

Analyzing the Fuel of Star Formation in the Early Universe

Molecular gas is a fundamental building material for structure in our universe: its properties influence where and how many (and possibly what type of) stars will form, governing how galaxies evolve. Molecular gas is also the building material for chemical reactions: molecules in space are observed to form compounds of increasing complexity, including prebiotic molecules (Hollis et al. 2000), which may then be delivered to forming solar systems. Given observational limits, our best understanding of molecular gas is for the present-day environment of our own Galaxy. However, star formation (and thus likely planet formation, e.g. Howard et al. 2012) peaked around 10 billion years ago (Madau et al. 1998). If, as suggested, star formation at these epochs proceeds differently than star formation in the local universe (e.g., van Dokkum and Conroy 2010), then studying the detailed properties of molecular gas at high redshifts is critical to understanding how and why these processes occurred differently than in the the present-day.

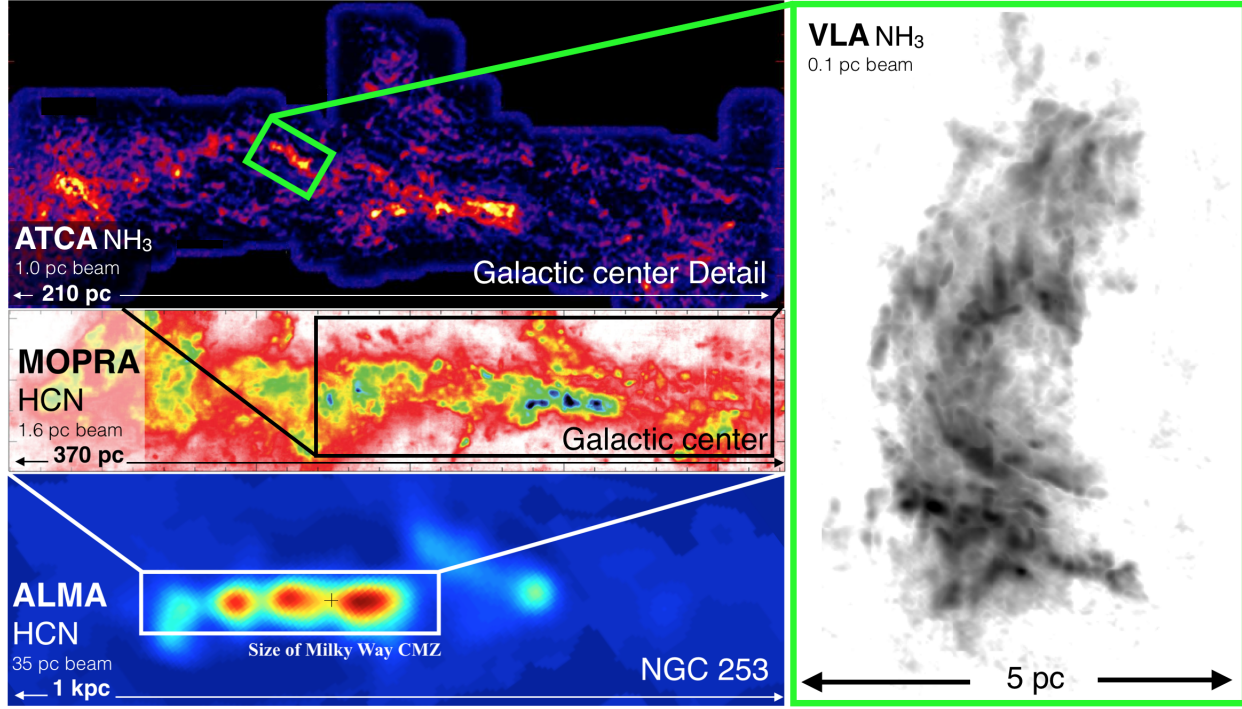
My research focuses on the best local analogue of high redshift systems (e.g., Kruijssen and Longmore 2013): the center of our Galaxy, the proximity of which allows for high-resolution probes of molecular gas properties that will never be possible for distant galaxies. I will use measurements of gas in this region as the first step in a process of comparison with gas in progressively more distant and extreme extragalactic environments, culminating in the first measurements of the variation of gas properties with cosmic time. **My work will provide accurate constraints on the range of chemical and physical conditions present in the molecular gas in the early universe, at the peak of star and planet formation, and galaxy assembly.**

