Abstract

My project will develop crucial optical technologies for upcoming millimeter and sub-millimeter astronomical instruments such as Cornell's CCAT-Prime telescope and NASA's HIRMES airborne spectrometer. The technologies I will develop will enable the study of both the epoch of reionization, around 1 billion years after the Big Bang when the first galaxies were assembling, and star formation in the Milky Way and nearby galaxies. Both CCAT-Prime and HIRMES will implement novel optical designs that require fabrication and testing. Thus, for this upcoming summer, I will be fabricating metal mesh mirrors and filters on silicon for high resolution spectrometers and metamaterial anti-reflection coatings for refractive silicon optics. This will involve working in the Cornell Nanofabrication Facility (CNF) and learning about cleanroom processes such as photolithography, thin film deposition, deep reactive ion etching, and scanning electron microscopy.

The silicon-based metal-mesh mirrors I will produce will be used in high resolution Fabry-Perot interferometers (FPI), and the resonant filters I will make will be used to limit the frequencies of light entering spectrometers. I will test and characterize the optical performance of these devices using the mm-wave Fourier Transform Spectrometer (FTS) in Professor Niemack’s lab and the far-infrared FTS in Professor Stacey’s lab. Upon successful fabrication and testing, we will write and submit an article to the Applied Optics journal on our novel optical devices. The FPIs that I fabricate may go into NASA’s HIRMES, which is expected to launch in 2019, and Cornell’s CCAT-Prime telescope spectrometer, which is expected to achieve first light in 2021.
My advisor for this project is Professor Michael Niemack in the Physics department. I will also work directly with graduate student Nicholas Cothard in CNF, and attend Professor Gordon Stacey’s (Astronomy) fabrication meetings both for the CCAT-prime FPI and HIRMES FPI development.

**Biographical Sketch**

I am a sophomore in the College of Arts and Sciences, majoring in Physics. I joined Professor Niemack’s research group last fall semester. My current research focuses on instrumentation within the astrophysics field, and is an exciting hands-on experience where I have access to an impressive array of nanofabrication tools. Outside of research, I am currently a member of the Cornell Mars Rover engineering project team, where I design onboard experiments for a rover that our team builds each year. Previously, I have also worked on a project in the Space Systems Design Studio. Cornell has allowed me to explore my broad interest in space from many different angles, which has helped me greatly in deciding on a career path. My other interests include chess, shogi (which is a Japanese board game similar to chess), and cooking.
Tanner Dean’s Scholar Grant Proposal
2018

Mahiro Abe, 2020
Physics
“Fabricating Interferometers for Next-Generation Astronomical Instruments at CNF”
**Statement of Purpose**

My summer project is in the field of observational astronomy and astrophysics. I will be developing optical technologies for upcoming millimeter and far-infrared cameras and spectrometers. In particular, I will work on the fabrication of Fabry-Perot Interferometers (FPI). FPIs are often used as spectrometers to detect specific wavelengths of light. They utilize the concepts of constructive and destructive interference to obtain accurate measurements of resonance wavelengths, and filter out unwanted signals. By choosing the right resonance wavelengths, FPIs enable astronomers and physicists to study phenomena such as the heating and cooling of the interstellar medium, which traces regions of recent star formation, and the gas density and composition in protoplanetary disks, which will uncover the process of planet formation.

For my project, I will develop FPIs specifically designed for Cornell’s CCAT-prime telescope and NASA’s HIRMES spectrometer. CCAT-prime is a next-generation telescope for observing phenomena relevant to the early evolution of the universe, including star and galaxy formation, inflation, and the Cosmic Microwave Background (CMB), which is the earliest observable light in the universe, generated 400,000 years after the Big Bang. The CCAT-prime imaging spectrometer will be based on the mirror technology I am helping to develop. Its primary goal is to detect ionized carbon (C\(^{+}\)) in the epoch when the first galaxies were forming, 500 million to 1 billion years after the Big Bang. The C\(^{+}\) line traces the UV light of young stars so that we can trace the formation of the first galaxies in the universe. [2]

The HIRMES project will go aboard SOFIA, a NASA-owned Boeing 747 SP modified to carry a 2.5 m aperture infrared telescope at an altitude of 41,000 feet. HIRMES is designed to
detect water, ice, oxygen, molecular hydrogen $\text{H}_2$, and its isotope deuterium. The wavelengths of light associated with these molecules are not possible to detect from the ground due to the water vapor in the Earth’s atmosphere. By calculating the distance from the gas emitting source to the central star of a system, we can see how materials are gathered to form planets around the parent star. [4]. I will work with Professor Stacey’s research group to help develop technologies for 8 fully tunable cryogenic FPI and 5 fixed wavelength FPI filters that will be used in the HIRMES spectrometer.

A FPI consists of two parallel, reflective surfaces which create a cavity known as an etalon. Light whose wavelength is a half-integer multiple of the cavity width enters the etalon and is reflected in the cavity multiple times, each time transmitting a fraction to a photodetector on the other side. The resonant wavelengths of light can be selected by adjusting the distance between the reflective surfaces. Our group’s FPI design uses two silicon wafers as the parallel surfaces. These wafers have nanoscale features on both sides that give them certain optical properties.

First, the outside etalon surfaces will feature a metamaterial anti-reflective coating (ARC) layer. Silicon has a high refractive index, meaning light bends significantly when passing through it. This is advantageous for telescope optics since it means the lenses can be compact and efficient. However, this also means silicon has a high Fresnel reflectance rate. Light that travels between vacuum and silicon will lose up to 30% of its signal due to reflections off the vacuum-silicon interface. In order to preserve the original signal, we require an ARC to prevent these reflections. We are developing a fabrication procedure for creating an ARC layer considerably more accurately and efficiently than existing methods. This involves etching a
multi-layered pattern into the silicon wafer itself to give it higher microwave transmission properties. [3]

Second, the inner surfaces of the etalon will be patterned with metal meshes that optimize the device’s reflection properties. There are two types of mesh patterns, with complementing properties. A mesh with vertical and horizontal metal grid lines behaves like a high-pass filter, only transmitting light frequencies above a certain threshold. Conversely, a mesh with an array of metallic squares behaves like a low-pass filter, only transmitting light frequencies below a certain threshold. Combining these two patterns, we can narrow the range of resonance frequencies for the FPI. [5] The metal patterns can be imprinted onto the silicon wafer by heating the metal to high temperatures in vacuum, and evaporating them onto the silicon wafer.

My project therefore consists of two main parts: fabricating etalons at the Cornell Nanofabrication Facility (CNF), and testing them in Cornell labs to measure their optical properties. My work in CNF will largely be a continuation of what I have been doing over the past two semesters; I will attend training sessions for new machines as necessary, and fabricate prototypes of the etalon until I can consistently produce the desired patterns. In particular, I will be using equipment for deep-ion etching to develop the ARCs, and thin-film deposition to pattern the metal meshes. Once I produce a successful prototype, I will take measurements using the Fourier Transform Spectrometers (FTS) to test for its light transmission properties. These FTSs are located in Professor Niemack’s lab, in the Physical Sciences Building, and in Professor Stacey’s lab in the Space Science Building.

The eventual goal of this project is to develop high efficiency silicon FPIs at wavelengths between 25 μm and 1.6 mm with a reliable and fine-tunable fabrication procedure. We plan to
implement the devices as early as Spring 2019 for the HIRMES project, and 2021 in CCAT-prime spectrometer.
Bibliography


