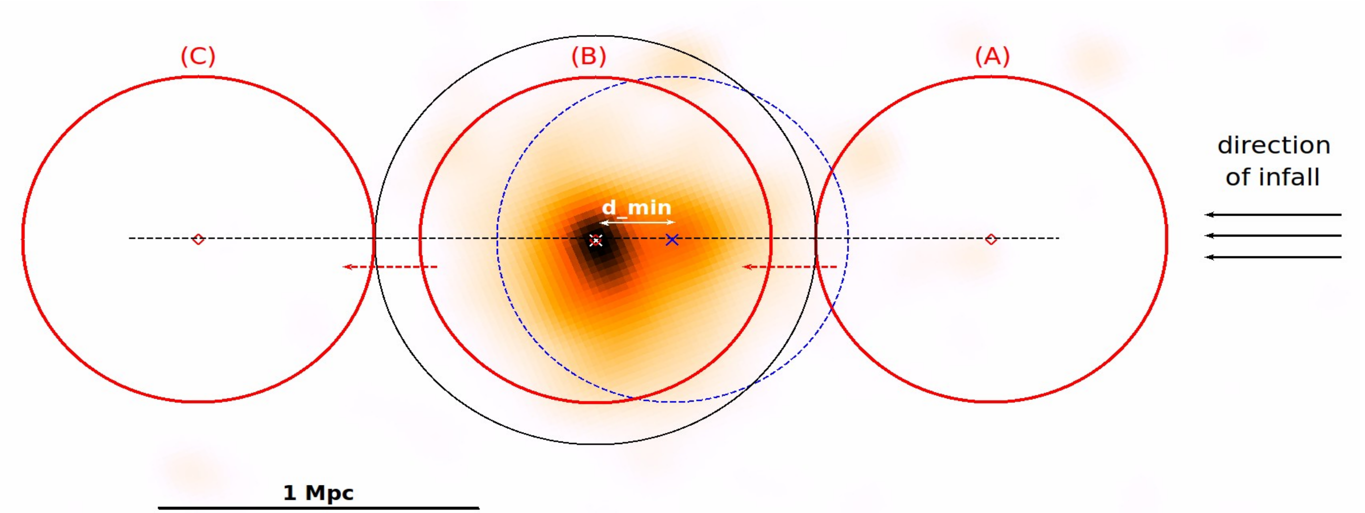


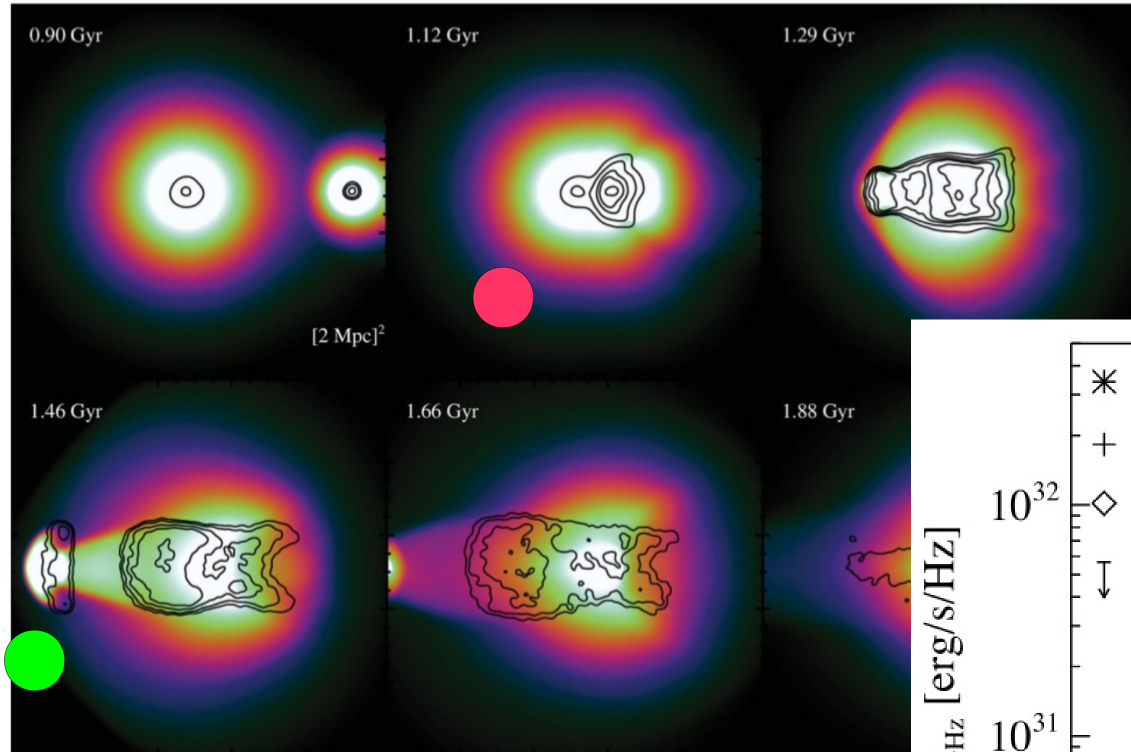
- 85 cluster members
- z = 0.363
- Bimodal L.O.S. structure
- Gaussian Mixture Modelling shows peaks are statistically significant
- v_{LOS} = 1986 ± 390 km/s
- $M_{500,opt}$ = 3.8 x 10^{14} M_{sol}

