

September 30, 2007

Prof. Patricia Burchat  
Stanford University  
382 via Pueblo Mall  
Varian 158  
Stanford, CA 94305-4060

Dear Prof. Burchat:

Please accept my attached application for your postdoctoral position in galaxy cluster studies advertised in the September edition of the AAS Job Register. For my thesis, entitled '*Feedback, Evolution, and Dynamics in Galaxy Clusters*', I am studying the connection of feedback mechanisms – such as AGN, star formation, and radiative cooling – to gas entropy, and the role of this feedback in altering global properties of the ICM and the impact on galaxy formation. I have also been studying a method for quantifying the virialization state of clusters through the band dependence of X-ray temperatures.

For my thesis I assembled a sample of 350 archival *Chandra* observations for 276 clusters. The results of this laborious task have been many and mighty. Looking forward, I am excited to apply my expertise in analyzing X-ray data to further study the details of feedback in clusters, as well as expanding my analysis to the radio, optical, and infrared bands, taking my work completely “in-house”. Better understanding clusters from a multiwavelength perspective is what will make massive optical surveys like those from LSST useful beyond the survey’s primary scientific goals.

Along with this letter are my resumé, a summary of past and current research, and a brief description of possible future research directions. Letters of recommendation from Megan Donahue, Mark Voit, and Jack Baldwin will arrive under separate cover. Please do not hesitate to contact me if there is any further information I can provide as you review my application.

Thank you for your consideration.

Sincerely,

A handwritten signature in black ink, appearing to read 'Ken Cavagnolo', written over a light blue rectangular background.

Kenneth W. Cavagnolo  
Michigan State University

# KENNETH W. CAVAGNOLO

## Resumé

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<b>Education</b>	<b>Michigan State University</b>	2005 - Present
	Ph.D. Astrophysics, Expected August 2008 Thesis Title: "Feedback, Evolution, and Dynamics in Clusters of Galaxies" Thesis Advisors: Dr. Megan Donahue & Dr. G. Mark Voit	
	<b>Michigan State University</b> M.S. Astrophysics	2002 - 2005
	<b>Georgia Institute of Technology</b> B.S. Physics <i>Cum Laude</i>	1998 - 2002
<b>Research Experience</b>	<b>Graduate Research Assistant</b>	2003 - Present
	Supervisor: Dr. Megan Donahue, <i>Mich. St. Univ.</i> Studying clusters of galaxies via their X-ray properties to investigate feedback mechanisms, galaxy evolution, and the process of cluster virialization.	
	<b>Graduate Research Assistant</b>	2002 - 2003
	Supervisor: Dr. Jack Baldwin, <i>Mich. St. Univ.</i> Analyzing echelle spectra for use in studies of <i>s</i> -process abundances in planetary nebulae.	
	<b>Undergraduate Research Assistant</b>	2000 - 2002
	Supervisor: Dr. James Sowell, <i>Georgia Tech</i> Obtaining orbital solution for the eclipsing Algol binary ET Tau via UVB light curves and spectroscopic radial velocity curves.	
<b>Research Interests</b>	• LARGE SCALE STRUCTURE FORMATION AND COSMOLOGY	
	• FEEDBACK MECHANISMS IN GALAXY CLUSTERS	
	• GALAXY FORMATION	
	• GALAXY CLUSTER EVOLUTION	
	• HIGH-REDSHIFT CLUSTER FINDING	
<b>Teaching Experience</b>	<b>Substitute Instructor</b>	Fall 2006
	Course: "Visions of the Universe" Gave lectures covering stellar evolution, supernovae, white dwarves, neutron stars, and black holes.	
	<b>Physics Tutor</b>	Summer 2003
	Course: "Introductory Honors Physics I & II"	

Tutored physics students taking introductory physics courses such as classical mechanics, optics, and electromagnetism.

### Graduate Teaching Assistant

2002 - 2003

Course: "Visions of the Universe"

Directed and supervised laboratories for non-calculus based astronomy course.

