1 Background

Spectra are one of the most important features of light sources into the universe. They give insight into information such as an object’s chemical composition or its radial velocity. Over the past few years, the UM Astronomy Dept has been operating a powerful spectroscopic facility on the Magellan/Clay 6.5m telescope in Chile named the Michigan/Magellan Fiber Systems (M2FS) [Mateo et al., 2012]. My REU work has consisted of three distinct subprojects that support this effort. The first project focused on the development of optical fibers for M2FS. This required operation of various devices to fabricate and polish fibers and fiber assemblies, as well as working out procedures for carrying out these tasks. The second aspect of the project was updating the programs used to prepare fiber plug plates for M2FS. Finally, the third part was to prepare an observational project to use M2FS in Aug 2018 to study globular clusters and field stars near the Galactic Center in the direction of Baade’s Window.

1.1 M2FS Optical Fibers

M2FS is a multiobject spectrograph in use at the Magellan/Clay telescope in Chile. The instrument can be divided into four parts, two of which were important for this project. MSPec, a pair of spectrographs that each take in 128 optical fibers, producing a total of 256 spectra. MFib, a mounting structure which is used to lock the fibers and equipment into place on the telescope. Part of this structure are plates which are drilled with holes to position the fibers on celestial sources [Mateo et al., 2012]. Each fiber assembly consists of two hypodermic sections that make up the end ferrules connected by a larger fiber protected by stainless steel tubing. The fiber ends must be polished to sub-optical wavelength smoothness. These new fibers were meant to provide a final set of spares that could last the remaining lifetime of the instrument.

1.2 M2FS Plate Programs

Two programs written in Python 2.7 are used to prepare plug plates for use on M2FS. The first program, plate_driller, produces a group of files which specifies where holes need to be drilled into the plates. The program reads data from files containing celestial coordinates of potential targets to be included on the plates. It then decides which targets can have corresponding holes drilled in the plates based on a variety of factors, such as required amounts of specific types (a minimum number of targets, for example) or user assigned priority. Multiple input files for different fields can be used to prepare a single plate in order to reduce the cost of plates and the time spent exchanging them during a night. The second program, fiber_assigner, determines the optimal route for the fibers to follow to reach the required holes for each assembly. The program assigns fibers along optimal paths and positions to best match the distribution of the fibers on M2FS. The paths are drawn using an algorithm that matches the efficiency and ordering that an experienced human user would adopt.

1.3 Baade’s Window Clusters

Baade’s Window is an area near the Galactic Center in the constellation Sagittarius [Baade, 1946]. The Galactic Center is believed to be the oldest part of our Galaxy. This makes it an interesting region to compare and contrast its evolution with that of the rest of the galaxy. For example, differences in chemical evolution, which can be observed using spectroscopy, are of particular note. The Galactic Center is home to not just Bulge stars but also Halo stars which are another interesting
target. Baade’s Window is notable for its comparatively low extinction, making it an ideal location to study stars near the Galactic Center. A recent release of Gaia [Collaboration et al., 2016] [Brown et al., 2018] proper motions provides an opportunity to study field stars associated with the Galactic Bulge and Halo in fields such as Baade’s Window. Two globular clusters, NGC6522 and NGC6528 are located within this region. These clusters are among the few near the Galactic Center that can be studied in detail and using spectroscopy the masses, dispersions, and metallicities of clusters can be found. Part of my work was to prepare for M2FS observations of these clusters and the interesting region near the Galactic Center.

2 Optical Fiber Assembly

Main construction of the optical fibers was handled by Dr. Mateo. Fiber were cleaned before being epoxied to the fiber ends, allowing a short length of cleaved fibers to protrude from the end ferrules. The end ferrules were just large enough to hold the fiber while keeping them centered. They also had thin enough walls that they could be closely packed together. Finally, the full fiber was fed through a larger steel tube for protection. Approximately 160 fibers (125 in. in length) were produced.

