Background and Motivation: Observation of the 21cm hydrogen emission line has the potential to provide tremendous insights into the evolution of the universe, and is one of the most exciting frontiers in cosmology. Roughly 400,000 years after the Big Bang, the universe began cooling enough for neutral atoms to form in a period known as recombination. After recombination came a period known as the 'dark ages', during which the universe consisted mainly of neutral hydrogen. It gets that name because, although the universe was transparent, no stars had formed yet, so the only radiation was photons from the CMB and 21cm emission coming from the hyperfine spin-flip transition of neutral hydrogen. Thus far, researchers have been unable to directly observe this period of the universe. Eventually, gravitational collapse allowed the first stars and galaxies to form. Radiation from these galaxies then began ionizing the neutral hydrogen in a time period known as the Epoch of Reionization (EoR). Roughly one billion years after the Big Bang, reionization was complete, and the universe became observable again. **My research aims at detecting the cosmological 21cm emission line, which will allow us to study the mechanisms driving the evolution of the early universe.** Improving our understanding of this period of the universe is crucial to the field of cosmology. In the most recent decadal survey by the National Academy of Sciences, experiments aimed at detecting the cosmological 21cm signal were listed as the highest priority in radio astronomy [1].

There are many barriers to observing the 21cm emission line, including the weakness of the cosmological signal and instrumentation challenges. Most experiments searching for this signal use interferometers, rather than traditional dish telescopes, due to their higher resolution, which is particularly important for long wavelength radio waves. The signal we are searching for is 4-5 orders of magnitude weaker than the foreground sources, which means that our instruments must achieve an extremely high level of precision. **With interferometry, calibration of the array can be extremely challenging, but without exceptionally precise calibration, systematic errors dominate the experiment and will prevent any attempt to recover the 21cm signal.**

There are two primary methods of calibrating an interferometer: sky-based calibration and redundant calibration. Sky-based calibration, performed here using Fast Holographic Deconvolution (FHD), relies on an a priori sky model to solve for the antenna gains. Incompleteness in current sky models has been shown to produce sufficient contamination of the power spectrum to obscure the desired signal [2]. Redundant calibration makes use of the redundancies in the arrangement of array antennas in solving the calibration equations. This method can largely be performed without the use of a sky model, and in fact an estimated sky model is actually produced during calibration without using prior knowledge [3]. **My research will improve the redundant calibration pipeline and use the estimated sky model to inform the model used for sky-based calibration, thus increasing the precision of current calibration techniques.**

Research Project: For my research, I will work primarily with data from the Murchison Widefield Array (MWA), which is a low-frequency radio interferometer containing 256 tiles, each of which is composed of 16 dipole antennas. Specifically, my work will be based on phase II of the MWA, which has been running since 2016, and whose data is yet to be fully analyzed. The MWA provides unique opportunities for studying interferometric calibration because it is composed of two highly redundant hexagonal arrays and a pseudo-random extended array, which makes it workable for both sky-based and redundant calibration. I began working with this data set during my research as an undergraduate, where I created the first images of the sky model produced through redundant calibration and uncovered sources of error that were propagating into the model. My undergraduate work was aimed at finding relative agreement between the estimated sky model produced through redundant calibration and the observed data. If achieved, this estimated sky model could be used to inform the sky model used for sky-based calibration, thus lowering the necessary precision of the a priori sky model. Through this research, I found evidence that positional errors in the antennas were propagating into the estimated sky model and contaminating the calibration solutions.

As a first year graduate student at the University of Washington, I have already joined the radio cosmology group, led by Miguel Morales. This group is one of the leaders of the MWA and the Hydrogen Epoch of Reionization Array (HERA) collaborations, and has developed some of the most important data analysis pipelines for precision calibration. By joining this group, I have gained access to better resources and more robust software, which positions me well to study the calibration systematics I uncovered as an undergraduate. My research will proceed as follows:

Phase I: I will run simulated data through the same pipeline I used on the real data in my undergraduate research, which will allow me to more precisely examine the systematics contributing to positional error propagation. I will subtract the model produced through redundant calibration of the simulated data from the a priori sky model given by FHD. This result will provide insight into significant sources of flux that may be missing from our sky model.

Phase II: I will work with collaborators at the University of Melbourne, led by Professor Rachel Webster, to supplement any missing sources in the catalog currently being used for sky-based calibration. During my semester abroad in Melbourne I worked on a piece of code, *PUMA*, that is used to produce and combine source catalogs, so I am well prepared to study these catalogs further. Then, I will run the MWA Phase II data back through this adjusted pipeline, and reexamine the propagation of positional uncertainties.

Phase III: I will work with the HERA collaboration as they begin collecting data from the telescope, which is expected to happen in Spring, 2019. I will compare the results from HERA with those from the MWA, which will allow me to better determine which systematics are specific to the instrumentation of the MWA, and which are due to the calibration pipeline.

This research plan will allow me to systematically track and eliminate the propagation of position errors into the sky model and calibration solutions, which will greatly increase the precision of interferometric calibration, and bring us closer to a true detection of the 21cm hydrogen emission line.

Broader Impacts: Observing the EoR will provide insight into what the early universe looked like and the processes that led to the formation of the first stars and galaxies. Understanding the early universe is fundamental to understanding the modern one, and measurement of the 21cm signal will have tremendous influence in almost every area of astrophysics. In addition to my research, I will work with Professor Morales' group to continue their long history of supporting community college transfer and other historically underrepresented students through the CHAMP program, as detailed in my personal statement.

[1] National Academy of Sciences, *New Worlds, New Horizons in Astronomy and Astrophysics*
[2] Barry, N., Hazelton, B., Sullivan, I., et al. 2016, MNRAS, 461, 3135B
[3] Li, W., Pober, J., Hazelton, B., et al. 2018, ApJ, 863, 170