# Radio Sources Toward Galaxy Clusters at 30 GHz

Kim Coble

Chicago State University
Department of Chemistry and Physics

# Collaborators

## University of Chicago:

John Carlstrom, Sam Laroque, Dan Marrone (Jansky Fellow)

## Marshall Space Flight Center and U. Alabama:

Max Bonamente, Nicole Hasler, Marshall Joy

## U. C. Berkeley:

Kyle Dawson (now at LBNL), Bill Holzapfel

## U. C. Davis:

Erik Reese

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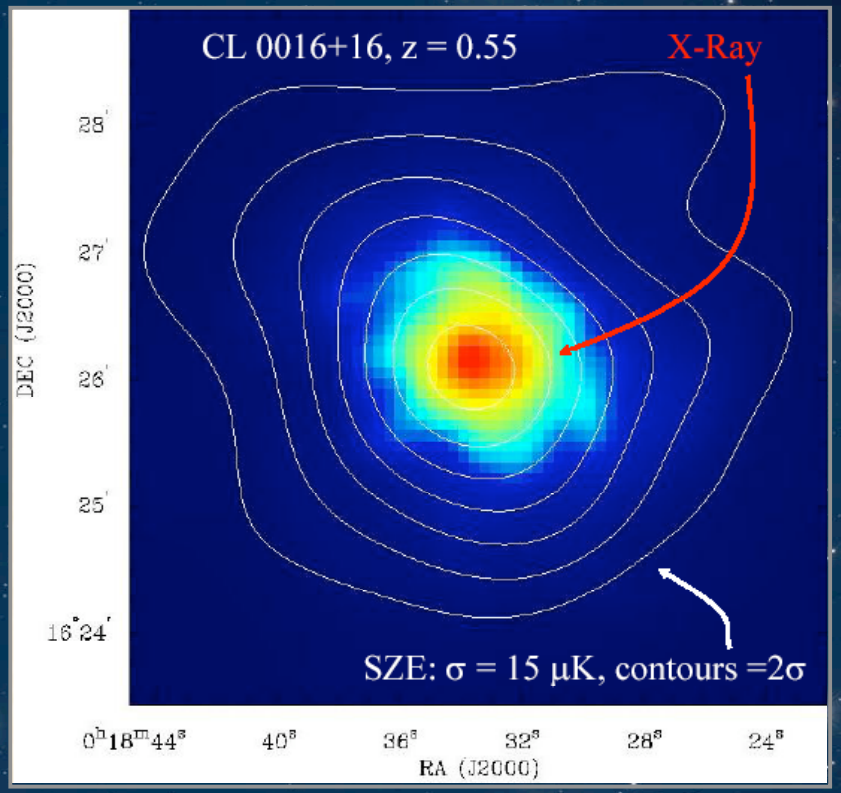
# Introduction

- Extra-galactic radio sources are a significant contaminant in cosmic microwave background (CMB) and Sunyaev-Zel'dovich effect (SZE) experiments.
- Measurements of the CMB and SZE have the potential to yield a wealth of cosmological information if foreground contaminants are well understood.
- Using 89 fields centered on known massive galaxy clusters and 8 non-cluster fields, we:
  - Obtain source fluxes at 28.5 GHz in cluster and non-cluster fields
  - Compute counts of mJy source fluxes in the inner and outer regions of cluster fields, as well as those in non-cluster fields
  - Compute spectral indices of mJy sources in cluster fields between 1.4 and 28.5 GHz

