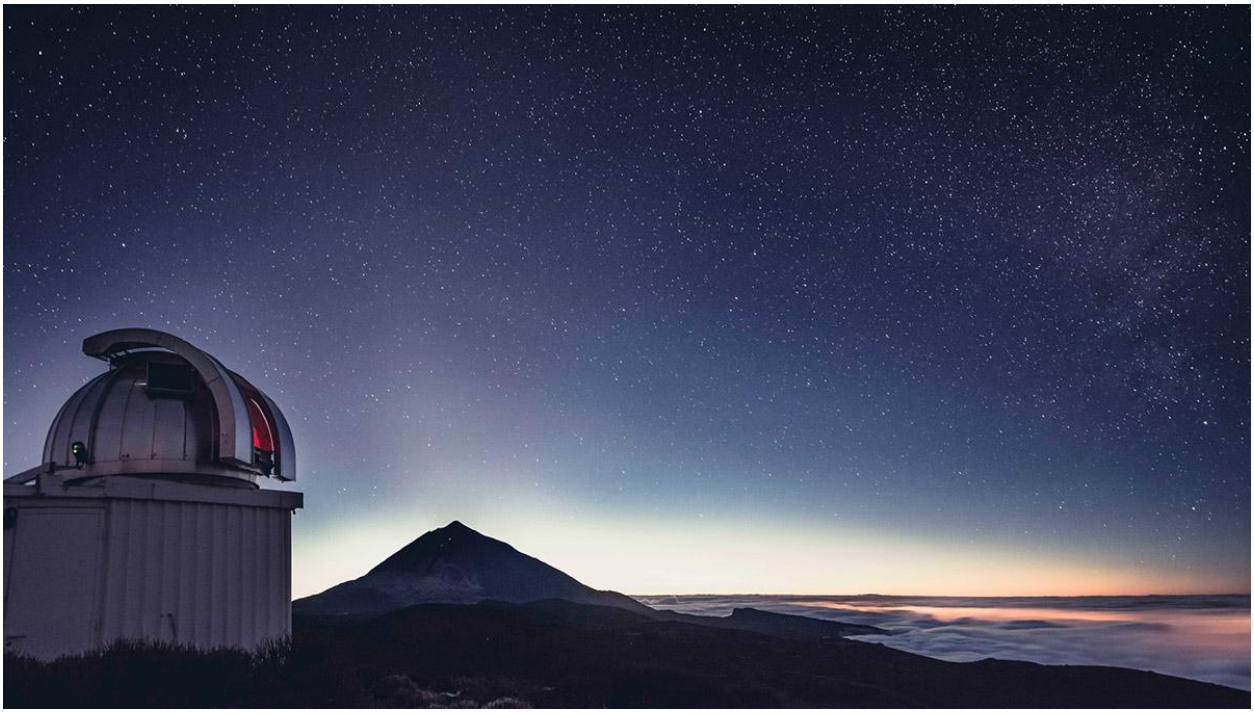

Building an 8" Reflector Telescope

A project by Ander Crespo Bereciartua 22’

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Introduction to the Project

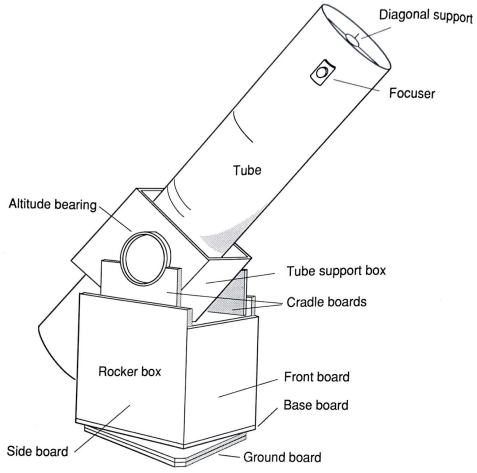
Motivation and overview

To begin with, let's offer some background: I am an exchange student from Spain and Spain has particularly strict credit requirements in place for students taking part in an exchange program. to obtain credits . The first challenge was that I needed to take at least 3 subjects from these specific blocks to follow a path so I'm able to have enough credits for college. I chose the "Technological sciences" block, which meant I needed to take Math, Environmental Science and Physics. I have always been interested in physics and, because I took Advanced Physics last year, I realized I could do my senior project based on a physics subject and just name it an independent physics program to obtain the credits.

With that out of the way, it was time to hone in on a project. I have always had the idea of doing a year-long project in any subject I liked. This was an opportunity I looked forward to since little. I would always watch hour-long videos of people making guitars and various different projects, learning how to do a project, the inconveniences, the errors, the thought process, wishing that I could make one in the future. But interestingly, when I met with Mr. Almeida, my advisor, I actually had no specific idea in mind. I considered doing some kind of difficult research project just to see how far I could push my math, physics etc. knowledge but I quickly realized that, if I had no idea what to do, finding something to just research was going to be boring and difficult. So Mr. Almeida sat me down and asked me, "I know you like physics, but what kind of physics?" to which I responded, "Astronomy". he said "Build a telescope then" and then I thought it was going to be too difficult because I had already done some research on telescopes prior. Then I rethought about it and about all the abilities that I could gather for the

future, as I'm thinking about doing an engineering major, and the fact that this was also a great opportunity to push my limits in physics and math, which was what I was also looking for.

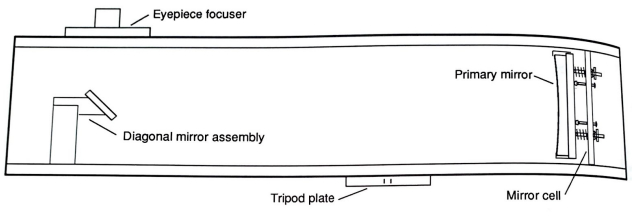
So it was established, I was going to build a telescope for my senior project. We also talked about doing some astrophotography with the telescope and doing some observation nights at the academy.