J0256 – Merger Analysis

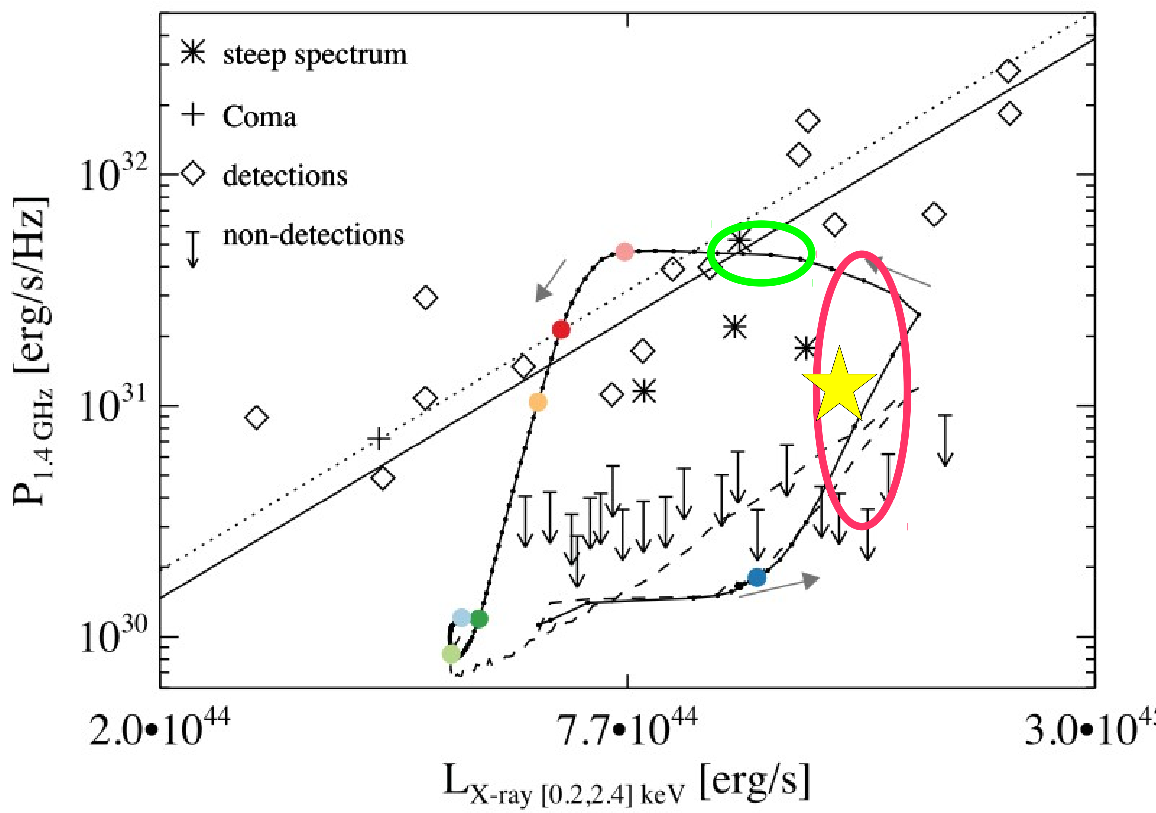


- Improved on work by Majerowicz et al. 2004
- NFW profile for main cluster + more spec-z's
- Two sets of solutions for v, d and θ
- Can use these to estimate merger timescale





Plots from Donnert+ 2013



Case 1 ~ 1.35 Gyr

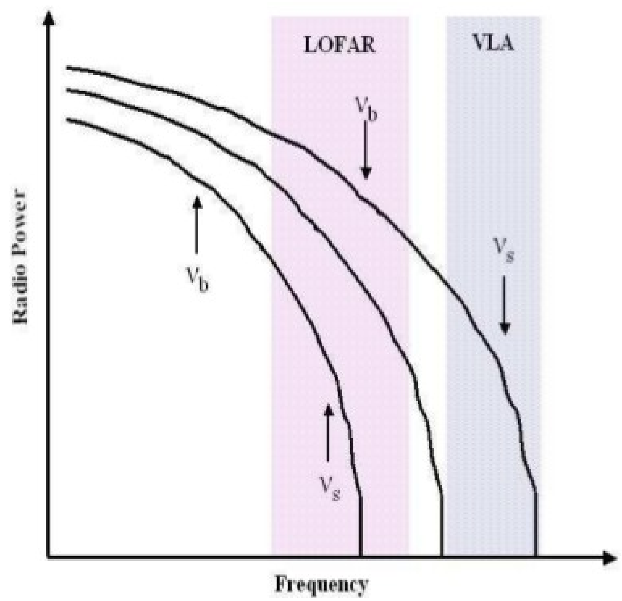
Case 2 ~ 1.19 Gyr

Knowles+ 2015, in prep

	v km s^{-1}	d kpc	θ degrees	t_A [a] Gyr	t_B [b] Gyr	t_C [c] Gyr	MF [d] %
Case 1	$3087.1^{+58.2}_{-142.9}$	$310.2^{+92.1}_{-34.5}$	$50.0^{+9.5}_{-13.8}$	$1.12^{+0.01}_{-0.03}$	$0.09^{+0.03}_{-0.01}$	$1.31^{+0.03}_{-0.01}$	$46.2^{+0.5}_{-1.2}$
Case 2	$2019.2^{+481.3}_{-411.5}$	$1306.7^{+613.3}_{-545.3}$	$10.5^{+7.7}_{-3.4}$	$0.71^{+0.24}_{-0.34}$	$0.50^{+0.34}_{-0.24}$	$1.71^{+0.34}_{-0.24}$	$29.4^{+10.1}_{-14.0}$

GRH: Looking to the Future

- New and Upcoming radio telescopes will increase the number of GRH known, e.g. TGSS, MWA, JVLA S82



Cassano+ 2009

- LOFAR (< 150MHz)
  - should pick up steep spectrum sources not seen at current higher frequencies

- MeerKAT, SKA (increased sensitivities)
  - Can probe deeper in redshift and find GRH too faint to detect with current telescopes

Summary

- Have a program for radio follow-up of ACT-E sample
- Successful in acquiring new radio data – has lead to a new GRH detection
- Finding GRH is important, but a multi-wavelength approach can provide the bigger picture
- Merger timescale analysis is an interesting avenue to explore – quantify transient nature of GRH?
- Need MeerKAT & SKA to find GRHs in lower-mass clusters (excellent SB sensitivity & high resolution)