# The Sunyaev-Zel'dovich Effect

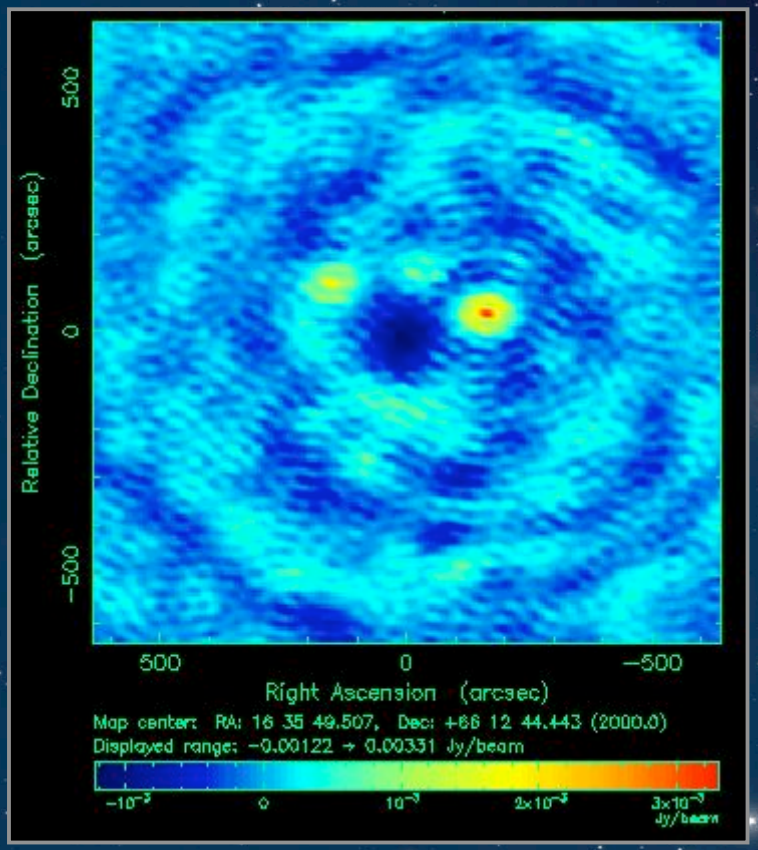
- Arises from the interaction of CMB photons and the hot x-ray gas associated with galaxy clusters.
- Spectral distortion in the CMB.
- At 28.5 GHz, cluster is a cold spot in the CMB.
- Can be used to measure cosmological parameters, constrain models of structure formation, constrain cluster physics.
- Can be used to search for distant galaxy clusters because effect is redshift independent.




Overlay of x-ray image and SZE contours.

# Radio Sources

- Extra-galactic sources are a significant contaminant in CMB and SZE data.
- Radio sources are powered by active galactic nuclei.
- In SZE data, radio sources are often associated with the clusters themselves.
- Potential bias in current and planned SZE cluster surveys.
- Critical to characterize the spatial, spectral, and flux distribution of sources associated with clusters.




Raw image of Abell 2218 taken at BIMA. Several sources and the SZE decrement are visible. Radio sources are an important issue for SZE measurements.

# Observations

- Made from 1995 - 2002 as part of the OVRO/BIMA SZE imaging project.
- Frequency of 28.5 GHz.
- BIMA: nine of ten telescopes, 6.1m in diameter, with a primary beam of 6.6' FWHM.
- OVRO: six telescopes, 10.4m in diameter with a primary beam of 4.2' FWHM.

The BIMA Array. Hat Creek, CA.

# Field Selection

- Total of 89 unique fields centered on known massive galaxy clusters. 62 cluster fields were observed at BIMA and 55 cluster fields were observed at OVRO, with 28 fields of overlap.
- 18 non-cluster fields were observed as part of the BIMA CMB project, 8 of which were selected without regard to possible radio source contamination.
- Cluster fields were chosen mainly from x-ray catalogs and one optical survey, including ROSAT BCS, EMSS, XBACS, WARPS, MACS, and RCS.
- Cluster field selection is heterogeneous; fields were chosen to obtain precise measurements of the SZE in massive clusters.
- Potential targets were screened for strong sources. We analyze faint sources found serendipitously toward massive clusters.

