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Low Frequency Detection of Diffuse Radio Emission from Low-mass PSZ Clusters

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Abstract: Observations of diffuse radio emission from the intra-cluster medium (ICM) in galaxy clusters due to synchrotron processes reveal the dynamical state and the non-thermal energy evolution in these structures. However, Low-mass ($M^{500} < 5 \times 10^{14} M_{\odot}$) galaxy clusters have been largely unexplored in radio observations, because of the limited sensitivity of existing telescopes. But study of these low mass objects has become possible with exceptionally sensitive low frequency telescopes like upgraded Giant Metrewave Radio Telescope (uGMRT) and the Low Frequency ARray (LoFAR). In this study, we present the first largescale program to systematically search for diffuse radio emission from low-mass galaxy clusters, chosen from the Planck Sunyaev–Zel'dovich cluster catalogue. We report here the detection of diffuse radio emission from four of the 12 objects in our sample, shortlisted from the inspection of the LoFAR Two-Meter Sky Survey data release 1 (LoTSS-I), followed up by uGMRT Band-3 deep observations. The clusters PSZ2 G089 (Abell 1904) and PSZ2 G111 (Abell 1697) are detected with relic-like emission, while PSZ2 G106 is found to have an intermediate radio halo and PSZ2 G080 (Abell 2018) seems to be a halo-relic system. PSZ2 G089 and PSZ2 G080 are among the lowest-mass clusters discovered with a radio-relic and a halo- relic system, respectively. A high ($\sim$ 30 per cent) detection rate, with powerful radio emission found in most of these objects, opens up prospects of studying radio emission in galaxy clusters over a wider mass range, to much lower-mass systems.

Context

Low mass clusters $\leq 5 \times 10^{14} M_{\odot}$ are largely remained undetected so far in radio waves because

- limited sensitivities of radio telescopes
- steep scaling for cluster mass and power of radio halo and
- biased observations

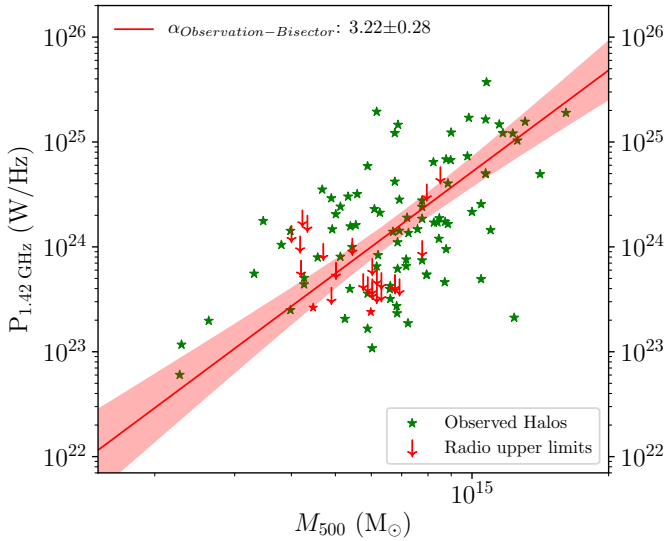

Figure 1: Scaling between radio power of halos at 1.4 GHz and mass of the galaxy clusters

Sample: 4 PSZ clusters followed with uGMRT

1. PSZ2 G080.16+57.65 ($z = 0.08780$)
   - $M_{500} = 2.51 \times 10^{14} M_{\odot}$, $L_x = 0.81 \pm 0.01 \times 10^{44} ergs^{-1}$
2. PSZ2 G089.52+62.34 (0.07008)
   - $M_{500} = 1.83 \times 10^{14} M_{\odot}$, $L_x = 2.54 \pm 0.025 \times 10^{44} ergs^{-1}$
3. PSZ2 G106.61+66.71 ($z = 0.3314$)
   - $M_{500} = 4.67 \times 10^{14} M_{\odot}$, $L_x = 3.97 \pm 0.20 \times 10^{44} ergs^{-1}$
4. PSZ2 G111.75+70.37 (0.1813)
   - $M_{500} = 4.34 \times 10^{14} M_{\odot}$, $L_x = 5.26 \pm 0.35 \times 10^{44} ergs^{-1}$