### Honors

- College of Natural Science Dissertation Fellow 2007 - Present
- American Astronomical Society Member 2002 - Present
- American Physical Society Member 2002 - Present
- NASA Center for Astronomy Education Participant 2007
- Sigma Pi Sigma National Honor Society 2001 - Present
- Dean's List, Georgia Tech 1998-2002

### Scientific Skills

- Profound skills in reducing and analyzing data taken with *Chandra* X-ray Telescope.
- Extensive experience with CIAO and CALDB.
- Familiarity with multiwavelength analysis packages: AIPS, IRAF, and PyRAF.
- Fluent in Perl, IDL, and HTML.
- Working knowledge of Bash, C, CSH, Flash, Fortran, MySQL, SLANG, and Supermongo.
- Mastery of multiple computing architectures: UNIX/Linux, Windows, and Macintosh.
- Expert of computer troubleshooting, maintenance, and system construction.

### First Author

*"Feedback Mechanisms in Galaxy Clusters and Alteration of ICM Entropy"*

### Refereed Publications

**Cavagnolo, Kenneth W.**; Donahue, Megan; Voit, G. Mark; and Sun, Ming  
2008, in prep.

*"Library of Galaxy Cluster Entropy Profiles"*

**Cavagnolo, Kenneth W.**; Donahue, Megan; Voit, G. Mark; and Sun, Ming  
2007, in prep.

*"X-ray Band Dependence of X-ray Temperatures in Galaxy Clusters"*

**Cavagnolo, Kenneth W.**; Donahue, Megan; Voit, G. Mark; and Sun, Ming  
2007, near ApJ submission.

### Other Refereed Publications

*"Star Formation, Radio Sources, Cooling X-Ray Gas and Galaxy Interactions in the Brightest Cluster Galaxy in 2A0335+096"*

Donahue, Megan; Sun, Ming; O'Dea, Christopher P.; Voit, G. Mark; **Cavagnolo, Kenneth W.**  
[2007AJ....134...14D](#)

*"Entropy Profiles in the Cores of Cooling Flow Clusters of Galaxies"*

Donahue, Megan; Horner, Donald J.; **Cavagnolo, Kenneth W.**; Voit, G. Mark  
[2006ApJ...643..730D](#)

*"s-Process Abundances in Planetary Nebulae"*

Sharpee, Brian; Zhang, Yong; Williams, Robert; Pellegrini, Eric; **Cavagnolo, Kenneth**; Baldwin, Jack A.; Phillips, Mark; Liu, Xiao-Wei  
[2007ApJ...659.1265S](#)

### Conference Proceedings & Talks

*"Library of Galaxy Cluster Entropy Profiles: A Study in Feedback"*

**Cavagnolo, Kenneth W.**; Donahue, Megan; Voit, G. Mark; and Sun, Ming  
2008 Winter Meeting of the American Astronomical Society, Thesis Talk and Poster

*"The Entropy-Feedback Connection and Quantifying Cluster Virialization"*

**Cavagnolo, Kenneth W.**; Donahue, Megan; Voit, G. Mark; and Sun, Ming  
2007 Eight Years of Science with Chandra Symposium, Poster

*"Chandra Studies of Dark Matter and Galaxy Formation: Signatures from the Intracluster Medium"*

Donahue, Megan; Sun, M.; **Cavagnolo, K.**; Voit, G.

2006 Winter Meeting of the American Astronomical Society, Poster

*"Abundances of s-process elements in planetary nebulae: Br, Kr & Xe"*

Zhang, Y.; Williams, R.; Pellegrini, E.; **Cavagnolo, K.**; Baldwin, J. A.; Sharpee, B.; Phillips, M.; Liu, X.-W.

2006 IAU Symposium, Proceeding

*"Studies of Entropy Distributions in X-ray Luminous Clusters of Galaxies"*

**Cavagnolo, K. W.**; Donahue, M. E.; Voit, G. M.; Sun, M.; Evrard, A. E.

2005 Winter Meeting of the American Astronomical Society, Poster

*"Entropy Distributions in the Cores of Nearby X-ray Luminous Clusters of Galaxies"*

**Cavagnolo, K. W.**; Donahue, M. E.; Voit, G. M.; Horner, D. J.; Evrard, A. E.

2004 Winter Meeting of the American Astronomical Society, Poster

*"Radio-Free Cluster Cooling Flows"*

Donahue, M. E.; Voit, G. M.; **Cavagnolo, K.**

2004 Winter Meeting of the American Astronomical Society, Poster

## References

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## Personal Interests

- Non-physics academic: environmental sciences, "Cradle2Cradle" design, and urban planning.
- Athletics: triathlons, baseball, and everything Georgia Tech.
- Hobbies: reading, building model airplanes, and raising bonsai trees.