# Flux Measurements

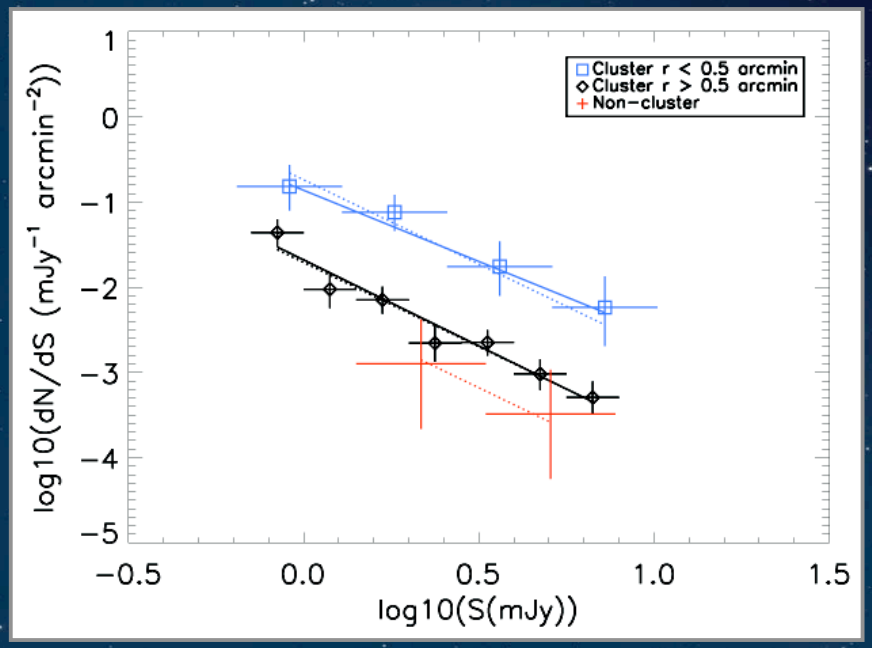
- Positions and fluxes of 28.5 GHz sources and SZE decrements are jointly determined using DIFMAP.
- Sources are initially modeled as point sources but are examined for extended emission.
- The SZE decrement (if any) is modeled as an elliptical, isothermal $\beta$-model.
- Noise levels are extracted from residual images.
- At the $5\sigma$ level or greater, we detect 95 unique sources in the 89 cluster fields (62 at BIMA, 55 at OVRO, 22 overlap).
- We detect 2 sources in the 8 non-cluster fields at $5\sigma$ or greater.

# Source Counts: Analysis

- Two radial bins: inner ($r < 0.5'$) and outer ($r > 0.5'$) from cluster center.
- We compute differential source counts in several flux bins, accounting for the varying noise levels from field to field.
- The survey area for each field is set by the noise level for the field. For each flux bin and field, the minimum flux in the bin sets the allowable beam-corrected noise level and corresponding maximum attenuation radius for the field.
- The outer boundary on the survey area for a field is the lesser of the attenuation radius or a max cutoff radius of 6.6' for BIMA and 4.2' for OVRO. Relative to pointing center.
- Total survey area for each flux bin is the sum of the area in all fields.
- For each field we pick out all $5\sigma$ sources within the survey area for the field, between the min and max fluxes of each flux bin. We count all sources detected in this way to get total counts in each flux bin.

# Source Counts: Results

- Simultaneously fit the normalizations for the inner, outer, and noncluster regions and a common power-law index.
- Source counts are found to be greatly elevated toward the central core of the cluster fields.