The Dobsonian telescope

I went to the library in the school and, serendipitously, I found a book about building telescopes with 6 fully-documented projects. Reading the book to obtain a sense of scope of the project at hand, I realized that I realized that making a reflector (a telescope that uses mirrors) rather than a refractor (a telescope that uses clear lenses) was going to be much easier, as it only consisted of 2 mirrors and an easier mechanism.

So I had decided what I would make. I would make an 8" diameter dobsonian telescope. This meant that the size of the main mirror would be 8", which gathers more light than a 6" or a 4" one, and it would have a dobsonian mechanism, meaning that it would have two separate parts: a tube and a rocker box that would be under the tube and it serve as a mechanism. [1]



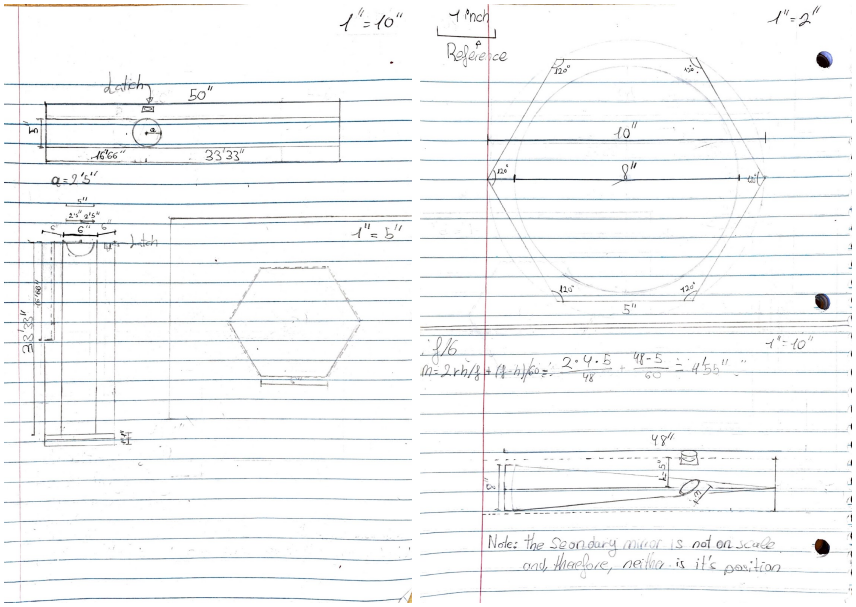
[1] The lower image in this page is the anatomy of a newtonian/dobsonian telescope.

1. Building the telescope

1.1 Design

1.1.1 First design

As soon as I got the idea to build the telescope I decided to make a scaled design so I could solve some problems before I had them. One of the main goals I considered was a desire for portability by making the telescope collapsible. So, I came up with an idea that looked like this:



The idea was that the tube would fit into the rocker box thereby making it portable. It would be made out of wood and, as you can see, composed of two hexagonal tubes, which are much stronger than other shapes. I ended up discarding this design, after my mentor suggested me to do so as it was going to be too heavy and big to be able to make it effectively transportable

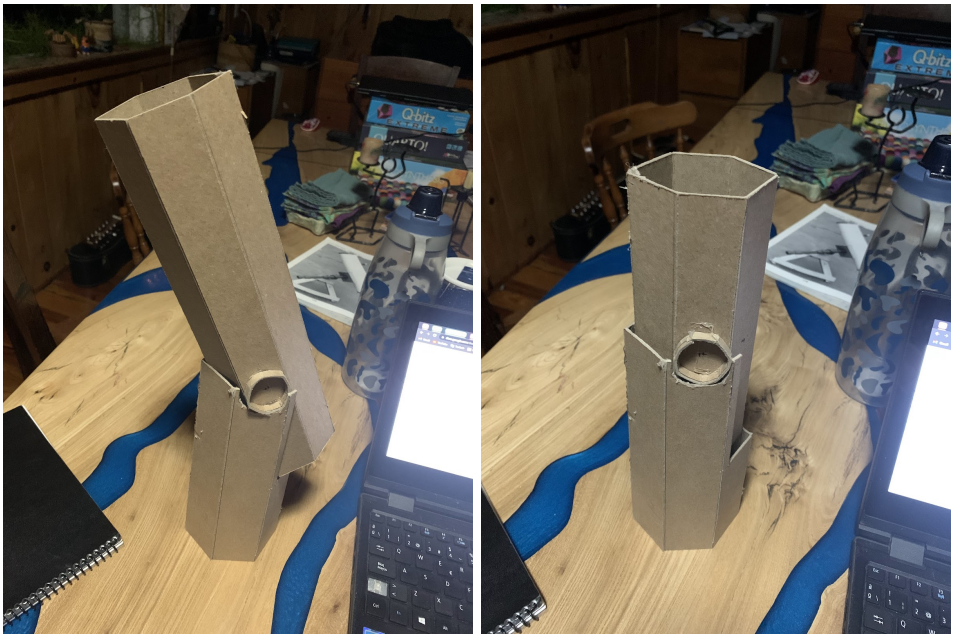


Figure 1: This is a model that I did out of cardboard to see how the body could look

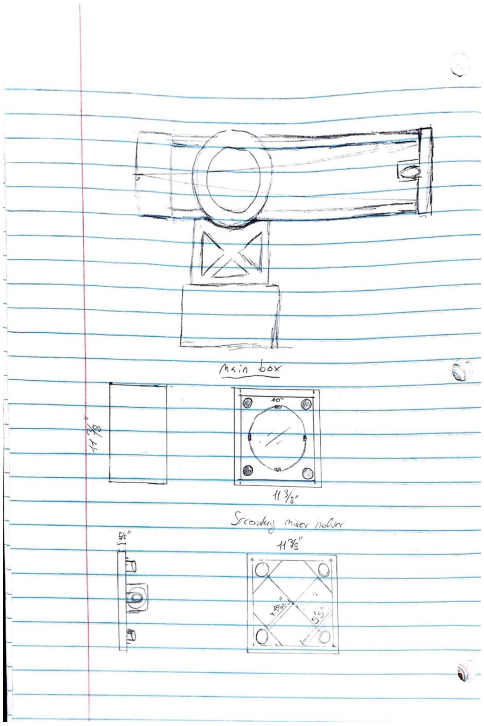
1.1.2 Second Design

Now keeping in mind that the new design had to be light, compactable and easy to make, I started researching designs that could follow those requirements. My mentor gave me a couple of examples and I came across a design by Gary Seronik. He made an 8” travelscope, just as I wanted to make, and he made a 2.0 version that fixed a lot of the problems that the first version had, so I learned from that too. The main ones being, an error in the balance point, more rigid tube and weight.

