

December 1, 2009

Attention: Greg B. Taylor, Associate Professor
UNM Physics and Astronomy Dept.
800 Yale Blvd. NE
1 University of New Mexico
Albuquerque, NM 87131-0001

Dear Prof. Taylor:

Please accept the attached application for your postdoctoral position advertised through the AAS Job Register. I feel UNM is an excellent fit for me, and the UNM research environment will benefit from my addition. My expertise in radio and X-ray astronomy – in addition to experience with infrared, optical, and UV analysis – ideally suits me to pursue research projects relevant to the LWA key science projects. I am most interested in the formation and evolution of SMBHs, and subsequent AGN feedback as it relates to large-scale structure formation.

Along with this letter are my CV, a list of publications, and a summary of my research interests. Letters of recommendation from Megan Donahue, Brian McNamara, and Chris Carilli should 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 gray rectangular background.

Dr. Kenneth W. Cavagnolo
University of Waterloo

Dr. Kenneth W. Cavagnolo Curriculum Vitae

Last updated December 1, 2009; [Hyperlinks colored blue](#)

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Education	Michigan State University Ph.D., Astronomy & Astrophysics	2005 - 2008
	Michigan State University M.S., Astronomy & Astrophysics	2002 - 2005
	Georgia Institute of Technology B.S., Physics	1998 - 2002
Research Experience	Postdoctoral Fellow Supervisor: Dr. Brian McNamara, <i>Univ. of Waterloo</i>	2008 - Present
	Graduate Research Assistant Supervisor: Dr. Megan Donahue, <i>Mich. St. Univ.</i>	2003 - 2008
	Graduate Research Assistant Supervisor: Dr. Jack Baldwin, <i>Mich. St. Univ.</i>	2002 - 2003
	Undergraduate Research Assistant Supervisor: Dr. James Sowell, <i>Geor. Inst. of Tech.</i>	2000 - 2002
Research Interests	<ul style="list-style-type: none"> • Active galactic nuclei and jets • Galaxy clusters and groups • Black hole formation and evolution • Galaxy evolution and formation • Large scale structure and cosmology 	
Honors	• Referee for ApJ, AJ, and CanTAC	2008 - Present
	• Sherwood K. Haynes Award for Outstanding Graduate Student	2008
	• MSU College of Natural Science Dissertation Fellow	2007 - 2008
	• American Physical Society Member	2002 - Present
	• ΣΠΣ National Physics Honor Society Member	2001 - Present
	• ΣΞ National Scientific Research Society Member	2009 - Present
	• Perimeter Institute Black Hole Reading Group Member	2009 - Present
	• Dean's List, Georgia Inst. of Tech.	1998-2002

Scientific Skills	• Extensive experience with X-ray and radio data analysis	
	• Familiarity with infrared, optical, and UV data analysis	
	• Understanding of AIPS, CASA, CIAO, and IRAF analysis software	
	• Fluent in HTML, IDL, \LaTeX , and PERL programming languages	
	• Worked with C, FLASH, FORTRAN, MYSQL, PYTHON, SUPERMONGO, and TCL	
	• Mastery of DOS, Linux, Macintosh, and Windows computing architectures	
	• Expert of computer maintenance, system construction, and troubleshooting	
Observing Experience	Giant Metrewave Radio Telescope (GMRT) 59 hours observing 13 galaxy groups	Jan. 2010
	GMRT 109 hours observing 20 galaxy clusters	Feb. 2010
	Chandra X-ray Observatory (CXO) 21 hours observing IRAS 09104+4109	Jan. 2009
	Very Large Array Radio Telescope (VLA) 39 hours observing 13 giant ellipticals	Dec. 2008
Proposals & Grants	GMRT Cycle 17, Co-I The Power and Particle Content of Extragalactic Radio Sources PI: Dr. Somak Raychaudhury, <i>Univ. Birmingham</i>	2009
	GMRT Cycle 17, Co-I The Morphology of Steepest Spectrum Radio Sources in Galaxy Cluster Cores PI: Dr. Alastair Edge, <i>Durham Univ.</i>	2009
	GMRT Cycle 16, Co-I The Content of Giant Cavities in the IGM of Galaxy Clusters PI: Dr. Somak Raychaudhury, <i>Univ. Birmingham</i>	2008
	CXO Cycle 10, PI IRAS 09104+4109: An Extreme Brightest Cluster Galaxy	2008
	CXO Cycle 10, Co-I Conduction and Multiphase Structure in the ICM PI: Dr. Mark Voit, <i>Mich. St. Univ.</i>	2008
	Spitzer Cycle 5, Co-I Star Formation and AGN Feedback in BCGs PI: Dr. Megan Donahue, <i>Mich. St. Univ.</i>	2008
	Spitzer Cycle 5, Co-I Infrared Properties of a Control Sample of Brightest Cluster Galaxies PI: Dr. Megan Donahue, <i>Mich. St. Univ.</i>	2008
	NSF Grant, Co-I Star Formation in the Universe's Largest Galaxies PI: Dr. Mark Voit, <i>Mich. St. Univ.</i>	2008