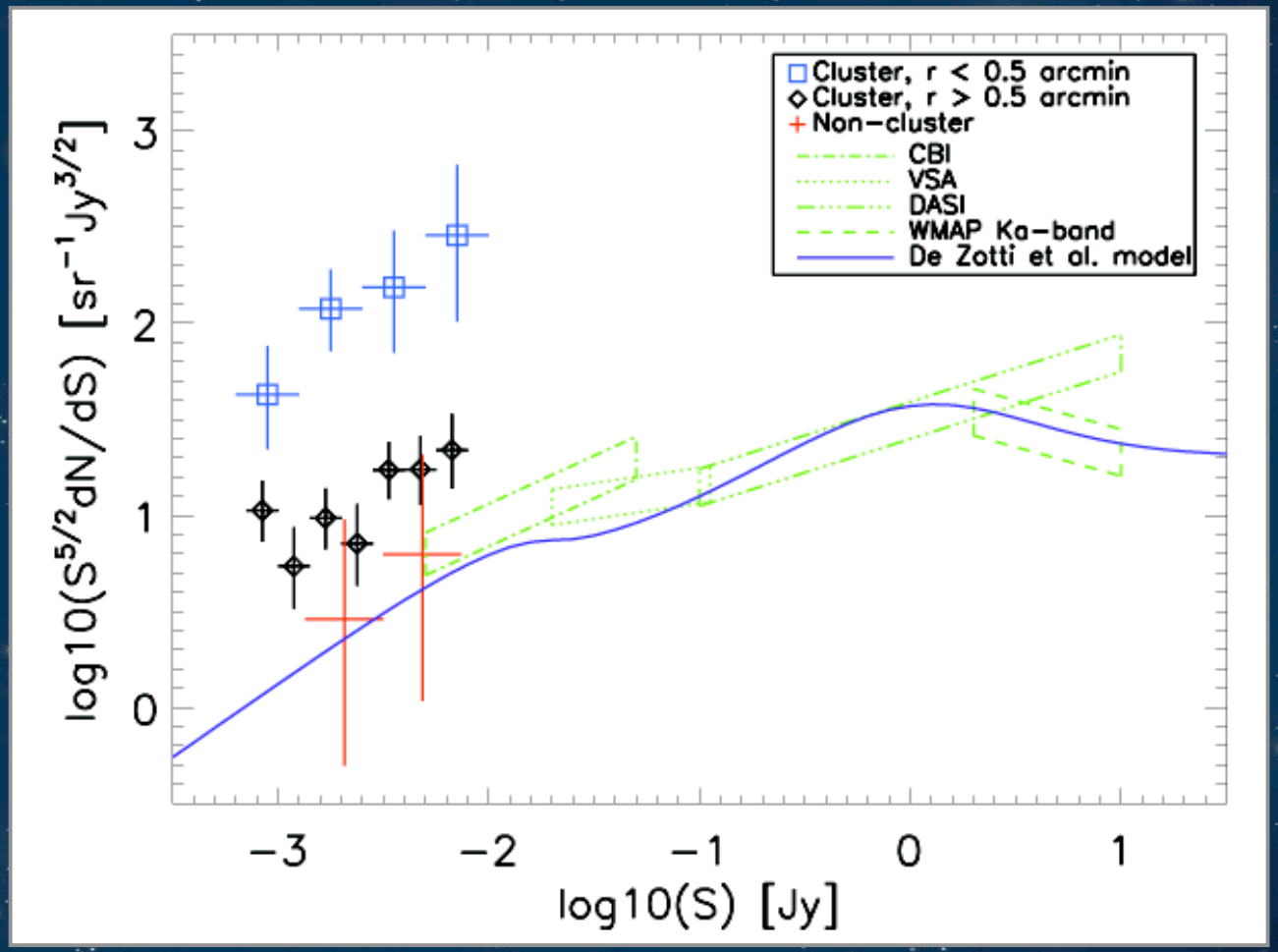

Counts as a function of flux, and best fit power laws. Solid lines indicate the best fit power laws for each set individually and dotted lines indicate the best fits using a Markov chain algorithm to simultaneously estimate the normalizations and a common power law index.

# Source Counts: Results

- Source counts in the inner regions of the cluster fields (within 0.5' of the cluster center) are a factor of 8.9 (+4.3, -2.8) times higher than counts in the outer regions of the cluster fields (r > 0.5').
- Source counts in the outer regions of the cluster fields are in turn a factor of 3.3 (+4.1, -1.8) greater than those in the non-cluster fields.
- Counts in the non-cluster fields are consistent with extrapolations from the results of other surveys.

# Source Counts: Results

Source counts as a function of flux.



