Discovery of New Large Scale Cluster Radio Structures

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Abstract

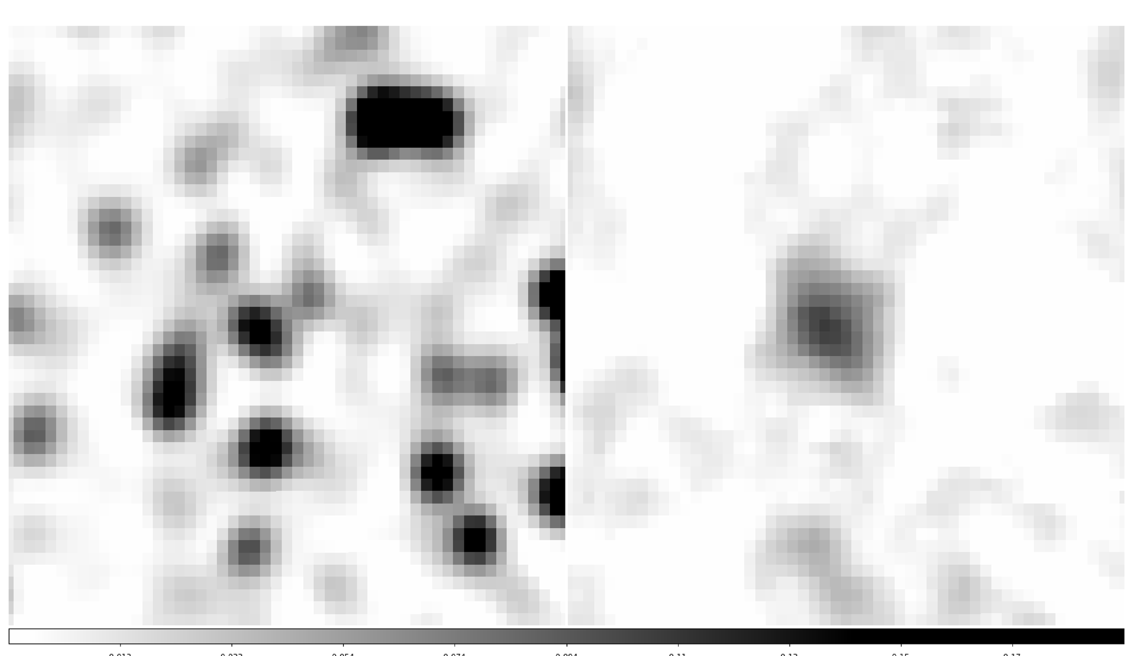
Large-scale nonthermal (synchrotron) emission in galaxy clusters may go undetected by radio interferometers. We present results from a study of X-ray clusters at 1.4 GHz with the 100-m Green Bank Telescope (GBT). After subtraction of point sources and diffuse emission using pre-existing interferometer data (NVSS), we find a significant excess of diffuse emission in four of seven Abell clusters observed. In particular, we find: ~3x more radio halo power in the non-cool-core cluster A2319; a ~2 Mpc radio feature in A2142 (a sloshing cool-core cluster with a known mini-halo); a 700 kpc diffuse radio structure (roughly coincident with the X-ray halo) never before observed in A119; a doubling of the integrated flux and increase to the observed extent of the peripheral radio relic in A1367 to ~350 kpc. Some implications of our findings are: (1) The large scale radio structure in A2142 spans a known X-ray cold front, and raises questions about how a cool-core can survive in the presence of the major shock/turbulent processes implied by the synchrotron flux; (2) Our observations may both help and hinder hadronic models of cosmic ray production in clusters; (3) If unseen excess flux on large scales is common in clusters, the evolution timescale for radio halos of Brunetti, et al (2009) may need revision.

Why Radio, and Why Single Dish?

Because radio interferometers have limited response to extended emission, we have used the 100-m single dish GBT to observe seven X-ray clusters. The GBT is well suited for detection of diffuse, low surface brightness features on scales of several arcminutes, such as radio halos and relics found in merging clusters. Observations of large scale synchrotron structures are particularly important galaxy clusters because they can be used to place constraints upon the state of the relativistic plasma (e.g. pressure, density), origins of cosmic ray electrons (CRe; e.g. hadronic collisions vs. shock/turbulent acceleration), and evolutionary timescales of the radio synchrotron halo as pertains to the merger history.