This second design consisted of two separate wooden pieces connected by 4 PVC tubes and ropes to reinforce the tube as well as a much lighter rocker box that was smaller and compactable. It was going to rotate over two circular pieces of wood that would be attached to the sides by screwing them to the tubes, this would also give the entire apparatus more strength. The 4 tubes would be subdivided in 8 and connected between themselves with connectors in the

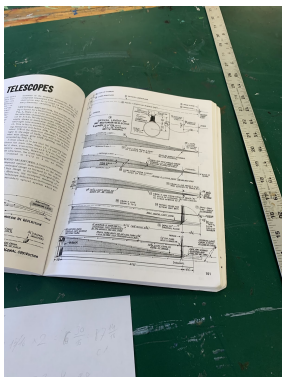
middle, and dowels with electrical tape on the lower and upper parts that would go in the inside of the tubes.

Here is an image of the design to make it more clear:

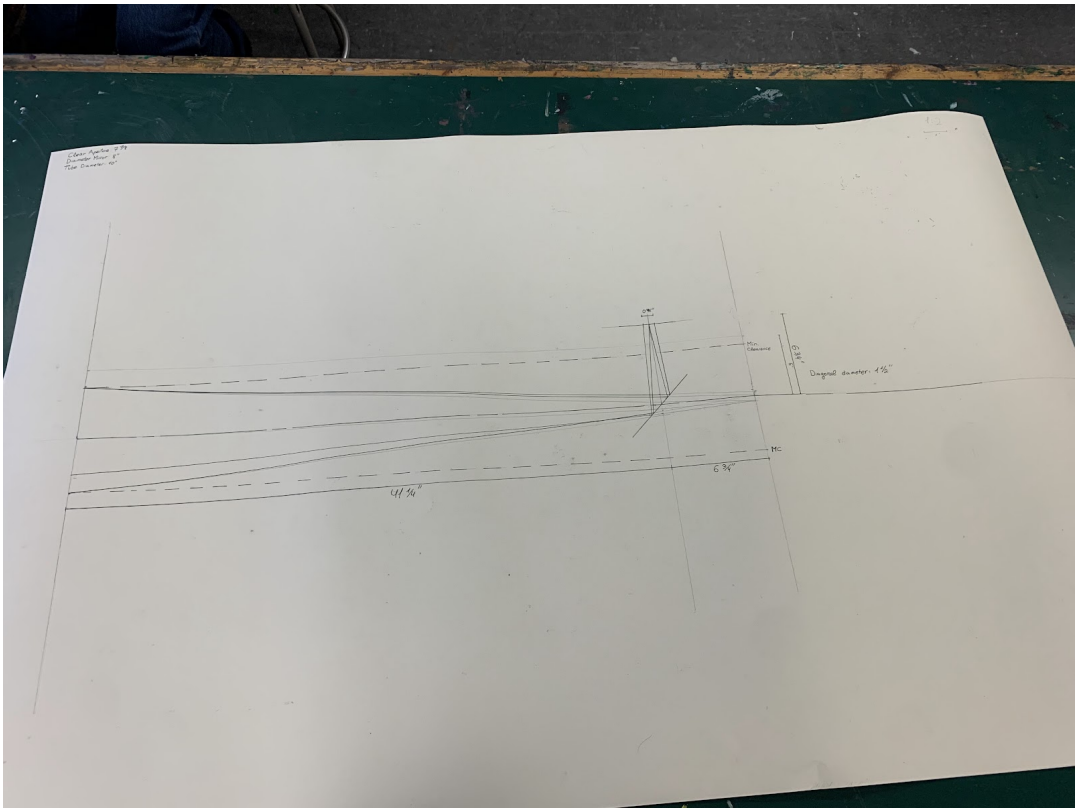


1.1.3 Layout of my telescope

Once I was in a more advanced stage of my project and because COVID-19 made the mirror making classes impossible, my mentor recommended that I should make a layout of what the lightrays do when they travel through my telescope so I would be able to obtain certain measurements. It was going to be a 1:2 scaled drawing, meaning that it was half the size of the real tube.



I followed the instructions from a book that my mentor gave me and thanks to Rafael Kelman, who was really helpful in this process, I was able to complete the drawing.



This drawing was really helpful to know how small I could make the tube, where I should put the focuser, how long the tubes had to be, how big the secondary mirror had to be and overall to also have more clear how the telescope works.

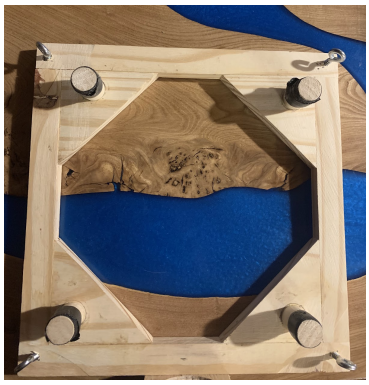
1.2 Building the Body

Starting to build the body I had no idea how things were going to turn out. The initial building of the body was highly experimental. I started building parts little by little without a clear goal till the project as a whole made more sense.

