1 Introduction

Modern research into inflation and the first moments of our universe focuses studying the Cosmic Microwave Background (CMB). The CMB can be observed in the millimeter and sub-millimeter wavelengths and by probing the CMB we hope to learn about the properties of neutrinos and the potential existence of gravitational waves due to inflation. The McMahon lab works to answer these key questions by developing instrumentation that will detect faint signals from the cosmic dawn. They are working with the Simons Collaboration to develop and produce a new array of telescopes in the Atacama desert in Chile that will focus on measuring CMB radiation.

The Collaboration is currently in the process of designing and choosing what technology will be used in the new array, and consequently it is important for the proposed technology to be properly understood and characterized in order to enable the group to make an informed decision.

My time at the University of Michigan in the McMahon Lab has been spent developing apparatus that will enable them to fully characterize the proposed optics and understand the diffraction of light through out the system. This diffraction can be modeled on a simple level using simulations, however, with multiple optical parts in plate - and with multi layer filters it rapidly becomes incredibly computationally expensive and it so physically testing the diffraction pattern is much more efficient than modeling it. These characterizations will also allow us to account for the systematics, that have limited past observatories, ahead of time and effectively reduce the data analysis time.

2 The Beam Mapper

In order to measure the diffraction I designed and built a beam mapper. The mapper is a stand that can rotate in two axes meaning that when an optical tube is attached to the stand a detector placed in front of it can measure the varying diffraction pattern for different angles of incidence.

The stand had to be able to accommodate optical tubes of length 1 meter and diameter 0.5 meters as well as a larger, 1 meter cube, telescope. In both cases it needed to rotate the object through the largest possible angles with as little error as possible. The final issue, which proved to be the hardest to overcome, was that it needed to be able to hold the weight of both objects. In both cases final numbers weren’t available to me so I did not have weights to go off of. After discussing with my supervisor and the student designing the larger telescope, it was agreed that the stand needed to be able to handle up to 200 pounds.
The two figures above are drawings of the objects my stand needs to handle. To the left is a drawing of the telescope that will be built on a smaller scale, the green part of it represents the section my beam mapper will rotate and the cylindrically shaped part on the right hand side needs to be accounted for and allowed to protrude to one side of the stand. On the right hand side is a preliminary depiction of the Simons Observatory optical tubes.

The initial plan involved using a Velmex rotary stage to turn the whole structure while a linear stage would lift the end of the optical tube. While the linear stage functioned well, the rotary stage had a weight limit of 200 lbs which, given the weight of the materials and the weight of the test object, was far to low a limit. Overcoming this weight problem remained a major issue for the construction of the stand and I found it difficult to develop a way to rotate a structure of both the size and the weight of the one I needed to move.

The final solution was to employ a second linear stage as well as a turntable. The structure was placed on the turntable and the linear stage was then used to rotate the entire structure. The final structure was able to rotate through an angle of 88° and lift through an angle of 40°.

In order to construct the instrument I first drew up designs by hand and then made digital drawings of parts of the design in AutoCAD. The overall idea was to build a bracket that would be attached through bearings to two vertical support posts. These posts would attach to a base frame that would rotate above a second base frame. Bellow are photos of the process and final product.
Left: Parts used to assemble the rotating base are shown, including a metal plate, a frame made of T-slots and a turntable. Center: The assembled base that consists of one frame rotating above another, also shown are the edges of the two support beams. Right: Side view of one support beam, the beam has a turntable instead of a shaft and bearing so that the cylindrical part of the larger telescope can later fit through the turntable.

Left: a view of the cradle connected to the linear stage that will allow the cradle to be lifted. Center: Velmex controllers that are used to control the two BiSlides. Right: A view of the entire structure looking through the center towards the lifting linear stage.
3 Future Work

Going forward the lab will need to use the beam mapper I have built to characterize optical tubes for the Simons Observatory. I was unable to focus on this part of the project this summer as the optical tubes have yet to be constructed and I was constrained by time.

4 Acknowledgements

I would like to thank Professor Jeff McMahon, my supervisor, for his endless positivity and support. I would also like to thank the rest of the McMahon lab group, who helped me throughout the process by answering my endless questions about everything from how to order parts to how exactly the CMB is polarized. I would like to thank James Tice in the machine shop for his patience and help throughout the summer. I spent many long hours working in the shop and James helped me every step of the way - without him I doubt my stand would exist. Thank you to Myron Campbell, Jim Liu and Angela Germaine for making this program possible and for your support throughout. Finally, thank you to the National Science Foundation for funding this REU and making experiences like this possible.