	CXO Cycle 9, Co-I Quantifying Cluster Temperature Substructure PI: Dr. Mark Voit, <i>Mich. St. Univ.</i>	2007
	VLA A-configuration Cycle, Co-I Radio Feedback in Clusters and Galaxies PI: Dr. Brian McNamara, <i>Univ. Waterloo</i>	2007
Public Outreach	Astronomers Without Borders (AWB) Organized the affiliate chapter of AWB at the University of Waterloo.	2009-present
	International Year of Astronomy (IYA) Helped with events in Waterloo, Ontario for IYA such as observing nights, public talks, and workshops.	2009
Teaching Experience	Substitute Instructor Course: “Visions of the Universe”	Fall 2006
	Honors Physics Tutor Course: “Introductory Honors Physics I & II”	Summer 2003
	Graduate Teaching Assistant Course: “Visions of the Universe”	2002 - 2003
References (ordered by preference)	Dr. Megan Donahue, donahue@pa.msu.edu Tenured professor, Michigan State University	+00-1-517-884-5618
	Dr. Brian McNamara, mcnamara@uwaterloo.ca Tenured professor, University of Waterloo	+00-1-519-888-4567 ext. 38170
	Dr. G. Mark Voit, voit@pa.msu.edu Tenured professor, Michigan State University	+00-1-517-884-5619
	Dr. Chris Carilli, ccarilli@nrao.edu National Radio Astronomy Observatory Chief Scientist	+00-1-505-835-7000
	Dr. Jack Baldwin, baldwin@pa.msu.edu Associate Chair for Astronomy, Michigan State University	+00-1-517-884-5611
	Dr. Paul Nulsen, pnulsen@cfa.harvard.edu Research Scientist, Center for Astrophysics at Harvard University	+00-1-617-495-7043
	Dr. Mike Wise, wise@science.uva.nl LOFAR Radio Observatory Chief Scientist	+31-0-521-595-564
Personal Interests	<ul style="list-style-type: none"> • Academic: Environmental sciences, “Cradle2Cradle” design, and urban planning • Athletics: Triathlons, baseball, rock climbing, and Georgia Tech sports • Hobbies: Backpacking, reading, building model airplanes, and raising bonsai trees 	

Dr. Kenneth W. Cavagnolo List of Publications

Last updated December 1, 2009; [Hyperlinks colored blue](#)