Radio relic and trailing diffuse emission in PSZ2 G111.75+70.37 and radio relic in PSZ2 G089.52+62.34

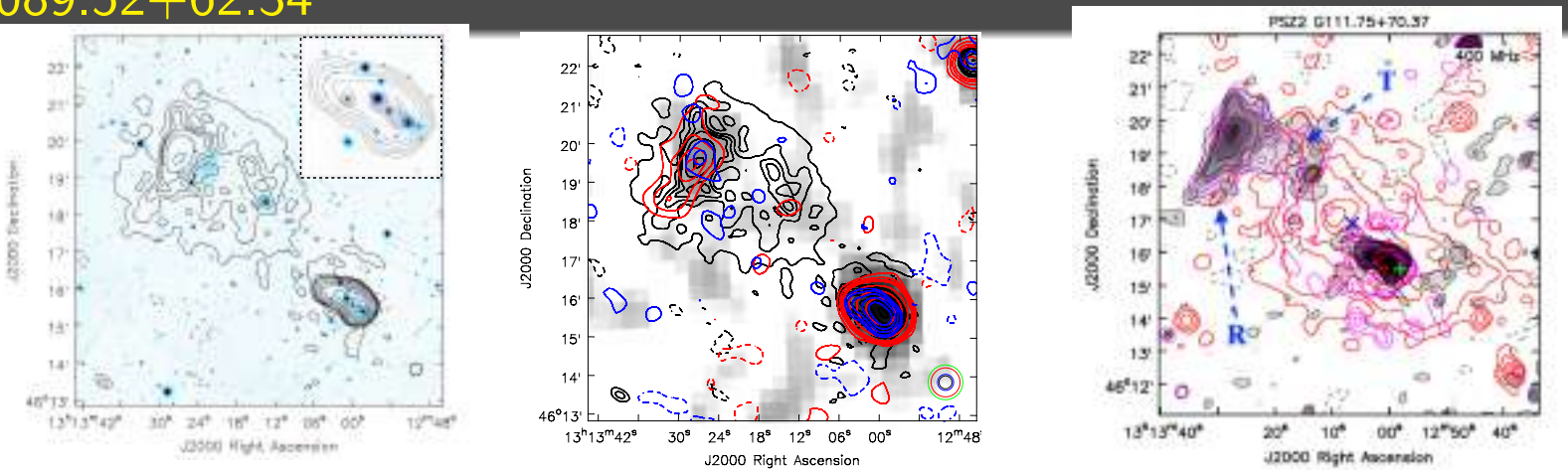

Figure 2: **Left panel:** Raster: Optical, black contours: LoTSS (144 MHz), red contours: VLA-First (1.4 GHz). **Middle panel:**Raster: WENSS (325 MHz), Black contours: LoTSS (144 MHz), Blue contours: TGSS-ADR (150 MHz), Red contours: NVSS (1.4GHz). **Right panel:** Raster: Optical, black contours: LoTSS (144 MHz), red contours: VLA-First (1.4 GHz)