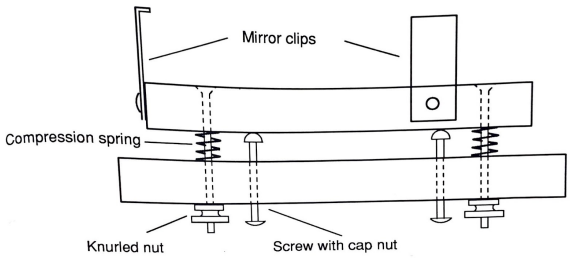
1.2.1 The Tube

I started with the tube. The main parts of the tube were the mirror holder and the secondary mirror space.

Fortunately the secondary mirror space wasn't so difficult, as it was just a 10×10" square in the inside, with some triangular pieces for reinforcement and the dowels. The tricky part was how much in the triangles could go in because there is a maximum radius where the light rays striking the mirror enter the tube from a little farther than 8" and, to make the telescope gather as much light as possible, you don't want to stop those rays from entering the tube. So I had to run some calculations on that and, serving myself with the measurements from the layout, I ended up calculating that they could go 2 ⅝". Then I added the dowels on the triangles, some hooks for rope to go through and, finally; the focuser[2], screwed to a piece of wood with a hole the same size; the finder[3]; by screwing the shoe of it to one of the sides; and the secondary mirror or diagonal holder[4], screwed to a 1" block of wood screwed to a bent ruler screwed to the inside of the top square.



To make the mirror holder I followed the instructions from the book I found in the library. It had detailed instructions on how to make it in an easy way. First I cut two 8" circles and a 11⅜" x 11⅜" square. I cut an 8" circle inside the square and added the dowels on the



[2] The focuser is a moving part used to focus the image by moving in or out the eyepiece.
[3] The finder is a low magnification scope used to locate and point at the object desired to watch.
[4] It's what holds the secondary mirror. It normally has 3 bolts that helps adjust the level of the secondary mirror so you can align it with the primary one.

sides. To make the mirror holder, I drill 3 holes at 120° of each other in both discs and through then I put 3” flushed screws. I would pass the screws through some stiff springs, one on each screw, and put the spring between the two discs and, at the end of the screws, pass some nuts. The reason behind all this is that the springs will make force against the two discs allowing you to level the mirror holder by screwing or unscrewing the nuts. This is helpful for collimation.[5] I then added the supporting components of the mirror. I made three L-shaped pieces by attaching two 2”× 1½” hardwood pieces perpendicular to each other. At the end of those pieces I added a little piece of wood screwed to the top to be able to rotate and just get a little inside so they could fasten and support the mirror and. I then attached them under the top disc again at 120º off of each other. Finally, I added some hardwood pieces under the bottom disc just so I could attach the holder to the main square.

I didn’t really know until recently how long the length of the tubes was supposed to be because I didn’t know the exact focal length[6] of the mirror. Once I knew that – 59” – , I subtracted 7” corresponding to the distance between the eyepiece and the secondary mirror and I ended up with 55” tubes, with the additional three inches coming from the height at which the mirror was -3”. I just put them on the dowels and I surrounded the dowels with electrical tape till there was

[5] Collimation is the act of aligning the two mirrors so the image is centered at the focuser and therefore be able to focus the image.

[6] The focal length is the length at which the mirror makes an image. This depends on the curvature of the mirror and the radius of it. In my example my mirror had a sagitta (depth of the radius of the mirror) of 0.0681”. This means that the focal ratio (focal length divided by the diameter of the mirror) is f/7.37 and this number times the diameter of the mirror equals the focal length.

enough friction for the tubes to stay in place but also lose enough to be able to take the tubes off without breaking the dowels.

Now if I assembled everything together it would look something like this:

Figure 2: This is a previous version: I decided to take the lower box out; the finder, secondary mirror etc. are not there; the tubes are not divided in 2 and more

1.2.2 The Rocker box

The rocker box was simple to construct but challenging to initially figure out. First I needed to find the balance point of the tube to know the height of the rocker box, as it has to be a little taller than the tubes' lower part so the tube can rotate in and therefore be able to look straight up. To figure out the balance point I put the whole tube (mirror included) on top of a spare

PVC tube I had and put it in between two chairs. Then I moved the tube back and forth till it more or less stayed balanced over the tube. Using this method, I determine the balance point to be about 17" starting from the bottom

Once I knew that I could work on the design of the rocker box itself. Because the balance point was in such an upper position, I realized that I wouldn't be able to collapse the telescope all into a box to make it portable if I just put two pieces of wood over what the telescope would rotate over. So then I realized that I could cut the pieces in half and match them with some metal plates. The top pieces would be smaller than the bottom ones because, by doing so, I could use them to make them the lasting sides of the box. So then I did so: cut all the pieces, glue and nail the bottom ones and finally put the metal plates matching both of the pieces. The outcome was pretty bad. First, the sides were really unstable and wiggly, and second, the distance between the two pieces was too thick – the moving parts of the tube were not matching with the sides. But then I found an easy solution: screw the top pieces to the bottom pieces from the inside. And so I did, and it turned out great.

So now that I had figured out how the whole thing was going to be mounted, I started working on the mechanical parts. These basically consisted of two wooden rings that would be attached to the sides of the tube with the center on that 17" measurement, half covered with a Formica™ strip and some Teflon blocks over which the Formica™ would slide[7]. We went to the store to buy both, a Formica™ stripe and a teflon block, but apparently those are not common things to find around. Formica™ normally comes in big sheets that cost around $80, which was not suitable for the little amount that I was going to need, and teflon is not usually found in a block (The teflon block was recommended by the book I took from the

[7] These are the optimal materials due to the low friction resistance that they offer because they are both hard slippery plastics. But when the weight is put on them, there is enough friction to maintain their position.

library). But looking around the internet we found that some chair sliders, the ones that are made out of hard plastic, are actually made out of teflon so that made it easy. And my host dad had the brilliant idea of just taking free samples of formica at Home Depot. Now having all the materials, I made 10” diameter wooden rings with a jigsaw and cut the middle just to make them lighter and I just added the formica in stripes to the rings with contact concrete. Then I made a slight circle hole on the top of the top piece of wood and then nailed the teflon slides to it so the rings can slide over them.

