

UMSAEP UM-UWC Linkage Report
Visit to Cape Town Nov. 12 – Dec. 10, 2015
Toward Building a New UMKC-UWC Collaboration to Survey the Cold HI Gas Supply
of Massive Quenched Galaxies Across Cosmic Time

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1. Overview

Thanks to support from the UMSAEP Linkage program, my first (*and definitely not last!*) visit to Cape Town and the Western Cape region of South Africa was a successful and rich experience. During four weeks in late 2015, I visited UWC and six additional research/education institutions, plus I attended a collaborative workshop and a scientific meeting. The primary purpose of this trip was to work with a current collaborator, Prof. Davé (SARChI¹ Chair, UWC), to initiate a *long-term* UMKC-UWC collaboration together with other international partners toward an ambitious survey of the neutral atomic hydrogen content in evolutionarily important galaxies using major upcoming advances in radio astronomy that will make South Africa the global focal point of such scientific research. Additionally, my visit included presentations and discussions related to my other scientific pursuits and my education innovations.

2. Proposed Objectives (*abbreviated*)

The goal of the Linkage proposal was to initiate two pilot studies to set the stage for an ambitious new survey to constrain how much neutral atomic hydrogen (HI) gas is available to *novel* samples of massive galaxies that theoretically *should* be forming stars but are not. The growth of galaxies is one of the most active areas in astrophysics. A primary growth channel is the gravitational accretion of fresh HI that fuels subsequent production of new stars. Yet, a key empirical finding is the observed buildup of the galaxy population appears dominated by massive ‘dead’ (non-star-forming or ‘quenched’) objects, rather than star formers like the Milky Way. Thus, it is clear that the quenching (shutdown) of star production is a key aspect of galaxy growth, yet, there is a critical gap in our knowledge about the external gas supply available to such galaxies, which impedes our ability to properly model important quenching physics at play in galaxy evolution. HI provides a unique opportunity to explore the fueling and quenching of star formation in massive galaxies. Thus, what is ultimately needed is a major census of the HI reservoirs of carefully targeted galaxies at different phases of the quenching process, but until recently the ability to survey the cold HI content of galaxies using 21cm emission has been severely limited. With the upcoming (MeerKAT) and future (Square Kilometer Array Phase 1, SKA1) radio astronomy advances in South Africa, plus the existing UMKC-UWC connection, the time is ripe for the ambitious **Quenching HI Survey** (QHIS). This UMKC-UWC collaboration aims to provide critical information about the available fuel for star formation around carefully selected galaxies from two premiere resources: (i) the Sloan Digital Sky Survey (SDSS), and (ii) CANDELS² the largest ever Hubble Space Telescope survey of which myself and Davé are Co-I’s. The following 4 key objectives were defined to investigate the feasibility and lay the ground work for the QHIS collaboration:

- 1) Calculate 21cm HI emission (absorption) detection limits for SDSS (CANDELS) galaxies.

¹ South African Research Chairs Initiative

² Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (<http://candels.ucolick.org/>)

- 2) Write a MeerKAT proposal to probe HI environment of SDSS galaxies in low-mass halos.
- 3) Write a LADUMA-CANDELS proposal to probe HI evolution in massive galaxies.
- 4) Assemble team for pilot studies and future Quenching HI Survey (QHIS) collaboration.

3. Status of Proposed Objectives

My Cape Town visit was instrumental for formally establishing the initial QHIS collaboration and for refining the planning to execute this ambitious survey. Networking with key individuals, visiting the SKA South Africa Office, and attending the 10th Annual SKA Bursary “Meeting of Minds” were all important for understanding the current state of the telescope array and data center infrastructure, the South African National Research Foundation (NRF) funding and strategic science goals, and UWC’s role in SKA. This information, plus my efforts in Cape Town and subsequently, have led to a modest UMKC proposal (7.1e) to formalize pilot (proof-of-concept) observations (QHIS Phase 1) with MeerKAT in 2017, now that the promise to detect HI gas to unprecedented depth and distance is finally here with first light achieved on the MeerKAT 16-dish radio interferometer array (AR1³) earlier in 2016 (see Fig. 1, left). The proposed work will be leveraged for a major National Science Foundation (NSF) proposal submission in Nov. 2017 to support the execution, analysis and publication of QHIS Phase 1, and to prepare for Phase 2 proposals starting 2018 when the MeerKAT 64-dish array (AR3) is fully operational and world-class. In what follows, I briefly describe the status of the 4 originally proposed objectives.