Method

We observed seven X-ray clusters at 1.4 GHz with the GBT, producing images ~5 degrees to a side at a resolution of ~10'. Because the GBT is sensitive to point sources as well as the desired extended emission, our images are confusion limited by the extragalactic point source background (rms ~30 mJy/beam). The NVSS (VLA, 1.4 GHz, 45" resolution) has good sensitivity (rms <1 mJy/beam) to point sources and is well suited for the mitigation of our confusion level. After convolving the NVSS images to match the GBT beam, interpolating to the corresponding geometry, and applying appropriate flux scaling, we produced a GBT-NVSS residual image for each cluster field. Some fields exhibit irregular residuals from imperfect subtraction of bright radio galaxies; luckily these artifacts are far enough from the features of interest to have minimal quantitative effect.



The above image demonstrates the effect of the confusion subtraction method on A2319. Left panel: NVSS image convolved and interpolated to GBT beam/geometry. Right panel: GBT residuals after NVSS subtraction. Before subtraction, GBT images have rms fluctuations ~30 mJy/beam, dominated by extragalactic confusion. After subtraction, the rms fluctuations are typically 5-10 mJy/beam, dominated by Galactic structure on >10' scales and ~2% residuals from background source subtraction. Colorbar at bottom shows the flux scale in Jy/beam, which is the same for both panels.

Table of Results

Cluster	Redshift	Literature Classification (e.g. Halo, Relic)	Interferometer / GBT Excess Flux (mJy)	Interferometer / GBT Excess Largest Linear Scale (kpc)	Revised P_1.4 (10^24 W/Hz)	Revised L_X (0.1-4 keV, 10^44 erg/s)
A2319	0.0559	Halo	153 / 470	1000 / 1200	3.7	7.0
A2142	0.0894	Mini-halo	18 / 91	190 / 2000	2.0	11
A119	0.0444	None	0 / 280	0 / 730	1.3	1.6
A1367	0.215	Relic	69 / 260	210 / 350	0.28	0.83

REFERENCES

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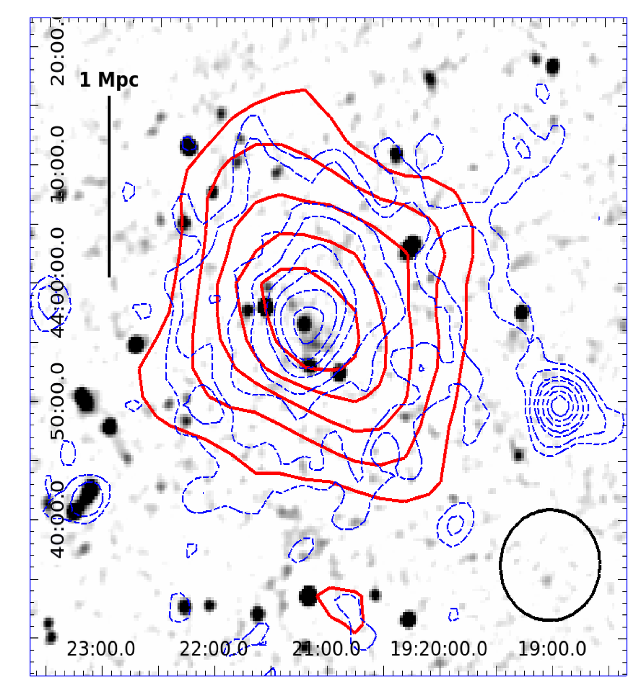
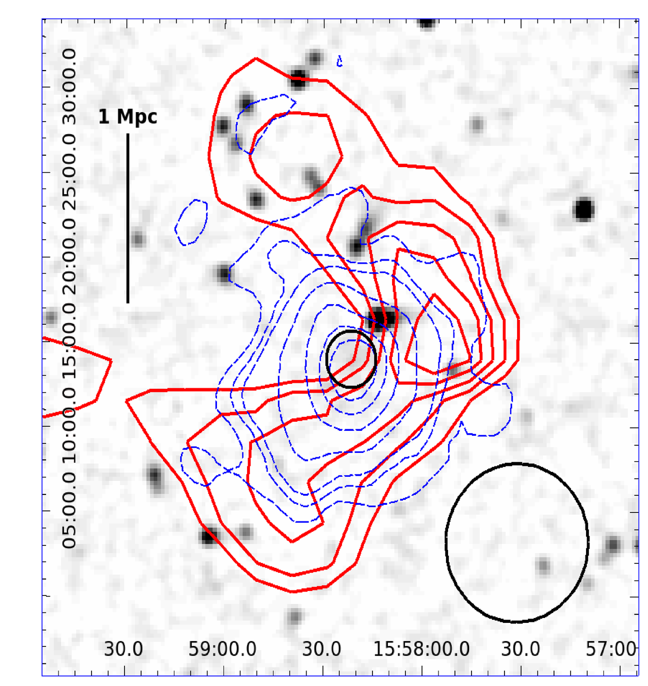
RESULTS