Now to the X-axis rotational part. This was much more simple. It basically consists of a ground board the same size as the lower bottom board of the telescope with a ½” bolt going through both of them and putting a ring and a nut on top of both of the boards. In between the boards we find the same mechanism, Formica™ glued with contact concrete to the lower part of the bottom board and a circle of teflon chair sliders nailed to the top of the ground board. Apart from that it was just having to grind down the top of the bolt to flush it to the wood so the whole thing can rest flat.

1.2.3 Mounting everything

I tried to make the assembly of everything as simple as possible. Let’s start from the bottom and go all the way up to the top.

First, we have the ground box, this is screwed with the ½” bolt to the bottom board of the rocker box.

This bottom box has the bottom side boards screwed and glued. Now screw the upper side boards to the inside of the bottom side boards.

Now with the tube. First match the bottom part to the top part with the tubes, remember to have the holes for the rings on the bottom and closer to the connectors.

Then, add the rings to the sides with the Formica™ facing down and to the lower part of the tube.

Put the rope through all the eye-hooks forming big triangles from the top to the bottom.

Then just add the finder with a screw and put the whole tube on top of the rocker box.

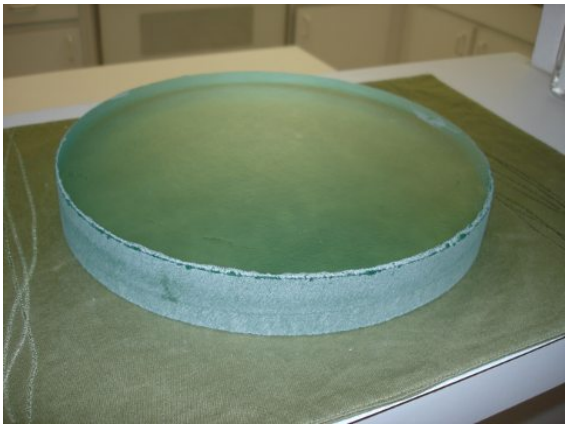
Then just add the mirror And now you should be all set to watch the stars!


2. Making the mirror

Most of the things that I have learned about mirror making are from the mirror making classes at Stellafane. Stellafane is a club of telescope making experts that come together to teach new telescope makers about telescope building and everything about it. They offer a class every month in Springfield VT.

2.1 The blank and tools

The mirror blank is a pyrex cristal flat circle about 1½” thick.



The grinding tool is a circular piece of wood the same size as the mirror. Glued to it with epoxy are hexagonal tiles covering the surfaces while also leaving some spaces.

With the grinding tool is used a grit powder from different grit sizes. The grit size numbers come from how many particles of those grit sizes can be stacked in an inch. For example: if I'm using a #60 grit size, that means that you can stack 60 pieces of grit particles on next to each other in one inch. The higher the grit size number, the less abrasive it is.

2.2 Making the mirror

There are 4 main parts to making a mirror (apart from putting the silver coat on which is done in a lab): Rough grinding, fine grinding, polishing and figuring.

2.2.1 Grinding

2.2.1.1 Rough Grinding

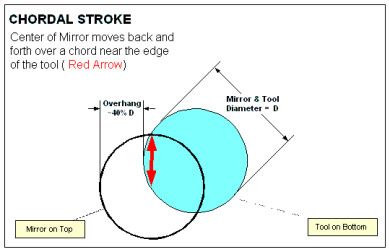
This grinding phase is called rough grinding because you use abrasive grits to grind off the mirror to a certain sagitta[8]. I started with a #80 grit size. The objective of this phase is to make the mirror concave.

Before I started grinding I needed to make sure that my mirror had a bevel[9] on the outside. This is important, because with a good bevel, the mirror is a lot less prone to chip on the outside while grinding.

Once I had the bevel I would prepare the space where I was going to grind. This space needs to be a fairly tall table around which you can move, this is necessary because all of the movements involve moving around the table in what is called “walking around the barrel”. I would cover the table with wet newspapers in order to catch all the particles that came out of the grinding tool.

[8] Term used to talk about the depth of the curvature of the mirror.
[9] The bevel of a mirror is an edge that has been grinded off normally with a wet stone in a 45º angle, making the edges round instead of sharp.

Once everything was ready, I would add the grit powder on the tool and then wet it with a spray bottle full of water. Then wet the mirror and carefully put it on top of the tool. Now the grinding began. To wear down the middle of the mirror more than the top and therefore make a concave mirror, the idea is to put the mirror on top of the tool slided a little to the outside, about an inch or inch and a half. Then start doing a back and forth movement while also rotating the mirror and walk around the table applying some pressure on top of the mirror. Initially the sound of the grinding was loud, then it would quiet down. This happened because the grit would start to break down into smaller pieces and stop being so abrasive. If the grinding gets quieter, the idea is to clean the tool and the mirror from all the mud (a mixture of water and broken grit powder) that started formatting by dumping it in a bucket full of water and keep adding more grit with water. This would have to be done till the sagitta was the one desired. For me it was 0.083" for the focal ratio[10] to be f/6. The ways to measure this sagitta were various but I mainly used two. First one is with a sagitta measuring tool, like the one on the bottom left corner. The second way is to water the surface of your mirror, put it against the sun and then focusing the ray that is reflected off of it into the smallest point possible, that would be were the image is being formed and therefore the focal length, if you divide that by the diameter of your mirror (8" in my case) you would get your focal ratio. For me the focal length would have to be 48" for me to have an f/6 mirror, which is what I was aiming for.



