# RESEARCH STATEMENT

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Research in the field of astronomy has one overarching goal: understanding our place in the universe. I hope to add to this understanding by refining some of the tools that allow us to measure how galaxies evolve over time. In particular, by refining the diagnostic capabilities of the [CII] 158 $\mu$m emission line and our understanding of the energy balance in the interstellar medium, we will gain an improved strategy for peering into the properties of some of the earliest galaxies. Supplementing these [CII] measurements with a deeper understanding of the microphysics of heating and cooling in the interstellar medium (ISM) will provide important context for future studies of both distant and nearby galaxies.

My research so far has focused on utilizing the wealth of available data for nearby galaxies to build a comprehensive picture of the processes occurring around sites of recent star formation. By compiling archival data from across the electromagnetic spectrum, I have been able to model the detailed properties of the dust and gas that permeates galaxies. This work informs future studies of galaxies across universal time by establishing how we can use the brightness of specific emission to determine galaxy properties and provides important context to our understanding of galaxy ecosystems.

## 1 Probing a Multi–Phase ISM

Understanding the properties interstellar gas and dust that fill galaxies and provide the fuel for future star and planet formation is essential for determining how galaxies grow and evolve. It has long been know that the interstellar medium (ISM) of a galaxy can be divided into isolated 'phases,' each with different properties and roles to play. From the dense molecular gas that hosts stellar nurseries to the diffuse ionized gas that occupies the largest part of galaxies volume, each phase can provide vital information about the past and future of a galaxy. I have worked to understand the interplay between the different phases through studies of infrared emission lines that can originate in one or more of these phases. By using these measurements paired with detailed models of the ISM to determine the properties of each phase, I can build on the current knowledge of inter–galaxy structure. Implementing these methods, I have showed that emission that had been assumed to originate predominately in the areas surrounding active star formation can often be produced in the more quiescent ISM phases. This knowledge is important for determining the reliability of emission–line based tracers of star formation or other galaxy properties. The structure of a galaxy can determine its future, so building and verifying our models of the ISM will provide key context to our understanding of what accelerates or dampens a galaxy's growth.

## 2 Developing an Understanding of the [CII] Deficit

The main goal of my research for the past few years has been to better understand the causes and consequences of the [CII] deficit. In order to do this, I have worked with resolved multi–wavelength data from nearby galaxies. These galaxies have all been observed at both the [CII] 158 $\mu$m line and the [NII] 205 $\mu$m line with the Herschel Space Telescope or the Stratospheric Observatory for Infrared Astronomy (SOFIA). Working with galaxies with both [CII] 158 and [NII] 205 $\mu$m data allowed me to separate the [CII] emission by the phase of the interstellar medium (ISM) in which it originated. As carbon has an ionization potential of just 11.3 eV, lower than the 13.6 eV needed to ionize hydrogen, $C^+$ is found in both the ionized and neutral phases of the ISM. On the other hand, nitrogen has an ionization potential of 14.5 eV, well above that of hydrogen, restricting the presence of $N^+$ almost exclusively to the ionized phases of the ISM. Therefore, the predicted ratio of the [CII] 158 $\mu$m line to the [NII] 205 $\mu$m line that originate co–spatially can be used to estimate the fraction of the [CII] emission from the ionized and neutral phases of the ISM. By splitting up the [CII] emission by ISM phase of origin, I can better test what conditions lead to decreases in the [CII]/TIR luminosity ratio. So far, these studies have concluded that although a majority of the [CII] emission from these normal, star–forming galaxies comes from the neutral phases of the ISM, the deficit is almost exclusively observed in the ionized phases of the ISM. This suggests that the cause of the deficit must be a physical process that primarily occurs in the ionized phases of the ISM. In addition to phase–separating the [CII] emission, the wide range of wavelength information for these galaxies can be used to test different potential causes of the [CII] deficit. I have used photometeric data from the far–ultraviolet to the far–infrared along with the spectral energy distribution (SED) fitting programs to probe a full suite of properties of the ISM in these galaxies. I also gathered further information on these galaxies through the use of photodissociation region (PDR) models. Comparing the inferred conditions determined using these methods with other diagnostic tools and our phase-separated [CII] emission has allowed me to carefully test six of the proposed causes of the [CII] deficit in the range of conditions covered by these galaxies.