- | | |
|---|---|
| In
Preparation | <p><i>“A Relationship Between AGN Jet Power and Radio Luminosity”</i>
 K. Cavagnolo, B. McNamara, P. Nulsen, C. Carilli, C. Jones, W. Forman, L. Bîrzan, & S. Murray
 In prep. for ApJ</p> <p><i>“Gas Uplift and AGN Heating from the Changing-Look QSO in IRAS 09104+4109”</i>
 K. Cavagnolo, M. Donahue, B. McNamara, & G.M. Voit
 In prep. for ApJ</p> <p><i>“A Multiwavelength Analysis of the Galaxy Cluster RBS 797: Evidence for a Cluster-scale Line-of-Sight AGN Outburst”</i>
 K. Cavagnolo, B. McNamara, P. Nulsen, M. Wise, M. Gitti, & M. Brüggen
 In prep. for ApJ</p> <p><i>“Entropy Scaling Relations of ACCEPT Galaxy Clusters”</i>
 K. Cavagnolo, G.M. Voit, & M. Donahue
 In prep. for ApJ</p> <p><i>“Constraining the Spin of Black Holes Using Measured AGN Jet Powers”</i>
 M. Rohanizadegan, B. McNamara, F. Kazemzadeh, P. Nulsen, K. Cavagnolo, & C. Kirkpatrick
 In prep. for ApJL</p> |
| First
Author
Refereed
Papers | <p><i>“Intracuster Medium Entropy Profiles for a Chandra Archival Sample Of Galaxy Clusters”</i>
 K. Cavagnolo, M. Donahue, G.M. Voit, & M. Sun
 ApJ Accepted, 2009</p> <p><i>“An Entropy Threshold for Strong Hα and Radio Emission in the Cores of Galaxy Clusters”</i>
 K. Cavagnolo, M. Donahue, G.M. Voit, & M. Sun
 ApJ Accepted, 2008</p> <p><i>“Bandpass Dependence of X-Ray Temperatures in Galaxy Clusters”</i>
 K. Cavagnolo, M. Donahue, G.M. Voit, & M. Sun
 ApJ Accepted, 2008</p> |
| Co-Author
Refereed
Papers | <p><i>“Direct Evidence for an Outflow of Metal-Enriched Gas Along the Radio Jets of Hydra A”</i>
 C. Kirkpatrick, M. Gitti, K. Cavagnolo, B. McNamara, L. David, P. Nulsen, & M. Wise
 ApJL Accepted, 2009</p> |

“A Chandra X-ray Analysis of Abell 1664: Cooling, Feedback and Star Formation in the Central Cluster Galaxy”

C. Kirkpatrick, B. McNamara, D. Rafferty, P. Nulsen, L. Birzan, F. Kazemzadeh, M. Wise, M. Gitti, & **K. Cavagnolo**

[ApJ Accepted, 2009](#)

“Conduction and the Star Formation Threshold in Brightest Cluster Galaxies”

G.M. Voit, **K. Cavagnolo**, M. Donahue, D. Rafferty, B. McNamara, & P. Nulsen

[ApJ Accepted, 2008](#)

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

M. Donahue, M. Sun, C. O’Dea, G.M. Voit, & **K. Cavagnolo**

[AJ Accepted, 2007](#)

“s-Process Abundances in Planetary Nebulae”

B. Sharpee, Y. Zhang, R. Williams, E. Pellegrini, **K. Cavagnolo**, J. Baldwin, M. Phillips, & X. Liu

[ApJ Accepted, 2007](#)

“Entropy Profiles in the Cores of Cooling Flow Clusters of Galaxies”

M. Donahue, D. Horner, **K. Cavagnolo**, & G.M. Voit

[ApJ Accepted, 2006](#)

**Presented
Work
& Talks**

TALK: *“The AGN Jet Power and Radio Power Relationship for Isolated Giant Elliptical Galaxies”*

Jun. 2009 – The Monster’s Fiery Breath: Feedback in galaxies, groups, and clusters; University of Wisconsin-Madison

INVITED TALK: *“Using Galaxy Clusters as Galaxy Formation Labs”*

Oct. 2008 – Undergraduate Seminar Series; University of Waterloo

INVITED TALK: *“Understanding Cluster Cores: The Role of Core Entropy”*

Sep. 2008 – The Cool, Cooler and Cold - Cluster Cooling Flows in a New Light; Lorentz Center, Leiden University

INVITED TALK: *“Investigating Feedback and Relaxation in Clusters of Galaxies”*

Jul. 2008 – Center for Study of Cosmic Evolution; Michigan State University

INVITED TALK: *“From Cluster Cosmology to Galaxy Formation in Under One Hour”*

Mar. 2008 – Astrophysics Seminar; University of Waterloo

INVITED TALK: *“The Effect of Cluster Feedback on High-Precision Cosmology”*

Feb. 2008 – NASA Space Science and Technology Center; UAH-Huntsville

INVITED TALK: *“Understanding Feedback in Galaxy Clusters”*

Jan. 2008 – Center for Study of Cosmic Evolution; Michigan State University

INVITED TALK: *“Band Dependence of X-ray Temperatures”*

Oct. 2007 – Astrophysics Seminar; University of Michigan

POSTER: “*The Entropy-Feedback Connection and Quantifying Cluster Virialization*”
Oct. 2007 – Eight Years of Science with Chandra; UAH-Huntsville