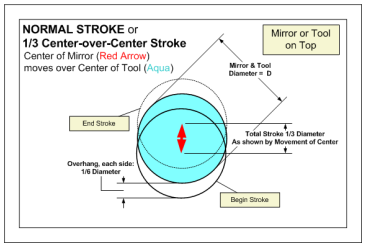
[10] The focal ratio is the relationship between the focal length of the mirror and its diameter. It is obtained dividing the focal length over the diameter of the mirror and is normally show as f/# (f/8, f/7, f/6 etc.). A lower focal ratio means that the curvature of the mirror is higher and the focal length shorter.

So once I started getting closer to that sagitta measurement, I changed the grit size to #180. It is reeeaaally important to clean all parts included in the process really really well every time you change grit sizes. I would change all the newspapers, change the water from the bucket and clean really really well the tool and everything that was going to be in contact with the mirror from every residue of the mud that was there, some people even change their clothes. If these measures weren't taken, some pieces from the broken down grit could make scratches in the mirror. The reason behind changing grits was because it would give me more control over how much crystal I was grinding off, and because it would put me closer to starting fine grinding. Then, once I got the desired sagitta I changed to fine grinding. I think that the whole process took me about 8-10 hours of grinding, in addition to all the setting up and cleaning up.

2.2.1.2 Fine grinding

Fine grinding is the process of making the surface of the mirror smoother by using smaller grit sizes each time. The sequence of grit sizes varies depending on the person but the one I used was: #220, 40 micron[11], 32 micron, 25 micron, 15 micron, 12 micron, 9 micron and 5 micron.

This time the stroke changed. Now I would use what is called a "normal stroke", that just consists of putting the mirror on top and just sliding it back and forth without the mirror being uncentered, meaning that it is centered. This movement has to be complemented again with walking around the barrel. Again you would clean off the mud and the mirror every once in a while and just keep adding more grit. This process would take around



[11] The micron measurement is another way of measuring grit sizes. It is normally used when the grit sizes start getting smaller.

2-3h per grit size. Also, normally, people would change between having the mirror and or tool on top. The mirror on top technique makes the sagitta longer and therefore the focal length shorter, and the tool on top technique makes the sagitta shorter and therefore the focal length longer. I realized that my focal length was actually a lot longer than I measured before, I don't know why still nowadays. So I did this whole process with the mirror on top trying to make the focal length shorter. I wasn't extremely worried about that because my telescope's length is adjustable, I can change the length of my telescope however I needed to (between some limits because of the size that the secondary mirror had to be and other factors) by changing the length of the tubes.

The crucial moment of this phase is to know when to change grits. To know this information you could either just grind a bunch of time and just hope that this last grit cleared up all the mess[12] that the last one made or stick to the science and actually see and measure if the work with the last grit is done. To do that the main technique is to take a magnifying glass and search for pits in the surface of your mirror. I would dry the surface of the mirror and put it against a source of light, because the pits would reflect the light off and therefore show up. I didn't have a magnifying glass but I did have a low power eyepiece that, used the other way around, serves as a magnifying glass. Here is a photo of a pit:

[12] When grinding, what actually happens, is that all the little grit particles make miniscule controlled chips. The idea is that you start with a rougher grit that makes bigger chips and then you pass to a smaller one that makes smaller chips around the area where the bigger grit has made bigger chips. The final goal is to have the whole surface of the mirror with chips the size of the last grit used, without exceptions. And continue this process with all the grits.

If I checked the whole surface and there were no pits, I would change grit sizes, again being super careful and changing and cleaning everything.

I just continued following this process till I was done with the 5 micron grit. That took me around 20h of grinding. Now it was time for polishing.

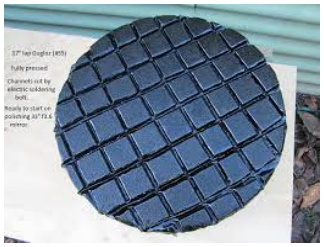
2.2.2 Polishing

2.2.2.1 Pouring a lap

To pour a lap is the act of making a polisher for your mirror. Each polisher has to be made unique for each mirror, as it has to adapt perfectly to the surface of the mirror. First, I heated up the pitch (a petroleum-derived solid that adapts its shape when force is applied and gets more malleable with heat) so that it was liquid.

Then I prepared the base of my polisher by making a dam around the base with tape so I could pour the liquid without it getting out. Then I waited till it cool off a little (then for some reason some bubbles appear but that's not supposed to happen, anyways we fixed it) and then David Kelly, who I was working with at the moment, took some polishing compound, put it on his hands, and he pushed a little the pitch to the inside so there was more material on the middle. Now the important moment comes. We heat up the polisher a little, just so it could change its shape easily and put the mirror in warm water. Then take the mirror, put

some polisher compound on it, and we pressed the surface against the polisher so the polisher adapted its surface exactly like the mirror. Then it was time to trim the edges that came out of the circumference and trim the channels of which the polishing compound could get out of. We did this by trimming with a razor blade in parallel lines and then perpendicularly. Then we trimmed subchannels in between the squares that were made. The result was something like this:



2.2.2.2 Polishing

For polishing the stroke changes again but is pretty simple. It is basically the same as the normal stroke but, instead of going the same distance back and forth, this time the mirror goes a longer distance forward than backwards. This is complemented by rotating the mirror and walking around the polisher again. This time instead of using grits, polishing compound is used. Every once in a while the polisher had to be cleaned with a brush and heated up and pressed again so it maintained good contact with the mirror. Also, because the pitch is such a changing material, nothing can be left on top, not even a piece of paper or the polisher will adapt that shape and totally ruin the contact.

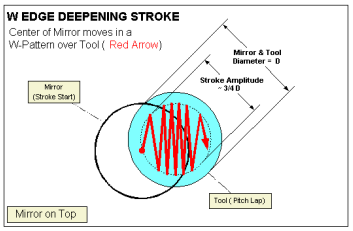
I polished for about 8h and probably around 7h with a machine so by hand it would have taken a lot more time, probably around +20h for sure.

To check if the mirror was polished out I pointed it with a laser pointer, if the laser didn't show up on the surface of the mirror, the mirror was polished, if not, still more work to do.