1. The Need to Better Understand Molecular Gas Tracers

As molecular gas tracers are faint, much of our understanding of the gas in other galaxies is based just on observations of only one bright transition of a few common molecules (e.g., HCN 1-0 or CO 1-0 Kennicutt 1998; Gao and Solomon 2004a,b; Lada et al. 2012). However, relying on a single molecular line to trace physical quantities, such as the mass of gas present in a galaxy, can be subject to significant systematic errors due to variations in chemistry (Sandstrom et al. 2013) physical conditions (e.g., Gao and Solomon 2004a; Rosolowsky et al. 2015) or excitation mechanism (e.g., Ziurys and Turner 1986; Sakamoto et al. 2010; Mills et al. 2013). This problem is coming to a head with the advent of the highly sensitive Atacama Large Millimeter Array (ALMA), which is allowing molecular tracers to be used as probes of the more and more extreme environments of the luminous galaxies that are most commonly observed in the distant universe. To continue to employ the efficient approach of using a few bright lines to accurately derive physical conditions in such sources, new studies are necessary to determine whether tracers calibrated for use in the local universe are still valid for gas in the more extreme environments of high- z galaxies (e.g., Swinbank et al. 2011)

2. Testing Molecular Gas Tracers in Extreme Environments

I will conduct the first high-resolution observations of the molecular gas conditions in the extreme environment of extragalactic nuclei and directly compare them to studies of the molecular gas properties in our own Galactic center. Through this comparison I will calibrate the accuracy of individual molecular tracers for determining the molecular gas conditions in the extreme environments of galaxies in the early universe.



Clockwise from bottom left: Meier et al (2015) , Jones et al. (2011) , SWAG Survey (PI: Meier, Mills, Ott), Mills et al. (2015)

Fig. 1.— *Illustration of the steps I will use to calibrate tracers of molecular gas properties in distant galaxies based on those observed locally.* Clockwise from Bottom Left: (1): An ALMA map of the center of NGC 253 with 35 pc resolution, highlighting the current inability to pinpoint the scales on which extragalactic molecular emission occurs and the substructure of the emission. (2): A 1.5 pc resolution map of the Galactic center (GC) over a comparable area, showing the resolution that I will achieve with my ALMA observations of NGC 253 (3): A parsec-scale NH_3 map from the SWAG survey for which I am co-PI, used to measure gas temperatures. (4): VLA NH_3 observations of a GC cloud with 0.1 pc resolution, illustrating the detailed observations of extreme gas that can only be performed in the center of our Galaxy.

I will first use ALMA data to constrain gas temperatures and density in individual GC clouds on sub-parsec size scales which cannot be resolved outside of our Galaxy (Mills et al. 2013; Mills et al. 2014, 2015). I will follow this with comparison to parsec-scale surveys of gas properties that cover the entire Galactic center: for this I will continue to work with a network of European and Australian collaborators (Ginsburg et al. 2015; Ott et al. 2015). Finally, I will directly compare gas properties from these surveys with identical parsec-scale (milliarcsecond) ALMA observations of the nearby starburst galaxy NGC 253 (Leroy et al. 2014; Meier et al. 2015, See Figure 1, left). My observations will determine the range of conditions in some of the most extreme sources in the local universe, identifying the environments in which standard tracers are reliable probes of gas conditions, and alternative tracers for environments where they fail.

Using the molecular tracers calibrated by this work I will be able to accurately trace the quantity, temperature, and density of molecular gas in distant high-redshift systems as a function of cosmic time. This will allow the first comparison of these properties with studies of star formation rate as a function of redshift (e.g., Madau et al. 1998), determining the impact of gas conditions on the formation of stellar systems and the galaxies they make up. **By measuring the properties of the most extreme gas in the local universe, my research will lead to an unprecedented understanding of the relationship between gas conditions and star formation over the history of our universe.**

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The dynamics and structure of present-day galaxies on kiloparsec scales are thought to result from physical processes which occurred in just a few tens or hundreds of parsecs, in their very centers. In the center of our Galaxy, molecular gas properties are markedly different from those in the Galactic disk. They are characterized by large, turbulent line widths, high temperatures, and substantial densities, however the extremes of these conditions are poorly constrained. Measuring the range of conditions that are present in the gas is critical for constraining the processes that could be responsible for shaping galaxy evolution on larger scales. My thesis comprises a multiwavelength probe of the Galactic center (GC) gas that places new limits on its temperature, density, and structure, and is a necessary first step to identifying the mechanisms which are responsible for the more extreme nature of gas in this environment.