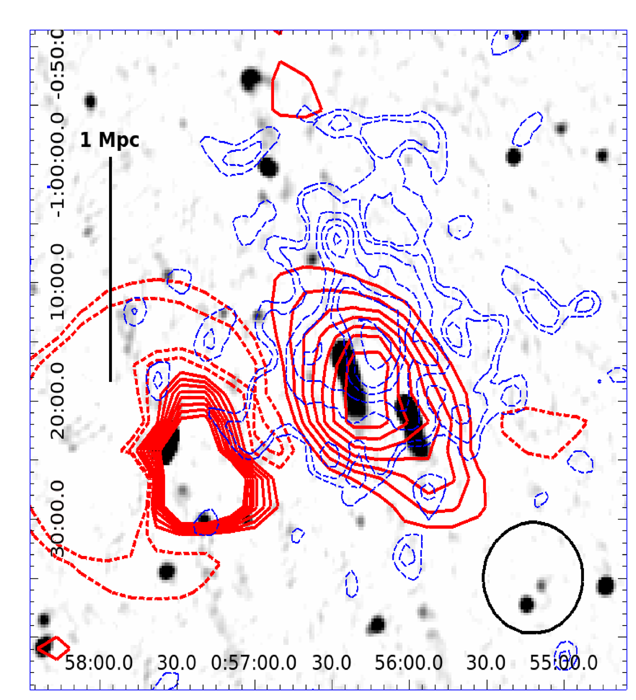
Below are plots of the four clusters containing: NVSS greyscale (45" resolution), smoothed Rosat X-ray contours in dashed blue, GBT 1.4 GHz excess contours in red; there are no negative contours at the same levels as shown for A2319 and A2142. The GBT beam (577"x561", 99.5°) is shown as a thick black ellipse, lower right corner.



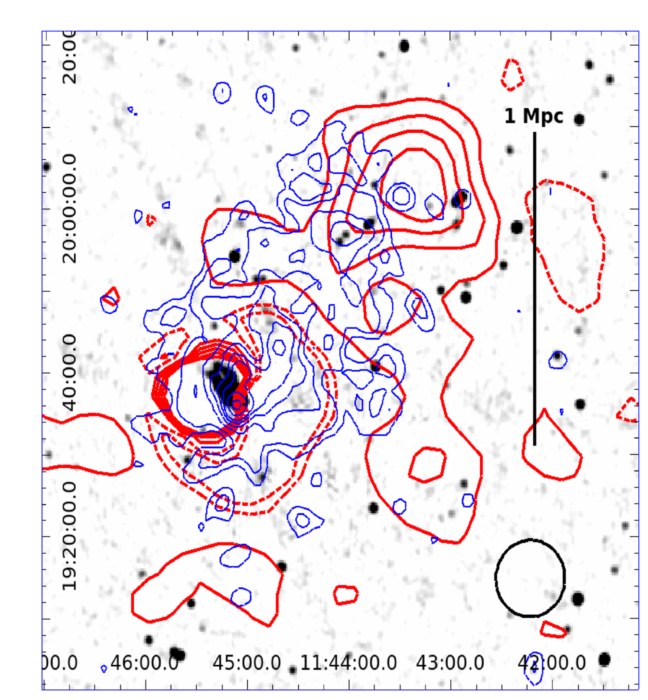
A2319 - The radio halo extends ~1.2 Mpc, ~20% larger than the previously measured extent. We have also recovered ~3x the integrated flux as detected by previous studies. GBT: rms 10 mJy/beam; contours (1,2,3,4,5) x 20 mJy/beam.