The story of hierarchical galaxy cluster formation is well understood up to the breaking of self similarity; however, model details, such as galaxy formation, impact of feedback sources on the cluster environment, and radiative cooling, are not. My thesis research has focused on studying these details via X-ray properties of the ICM in clusters of galaxies. I have paid particular attention to ICM entropy distribution, the process of virialization, and the role of AGN feedback in shaping large scale cluster properties. In addition to my present research I previously studied  $s$ -process abundances in planetary nebulae.

My primary research makes use of a 350 observation sample (276 clusters) taken from the *Chandra* archive. This massive undertaking necessitated the creation of a robust reduction and analysis pipeline which 1) interacts with mission specific software, 2) utilizes analysis software (i.e. XSPEC, IDL), 3) incorporates calibration and software updates, and 4) is highly automated to free-up my time for multiple, on-going projects.

Because my pipeline is written in a very general manner, dropping in pre-packaged analysis tools from missions such as *XMM*, *Spitzer*, and *VLA* will be straight forward, thus making incorporation of multiwavelength data smooth. Most importantly, my pipeline deemphasizes data reduction and accords me the freedom to move quickly into an analysis phase and generating publishable results.

The emerging picture of the ICM entropy-feedback connection suggests cD radio luminosity and  $H\alpha$  emission should be correlated with cluster central entropy. I have explored these relations with my thesis sample and am finding a trend of high central entropy favoring low  $L_{H\alpha}$  and low  $L_{Radio}$ . I am following-up these results by examining the distribution of central cooling times as a window onto the timescale of AGN feedback. In addition, I am exploring the dependence of the X-ray loud AGN distribution on redshift and amount of cluster substructure.

This work, while broad and deep in scope, has been very fruitful thus far: I am a co-author for two refereed journal papers ([1], [2]), presented new and unique work each year ([3], [4], [5], [6], [7], [8]), a first author paper which is in draft, and another first author paper in preparation containing my thesis results. I have also contributed to several successful *Chandra*, *XMM*, *Suzaku*, and *Subaru* proposals in addition to writing my own high scoring—although unsuccessful—*Chandra* proposal for time observing an amazing ULIRG. I am also planning  $H\alpha$  imaging observations for several previously unobserved clusters with MSU's SOAR telescope.

In another part of my research I have studied bandpass dependence in determining X-ray temperatures and what this dependence tells us about the virialization state of a cluster. The ultimate goal of this project is to find an aspect independent measure for a cluster's dynamic state. Prompted by the work of [9] I have investigated the net temperature skew in my sample of the hard-band ( $2.0_{rest}$ -7.0 keV) and full-band (0.7-7.0 keV) temperature ratio for core excised apertures. I have found this temperature ratio is statistically connected to mergers and the presence of cool cores. This work has produced a first author paper which is near ApJ submission and was used in a successful *Chandra* theory proposal.

In my earliest work as a graduate student I identified and analyzed spectral lines in planetary nebulae using double echelle spectrograph data. In this work we found enhancements above Solar of  $s$ -process element abundances. This result indicates slow neutron capture and dredge-up took place during the progenitor star's AGB phase. These results go directly to the efficiency of the  $s$ -process in stellar models, and ultimately to a better understanding of ISM enrichment. From this work came a co-author paper ([10]) and the foundations for the thesis work of a fellow graduate student.

