

The current proposal will extend the ongoing project to measure SFRs of galaxies in the local filaments. The requested funding will be used to hire a physics or astronomy graduate student interested in education or an employee with similar qualifications. This employee will be the main contact person in the classroom and will lead the day-to-day instruction and supervision of the learning teams during the execution of the project. Rudnick's main tasks will be to coordinate the program, decide on the exact curriculum based on our assessment process (see below), attend the class once every week, and ensure that the program becomes sustainable in future years. Through Rudnick's *continuous* support and heavy involvement in the program, the high school teacher is able to devote more of his time to training students to aid in peer instruction, which will allow us to expand in future years without additional personnel costs.

Assessment: The assessment consists of an end of project presentation and paper for each student. Their presentations are made to KU faculty during a mini-conference at KU. All students are given the pre- and post-course Light and Spectra Concept Inventory (?). We also make students give multiple oral presentations throughout the semester and have a rubric to evaluate their improvement over the course of the project. This project satisfies important elements of several of the Kansas state science standards, i.e. "Science as Inquiry" via the process of research and of communicating their results, benchmark 2 and 3 of the Physics standards via learning about the electromagnetic spectrum and how it relates to astronomical phenomena, benchmark 4 of the earth and space sciences standards relating to general astronomy, and benchmark 2 of the "history and nature of science" via the understanding gained of the scientific process.

4.4. co-PI Rudnick

4.4.1. *Molecular Gas in Distant Galaxies'*

Co-PI Rudnick has recently completed his NSF project 1211358 "Characterizing the Molecular Gas Contents of High Redshift Galaxies" (\$306,754; 8/1/12-7/31/16).

Intellectual Merit: This study was based on a large body of JVLA data (200 hrs) on a $z = 1.62$ galaxy cluster that was collected between 2012 and October of 2014. The goal of this study was to characterize the molecular gas content of high- z galaxies by observing CO. As a result of the studies of this cluster and of the CO gas content of distant galaxies, Rudnick has authored or co-authored seven papers since 2012 with a total of 185 citations (???????) as well an ApJ paper that is in the resubmission process (Rudnick et al.). Since 2012, Rudnick has also given 28 oral presentations on this NSF project. Using the full JVLA data, Rudnick has securely detected CO(1–0) in two massive and gas-rich galaxies in the $z = 1.62$ cluster. These galaxies have surprisingly low star formation efficiencies (SFE) for their high mass and gas fraction (e.g. ?). This may indicate the presence of environmental effects on the physical conditions of the molecular gas and on the accretion of gas from the cosmic web in a massive halo. These results appear in a paper that is being resubmitted to ApJ after a favorable referee report. The expected publication date is early 2017. As a direct result of this project Rudnick has also organized a large consortium of scientists who are seeking to use ALMA to make a census of the CO gas in distant cluster galaxies. They will resubmit a significantly sized proposal in April 2017.

Broader Impact: Rudnick has completed the third year (2013-2016) of an outreach program in close collaboration with Andrew Bricker, a Physics teacher at Lawrence High School (LHS). Rudnick developed and executed a year-long program in which the students receive an introductory calculus-based astronomy course and perform a bona fide research project. The goal of the class is to teach high school students research methods, computing skills, the electromagnetic spectrum, the nature of science, and science communication while also giving the teacher new tools to teach research-based activities in the classroom. The project involves using *Spitzer*/MIPS $24\mu\text{m}$ data to measure L_{IR} and SFRs for the galaxies in the infall regions of intermediate redshift clusters from the ESO Distant Cluster Survey (EDisCS). The students meet every day in a special class period. The teaching assistant funded by the grant performed most of the instructional duties and Rudnick attended class once a week. 30 students have gone through the program during these three years. This total was comprised of $\sim 50\%$ underrepresented student groups: four African American, three Hispanic, one Native American, and 10 female students, two of which were also women of color. As described in §4.3 we employ extensive assessment to understand our success at meeting learning goals. This program is continuing in 2016-2017 funded by another NSF project (see §4.4.2).