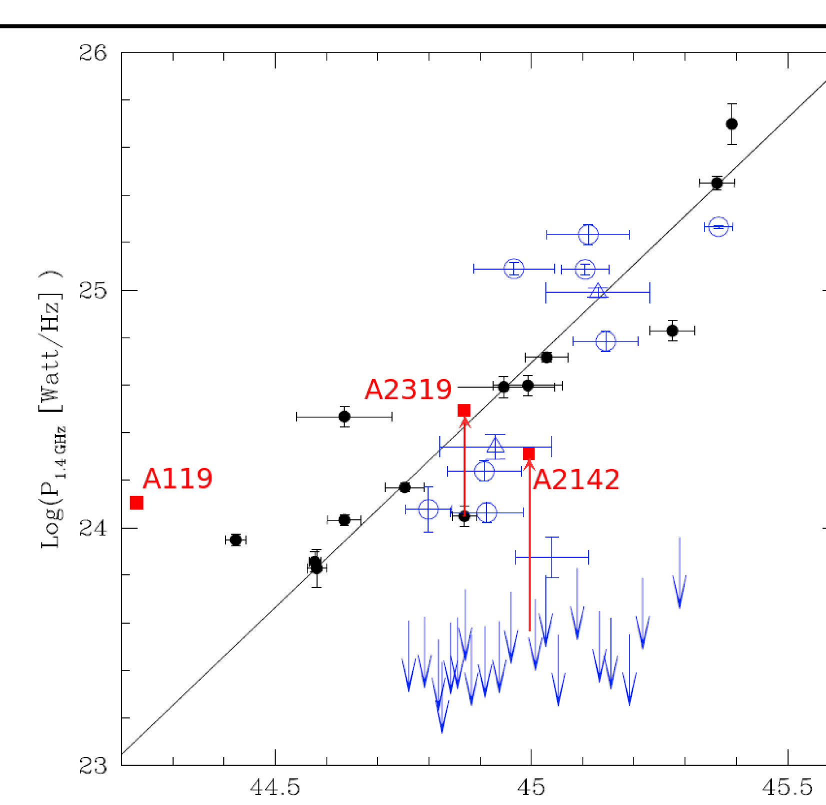
A2142 – We have detected a ~2 Mpc synchrotron feature spanning the known X-ray cold front, something never seen in a cool-core cluster. This may be an extended radio halo, or possibly some combination of halo + relic(s). The rough location and size of the mini-halo detected in NVSS is shown by the small black circle near center. GBT: rms 6 mJy/beam; contours (1,2,3,4,5) x 12 mJy/beam.



A119 - We detect, for the first time, large scale (~730 kpc) diffuse emission in this cluster. Given its location, it could be very diffuse emission associated with the two strong tailed radio galaxies or it could be a cluster halo. The bright (~1.8 Jy/beam peak) radio galaxy to the SW, 3C29, displays irregular residuals related to beam imperfections. GBT: rms 10 mJy/beam; solid contours (1,2,3,4,...) x 20 mJy/beam; dashed contours (-1,-2) x 20 mJy/beam.



A1367 – Compared to previous measurements, we increase the observed scale of the relic by ~20% to 350 kpc and more than double the integrated flux. In addition, the relic seems to extend radially inward toward the X-ray core along the direction of the known merger. The bright NAT, 3C264 displays irregular residuals related to beam imperfections. GBT: rms 9 mJy/beam; solid contours (1,2,3,4,...) x 18 mJy/beam; dashed contours (-1,-2) x 18 mJy/beam.



Plot of radio power vs L_X for bright X-ray clusters taken from [2]. Points are clusters with a Mpc-scale radio halo, and blue arrows are clusters with upper limits. Overlaid are red squares marking diffuse cluster sources measured in this work, including revised radio power for A2319 and A2142 (red arrows point from original to new positions), and the first measurement of diffuse emission from A119. A2319 now fits nicely to the correlation. We cannot distinguish between a giant radio halo associated with A2142's mini-halo, or relic-type emission at the cluster peripheries. A119 shows a striking diffuse radio excess for its X-ray luminosity which might be related to the pair of strong NATs in this cluster.

Discussion

The discovery of significant excess of diffuse radio emission in clusters has major implications:

– The presence of large scale diffuse emission in A2142, which spans an X-ray cold front, raises the question: How can a cool-core survive in the presence of the shock/turbulent processes (associated with merging activity) implied by the synchrotron profile?

– If the extent and luminosity of radio halos/relics are underestimated in clusters, it may both support and refute theories of CRe production by hadronic collisions. On one hand, hadronic models seem to overproduce the number of clusters with synchrotron halos – a problem alleviated if more halos actually exist. On the other hand, hadronic models produce a steeper radial decline in the synchrotron brightness than is observed – a problem exacerbated if halos are more extended that previously thought.

– The bimodality suggested by Brunetti et al. (2009) hints at a transition timescale to/from a radio halo, depending on the phase of merging activity. This timescale may be shorter than estimated if the number of clusters in the "intermediate" phase (blue cross) or "radio quiet" phase (upper limits) is actually lower due to missing radio flux.

Followup observations with higher resolution and greater sensitivity (e.g. EVLA, Arecibo 300-m), along with spectral index studies, are crucial to take this important work to the next level.