Looking ahead, the natural extension of my thesis is to further study questions regarding details of feedback and galaxy formation. What are the micro-physics of ICM heating, such as detailing the thermalization of mechanical work done by bubbles and observationally constraining the effect of non-thermal sources like cosmic rays. How prevalent are cold fronts and do they play a role in galaxy and star formation? Also of interest is how accretion onto the cD SMBH is regulated by large scale ICM properties, and exploring the energy range of AGN feedback states (i.e. what does the AGN energetic injection function look like and how does it correlate with cluster environment?).

There are also exciting theoretical cluster feedback model developments on the horizon which will need observational investigation, and for which I am well positioned to study. Developments such as: how exactly are AGN fueled? Does accretion of the hot ICM/ISM proceed via Bondi-eque flows? What is the efficiency of the accretion? Why do we see metallicity gradients in the ICM/ISM when some amount of mixing should take place? How is feedback energy distributed symmetrically throughout the ICM- is it through excitation of gravitational wave modes along equipotential surfaces?

The synergy of large X-ray and optical surveys, such as those which will come from LSST and Con-X, creates vast opportunities for the study of clusters. My expertise in X-ray astronomy, with *Chandra* specifically, ideally suits me to continue studying cluster feedback and galaxy formation models to prepare interesting and novel uses for these large samples. As Stanford is the epicenter for the future of my field, I'm eager to be a contributor in your research group. I am a great asset for anyone studying clusters both for my technical skills and to furthering their research objectives.

## References

- [1] M. Donahue, M. Sun, C. P. O’Dea, G. M. Voit, and K. W. Cavagnolo. Star Formation, Radio Sources, Cooling X-Ray Gas, and Galaxy Interactions in the Brightest Cluster Galaxy in 2A0335+096. *AJ*, 134:14–25, July 2007.
- [2] M. Donahue, D. J. Horner, K. W. Cavagnolo, and G. M. Voit. Entropy Profiles in the Cores of Cooling Flow Clusters of Galaxies. *ApJ*, 643:730–750, June 2006.
- [3] K. W. Cavagnolo, M. Donahue, G. M. Voit, and M. Sun. Library of Galaxy Cluster Entropy Profiles: A Study in Feedback. In *Bulletin of the American Astronomical Society*, Bulletin of the American Astronomical Society, January 2008.
- [4] K. W. Cavagnolo, M. Donahue, G. M. Voit, and M. Sun. The Entropy-Feedback Connection and Quantifying Cluster Virialization. Eight Years of Science with Chandra Symposium, October 2007.
- [5] M. Donahue, M. Sun, K. Cavagnolo, and G. Voit. Chandra Studies of Dark Matter and Galaxy Formation: Signatures from the Intracluster Medium. In *Bulletin of the American Astronomical Society*, volume 38 of *Bulletin of the American Astronomical Society*, pages 998–+, December 2006.
- [6] K. W. Cavagnolo, M. E. Donahue, G. M. Voit, M. Sun, and A. E. Evrard. Studies of Entropy Distributions in X-ray Luminous Clusters of Galaxies. In *Bulletin of the American Astronomical Society*, volume 37 of *Bulletin of the American Astronomical Society*, pages 1393–+, December 2005.
- [7] K. W. Cavagnolo, M. E. Donahue, G. M. Voit, D. J. Horner, and A. E. Evrard. Entropy Distributions in the Cores of Nearby X-ray Luminous Clusters of Galaxies. In *Bulletin of the American Astronomical Society*, volume 36 of *Bulletin of the American Astronomical Society*, pages 1595–+, December 2004.
- [8] M. E. Donahue, G. M. Voit, and K. Cavagnolo. Radio-Free Cluster Cooling Flows. In *Bulletin of the American Astronomical Society*, volume 36 of *Bulletin of the American Astronomical Society*, pages 1445–+, December 2004.
- [9] B. F. Mathiesen and A. E. Evrard. Four Measures of the Intracluster Medium Temperature and Their Relation to a Cluster’s Dynamical State. *ApJ*, 546:100–116, January 2001.
- [10] B. Sharpee, Y. Zhang, R. Williams, E. Pellegrini, K. Cavagnolo, J. A. Baldwin, M. Phillips, and X.-W. Liu. s-Process Abundances in Planetary Nebulae. *ApJ*, 659:1265–1290, April 2007.