Using a custom-made polishing machine, I took these assemblies and, 16 at a time, proceeded with polishing of these fiber ends. Fiber ends were polished three times on successively finer films. Periodic inspections were done to ensure that the fibers were being properly polished. The machine used two belts to control the y and x movement. Eight fibers could be locked into an aluminum puck and two pucks could be used simultaneously. The fibers required the attachment of a plastic cap (to lock them into the puck), a spring (to ensure they remained pressed against the polishing films), and a rubber cap (to hold the springs and provide the preload of the fibers against the polishing paper). Each of these pieces had to be attached by hand. Additionally, once polishing was completed, they needed to be removed and attached to the other ends of the same fibers. Before beginning the process, the machine required repair to one of belts which was loose. Inserting an idler cog kept tension in the belt, preventing skips on the track. This was essential since the film platform needed to follow a precise path. A water tank and tracks were placed above the machine. The tracks were used to hold the fibers while the machine ran and the water fed into the pucks, cleaning out the grit as the polishing occurred. The machine controlled a platform on which a film could be placed. It then ran the film in a figure eight pattern. The pattern was just large enough that three passes could be done on a single sheet. The film could then be swapped out for a finer polishing film. Each group ran through a 5µm, a 1µm, and then a 0.3µm film. After the 5µm film, fibers were inspected to check for any issues. Possible problems included excessive glue on the end or strained springs, which would prevent high quality polishing. Once the quality of the first polishing was ensured, the subsequent films were used. Between each film the pucks had to be removed so that the platform could be repositioned and the films replaced. Proceeding through all three runs resulted in approximately thirty minutes of polishing. Once both sides of the fibers were complete, fibers were inspected once again for quality. If any issues were found, the fibers were put aside to be polished a second time in a final group at the end. Completed fibers
were carefully placed on a secure tray with their ends sealed within plastic tubes to protect them from damage.

After all the fibers were polished, fibers were graded based on their core flatness and surface roughness. Each of the 16 fibers in a set were labeled with paint pen markings. The first two colors corresponded to the group, with a mix of four more black or white marks which were a binary label. Additionally, one end of the fibers had a blue mark to signal that is was to be the side inserted into the spectrograph. Fibers were loaded into special carrying cases and shipped to a company for AR (anti-reflection) coating. They will return to Michigan in early August for final assembly.

3 Revision of M2FS Support Code

As a multi-object spectrograph, targets must correspond to a plug plate that has been drilled. Additionally, the fibers must be assigned to each hole while avoiding overlapping holes and ensuring efficient pluggability. The coding work of this project centered on adapting programs plateplanner.py and platemapper.py developed for M2FS by 2016 UM PhD recipient Jeb Bailey. These programs, written in Python 2.7 work well technically, but they are not intuitively easy to use for non-M2FS specialists. Also, they lack some features that would improve their operation and use.
I updated the codes to make it so the programs could easily be understood and used by new users.

3.1 Updates to plate_driller

Multiple new features were added to plate_driller (formerly plateplanner). This program used files containing target information in order to produce files which specifies where holes need to be drilled into the plug plates. Users were granted the ability to select multiple directories at a time. Additionally, the program no longer automatically scanned into subdirectories for field files. A clear button was implemented so that directory selection could quickly be changed without closing
the program. Plates can be named prior to saving the plate information (the name will appear within the saved plate image) and the ability to disable points besides the conflicts was also added. A highlight object feature allows users to enter a target ID and see its location highlighted on the plot. The information display in the bottom left was updated to provide information on more totals and specific information for each data set. Color coded labels were added that support up to 10 fields simultaneously.

![Figure 4: The original GUI for the plate_driller program.](image)

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![Figure 5: The new GUI for the plate_driller program. Various features have been added or improved.](image)

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Many improvements were made to the layout for popup windows in order to improve the readability. Previously, windows displayed too much information for it all to be visible without adjusting column widths and columns appeared in a randomized order each time. The contents of the columns were also changed in order to add more relevant information and remove extraneous material.
Figure 6: A window that appears when a hole in the program is clicked on in the original program. Data appears in a random order. Additionally, if two holes are nearby both of their data would be displayed in a horizontal arrangement that ran off screen rather than the vertical arrangement seen here.

Figure 7: The new window displays a more succinct set of parameters in a predetermined order. If two or more holes are in close proximity they are shown side by side in the same vertical fashion.

Figure 8: The original window displayed when selecting field files.

Figure 9: The updated field selection window fixes the widths of columns and adds new columns to the display.

3.2 Updates to fiber_assigner

The program fiber_assigner (formerly platemapper) determines the optimal route for the fibers to follow to reach the required holes for each assembly. Initially, fiber_assigner required a specific group of directories (some already containing files) to be in the starting directory in order to function. I added new commands so that users could specify the locations of these directories even if they were not with the program. I also added the ability to choose where files are saved to, rather than a default output directory in the same location. Warnings were implemented so that users would know only select up to two plate files at a time (plate files always came as an individual file or a two files corresponding to the two spectrographs within M2FS). Names within the program
and outside (i.e. the directory and file names) were changed to have clear meanings. Finally, a real-time display of the current directories selected (for purposes such as setup files location or output location) was implemented.

Figure 10: The original GUI for the fiber_assigner program.