3.1 Objective #1

Our preliminary calculations indicate that the MeerKAT 32-dish array (AR2) and 64-dish array (AR3) configurations should be able to distinguish a number of key predictions regarding the HI fuel available to small-halo, central galaxies selected from the SDSS. More distant galaxies from CANDELS will be more difficult (see 3.3). Ultimately, South Africa will become the major player in comprehensive and deep HI surveys in the coming decade when SKA1-MID (197-dish) comes on line. For this reason, theorists like QHIS Co-I Davé are increasing their efforts to understand the HI gas content of galaxies in cosmological hydrodynamic simulations (Davé et al. 2013), which motivates and aids the QHIS. Using estimates of the HI gas mass content from new theoretical simulations (Davé et al. 2016, see Fig. 1, right), we computed expected 21cm emission detection limits for a range of HI reservoir masses (10^8 to 10^{10} Msun) based on the typical sample (see 3.2) stellar masses (2 to 4×10^{10} Msun) and different phases before and after quenching. We repeated these calculations for 3 separate MeerKAT configurations (AR1, AR2, AR3) tailored to the SDSS sample. These computations demonstrated the feasibility of the QHIS and helped optimize our observing strategy, which were instrumental in refining the Phase 1 target list and proposal draft in preparation for the *first* MeerKAT public CFP anticipated in early 2017 (see 3.2).

3.2 Objective #2

The excellent MeerKAT engineering has had several key successes in 2016, notably first light with AR1 and 30% better-than-expected sensitivity from the array receivers. Despite this, science commissioning observations have been delayed and the science infrastructure has met challenges. The SKA Cape Town office has been open for several years, yet only since spring 2016 has its administration included a Chief Scientist (Fernando Camillo). Additionally, the critical data center necessary to produce and provide science-ready data products, the Institute for Data Intensive Astronomy (IDIA), is yet to be finished or staffed. Initiated just prior to my visit⁴, the IDIA anticipates needing 100s of data scientists to analyze an unprecedented flow of Big Data from the SKA⁵. All of this has meant delays of at least one year from our original planned objective to submit an early 2016 Phase 1 proposal for pilot observations with MeerKAT AR1. The latest word from SKA is that an official early science CFP will be open to the international community in Mar. 2017. The expectation remains that early science observations will be allocated 30% during the next 5 years for

³ Array Release 1 (http://www.ska.ac.za/wp-content/uploads/2016/07/info_sheet_ar1_2016.pdf)

⁴ <http://www.uct.ac.za/dailynews/?id=9342>

⁵ <http://www.universityworldnews.com/article.php?story=20150906085207602>

PI-driven projects like QHIS Phase 1, with the remainder of the observation schedule allocated for previously awarded large key science projects and director's discretionary time. As such, we revamped our initial proposal which we are finalizing in late 2016 for MeerKAT AR2 observations. We will submit this QHIS Phase 1 proposal for the initial CFP in early 2017 with anticipation of observations to be carried out in late 2017.

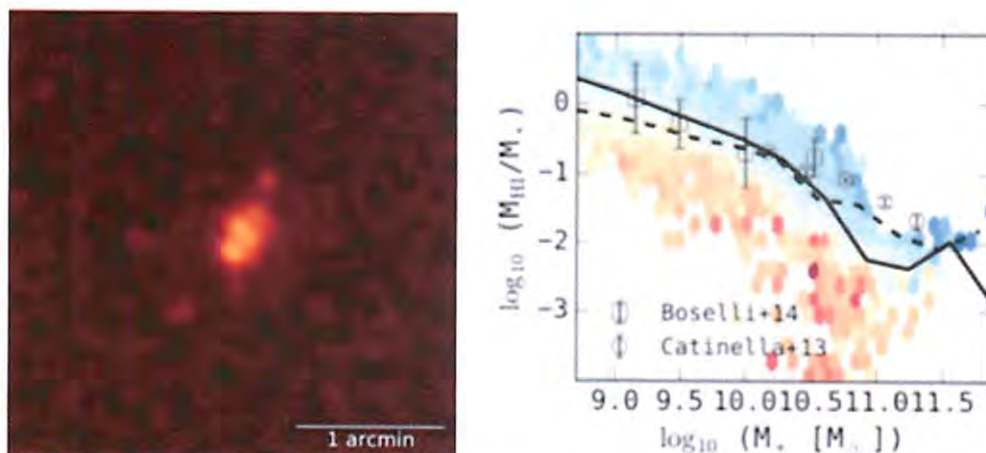


Figure 1: *Left (a):* A zoomed in sections of the MeerKAT first light image showing the 21cm emission from HI in the vicinity of a star-forming galaxy. Credit: SKA/MeerKAT *Right (b):* Predicted HI mass fraction (relative to stellar mass) as a function of the rate of star production (SF: blue data, quenched: red data) from MUFASA simulations. Comparison to observations by Catinella et al. (2013) and Boselli et al. (2014). From R. Dave, in prep.