Very Hot Molecular Gas in the GC: To investigate the highest temperatures at which GC gas exists, I led a project to survey a sample GC clouds with the Green Bank Telescope (Mills & Morris 2013). By observing highly-excited lines of ammonia (NH_3), I derived rotation temperatures of 400-500 K (Figure 1d), substantially higher than previous temperatures of 200-300 K measured for these clouds. My widespread detections of gas hotter than 400 K indicates that this hot gas must be heated by global processes such as shocks in the GC, rather than local processes such as star formation.

Dense Gas Around the Black Hole: More than any other region, the conditions in gas around the central black hole determines the fate of our GC: whether it will ultimately accrete onto the black hole, or collapse and form stars. Recent studies of this gas yield densities which are discrepant by 4 orders of magnitude. I carried out an excitation analysis of multiple transitions of HCN and HCO^+ using APEX data (Figure 1c), yielding significantly tighter limits on the density ($n < 10^7 \text{ cm}^{-3}$, Mills et al. 2013). These observations indicate that there is less gas around our black hole than previously thought, and as the bulk of the gas is not tidally stable, its apparent structure is a result of turbulent shocks, and not star formation.

Subparsec Structure of GC Clouds: Not only are the global extremes of GC gas properties poorly constrained, but the properties of the gas on subparsec scales are not well studied. This means the dependence of their temperature and density on local processes (e.g. star formation, or supernova-driven shocks) is not known. To begin to characterize the interior conditions of GC clouds, I led a VLA study of five GC clouds to determine the variation in temperature in these clouds on 0.1 pc scales and ultimately identify their heating sources. This work uncovered an unprecedented number of collisionally-excited methanol masers, indicating the importance of shocks in driving conditions in GC molecular clouds (Mills et al. 2015).

Cloud Interactions with the GC Environment: To determine the effects of the GC environment on the properties of the gas, their interactions must also be fully defined. The M-0.02-0.07 molecular cloud lies just 6 parsecs from the supermassive black hole, is being compressed by shocks from a supernova remnant (SNR), and has an embedded group of compact H II regions (Figure 1a). I led a study of the source extinctions and morphologies, determining that three of the H II regions formed at the front of the cloud, and are unaffected by the SNR. The fourth is embedded in the supernova-compressed ridge, and though younger than the other three, is still too old to be triggered by the SNR (Mills et al. 2011).

This thesis has yielded new limits on the physical conditions in some of the most extreme gas in our Galaxy. The results of this work emphasize the importance of shocks in the GC, and while they appear to be the dominant mechanism driving the extreme gas conditions in this environment, there is still no evidence that they are directly responsible for episodes of star formation.

Much of my educational background has been shaped by privilege. I am a white woman who by virtue of the neighborhood I lived in had access to an excellent public school education. I am at least a third generation college student with a father who is a professor. It was expected that I would attend college, and through my family I had knowledge of not only how to apply and succeed at university, but I had the support and economic resources to continue my education beyond that. Although as a physics major in college I experienced gender discrimination, I largely took for granted the systematic advantages afforded to me by my racial privilege. However, this changed as a graduate student at UCLA: I realized that the students I taught were largely latino/a, but this diversity was not reflected in our department which had only one latino graduate student, and no latino/a postdocs or faculty. I began to educate myself on the barriers and institutional structure that have perpetuated this inequality. This disparity is not unique to any one school— in fact, Astronomy is one of the least diverse disciplines in academia, with a fraction of Black and Hispanic faculty that is just 3% (compared to 5% in Physics, 11% across all academic disciplines⁴). As a result, Astronomy is losing access to a larger and larger pool of talent necessary for the health and survival of our discipline.

Since that realization I have begun working on initiatives to combat the inequalities and attitudes in astronomy that have led to the systematic underrepresentation of minority groups. As much as anything I am motivated by solidarity— based on my own experiences as a woman in astronomy, I feel strongly that providing equal opportunities and outcomes for all underrepresented backgrounds of race, gender, disability and sexuality is a necessary prerequisite for excellence in education and research. As a graduate student, I taught two week-long astronomy courses as part of a programs to prepare native Hawaiian students for STEM careers on the island. I led outreach from our department to underserved communities, and I taught science for a year in a largely latino middle school. However, I still did not feel like I was making a systematic difference that would actually change the demographics of professional astronomers.