POSTER: “*Chandra Studies of Dark Matter and Galaxy Formation: Signatures from the Intracluster Medium*”
Dec. 2006 – American Astronomical Society Winter Meeting

PROCEEDING: “*Abundances of s-process elements in planetary nebulae: Br, Kr & Xe*”
Jul. 2006 – International Astronomical Union Symposium

POSTER: “*Studies of Entropy Distributions in X-ray Luminous Clusters of Galaxies*”
Dec. 2005 – American Astronomical Society Winter Meeting

POSTER: “*Entropy Distributions in the Cores of Nearby X-ray Luminous Clusters of Galaxies*”
Dec. 2004 – American Astronomical Society Winter Meeting

POSTER: “*Radio-Free Cluster Cooling Flows*”
Dec. 2004 – American Astronomical Society Winter Meeting

Dr. Kenneth W. Cavagnolo Statement of Research Interests

Introduction

The gravitational binding energy liberated by active galactic nuclei (AGN), *i.e.* accreting supermassive black holes (SMBHs), plays a vital role in regulating the process of hierarchical structure formation [*e.g.* 1, 2, 3, 4, 5, 6]. Observations robustly indicate most, if not all, galaxies harbor a centralized SMBH which has co-evolved with the host galaxy giving rise to the well-known bulge luminosity-stellar velocity dispersion correlation [7, 8]. Current models for the evolution of dark matter halos (and the baryons within) invoke a feedback loop where the processes of environmental cooling and heating are coupled via AGN [9, 10]. In broad terms, AGN feedback has been segregated into two modes which occur at different cosmic epochs: an early-time radiatively-dominated mode, and a late-time mechanically-dominated mode. While this model is successful in reproducing the bulk properties of the Universe, the details (*i.e.* accretion processes, obscuration, power generation, energy dissipation) are poorly understood. It is these details which interest me most.

Relevant Completed and On-going Research

Up to now, my research has focused primarily on understanding the mechanical feedback from AGN and the associated effects on galaxy clusters. I have devoted particular attention to intracluster medium (ICM) entropy distribution [11], the process of cluster virialization [12], the mechanisms by which SMBHs might acquire fuel from their environments to become AGN [13], and how those mechanisms correlate with properties of clusters cores [14].

From these studies it has become apparent that certain conditions must be established within a cluster core (and presumably any environment which supplies fuel for a SMBH, *e.g.* a brightest cluster galaxy (BCG) corona [15]), namely that the mean entropy (K) of the large-scale environment hosting a SMBH must be $K \lesssim 30 \text{ keV cm}^2$. Coincidentally, this is the entropy scale above which thermal electron conduction is capable of stabilizing a cluster core against the formation of thermal instabilities, hinting at a method for coupling AGN feedback energy to the ICM and establishing a self-regulating feedback loop. This result is made more interesting if the heat-flux-driven-buoyancy instability [HBI, 16] is an important process in clusters with central cooling times $\ll H_0^{-1}$. Full MHD simulations have shown that the HBI, in conjunction with reasonable magnetic field strengths ($\sim 1 \mu\text{G}$), modest heating from an AGN ($\sim 10^{43} \text{ erg s}^{-1}$) and subsonic turbulence, can feasibly stabilize a core against catastrophic cooling [17, 18]. In addition, recent radio polarization measurements for Virgo cluster galaxies suggest the large-scale magnetic field of Virgo's ICM is radial oriented [19]. This result is tantalizing since it suggests the magnetothermal instability [20] may be operating within Virgo, furthering the case that conduction is a vital component of understanding galaxy cluster evolution. In total, these studies touch on a larger subject which is of great interest to me: magnetic fields in clusters.