As described in our original proposal, the targets are drawn from the identification by my team of recently-quenched and long-quenched galaxies (RQGs & LQGs; McIntosh et al. 2014) that live in cosmic environments that theoretically should still produce stars (Gabor & Davé 2012, Keres et al. 2012). The discovery of a significant number of such galaxies raises important questions about whether or not these galaxies have access to a fresh supply of gas, and if they do, why do they remain quenched? Having ruled out other possibilities, we speculated that most may be quenching as the result of the small host halos being dominated by hot gas that impedes cold gas flow to the center where the galaxy resides. An obvious experiment is to probe their halo's atmosphere (gaseous content bound to the dark-matter halo but external to the galaxy) using ultraviolet (UV) spectroscopy with the *Hubble Space Telescope* Cosmic Origins Spectrograph (*HST/COS*). UV spectra include important tracers of hot-gas as well as HI. In preparation for HST cycle24 CFP, we did a comprehensive search of the UV-bright AGN catalog (Veron-Cetty & Veron 2010) for good background light sources to probe the halo gas near our target galaxies. We found a paucity of viable UV targets, which *further motivates the need for the QHIS to achieve a direct connection between HI availability and quenching*. Our survey design involves a careful census of the HI gas properties for galaxies at different stages of the quenching process that are otherwise physically indistinguishable. We have selected the Phase 1 (proof-of-concept) targets from a refined subset of McIntosh et al. (2014) RQGs plus control samples of dead (LQGs) and alive (star-forming) counterparts matched in terms of stellar mass, redshift, shape (spheroidal), environment (centers of halos of mass $<3 \times 10^{12} M_\odot$ based on Yang et al. 2007 data), and observable from Northern Cape, South Africa. These criteria net at least 25 galaxies in each of 3 sets. We will request MeerKAT AR2 observations for 10 of each.

3.3 Objective #3

LADUMA⁶ is an ultra-deep survey of neutral hydrogen gas in the early universe planned for MeerKAT AR3. It is one of the previously approved Key Science Projects. Based on calculations (objective #1) and discussions with LADUMA Co-PI's Sarah Blyth and Andrew Benson during the

⁶ Looking At the Distant Universe with the MeerKAT Array (<http://www.ast.uct.ac.za/laduma/Home.html>)

SKA Bursary Meeting and a visit to University of Cape Town (UCT), we have decided to shelve a formal LADUMA-CANDELS proposal for now pending first results from LADUMA, which are not anticipated until 2018 or later. Nonetheless, we have identified CANDELS targets of interest in the LADUMA field, and Prof. Blyth is excited to bring her expertise to the QHIS collaboration as a Co-I. When LADUMA data becomes available we will be able to test the feasibility of extending QHIS to large cosmic look-back times when SKA1 comes on line in the next decade (Phase 3). Related to objective #3, I met D.J. Pisano at the SKA Bursary Meeting and we discussed his involvement with CHILES⁷, another ultra-deep HI survey (Fernandez et al. 2013) similar to LADUMA. This survey is targeting COSMOS⁸, which is one of the 5 CANDELS legacy fields. As such, we will work together to identify sources to further test the feasibility of QHIS Phase 3.

3.4 Objective #4

Networking at multiple Cape Town institutions and aided by connections from Prof. Davé during the SKA Bursary Meeting, we have succeeded in establishing the initial core collaboration of international observational and theoretical experts in the study of galactic gas accretion and star formation quenching needed to acquire, analyze and interpret the HI data for the QHIS, and to preliminarily investigate the survey's feasibility, and to define the initial samples for pilot study proposals. The team is listed here:

Name	Role	Institute	Expertise
Prof. Sarah Blyth	Co-I	UCT	HI with MeerKAT/SKA, Co-PI LADUMA MeerKAT Key Project
Prof. Michelle Cluver	Co-I	UWC	Multiwavelength galaxy surveys, GAMA ⁹ Scientific Advisory Committee
Prof. Daniel McIntosh	PI	UMKC	Observations of galaxy evolution, Co-I CANDELS
Prof. Romeel Davé	Co-I	UWC	Theoretical simulations of galaxy evolution, Co-I CANDELS & LADUMA
Prof. D. J. Pisano	Co-I	U West Virginia	Extended HI mapping of nearby galaxies, Co-I Chiles survey
Prof. Todd Tripp	Co-I	U Mass - Amherst	UV probes of halo gas, Co-I COS Halos Survey

4. Additional Noteworthy Activities

4.1 Scientific

In addition to the key objectives described above, my Cape Town visit included networking with international theory experts from the Max Planck Institute for Astrophysics (MPA) at the inaugural MPA-UWC collaboration meeting organized by Prof. Davé, and funded by the NRF and the German Research Foundation (DFG). The topic of discussion was the study of gas in galaxies across cosmic time using hydrodynamic simulations, with a particular focus on comparing to observations with MeerKAT and SKA1. I gave a contributed presentation (7.2a) about the McIntosh et al. 2014 study, and learned about Prof. Kauffmann's (MPA) efforts to measure HI in massive galaxies. Moreover, I had the pleasure to spend several days at the South African Astronomical Observatory (SAAO¹⁰). In the heart of Cape Town at the foot of Table Mountain sits the national observatory. Founded in 1820, it is the South African center for optical and infrared astronomy, my area of expertise. There, I met with scientists including Dr. Gilbank, learned about his ongoing projects with the South African Large Telescope (SALT¹¹), discussed related projects for possible future collaboration, attended a seminar

⁷ COSMOS HI Large Extragalactic Survey (<http://chiles.astro.columbia.edu/index.html>)

⁸ Cosmic Evolution Survey (<http://cosmos.astro.caltech.edu/>)

⁹ Galaxy And Mass Assembly (<http://www.gama-survey.org/>)

¹⁰ <http://www.sao.ac.za/>

¹¹ <https://www.salt.ac.za/>

on large projects with SALT, and gave a colloquium about my scientific research (7.2c). These meetings led to my visiting SALT to learn firsthand about this world-class facility.

4.2 Educational

Besides the broader impacts of building the QHIS collaboration, my Cape Town visit included a number of activities designed to advance understanding and promote teaching, training, learning, recruitment and retention in the astronomy-related sciences. These activities included giving a seminar (7.2b) to UWC and SKA faculty and students about the growth of galaxies through merging. Moreover, my visits to UWC included informal round-table discussions about science education with Physics faculty and lecturers, and a formal seminar (7.2d) to the department regarding my high-impact teaching and research training innovations for fostering success among graduate students, advanced undergraduate majors, and non-science majors. We also discussed my successes with strategies for engaging young minds with an eye toward recruiting the next generation of South African astronomers.

It is interesting to note that Introductory Astronomy courses, a mainstay of U.S. university science introduction and recruitment, are not offered in typical South African universities and colleges. Instead, the cultural expectation is that students start their university education with a very specific goal from day one; e.g., a degree in engineering or computer science. This is a professional degree model, and the rigidity of this model will be a challenge for inspiring youth to strive for careers in fundamental sciences like astrophysics, especially for the severely economically depressed, non-white population who have few science-related opportunities or preparation prior to higher education. These challenges are similar to those of underrepresented minorities in the U.S., the notable difference is that in South Africa these are the challenges of the *underrepresented majority*. To address this challenge, I learned that the UWC Department of Physics initiated a program in which majors with poor secondary school preparation will develop their year 1 education over a 2-year period. The idea is to help these students succeed especially the critical gateway courses like trigonometry, pre-calculus and introductory physics, so that they are ready to enter true sophomore coursework with their privileged peers. I believe that this UWC pre-STEM training idea has substantial merit, so much so that I have already begun to initiate plans for a similar program at UMKC, which included the submission of a formal preliminary proposal to the NSF (7.1a) in collaboration with the UMKC School of Computing and Engineering, the Institute of Human Development, and other departments plus community STEM organizations.

Finally, related to my success in developing an effective high school to college pipeline (*A Bridge to the Stars*¹²) for engaging and recruiting underserved urban youth, I had extremely fruitful discussions with Eli Grant from the International Astronomical Union's Office of Astro Development¹³. We met at both the IAU OAD office on the SAAO grounds and during the SKA Bursary Meeting. These discussions with Dr. Grant have led to significant improvements to my program and a number of related proposal submissions (7.1b, 7.1c, 7.1d).