As a postdoctoral researcher, I have been inspired by the APS bridge programs, which target undergraduates in the transition between an undergraduate and graduate education. While the fraction of underrepresented students getting PhDs is significantly lower than those getting bachelors degrees, the difference in numbers (~ 30 each year) represents an attainable goal for change. For two years, I have run an astronomy summer research program for students from traditionally underserved populations ¹. My goal is to prepare students for graduate school by building lasting relationships between students, mentors and role models, providing students with targeted professional development, and creating a safe community for the discussion of challenges and roadblocks to equal representation. I address these goals by training local advisors in effective mentoring techniques, implementing a weekly summer seminar that complements students research experience, and having significant extracurricular interaction (dinners at my home, camping and rafting trips). Unique to this program,

⁴AIP Report on African Americans & Hispanics among Physics Astronomy Faculty

¹<http://www.aoc.nrao.edu/~bmills/index4.html>

formal mentoring does not end at the conclusion of a ten-week summer research experience, but continues year round via monthly Skype seminars. Recognizing that my own background and experiences as a white woman differ from those of my students in many ways, I have also arranged an on-site Diversity Speaker Series to connect students to colleagues who can serve as additional role models and sources of advice specific to the intersectional backgrounds of my students.

In my two years of running this program, four students (3 African American and 1 Latina) have been accepted into graduate astronomy programs. Two other students have gotten jobs working for NASA and Spitzer. The student feedback from this past summer² indicates that I am successfully meeting my goals of training and supporting students. As a future faculty member, I will continue to run similar programs that work to make the astronomy community fully representative of the community that houses and funds its endeavors.

²<http://www.aoc.nrao.edu/~bmills/index4.3.html>

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Education

University of California, Los Angeles

Ph.D., Astronomy

Thesis: Extremes of Temperature and Density in Galactic Center Molecular Clouds

Advisor: Mark R. Morris

Los Angeles, CA

2007–2013

Indiana University

Bachelors of Science , Physics & Astronomy

Bloomington, IN

2002–2007

Primary Research Interests

The Galactic Center, the Molecular Interstellar Medium, Nearby Galaxies, Astrochemistry, Star Formation, Radio and Millimeter Astronomy

Appointments

Steward Observatory

Postdoctoral Researcher, Jansky Fellow

Leading radio and millimeter surveys of molecular gas in the Galactic center and nearby galaxies

Tucson, AZ

2015–present

National Radio Astronomy Observatory

Postdoctoral Researcher, Jansky Fellow

Lead radio surveys of molecular gas physical conditions and chemistry in the Galactic center

Socorro, NM

2013–2015

University of California, Los Angeles

Graduate Researcher, NSF GK-12 Fellow

Conducted radio, submillimeter, and infrared surveys of the ISM.

Provided new constraints on gas temperatures and densities in the Galactic Center

Los Angeles, CA

2007–2013

National Radio Astronomy Observatory

Undergraduate Researcher, REU Student

Studied the dust continuum from Galactic Center molecular clouds

Socorro, NM

Summer 2006

Indiana University

Undergraduate Researcher, IU STARS Scholar

Determined HI rotation curves for a sample of nearby dwarf galaxies

Bloomington, IN

2006

National Optical Astronomy Observatory

Undergraduate Researcher, REU Student

Measured intervening extinction toward a sample of planetary nebulae

La Serena, Chile

Winter 2005

Indiana University

Undergraduate Researcher, IU STARS Scholar

Performed optical photometry yielding constraints on open star cluster parameters

Bloomington, IN

2002–2005

Short-term Positions

Max Planck Institute for Astronomy <i>Visiting Scientist, Summer Visitor Program</i>	Heidelberg, Germany <i>Summer 2016</i>
European Southern Observatory <i>Visiting Scientist, Scientific Visitor Programme</i>	Garching, Germany <i>May 2015</i>
Max Planck Institute for Astronomy <i>Visiting Researcher, Planet & Star Formation department</i>	Heidelberg, Germany <i>2012-2013</i>
National Radio Astronomy Observatory <i>Visiting Researcher, NRAO Resident Shared-Risk Observing Program</i>	Socorro, NM <i>Summer 2012</i>

Grants and Awards

2015: ALMA Development Grant Co-I (\$185,000)
2013: Jansky Postdoctoral Fellowship (\$225,000)
2013: NSF Astronomy and Astrophysics Postdoctoral Fellowship, declined (\$267,000)
2013: NRAO Student Observing Support Program (\$10,000)
2010: NSF GK-12 Fellowship (\$30,000 + fees)
2010: NRAO Student Observing Support Program (\$35,000)
2008: Chancellor's Prize Graduate Summer Research Mentorship Award (\$5000)
2007: Chancellor's Prize (\$5000)
2005: Sigma Xi Grant-in-Aid of Research Award (\$500)