So now that the mirror was polished, it was time for figuring.

2.2.3 Figuring

Figuring a phase of mirror making that consists of giving an inside paraboloid shape to the mirror instead of a spherical one, which is what normally happens when doing the previous steps. The way I had to correct my shape was to first undercorrect it. I had an overcorrected surface and before I needed to get my mirror back to having a spherical shape. For this, I made the shape of my polisher different first. I added a 4" square paper on the center of the polisher and then I pressed the mirror against the polisher with the piece of paper in the middle. This would allow me to undercorrect the mirror because the polisher would have the shape of the mirror but with a lower center, then, the mirror would have less contact in the center and could adapt a spherical shape by continuing with the polishing stroke. After the mirror took a spherical shape, it was time to correct it. To acquire the desired shape I pressed the mirror against the polisher to get back the same shape as the mirror again. Then I started correcting the mirror by doing what is called "the W stroke". This movement is characterized by short strokes on the edges of the mirror and long strokes in the middle. Also, pressure had to be applied with the thumb that was on the edge of the polisher, just a slight pressure. The mirror had to be tested every little to avoid overcorrecting it.

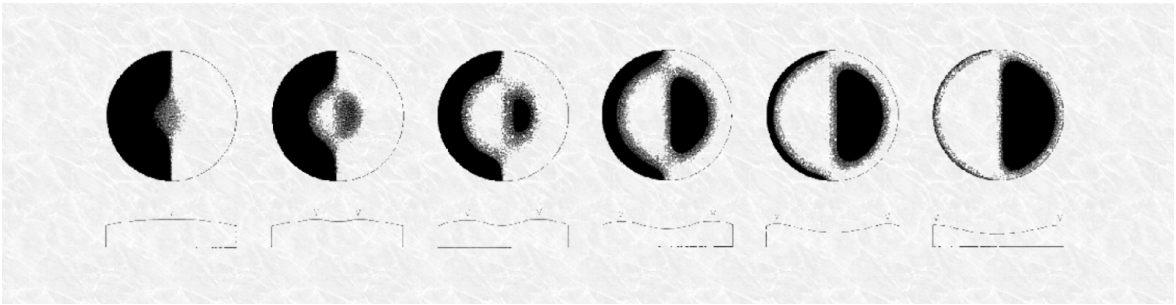


2.2.3.1 Testing

Testing the shape of the mirror was probably the hardest thing for me to understand about this whole project and I still don't fully understand it. The testing process is called the "knife-edge testing". It consists of a light next to a really thin sharp edge that is projected onto the mirror that

is set at a distance equal to the focal length of the mirror. The light gets then reflected off the mirror and then travels to a flat mirror that is surrounding the knife edge. Then it gets reflected back to the mirror and back to the knife edge, where the image is formed. This back and forth reflecting amplifies the image and shows the shape of the mirror clearly.

By moving the knife back and forth you would be able to focus the image and by moving it sideways some shadows appear that is what actually tells you the shape of the mirror. What we are aiming for is the image all the way to the right. I started with an image more or less like the third one and I needed to figure the mirror all the way to the last image. Once I reached this point, the mirror was prepared for coating.



2.2.4 Coating

While amateur telescope makers can coat their own mirrors, not many people do it nowadays. The process involves dangerous chemicals and the result of doing it at home is not nearly as durable as the result from a lab. So that's what I did. I sent the mirror to Optic Wave labs in California where they would coat my mirror for $113 with an enhanced coating, which is a pretty reasonable price. The problem came when they actually got the mirror. They sent me an email telling me that they were running late so my mirror would take 1 to 2 months till they send it

back to me. This means that it won't arrive on time for the exhibition or the project due date. Because of this I'm going to work on a website that I will upload with a QR code at the end of this booklet where I'm going to add upgrades I will make to the telescope, some astrophotography and pictures of the finished mirror.

3. Journal

This is my senior project diary, where I will be talking about my point of view, challenges and successes throughout the process of the project.

Sep 1, 2021

I've been talking with Mr. Almeida and, thanks to him, we end up with a pretty solid idea for the senior project. The idea consists in researching how to use a telescope, doing astrophotography, sharing this knowledge with the academy community and, finally, building a telescope.
For now, I got the permission to use a telescope from the school and Mr. Almeida handed me a previous senior project based on astrophotography made by an ex-student called Eva Gray. I'm going to focus on learning how to use the telescope for now.

Sep 6, 2021

I took the telescope home and I found out that the telescope's mirrors are in really bad condition. They are full of dirt. Without cleaning them the telescope is useless. Also the oculars are missing and the battery holder for the TeleStar™ system, a system that motorizes the telescope to guide you automatically towards an specific stellar object, is broken too. I think I might be able to find the oculars from the telescope in the school's attic.

Sep 7, 2021

I cleaned the mirrors and I looked for the first time (without an ocular)! I woke up at 4am and, because I couldn't sleep, I tried to look through the telescope, even though I didn't have an ocular to look through. I pointed to betelgeuse, one of Orion's brightest stars.

Sep 8, 2021

I looked in the attic for oculars and I found them. I got 2 oculars, one with a diameter of 9mm and another one of 25mm. The 9mm one will help me to look at deep sky objects and the 25mm gives me a wider point of view which could be helpful for more near objects like the moon or to look at more spread objects like globular clusters. Unfortunately I cannot try them because it's cloudy

Sep 12, 2021

I looked with the oculars for the first time! I pointed to Jupiter, which casually is really bright these days. I got a somewhat clear view of the lines that surround Jupiter. I realized that I need to clean the oculars. Here is a video of Jupiter through the telescope:

Sep 22, 2021

Meeting with Almeida:

- What manipulatives (sky map) are going to be helpful to communicate my project
- What *stories* are going to be helpful to communicate my project (M38, for example)

Sep 29, 2021

I met with Almeida and we revised the senior project proposal and the email for my future mentor. After the meeting, I sent the email and both of the mentors that I emailed to couldn't help me but one of them handed me another astronomer's email. This person is a retired astronomy professor, expert telescope builder and amateur astronomer; so he would probably be one of the best mentors to help me out.