5. Timeline of Activities and Meetings:

Here, I provide a summative timeline of key activities and meetings described above.

- Nov. 15-20, 2015 – MPA-UWC collaboration meeting (Gordons Bay)
Discussed the latest theoretical efforts on the physical processes that remove and fuel galactic halos. Networked with experts from Max Planck Institute for Astrophysics including Profs. T. Naab, S. White, G. Kauffmann, and Prof. Davé's students. Gave contributed presentation.
- Nov. 23, 2015 – visited SKA South Africa Office (Cape Town)
Gave UWC Astronomy Seminar (relocated owing to civic unrest on UWC campus), networked with SKA technical staff, and met potential QHIS collaborators. Established important contacts

¹² <http://cas.umkc.edu/hscp/bridge-to-the-stars.asp>

¹³ <http://www.astro4dev.org/>

with Profs. Michelle Cluver and Mario Santos (UWC), and Prof. Russ Taylor (UWC-UCT joint; Director IDIA).

- Nov. 24, 2015 – visited SAAO (Cape Town)
Met with staff astronomers to discuss various science projects related to my work including Dr. Ros Skelton. Participated in Prof. Davé's research group meeting in which his team discussed preliminary results from MUFASA simulation.
Personal note: the grounds and original (main) building are beautiful and rich with history.
- Nov. 25, 2015 – initial visit to UWC (Bellville)
Networked with various faculty and students in the Physics Department. Discussed ongoing efforts in the Astro Research Group with Profs. Davé, Cluver, Santos and their students. Discussed promoting science to African youth with Prof. Jarita Holbrook.
- Nov. 26, 2015 – visited SAAO
Gave SAAO/UCT Joint Colloquium. Established important contacts with Prof. Sarah Blyth (UCT; Co-PI of LADUMA). Met Dr. David Gilbank and learned about his research with SALT and discussed possible future collaborations and a visit to SALT.
Personal note: enjoyed a lovely Thanksgiving get-together at the home of Profs. Cluver and Jarrett.
- Nov. 27, 2015 – visited SAAO
Established important contact with Dr. Eli Grant at the IAU OAD office. Attended a seminar on SALT large programs science. Joined Dr. Gilbank's research group discussion.
- Nov. 30 – visited UWC
Met with Physics faculty and lecturers (Prof. M. Herbert, Honji Conana, Trevor Volkwyn, Rohan MacLons, and Masimba Paradza) to discuss science education ideas. Topics included the benefits of teaching concepts first, my Introductory Astronomy innovations, and successful strategies for improving reading/writing in advanced science courses.
- Dec. 1-4, 2015 – SKA Bursary Meeting (Stellenbosch)
Attended dozens of presentations on the engineering and scientific objectives of the SKA and its precursor, MeerKAT. Networked with dozens of radio astronomers and research students from African universities. Discussed QHIS collaboration logistics and proposal with Profs. Davé, Cluver, Pisano, Blyth and Tom Jarrett (UCT). Met with IAU OAD education specialist Dr. Grant to followup our discussion regarding *A Bridge to the Stars* pipeline improvements. Met Prof. Andrew Baker (Rutgers; Co-PI of LADUMA).
Personal note: it was wonderful to see so many young people of color engaged in the pursuit of science.
- Dec. 5, 2015 – VIP tour of South African Large Telescope (SALT) facility at the SAAO field station near Sutherland in the Northern Cape province. This world-class facility is the largest optical telescope in the southern hemisphere with a primary diameter of 11 meters. SALT is managed by SAAO and funded by a consortium of international partners include U.S. institutions. I learned about the engineering of the telescope and dome, the technical operations of the observatory, the external grounds, and the data acquisition management. I spent several hours in the control room during observations, and spent the night at the dorm.
Personal note: the drive to SALT is spectacular. I made a point to take the long way back to Cape Town so that I could see the true most southern tip of Africa in L'Agulhas. It is far outshined by the dramatic Cape of Good Hope just south of Cape Town.
- Dec. 7, 2015 (am) – visited African Institute for Mathematical Sciences (AIMS, Cape Town)
Discussed QHIS proposal with Prof. Davé. Unfortunately, Prof. Bassett's cosmology/data science group meeting was cancelled.
- Dec. 7, 2015 (pm) – visited UCT (Cape Town)
Discussed science projects with Prof. Jarrett. Met with Prof. Blyth to discuss QHIS proposal.
- Dec. 8, 2015 (am) – visited SAAO (Cape Town)
Participated in Prof. Davé's group meeting discussions about MUFASA simulation analysis. Discussed QHIS proposal and feasibility calculations.
- Dec. 8, 2015 (pm) – attended UWC Physics end of the year party in Stellenbosch