Honors

2013: AAS Doxsey Prize
2008: Honorable mention, NSF Graduate Research Fellowship
2007: Honorable mention, NSF Graduate Research Fellowship
2007: Outstanding Undergraduate Physics Major, IU Physics Dept.
2007: Honorable Mention, AAS Chambliss Award
2006: Johnson Award for Excellence in Student Research, IU Astronomy Dept.
2006: Alumni Award for Overall Academic Excellence, IU Astronomy Dept.
2005: Elected to Phi Beta Kappa
2002-2007: Indiana University Science, Technology, and Research Scholar

Students and Postdocs

Summer 2015:

- **Kevin Gima** (*Prince George Community College*):
Currently a Junior Astronomy major at the University of Maryland
- **Tierra Candelaria** (*College of Idaho*):
Currently a first-year Astronomy PhD student at New Mexico Institute of Mining and Technology
Paper in prep.: "Measuring the Fraction of Superhot Molecular gas in the Galactic Center", Candelaria et. al.

Summer 2014:

- **Jonathan Barnes** (*Norfolk State University*): How Dense are Galactic Center Clouds?
Currently a first-year Astronomy Masters student at CSU Los Angeles

Paper in prep.: "The Fraction of Dense Gas in the Central 300 pc of the Milky Way" Mills, Barnes et al.

- **Aspen Clements** (*University of Nebraska-Kearney*): Deuterated Ammonia in Sgr B2
Currently a first-year Chemistry PhD student at the University of Virginia
Paper in prep.: "Warm Deuterated Ammonia in Sagittarius B2 (N)", Mills, Clements et al.
- **Binqing "Iris" Sun** (*Nanjing University*): Measuring the Temperature of the Circumnuclear Disk
Currently a student researcher at the National Astronomical Observatories of China
- **Alex Teachey** (*Hunter College*): Characterizing Ammonia Masers in the Galactic Center
Currently a first-year Astronomy PhD student and NSF graduate research fellow at Columbia University
Paper in prep.: "The Discovery of New Ammonia (3,3) Masers in the Galactic Center", Teachey et. al.

Selected Accepted Observing Proposals

Date	Facility	Time	Status
2015	VLA	2 hrs	DDT search for new Galactic center OH masers (PI)
2015	ALMA	4.7 hrs	Dating the accretion flow around our supermassive black hole
2015	ALMA	28.6 hrs	Surveying the core of the NGC 253 Starburst at 1 pc resolution
2015	ALMA	2.1 hrs	Proper motion of gas around our supermassive black hole
2014	ALMA	16.4 hrs	Excitation study of the Galactic center Circumnuclear Disk (PI)
2014	ALMA	5.9 hrs	Study of atomic gas accretion onto our supermassive black hole
2014	ALMA	7.6 hrs	Search for neutral gas within 0.1 pc of our supermassive black hole
2014	ALMA	2.9 hrs	Studying Galactic center absorption filaments
2014	ALMA	22 hrs	Probing the star formation potential in Sgr B2
2014	GBT	74.5 hrs	Survey of Highly-Excited Ammonia in Nearby Galaxies (PI)
2014	ATCA	3 weeks	Large molecular lines survey of the GC (Co-PI with J. Ott, D. Meier)
2013	VLA	9 hrs	Constraints on dense gas in Galactic center clouds (PI)
2012	VLA	1.5 hrs	DDT search for star formation in a GC cloud (PI) , published in ApJ
2011	VLA	24 hrs	Survey of molecular lines in Galactic center clouds (PI) , published in ApJ
2010	GBT	9 hrs	Survey of hot ammonia in the Galactic center (PI) , published in ApJ

Teaching Experience

Summer 2015: National Astronomy Consortium Cohort Leader

- Developed curriculum and led 1 hr weekly professional development seminar

Summer 2015: Galactic Center Group Meeting Leader

- Led a weekly 1 hr research seminar covering star formation, molecular gas, the Milky Way, and nearby galaxies

2010–2011: NSF GK-12 Fellow at Culver City Middle School, Culver City, CA

- Taught in the classroom two days a week with a local teacher
- Created new lesson materials to enhanced the classroom science curriculum

2008–2010: Teaching Assistant, University of California, Los Angeles

- Astrophysics II: Stellar Evolution, Galaxies, and Cosmology Spring 2010
- Life in Universe Summer 2009
- Cosmology: Our Changing Concepts of the Universe Spring 2009
- Nature of Universe lab Spring 2009
- Stellar Atmospheres, Interiors, and Evolution Winter 2008