LOFAR came online fall 2009, and the order of magnitude improvement in angular resolution and sensitivity at low radio frequencies opens a new era in studying ICM magnetic fields via polarimetry [21]. Polarization measurements made with LOFAR will enable direct detection of ICM field strengths and structure on scales as small as cluster cores ($\lesssim 50$ kpc) and as large as cluster virial radii (\sim few Mpc). A systematic study of a cluster sample using LOFAR will expand our view of magnetic field demographics and how they relate to cluster properties like temperature gradients, core entropy, recent AGN activity, and the structure of cold gas filaments in cluster cores. In addition, we will be able to investigate the origin and evolution of the fields: were they seeded by early AGN activity? Are they amplified by mergers? Is there evidence of draping or entrainment? Understanding cluster magnetic fields will also place constraints on ICM properties, like viscosity, which govern the microphysics by which AGN feedback energy might be dissipated as heat, *e.g.* via turbulence and/or MHD waves.

My most recent research has focused on the SMBH engines which underlie AGN. One study recently completed [22] investigates a more precise calibration between AGN jet power (P_{jet}) and emergent radio emission (L_{radio}) for a sample of giant ellipticals (gEs) and BCGs. In this study we estimated P_{jet} using cavities excavated in the ICM as bolometers, and measured L_{radio} at multiple frequencies using new and archival VLA observations. We found, regardless of observing frequency, that $P_{\text{jet}} \propto 10^{16} L_{\text{radio}}^{0.7} \text{ erg s}^{-1}$, which is in general agreement with models for confined heavy jets. The utility of this relation lies in being able to estimate total jet power from monochromatic all-sky radio surveys for large samples of AGN at various stages of their outburst cycles. This should yield constraints on the kinetic heating of the Universe over swathes of cosmic time, and as a consequence, can be used to infer the total accretion history and growth of SMBHs over those same epochs.

An interesting result which has emerged from our work, and which is investigated in [23], is that FR-I radio galaxies (classified on morphology and not L_{radio}) appear to be systematically more radiatively efficient than FR-II sources. This may mean there are intrinsic differences in radio sources (light and heavy jets), or possibly that all jets are born light and become heavy on large scales due to entrainment. One way to investigate this result more deeply is to undertake a systematic study of the environments hosting radio galaxies utilizing archival *Chandra* and VLA data.

With tighter observational constraints on the kinetic properties of AGN jets, of interest to me is re-visiting existing models for relativistic jets in an ambient medium. Utilizing observationally-based estimates of jet power, it is possible to better understand the growth of a radio source including effects like entrainment and evolution of jet composition [à la 24]. Another interesting use of a universal $P_{\text{jet}}-L_{\text{radio}}$ relation is using radio luminosities, lobe morphologies, and age estimates to predict ambient gas pressures: $p_{\text{amb}} \propto (t_{\text{age}} L_{\text{radio}}) / V_{\text{radio}}$. This yields an estimate of ambient densities when basic assumptions are made about environment temperatures: $\rho_{\text{amb}} \propto p/T$. With an estimate of ambient densities, X-ray observing plans for very interesting radio sources which reside in faint group environments (*i.e.* FR-I sources) can be robustly prepared. An observationally-based estimate of P_{jet} also enables the investigation of relations between observable mass accretion surrogates (*i.e.* $\text{H}\alpha$ luminosity, molecular/dust mass, or nuclear X-ray luminosity) and AGN energetics for the purpose of establishing clearer connections with accretion mechanisms and efficiencies.

Future Research

The study of mechanically-dominated AGN feedback has advanced quickly in the last decade primarily because the process is readily observed at low-redshifts, and the hot gas phase which this mode of feedback most efficiently interacts is accessible with the current generation of X-ray observatories. However, our understanding of radiative feedback, and the associated early era of rapid SMBH growth, has not progressed as quickly. This is mostly because cold/dusty gas is required for high efficiency radiative feedback, but the presence of cold/dusty gas is typically accompanied by significant optical obscuration which prevents direct observational study [25]. Luckily, the quality and availability of multi-frequency data (radio, sub-mm, IR, optical, UV, and X-ray) needed to probe the epoch of SMBH growth and obscuration is poised to improve with new facilities and instruments coming on-line (*i.e.* LOFAR, Herschel, SCUBA-2, SOFIA, ALMA, NuStar, Simbol-X, LWA). As such, there are a number of questions regarding the formation and evolution of SMBHs that I would like to pursue.

