

This summer I was fortunate enough to be able to participate in a 10-week internship at the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts, in conjunction with their Research Experience for Undergraduate (REU) program. CfA, one of the premier astronomy research institutions in the world, is a fusion of the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO). The program allows students to work on a research project in an active field of astrophysical research with the guidance of CfA faculty and staff. I worked with Christine Jones and Ralph Kraft on a shock heating analysis of the galaxy NGC 1052. NGC 1052 has an active galactic nucleus (AGN), a powerful outburst of light and energy caused by the supermassive black hole at the galaxy's center, emitting high energy x-rays. By analyzing the x-ray photons received from this galaxy by the Chandra X-Ray Observatory, we are able to measure several key parameters for the galaxy outburst.

During my time at CfA, I received instruction and tutorials in several programs and computing languages that are key tools in a modern astrophysicist's repertoire. These included ds9 (indeed, named after a Star Trek series), Python, LaTeX, IDL, CIAO, and XSPEC. These new skills were instrumental in my research project, and I will continue to use them throughout my later academic career. For example, ds9 is used to view and perform non-invasive edits to images from Chandra, XSPEC allowed me to use mathematical models to fit to NGC 1052's energy spectra, and LaTeX allowed me to compile my results in a format recognized by the larger academic community. I also gained a large amount of experience using the Unix operating system, the norm in modern physics research. Besides technical knowledge, I was also able to

make new connections to researchers and students with similar interests and passions as mine. Collaboration is a crucial aspect of the scientific endeavor, so these friendships and connections I have made over the summer will be crucial, as these individuals will be colleagues in my field in the not-too-distant future.

NGC 1052's AGN outburst shock heats the surrounding gas around it, and the skills I learned at the CfA allowed me to learn several things about the galaxy. By making a radial profile plot and extracting energy spectra of the galaxy's diffuse gas and radio lobes, I was then able to use calculate and derive several of the galaxy's parameters. These include the age of the outburst, total power of the outburst, density, temperature, and pressure of the diffuse gas and lobes, as well as the outburst enthalpy. The results are currently being prepared to be submitted as an academic paper to the Astrophysical Journal (ApJ) later this Fall. While these methods are commonly used on giant clusters of galaxies, their employment on single, less powerful galaxy's such as NGC 1052 is much less common, making this study an interesting application of regarded scientific techniques being applied in an uncommon way. This project was also particularly good for me as it contained a mix of both experimental/analysis and mathematical modeling/theoretical work. Having compared this summer's experience to previous projects I have done (purely theoretical or experimental), I think I have enjoyed this project the most. I would like to pursue a career in research that uses both theoretical and experimental techniques; this seems to be a common in sub-fields of high energy astrophysics, such as AGN research.

Outside of my core project, the CfA program has provided other opportunities for professional development. Highlights of these opportunities include weekly lectures from staff scientists. These colloquia cover a variety of modern research topics, introducing us to material

not covered in standard undergraduate courses that we may even research one day. There have also been panels on graduate student life, alternative science careers, the general and physics Graduate Record Examination (GRE), and the National Science Foundation's Graduate Research Fellowship Program. These talks directly helped me prepare for my future endeavors and career, and added even more aspects to the internship program that strengthened my desire to pursue and succeed in academia.

While I gained a good deal of technical and scientific knowledge, I also acquired some less tangible benefits from my time in Cambridge. While learning about a galaxy millions of light-years away from Earth is naturally exciting, some of the day-to-day activities of research can be rather tedious. While pop science documentaries glorify the scientific endeavor with stories of brilliance and human advancement, they do little to adequately describe the difficulties in advancing humanity's knowledge of the natural world. Often would I find myself struggling with an error in a computer code or trying to find a small error in a mathematical derivation. This is hardly fun. However, during my time here at CfA I have learned to appreciate the scientific process itself, and not just buzzwords or results. Every action that I take in conducting research is a part of a larger body of work that will impact all the science that comes after it. That is both incredibly exciting and humbling. One great lesson I have learned in Cambridge is to appreciate the each little step in science. One learns so much from even compiling code and re-doing density calculations, and the knowledge gained has a broader impact. This is part of what makes scientific research even more rewarding than regular coursework.

My time at the CfA has been very valuable. The skills and connections I have made and acquired here will be very useful as I continue my development as a scientist. I hope to be able to

return to CfA one day as a graduate student, postdoctoral researcher, or a staff scientist. My internship this summer has renewed and strengthened my resolve and dedication to astrophysics, and expanded my knowledge and horizons. It is the culmination of the extraordinary opportunities I have been given during my time at Sewanee.