# 3 Finding the Proper Nail for the [CII] Hammer

In addition to understanding the cause of the [CII] deficit, I have used the phase–separated measurements of the [CII] emission from these galaxies to test the potential properties others have suggested [CII] could trace. Previous works have attempted to use [CII] emission as an indicator of star–formation rates, a tracer of shock–heated gas, a model for the atomic interstellar medium, or a tool to measure the properties of molecular gas in galaxies. Determining which of this wide–range of properties the [CII] line is best–equipped to measure is becoming more and more pressing with the plethora of new high–redshift [CII] detections obtained by the Atacama Large Millimeter Array (ALMA). So far, I have been able to compare the phase–separated [CII] measurements to the star–formation rates of the galaxies in the local universe as well as spatially–resolved environments across inclined galaxy NGC 7331. This method found that the [CII] emission from the neutral phase of the ISM traces the star–formation rates more closely that the [CII] emission from the ionized phases, but both relationships have a significant amount of scatter, especially in star–bursting galaxies. By following a similar method, I plan to test the other proposed uses of the [CII] 158 $\mu$m emission line and determine which relationships might be the best suited for use in the high-z universe. In addition to this, I plan to leverage the full suite of panchromatic spectral and imaging data available through nearby galaxy surveys like KINGFISH to determine if there are potential corrections to the [CII] measurements that could decrease the scatter in any relationships found. By initially doing this work with well–studied, Local Universe galaxies where we are able to spatially distinguish different environments, I can establish what conditions could negatively effect any observed correlation between [CII] emission and other properties of a galaxy.

# 4 Establishing a Coherent Model of Heating and Cooling in the ISM

Knowing how energy is transferred across a galaxy is essential for determining the accuracy of different tracers of galactic properties. As many models of the ISM rely on the presumption of energy balance between heating driven by young stars and cooling regulated by infrared emission, determining the processes that can upset this balance will inform how we trace ISM conditions across the universe. By comparing tracers of heating like the emission from polycyclic aromatic hydrocarbons (PAHs) and infrared luminosity to important cooling lines I have been able to investigate thermal regulation across diverse galaxy ecosystems. Using models of PDRs and grain emissions has further allowed me to see what specific conditions can reduce the photoelectric heating efficiency and therefore alter how young stars impart energy into the ISM. Specifically, I have found that PAH emission features produced by highly charged grains are strongest in ISM environments that show a deficit in cooling line emission. These measurements lend credence to the supposition that highly charged grains heat the ISM less efficiently. By carefully examining relationships between a diverse set of indicators, I can begin to narrow down the ISM properties that have the largest effect on the energy balance within a galaxy. These types of measurements will inform models of galaxy growth and stellar feedback.

# 5 Implementing Actively Learning in Physics and Astronomy Courses

In addition to my research in extragalactic astronomy, I am also very interested in finding the best methods for teaching astronomy and physics courses. I believe (and a wide range of studies suggest) that the best ways to facilitate learning require student involvement. These methods, often called 'active learning' include a range of different techniques that can be applied to get students engaged with the materials covered in a course. In addition, these methods give students an opportunity to see themselves as participants in the scientific process, providing a sense of belonging to the STEM fields which have traditionally been hostile environments for underrepresented minorities and women. So far, my research in this field has focused on the implementation of inquiry–based activities and labs in introductory astronomy and physics classrooms. These activities get students working with real data to answer important questions in these fields. In addition to creating new experiences for students, I am interested in finding the best way to evaluate the success of these materials. To do this, I have created a novel pre– and post– course scientific inquiry question for the introductory astronomy courses I teach. Being the best instructor I can be is incredibly important to me, and I believe that I can only achieve that goal if I am continuously trying new, research–based methods and monitoring the successes and failures of my students as I implement those new techniques.