2007–2009: Center for Adaptive Optics Professional Development Program

- Workshops:

- Re-Thinking Science & Engineering Learning & Teaching (Santa Cruz, CA) November 2007
- Inquiry in Science & Engineering Learning & Teaching (Maui, HI) March 2008
- Advancing Inquiry & the PDP Community (Santa Cruz, CA) April 2009
- Inquiry in Science & Engineering Learning & Teaching (Maui, HI) May 2009
- o Teaching:
 - *Po'okela program for Native Hawaiian high school students* (Maui, HI) July 2008
Developed and taught a week-long program of inquiry-based astronomy to encourage students to pursue science & technical careers in Hawaii.
 - *Akamai Internship program for Hawaiian college students* (Big Island, HI) June 2009
Led a team to develop & co-teach a week-long program of inquiry-based astronomy to prepare students for a 10-week internship at the Mauna Kea Observatories.

Colloquia and Invited Talks

Spring 2016: Herzberg Institute of Astrophysics Colloquium

Spring 2016: University of British Columbia Colloquium

03/2016: New Mexico State Colloquium

01/2016: Harvard-CfA Colloquium

10/2015: Bashfest Invited Review Speaker, University of Texas at Austin

05/2015: Max Planck Institute for Radio Astronomy Special Colloquium

05/2015: Invited ALMA Community Day Talk, Tucson, AZ

03/2015: Invited review, "The Soul of High Mass Star Formation" Puerto Varas, Chile

02/2015: National Radio Astronomy Observatory-Socorro Colloquium

12/2014: National Radio Astronomy Observatory-Green Bank Colloquium

07/2014: Los Alamos National Laboratory Astrophysics Colloquium

03/2014: Joint University of Virginia / National Radio Astronomy Observatory Colloquium

02/2014: University of New Mexico Astrophysics Colloquium

Selected Contributed Talks

12/2015: US Radio Futures Meeting, Chicago, IL

03/2015: Tools for Astronomical Big Data, Tucson, AZ

07/2014: Behind the curtain of Dust: The molecular view of activity in (U)LIRGS, Sesto, Italy

01/2014: Science with the Atacama Pathfinder Experiment (APEX), Ringberg Castle, Germany

01/2014: 223rd Meeting of the American Astronomical Society, Washington, DC

10/2013: IAU 303 The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus, Santa Fe, NM

06/2013: Regulation of Star Formation in Molecular Gas, Ringberg Castle, Germany

01/2013: 221st Meeting of the American Astronomical Society, Long Beach, CA

06/2012: 220th Meeting of the American Astronomical Society, Anchorage, AK

12/2010: Star Formation Under Extreme Conditions: the Galactic Center, Besançon, France

Service

2014–Present: Led a student summer program at NRAO-Socorro for the National Astronomy Consortium

2014–Present: Advisory Board Member of the National Astronomy Consortium

2014–Present: Technical reviewer for NRAO proposals

2014–Present: AAS Chambliss Poster Judge

2013–Present: Papers Refereed (MNRAS, ApJ, ApJL)

2015: Grant review panelist for NSF AAG program

2015: Scientific Organizing Committee

- Next Generation VLA Meeting at the 215th AAS (Seattle, WA)
- Life-cycle of gas in galaxies: A local perspective (Dwingeloo, The Netherlands)

2015: ALMA Community Day Organizer (Tucson, AZ)

- Gave invited talks on research and an overview of NRAO facilities; assisted users with proposal preparation

2014–2015: Lunch Talk Coordinator, NRAO-Socorro

2014: 14th NRAO Synthesis Imaging Workshop (Socorro, NM)

- Led observing preparation and data reduction tutorials
- Created and ran a Careers & Diversity Panel

2012: NRAO Resident Shared-Risk Observing Program (3 months, Socorro, NM)

- Tested and documented new tools for VLA proposal preparation
- Redesigned the user interface for the CASA software webpage

05/2012: 13th NRAO Synthesis Imaging Workshop (Socorro, NM)

- Led observing preparation tutorials

Outreach

2014-2015: Led public VLA tours

2013: Writer for Astrobits

- Author of blog posts to summarize recent papers for a target audience of Undergraduate students

2010–2011: UCLA Astronomy Outreach Co-Coordinator

2009–2012: UCLA Astronomy Outreach Volunteer

- Founding volunteer of an annual UCLA Astronomy Open House for hands-on science experience
- Developed and built new outreach activities for use at open houses and schools, including an interactive star wall
- Led more than 10 volunteer events on campus and at local underserved schools
- Presented over 20 planetarium shows to diverse audiences

Publications

Refereed Publications.....