# Spectral Indices

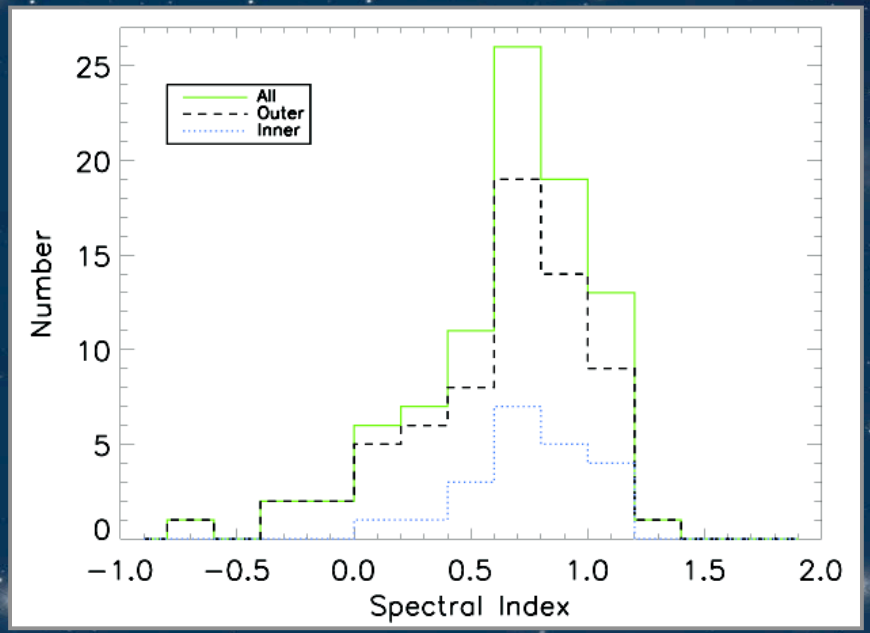
- Spectral index $\alpha$ is defined by $S \sim \nu^{-\alpha}$.
- We compute spectral indices between 1.4 and 28.5 GHz for sources in cluster fields (selected at 28.5 GHz).
- Use 1.4 GHz data from other surveys (NVSS, FIRST, VLA).
- Not contemporaneous with 28.5 GHz measurements.
- Of the 95 sources in the cluster fields, 88 have unambiguous counterparts at 1.4 GHz, including all sources in the central 0.5'. Since only seven sources lack 1.4 GHz detections, the bias in the mean spectral index due to omitting them is small.

# Spectral Indices: Results

- Average spectral index $\alpha_{1.4:28.5}$ = 0.66 with an rms of 0.36.
- The distribution is skewed, with a median index of 0.72 and 25th and 75th percentiles of 0.51 and 0.92, respectively.
- This is steeper than the spectral indices of stronger field sources measured by other surveys (CBI, 9C and follow-up, WMAP).
- Expect steeper indices for weaker sources.
- Similar to spectral indices of slightly stronger radio sources in clusters at lower frequency.

# Spectral Indices: Results

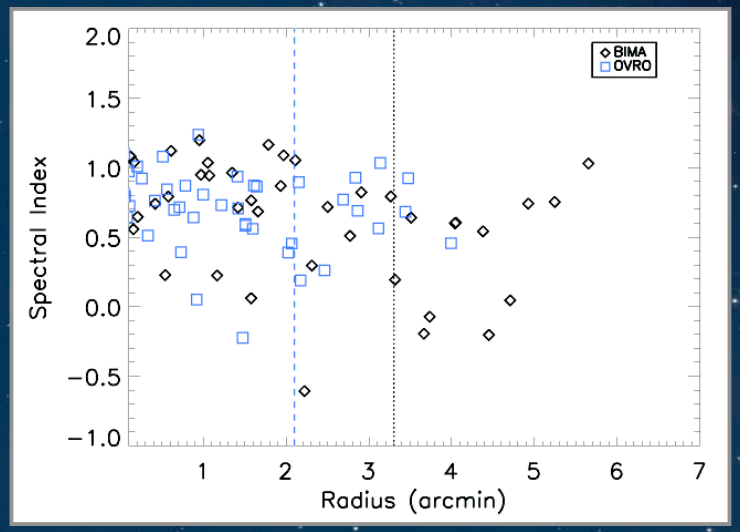
- All:
  - 88 sources
  - Mean = 0.66, rms = 0.36
  - Median = 0.72 [0.51, 0.92]
- Outer cluster regions:
  - 67 sources
  - Mean = 0.63, rms = 0.38
  - Median = 0.71 [0.42, 0.88]
- Inner cluster regions:
  - 21 sources
  - Mean = 0.75, rms = 0.24
  - Median = 0.76 [0.56, 0.94]
- Outer and inner consistent with same population.