4.4.2. Galaxy Evolution in Distant Clusters

co-PI Rudnick is in the beginning of his second year for the NSF project 1517815, “Collaborative Research: The GOGREEN Survey - Caring About the Environment” (\$347,556; 8/1/15-7/31/18).

Intellectual Merit: This study funds the US analysis efforts for the international Gemini Observations of Galaxies in Rich Early Environments (GOGREEN) project. This project is based on the largest Gemini Long and Large Program (PI: Michael Balogh), which is comprised of 443 hours of Gemini imaging and spectroscopic observations conducted over a 4 year period starting in Fall 2014. The two main components of this project are very deep Gemini optical spectroscopy of a stellar mass ($M > 10^{10} M_{\odot}$) limited sample of galaxies in 21 groups and clusters at $1 < z < 1.5$ and a large multiwavelength imaging program.

The goals of the project are to: **1)** Find the dominant modes of satellite quenching at $z < 1.5$; **2)** Determine how galaxies populate dark matter halos as a function of environment at $z < 1.5$; **3)** Measure the relative timing of morphological transformation and star-formation quenching; **4)** Constrain the dominant driver of size growth in the early-type population at $z < 1.5$.

co-PI Rudnick is in charge of the imaging efforts for the whole collaboration, which involves gathering *UBVRIZYJKs*[$3.6\mu\text{m}$][$4.5\mu\text{m}$] data on a broad suite of telescopes including Subaru, CFHT, Magellan, VLT, and *Spitzer*. The imaging of the southern clusters is 95% complete and the northern clusters only lack their NIR data. We expect the imaging to be completed by the Fall of 2017.

The strategy of the project is to obtain deep spectra over many semesters on the faintest targets, and thus many of the science publications will appear at the end of the proposal period. However, an initial data paper based on the first 30% of the spectroscopic data is in preparation with a Dec. 2016 submission target.

Broader Impact: Rudnick has extended his LHS outreach program into the 2016-2017 academic year and will continue it through the 2017-2018 AY. Changes that we have made this year include a much more aggressive targeting of URM students, which we have accomplished by going to more junior students and not having as high of a math prerequisite for entry into the program. As a result we have our highest fraction of URM students yet, with one Native American, three African American, two Hispanic students and three women, one of which is a woman of color. We are currently attempting to expand the program by using seniors who have already completed the program as peer instructors. This will allow us to grow without additional personnel costs.

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5. Summary

Intellectual Merit:

Broader Impact: This proposal resonates with the National Science Foundation's broader impacts criteria on many levels. First, the proposal helps promotes teaching and learning by promoting modeling approach to teaching HS physics, integrating problem-based learning into general physics, and the introduction an astronomy concentrations within the physics major to increase the number of majors. Nationally, astronomy traditionally draws a higher fraction of women than physics, so the introduction of the astronomy concentration should attract more female students, a group that is significantly under-represented in physics. Second, the project provides hands-on training and learning for tens of undergraduate students through research. The Siena undergraduate students will be encouraged to become involved in all aspects of research, including data acquisition at world-class observatories, on-campus data reduction and analysis, and presentation of results at national conferences and through publication in peer-reviewed journals. The computer analysis, data interpretation, and presentation skills the undergraduates learn will be essential for success in the workplace, the classroom, or graduate education in any field of science. Finally, the proposal enhances the infrastructure for research and education at Siena College by formalizing collaborations with the ALFALFA team, several of whom are located in New York State and already serve as an extended network of mentors for Siena undergraduates. The proposal will also enable Siena to conduct remote observing sessions at Arecibo.

Broad Dissemination of Results: The scientific results of will be disseminated broadly through publication in peer-reviewed journals, online database, presentation at regional, national and international meetings. I will provide a full catalog for the scientific community that will include an extensive array of primary and derived data products. This will be a much-needed reference for galaxy evolution modelers, particularly those who model the evolution of galaxies. The pedagogic results will also be disseminated broadly through publication in peer-reviewed journals and presentations at regional and national conferences. Of particular interest is the impact that problem-based learning has on student retention and research readiness. In addition, we will develop a new assessment tool that measures a student's ability to think independently and solve real-world problems. This will be of wide interest to institutions looking to implement similar research-focused curricular changes.

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