12. Lau, R.M., Hankins, M.J., Herter, T.L., Morris, M.R., **Mills, E.A.C.** *A Dusty Helical Outflow from an Interacting Massive and Evolved Binary* ApJ Accepted

11. Ginsburg, A., Walsh, A., Henkel, C., Jones, P.A., Cunningham, M., Kauffmann, J., Pillai, T., **Mills, E.A.C.**, Ott, J., Kruijssen, J.M.D., Menten, K.M., Battersby, C., Rathborne, J., Contreras, Y., Longmore, S., Walker, D., Dawson, J. *High-mass star-forming cloud G0.38+0.04 in the Galactic Center Dust Ridge contains H₂CO and SiO masers* A&A Accepted

10. Ginsburg, A., Ao, Y., Riquelme, D., Kauffmann, J., Pillai, T., **Mills, E.A.C.**, Requena-Torres, M.A., Immer, K., Testi, L., Ott, J., Bally, J., Battersby, C., Darling, J., Aalto, S., Stanke, T., Kendrew, S., Kruijssen, J.M.D., Longmore, S., Dale, J., Guesten, R., Menten, K.M. *Dense gas in the Galactic central molecular zone is warm and heated by turbulence* A&A Accepted
 9. Feng, S., Beuther, H., Henning, T., Semenov, D., Palau, A., **Mills, E.A.C.**
Resolving the Chemical Substructure of Orion-KL. 2015, A&A, 581:71-121
 8. **Mills, E.A.C.**, Lang, C.C., Butterfield, N., Ludovici, D.A., Schmitz, S., Ott, J., Morris, M.R.
Abundant CH₃OH Masers but no New Evidence for Star Formation in GCM0.253+0.016. 2015, ApJ, 805:72-97
 7. **Mills, E.A.C.**, Güsten, R., Requena-Torres, M.A., Morris, M.R.
The Excitation of HCN and HCO⁺ in the Galactic Center Circumnuclear Disk. 2013, ApJ, 779:47-67
 6. **Mills, E.A.C.**, Morris, M.R.
Detection of Widespread Hot Ammonia in the Galactic Center. 2013, ApJ, 772:105-124
 5. **Mills, E.A.**, Morris, M.R., Lang, C.C., Cotera, A., Dong, H., Wang, Q.D., Stolovy, S.
Properties of the Compact H II Regions G-0.02-0.07. 2011, ApJ, 735:84-96
 4. Dong, H., Wang, Q.D., Cotera, A., Stolovy, S., Morris, M.R., Mauerhan, J., **Mills, E.A.**,
Schneider, G., Calzetti, D., Lang, C.C. *Hubble Space Telescope Paschen α survey of the Galactic Centre: data reduction and products*. 2011, MNRAS, 417:114-135
 3. Stolte, A., Ghez, A.M., Morris, M.R., Do, T., Ballard, C., **Mills, E.A.**, Lu, J.R., Matthews, K.
L-band sources in the Arches cluster. 2010, ApJ, 718:810-831
 2. Bally, J., Aguirre, J., Battersby, C., Bradley, E.T., Cyganowski, C., Dowell, D., Drosback, M., Dunham, M.K., Evans, N.J. II, Ginsburg, A., Glenn, J., Harvey, P., **Mills, E.**, Merello, M., Rosolowsky, E., Shirley, Y.L., Schlingman, W., Stringfellow, G., Walawender, J., Williams, J. *The Bolocam Galactic Plane Survey: Dust Continuum Emission in the Galactic Center Region*. 2010, ApJ, 721:137-163
 1. Beers, T.C., Flynn, C., Rossi, S., Sommer-Larsen, J., Wilhelm, R., Marsteller, B., Lee, Y.S., De Lee, N., Krugler, J., Deliyannis, C.P., Simmons, A.T., **Mills, E.**, Zickgraf, F.J., Holmberg, J., Enehag, A., Eriksson, A., Terndrup, D., Salim, S., Andersen, J., Nordström, B., Christlieb, N., Frebel, A., Rhee, J.
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- Proceedings and Other Works**.....
8. Leroy, A.K., Murphy, E., Armus, L., Brogan, C., Donovan Meyer, J., Evans, A., Hunter, T., Johnson, K., Koda, J., Meier, D.S., Menten, K.M., **Mills, E.A.C.**, Momjian, E., Ott, J., Owen, F., Reid, M., Rosolowsky, E., Schinnerer, E., Scoville, N., Spekkens, K., van Zee, L., Wong, T. *Next Generation Very Large Array Memo No. 7 Science Working Group 2: "Galaxy Ecosystems": The Matter Cycle in and Around Galaxies* 2015
 7. **Mills, E.A.C.**, Ginsburg, A., Kruijssen, J.M.D., Sjouwerman, L., Lang, C.C., Mao, S.A., Walsh, A., Su, M., Longmore, S.N., Zhao, J.-H., Meier, D.M., Morris, M.R.
VLA SICK: The VLA Sky Survey in the Central Kiloparsec. 2014, A White paper for the VLA Sky Survey.
 6. **Mills, E.A.C.**, Lang, C.C., Morris, M.R., Ott, J., Butterfield, N., Ludovici, D., Schmitz, D., Schmeideke, A. *A Radio Survey of Galactic Center Clouds*. 2014, Proceedings of IAU 303: "The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus"
 5. Requena-Torres, M.A., **Mills, E.A.C.**, Güsten, R., Morris, M.R., Weiss, A., Martín-Pintado, J., Harris, A. *Opening again the debate: the transient nature of the Circumnuclear Disk*. 2014, Proceedings of IAU 303: "The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus"
 4. Sjouwerman, L. & **Mills, E.A.C.**
Galactic kU-band Thermal Survey (GUTS). 2013, A White paper for the VLA Sky Survey.
 3. **Mills, E.A.**, Morris, M.R., Lang, C.C., Cotera, A., Dong, H., Wang, Q.D., Stolovy, S.

