

October 1, 2007

Prof. B.R. McNamara
University of Waterloo
200 University Avenue West
Waterloo, Ontario N2L 3G1
Canada

Dear Prof. McNamara:

Please accept the attached application for your postdoctoral position in galaxy cluster studies advertised in the September 2007 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 in cluster cores – to gas entropy, and the role of this feedback in altering global properties of the ICM and impacting 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 are detailed in the research summary.

My expertise in X-ray astronomy, with *Chandra* specifically, ideally suits me to further work on cluster feedback and galaxy formation models. Adaptation of my skill sets to study clusters in the radio, optical, and infrared is the next step in my career and should come with a short learning curve thanks to my existing, mature programming ability. I am a great asset for anyone studying clusters both for my technical skills and to furthering their research objectives. I feel the post-doctoral position under your advisory at Waterloo is an excellent fit for me, and your research goals will benefit from my addition.

Along with this letter are my resumé, a summary of past and current research, and a brief description of possible 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.

I will be attending the Chandra Symposium in Huntsville, AL October 22nd-26th and would like the opportunity to meet with you and discuss this position further. 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

RESUMÉ OF KENNETH W. CAVAGNOLO

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Education	Michigan State University	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	
	Michigan State University M.S. Astrophysics	2002 - 2005
	Georgia Institute of Technology B.S. Physics <i>Cum Laude</i>	1998 - 2002
Research Experience	Graduate Research Assistant	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.	
	Graduate Research Assistant	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.	
	Undergraduate Research Assistant	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.	
Research Interests	<ul style="list-style-type: none"> • FEEDBACK MECHANISMS IN GALAXY CLUSTERS • GALAXY FORMATION • LARGE SCALE STRUCTURE FORMATION AND COSMOLOGY • SUPERMASSIVE BLACK HOLES • AGN ACCRETION PHYSICS 	
Teaching Experience	Substitute Instructor	Fall 2006
	Course: "Visions of the Universe" Gave lectures covering stellar evolution, supernovae, white dwarves, neutron stars, and black holes.	

Physics Tutor

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, and Supermongo.
- Mastery of multiple computing architectures: UNIX/Linux, Windows, and Macintosh.
- Expert of computer troubleshooting, maintenance, and system construction.

First Author Refereed Papers*"Feedback Mechanisms in Galaxy Clusters and Alteration of ICM Entropy"***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 Papers***"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](#)

**Presented
Work
& 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

DR. MEGAN DONAHUE
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DR. JACK BALDWIN
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**Personal
Interests**

- 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 general process of galaxy cluster formation through hierarchical merging is well understood, but many details, such as the impact of feedback sources on the cluster environment and radiative cooling in the cluster core 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.

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

The picture of the ICM entropy-feedback connection emerging from my work suggests that cD radio luminosity and $H\alpha$ emission are anti-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 has been very fruitful thus far: I am a co-author for two refereed journal papers ([1], [2]), generated 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 thesis 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.

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, including the thermalization of mechanical work done by bubbles and 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 are how accretion onto the cD SMBH is regulated by large-scale ICM properties and what the AGN energy injection function looks like and how it correlates 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?

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.