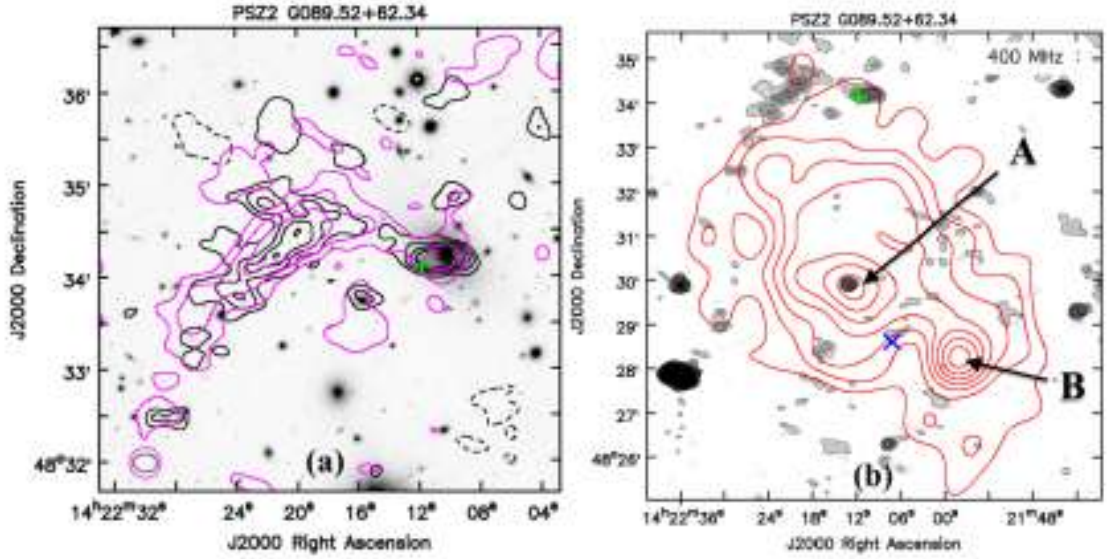

Figure 3: **Panel (a):** Contours of uGMRT (Black, at $\pm 3, 5, 7, 9, 18.. \times 50 \mu Jy/beam$) and LoTSS-I (Magenta, at $\pm 3, 6, 9, 18.. \times 150 \mu Jy/beam$) over-plotted on PanSTARRS-I 'i' band image. **Panel (b):** X-ray contours over-plotted on uGMRT colour and contour maps. Plank SZ centres are marked as blue '$\times$' and Abell centres as green '+'.

Radio relic and halo in PSZ2 G080.16+57.65 and radio relic and intermediate radio halo in PSZ2 G106.61+66.71