Extinction toward the Compact HII Regions G-0.02-0.07. 2011, PASP, 439:125-127

2. Rafelski, M., Foley, M., Graves, G. J., Kretke, K. A., **Mills, E.**, Nassir, M., Patel, S.

Teaching Astronomy with an Inquiry Activity on Stellar Populations. 2010, PASP, 436, 108-119

1. Sonnet, S., **Mills, B.**, Hamilton, J.C., Kaluna, H. *The 2009 Akamai Observatory*

Short Course Inquiry Activity: "Design and Build a Telescope" 2010, PASP, 436, 131-137

Submitted and In Preparation.....

8. **Mills, E.A.C.**, Ginsburg, A., **Barnes, J.M.***, Wiesenfeld, L., Morris, M.R., Faure, A. *The Fraction of Dense Gas in the Central 300 pc of the Milky Way* In Preparation

7. **Mills, E.A.C.**, **Clements, A.***, Corby, J., Butterfield, N., Lang, C.C., Remijan, A.J., Cunningham, M., Jones, P., Ott, J., Morris, M.R. *Warm Deuterated Ammonia in Sagittarius B2 (N)* In Preparation

6. **Teachey, A.***, **Mills, E.A.C.**, Ott, J., Meier, D., Minh, Y.C., Liu, H.B., Butterfield, N., Morris, M.R., Lang, C.C. *The Discovery of New Ammonia (3,3) Masers in the Galactic Center* In Preparation

5. Ludovici, D.A., Lang, C.C., Morris, M.R., Mutel, R., **Mills, E.A.C.**, Toomey, J.E. *The Unusual Galactic Center Radio Source N3* Submitted to ApJ

4. Liu, H.B., Wright, M.C.H., Zhao, J.H., **Mills, E.A.C.**, Requena-Torres, M.A., Matsushita, S., Martin, S. *The 492 GHz emission of Sgr A* constrained by ALMA* Submitted to A&A

3. **Mills, E.A.C.** *HCN 1-0 is not a Linear Tracer of Dense Gas Mass in the Galactic Center* Submitted to ApJ

2. Henshaw, J.D., Longmore, S.N., Kruijssen, J.M.D., Battersby, C., Moore, T.J.T., Burton, M., Ott, J., Dale, J., Pillai, T., Ginsburg, A., Schmiedeke, A., Davies, B., Kendrew, S., **Mills, E.A.C.**, Walker, D., Barnes, A., Immer, K., Zhang, Q. *Molecular gas kinematics within the central 250 pc of the Milky Way* Submitted to MNRAS

1. Feng, S., Beuther, H., Semenov, D., Henning, T., Linz, H., **Mills, E.A.C.**

Inferring the Evolutionary Stages of NGC 7538 S and NGC 7538 IRS1 from Chemistry.

Submitted to A&A.

* **Supervised Student**