4 Baade’s Window Survey

A recent release of the Gaia 2 dataset provided data on stars throughout the Milky Way, including those within Baade’s window [Collaboration et al., 2016] [Brown et al., 2018]. This data has far more precise astrometry than prior data of that region had, making it possible to identify viable candidates for the study with great ease. In order to study that area using M2FS, plates needed to be assembled. First, data on the stars within 14.65 arc minutes of 271.053, -30.0676 was extracted. This area matched the field of view of M2FS and contained two clusters, NGC6522 and NGC6528. In order to determine which stars were actually in the clusters (as opposed to Halo stars), the stars were first restricted to only those within 0.01 degrees of the clusters’ centers. Next, the proper motions for the selected stars were plotted. The group was narrowed down by selecting only those within a 1 milli-arcsecond (mas) per year radius of the center of the proper motion (which should be roughly equal for stars within the cluster). Following this, magnitude (Gmag<18) and parallax (Plx<0.5 mas) conditions were applied to restrict the data to viable targets. The proper motion (PM<1 mas/yr of the center) and distance (distance<0.0415 degrees) were applied. The initial, stricter distance requirement was loosened since it had only been necessary to ensure that the correct proper motion of the clusters was determined. This produced a set of ideal candidates
Figure 11: The updated GUI for the fiber_assigner program.

Figure 12: A plot of DE vs RA for all the stars within 14.65 arc minutes of 271.053, -30.0676 and with parallax less than 1 milli-arcseconds (corresponding to greater than 1 kpc away). NGC6522 and NGC6528 are both visible as the darker regions.

that were members of the clusters. Since there were so many, less stringent conditions were not necessary.
Figure 13: Stars within a 0.01 degree radius of the clusters’ centers were selected. This was the first step towards determining which stars were actually in the clusters.

Figure 14: The proper motions for stars that fell within the two regions of the clusters. As expected, the clusters exhibit different mean proper motions.
The DR2 data also provided the first opportunity to isolate Galactic Halo stars near the Galactic Center and so we developed a means of selecting candidate members from this component of the Galaxy. This was because Halo stars are normally only measured far from the galaxy (as they are easy to study there without the presence of Bulge stars). Thanks to DR2, we were able to isolate these Halo stars (primarily through their velocities). This will allow us to study this normally elusive group of stars in great detail. First, several restrictions were applied (Gmag<18, Plx<0.5 mas, Plx>1.5*Plx_error, 0<AG<1). Tangential velocities for these stars were plotted. A central region represented the movement of the Bulge (with the two clusters being smaller regions within) while the Halo stars ranged vastly in tangential velocity. Since it was possible for some of the Halo stars to be coincidentally within the central tangential velocity region, it would be incorrect to simply rule the region out. Rather, those outside of that region were given a higher priority than those within when sent to the plate assembly programs. This ensured that guaranteed Halo stars were included but that there were still some from within the central region. The stars that were grouped as the Bulge stars were required to have a tangential velocity within 75 km/s from the Bulge’s average tangential velocity in addition to the prior parameters. The reason we used tangential velocity rather than proper motion was because, in combination with the restriction on proper motion error, it became easier to identify the Halo stars from the Bulge stars.

Data from the three sets (NGC6522, NGC6528, and the Halo stars) was used to create three text files. These files were formatted in a fashion that they could be read by the plate_driller program. In addition to targets, a Shack-Hartmann star was identified at 271.053, -30.0676 (with Gmag=9.3812 and AG=1.014), guide stars (with 11< Gmag<12.25 and sqrt(square(pmRA)+square(pmDE))<2 mas/yr) and alignment stars (with 12.25< Gmag<13 and sqrt(square(pmRA)+square(pmDE))<2 mas/yr), and sky holes (locations where there were no stars within 4 arcseconds, identified via a program (Note for this we used a field without any parallax restrictions in order to account for foreground stars as well)). With all of these, the plate_driller program was able to produce a plate containing the holes for these three sets (as well as a few others which fit on the plate). Finally, the plate was drilled.

This August I will be travelling down to the Magellan/Clay telescope in order to assist with the operation of M2FS and participate in the observation of these targets. In the future, will analyze the clusters’ metallicities, masses, and dispersions.
Figure 16: The velocity plot for all of the possible Halo stars. Those outside of the condensed region were given a higher priority by the plate assembly program. The condensed region represents a radius of 75 km/s around the Bulge’s average velocity.

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References


Figure 17: A plot of all candidate locations sent to the drilling program. Certain groups, like the alignment stars, were necessary for M2FS to run while other groups, like NGC6522, were the targets. Sky hole locations were not included in this plot.