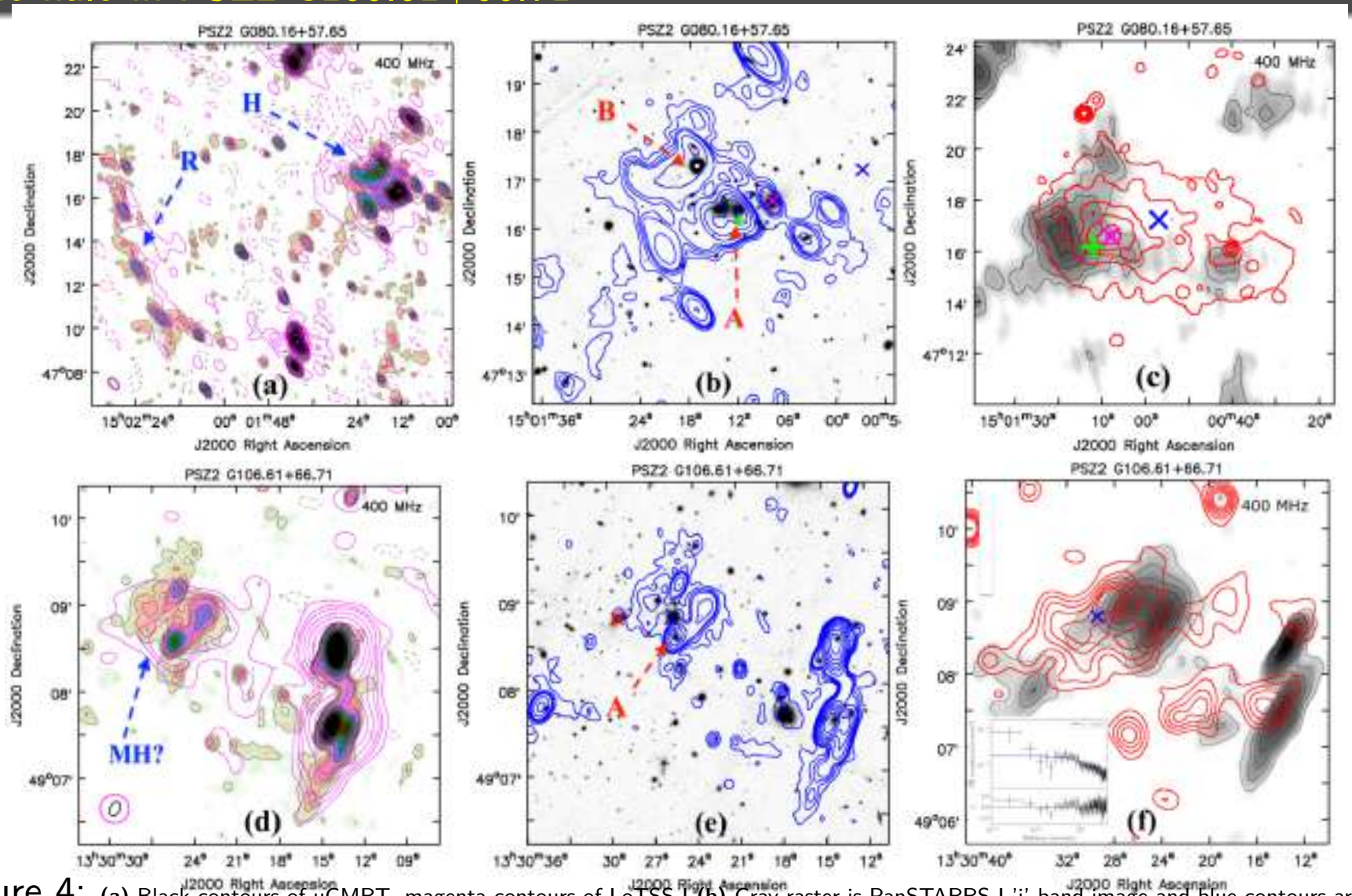

Figure 4: **(a)** Black contours of uGMRT, magenta contours of LoTSS-I **(b)** Gray raster is PanSTARRS-I 'i' band image and blue contours are from uGMRT, **(C)** Red contours is X-ray over-plotted with gray point source subtracted uGMRT image. **(d)** Contours of uGMRT (Black) and LoTSS-I (Magenta), **(e)** Gray raster is PanSTARRS-I 'i' band image and blue contours are from uGMRT, **(f)** Red contours is X-ray over-plotted with gray point source subtracted uGMRT image. Plank SZ centre is marked as blue '$\times$' and Abell centre as green '+'.

Summary and conclusions

- The relic in PSZ2 G111 has been confirmed.
- Discovered the cluster peripheral emission in PSZ2 G089 and PSZ2 G080 and are currently speculated to be the relics.

- Cluster PSZ2 G080 also hosts a radio halo along with the relic
- PSZ2 G106 is detected only with a central diffuse emission, which could be an intermediate radio halo.

- the cluster PSZ2 G089, is among the lowest mass clusters detected with a radio relic and PSZ2 G080 with is the lowest mass cluster hosting both a radio halo and a Mpc size relic.

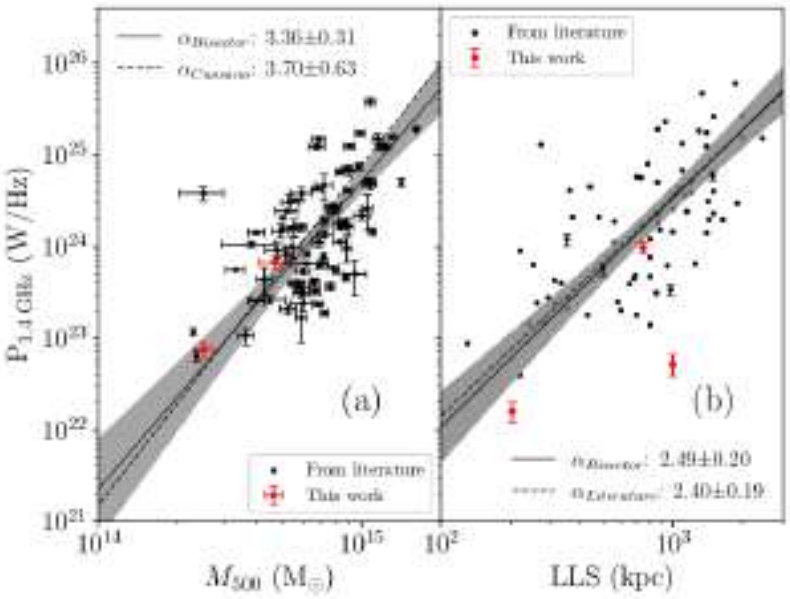

Figure 5: Correlation plots of (a) $P_{1.4GHz} - M_{500}$ and (b) $P_{1.4GHz} - LLS$.

Results are published in MNRAS (Paul et. al. 2021, mnras, 506, 5389)

Thank you