- Dec. 9, 2015 – visited UWC
Gave education innovations seminar to the Physics Department. Met with Prof. Cluver to discuss QHIS proposal, and presented abbreviated version of my Nov. 26 talk to her and her students. Established important SKA contact with Prof. Roy Maartens (SKA/SARChI Professor in Astronomy & Astrophysics). Met with Leolyn Jackson (Director, International Relations) for debriefing of my UMSAEP-sponsored visit.
Personal note: I enjoyed immensely my tour of the UWC grounds with Leolyn during which he gave me an insider's version of the historical Anti-Apartheid protests that occurred on the UWC campus.

6. Summary

My first experience with the UM-UWC exchange program has been very beneficial to my career during the 10 months since my short 4-week visit to Cape Town. Indeed, I would argue that my reflection now, nearly a year later, convinces me that the UMSAEP's impact on my professional development was much more significant than I would have thought just 1 or 2 months afterwards. Important to the proposed goal, the formal collaboration was established, all parties are interested in pursuing the ambitious QHIS project, and we made progress on the proposed objectives. Of course, giving 4 formal presentations and submitting 5 funding proposals directly related to ideas and discussions during my time in Cape Town are additional noteworthy metrics of success (listed in 7.1 and 7.2). Yet, foremost, it is the meeting of minds, both with known colleagues, but importantly with new scientific friends, and the collective brainstorm and sharing of ideas that is the cornerstone of this Linkage program. That's where the new ideas spring, and the seeds for new collaborations take root. In short, the UMSAEP should most definitely be continued. The modest investment in the cultivation of international partnerships and the inspiration of new ideas will always return great and unpredictable rewards!

Personal note: I extend particular thanks to my host, Romeel, for giving me a whirlwind tour of the many Cape Town astronomy institutions, and for introducing me to many new science friends. I had an amazing time!

7.1 Related Proposals

- (Role: Co-I) "Kansas City Urban STEM Collaborative," preliminary proposal submitted to the National Science Foundation under NSF INCLUDES program, Apr. 13, 2016 for \$150,00 over 2 years. Status: declined.
- (Role: PI) "A Bridge to the Stars: High School-to-College Pipeline to Increase Diversity in STEM," submitted to the American Honda Foundation, Aug. 1, 2016 for \$67,984 over 1 year. Status: under review.
- (Role: PI) "Develop Summer Research Training Course to Expand Highly Successful A Bridge to the Stars Program," submitted for Affiliates Award Competition through NASA Missouri Space Grant Consortium to NASA under National Space Grant College and Fellowship Program, Sep. 12, 2016 for \$9,990 over 1 year. Status: under review.
- (Role: PI, subawardee) "Augmentation to A Bridge to the Stars Recruitment Pipeline Program (FY2016)," submitted for Affiliate Augmentation Award through NASA Missouri Space Grant Consortium to NASA under National Space Grant College and Fellowship Program, Sep. 12, 2016 for \$13,000 over 1 year. Status: under review.
- (Role: PI) "Shedding New Light on Why Galaxies Die with the World's Greatest Radio Observatory," submitted to UMKC under Funding for Excellence program, Sep. 16, 2016 for \$14,999 over 1 year. Status: under review.
- (Role: PI) "Mapping the HI Content of Massive SDSS Galaxies in Different Stages of Quenching," to be submitted March 2017 as part of the initial CFP for public science projects

7.2 Formal Presentations

- Massive Recently-Quenched Galaxies*, Nov. 18, 2015, MPA-UWC Collaboration Workshop, Gordon's Bay, South Africa

- b. *Two Tests of the Modern Merger Hypothesis at $z \sim 0$* , Nov. 23, 2015, University of Western Cape, Special Astronomy Colloquium, Cape Town, South Africa (**invited**)
- c. *Galactic Capitalism: The Buildup of a Bimodal Galaxy Population*, Nov. 26, 2015, South African Astronomical Observatory, SAAO/UCT Joint Colloquium, Cape Town, South Africa (**invited**)
- d. *Education Innovations*, Dec. 9, 2015, University of Western Cape, Special Physics Seminar, Cape Town, South Africa (**invited**)

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