(1) What is the evolutionary track from young, gas-rich, dusty galaxies to present-day old, parched gEs? It has been argued that high- z sub-mm galaxies (SMGs) are the progenitors for low- z Magorrian spirals and ellipticals, suggesting SMGs are useful for studying the co-evolution of SMBHs and host galaxies. It has been shown SMGs are found in very dense environments and have high AGN fractions ($\gtrsim 50\%$) [26], so they are excellent for identifying the rapidly cooling high- z gas-rich regions where star formation and AGN activity can be fueled. Hence, SMGs identify a population primed for follow-up with far-IR and X-ray spectroscopy to study feedback and cooling in unique environments. In total, SMGs may be the missing piece to understanding how SMBH evolution and AGN activity regulate the transition from gas-rich progenitors to “red and dead” ellipticals. It has also been posited that SMGs are high- z analogs of low- z ULIRGs (objects typically associated with the sites of merging gas-rich spirals). If this is the case, insight to ULIRG evolution can be gained from studying SMGs. ULIRGs are an interesting population on their own, one for which limited X-ray spectroscopic studies have been undertaken. We know these systems to, on average, be dominated by star formation, however, some systems may have significant contribution from AGN, and these systems can be used to further understand the nature of evolving gas-rich systems.

(2) How does SMBH activity depend on environment? Specifically what is the relationship between redshift, environment, and feedback energy? The answer thus far is unclear, most likely because the influence of environment on AGN jets (through entrainment and confinement) has been neglected or treated too simply in models. This is where observations step in to place interesting constraints on the problem. To this end, a study of the faint radio galaxy population using archival *Chandra* and VLA data would be interesting. Undertaking a systematic study of radio galaxy properties (*i.e.* jet composition, morphologies, outflow velocities, magnetic field configurations) as a function of environment (*i.e.* ambient pressure, halo compactness) can help address how AGN energetics couple to environment, which ultimately suggests how accretion onto the SMBH couples to environment on small and large scales. Deep *Chandra* observations for a sample of FR-I’s (a poorly studied population in the X-ray) would also be useful for such a study, using the $P_{\text{jet}}-L_{\text{radio}}$ relation to define robust observation requests.

(3) How does the transition from an obscured to unobscured state correlate with AGN feedback and SMBH growth? As suggested by the low AGN fraction in the *Chandra* Deep Fields, a significant population of obscured AGN must exist at higher redshifts. One method of selecting unbiased samples

of these objects is to assemble catalogs of candidate AGN using hard X-ray (*i.e.* NuStar), far-IR (*i.e.* SOFIA), and sub-mm (*i.e.* SCUBA-2) observations. Because current models suggest the luminous quasar population begins in an obscured state, and rapid acquisition of SMBH mass may occur in this phase because of high accretion rates (possibly exceeding $10 - 100 L_{\text{Edd}}$), understanding the transition from obscured to unobscured states is vital. How does accretion proceed and where does the accreting material come from: gas cooling out of the atmosphere? Gas stripped from merging companions? Is accretion spherical and dictated by local gas density (*e.g.* Bondi)? A key component which has been neglected in AGN studies is the contribution of dust (which should be a significant component in the atmospheres of obscured AGN) in increasing the allowed Eddington luminosity for an accreting SMBH (*i.e.* $L_{\text{Edd}} \propto \mu$). A curiosity which has emerged in recent years which may be interesting, particularly during the obscured stage when the merger rate is presumably high, is the role of multiple SMBHs within the core of a host galaxy. At a minimum, SMBH mergers occur on a timescale determined by dynamical friction, which for a typical dense bulge is $\gtrsim 1$ Gyr, which is $\gg t_{\text{cool}}$ of an obscuring atmosphere. If the SMBHs which are merging have their own accretion disks, then it is reasonable to question how the atmospheres surrounding a host galaxy with multiple AGN is affected, particularly since the transition from obscured to unobscured should proceed more quickly.

Summary

My research interests span the formation and evolution of SMBHs, particularly during their accreting mode as AGN. The general picture of structure formation is complete, and the influence of SMBHs is undeniably important, but missing is a better understanding of the details of accretion, interaction with ambient atmospheres, and energy redistribution via AGN. To this end, more observational constraints are needed, particularly using multiwavelength datasets from upcoming missions. I am well-positioned to make meaningful contributions in such a pursuit, and would like to do so as a UNM post-doc.

References

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