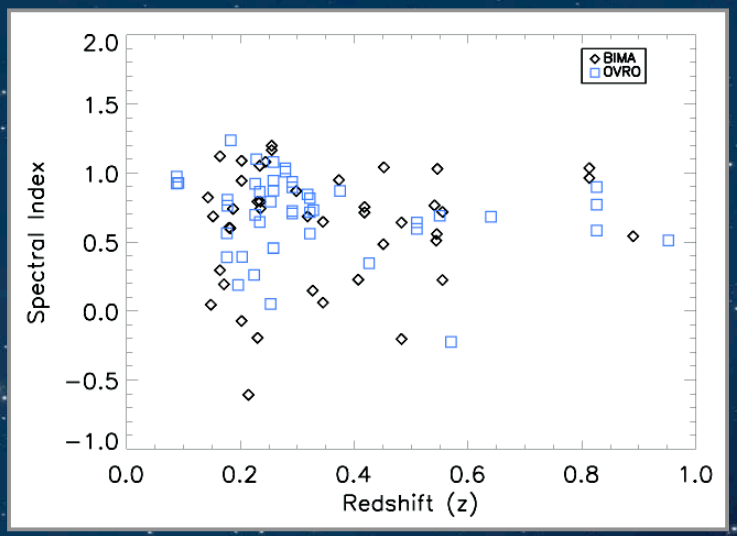

Histogram of spectral indices.

# Spectral Indices: Results

- Spectral index as a function of radius.
- No radial dependence.




- Spectral index as a function of redshift.
- No redshift dependence.



# Conclusions

- Deep interferometric observations of faint radio sources at 28.5 GHz.
- 89 fields centered on massive galaxy clusters and 8 noncluster fields.
- Source counts are greatly elevated in the centers of cluster fields; counts in central regions are 8.9 (+4.3, -2.8) times higher than counts in the outer regions of the cluster fields.
- Counts in the outer regions of the cluster fields are in turn a factor of 3.3 (+4.1, -1.8) greater than those in the non-cluster fields.
- Counts in noncluster fields consistent with those expected from model and extrapolations.
- Spectral index: 0.66 +/- 0.36, skewed with median 0.72 [0.51, 0.92].
- Spectral indices for faint sources in massive clusters steeper than those of stronger field sources measured by other groups.
- Sources are an important issue for SZE cluster-finding surveys. If sources are well-understood, CMB and SZE measurements can yield a wealth of cosmological information.

# References

Check out the paper: Coble et al. 2007, *AJ*, 134, 897


- Bennett, C. L., et al. 2003, *ApJS*, 148, 97
- Bolton, R. C., et al. 2004, *MNRAS*, 354, 485
- Cleary, K. A., et al. 2005, MNRAS, 360, 340
- Condon, et al. 1998, *AJ*, 115, 1693
- Dawson, K. S., Holzapfel, W. L., Carlstrom, J. E., Joy, M. LaRoque, S. J., Miller, A., & Nagai, D. 2002, *ApJL*, 581, 86
- de Zotti, G., Ricci, R., Mesa, D., Silva, L., Mazzotta, P., Toffolatti, L., & Gonzalez-Nuevo, J. 2005, *A&A*, 431, 892
- Kovac, J. M., Leitch, E. M., Pryke, C., Carlstrom, J. E., Halverson, N. W., & Holzapfel, W. L. 2002, *Nature*, 420,772
- Mason, B. S., et al. 2003, *ApJ*, 591, 540
- Reese, E. D., et al. 2000, *ApJ*, 533, 38
- Slee, O. B., Wilson, I. R. G., & Siegman, B. C. 1983, *Aust. J. Phys*, 36, 101
- Waldram, E. M., Pooley, G. P, Grainge, K. J. B., Jones, M. E., Saunders, R. D. E., Scott, P. F., & Taylor, A. C. 2003, *MNRAS*, 342, 915
- White, R. L., Becker, R. H., Helfand, D. J., & Gregg, M. D. 1997, *ApJ*, 475, 479