Oct 8, 2021

I have a mentor!! The person I talked about in the previous entry accepted to mentor me. We will be meeting over zoom sometime on wednesday or thursday to see how much knowledge I already have and to see what would be the best approach to the project. His name is Douglas Arion and I found out that he started an association to make astronomy affordable at the best quality possible. He will be extremely helpful because of his broad knowledge of telescope making.

Oct 13, 2021

I met with Doug today!! He really helped me to figure things out, now I know what I'm going to build and in what times. I'm going to build a 6-8" Dobsonian telescope with mirrors grinded by myself.
He told me that the telescope that I have needs adjustment and I could go to a Stellafane meeting to fix it. In Stellafane, I'm going to be able to see people starting to grind their mirrors and, therefore, I could start my owns.
Doug also helped me to focus on what I want to talk about in the community outreach talks. I'm going to talk about certain constellations, planets, galaxies and nebulosas but I'm also going to talk about light pollution and how it is a big problem in the contemporanean society.
I'm going to email kshustock@gmail.com to get information about grinding mirrors.

Oct 23, 2021

I emailed the Stellafane mirror class and they are going to help me throughout the process of making the mirrors and they are going to facilitate a mirror making kit. They also told me they could help with the problems I have about the telescope.

About the community outreach part, once I get the telescope fixed, I thought I could give a talk about the zodiacal signs and constellations more related towards astronomy to get people interested in my project.

Oct 28, 2021

Today I went to the astronomy convention in Smith college. I saw Jupiter, and 3 of its moons; Saturn and a dead red giant. This really helped me to realize how my telescope should be looking, more or less, and to know how well my work is going in comparison to professional equipment. I realized that what I was looking at made no sense because my telescope has problems that need to be fixed. But now I know what I should be looking for for my future goals.

Nov 6, 2021

I went to the Stellafane telescope making class and started to make my own mirror!! I met incredible people that were really helpful and passionate about what they were doing. They taught me how to start

the parabolic shape in the mirror and how to keep the mirror safe. They gave me a tool to measure the depth of my mirror. It's actually a much simpler process than I thought it would be, I can even continue at home easily! This is definitely going to be a big part of my senior project timewise, because it takes a lot, but it's definitely going to be such a great part of it!

Some of the teachers also helped me collimating (adjusting) my telescope. I tried to do it in the past but I was always collimating the primary mirror and not the secondary one when, what the telescope actually needed, was to collimate the secondary mirror. This will be really useful in the future.

Nov 10, 2021

Today I went out to observe and had the greatest of experiences!! I first aimed at what I thought was Venus and then I saw 4 little bright dots in a line around it and then realized I was looking at Jupiter!! I was able to see the brownish stripe that Jupiter has and, what most amazed me, 4 moons!! The fact that such little, astronomically talking, objects are visible in such a clear way from here was something that completely astonished me.

After that I went home and realized that there was a night sky map in the house. I looked it for a while and realized that Andromeda, the closest galaxy, is just at the right of Cassiopeia, a constellation that I know really well and can identify almost always that I look at the night sky. So I decided to take the telescope out once again, and I'm really glad I did. It took me a while to find Andromeda, mainly because I didn't know the constellation with the same name, so I couldn't guide myself really well and it was really up in the sky so aiming with the telescope was difficult. But once I got the object in the viewpoint I realized it was just a dot of light. The thing is that, first my eye wasn't adjusted to the dark enough, and second, I didn't know what I was looking for. Because of this I kept looking, forcing my eye to try to look deeper and, all of a sudden, there it was, a beautiful ring of dust around the white dot. It was probably the most exciting experience I had in the span of my project.

I now know what I'm going to be looking for when I look at deep sky objects and feel like I have a much better understanding of orientation in the night sky and a much better knowledge on how to use the telescope properly.

Nov 12, 2021

Today I looked at Saturn and at the Moon!!
I started by looking at the moon towards some of its craters. It was truly incredible, it felt like I was just above it and the craters were so clear. The bad part was that it was half Moon and just a few craters near the shadow of the moon were clear. I realized that, if I'm looking at the Moon, I should do it when is in a crescent phase, because the craters will be more highlighted.

Then I pointed at Jupiter, which was really interesting because this time I didn't see 4 Moons but 2.

Finally, I pointed at Saturn and it was definitely an incredible experience because I was able to look at the rings so clearly!! I wonder if I'm in a really dark environment with my eyes adopted to the dark if I would be able to see the Cassini division, which is a separation between A and B rings in Saturn. I don't know if my telescope would be powerful enough.

Dec 6, 2021

Today I went to my 2nd mirror making workshop and I came back with some bad news. One of the main things is that the tile tool, the tool I was using to make my mirror, had worn down. This is extremely annoying because if I don't have that tool I can't work on the fine grinding part with my mirror and I don't have an excess of time.
The second thing is that I have to remake the whole design of my telescope. I realized that the design that I was going to make was going to be to heavy to be able to transport it to Spain. The good part is that I have an idea of how I'm going to change it. I thought about making it tubeless and dismountable into a 1ft x 1ft box that I could carry around. Sounds difficult but it will get simpler, at least that's what my mentor told me.

One of the other things that the people in the class made me realize is that I have to really figure out the inner mechanics of the telescope (where the secondary mirror is going to go, where the ocular holder is going to go, at what height etc.). For that, I was told to make a 1:2'' scale drawing of the whole inner tube and draw the rays of light.

These are some big bumps on the road that will definitely affect how much time I have for the project and how I'm going to approach it. I also think I should be researching a lot more, I found myself lacking knowledge when I talked with experts about my project, which is to be expected, but it felt like I had no answers to their questions just because I haven't read enough. Doug gave me a great book from which I'm going to be able to learn a lot so i can be prepared for next time.

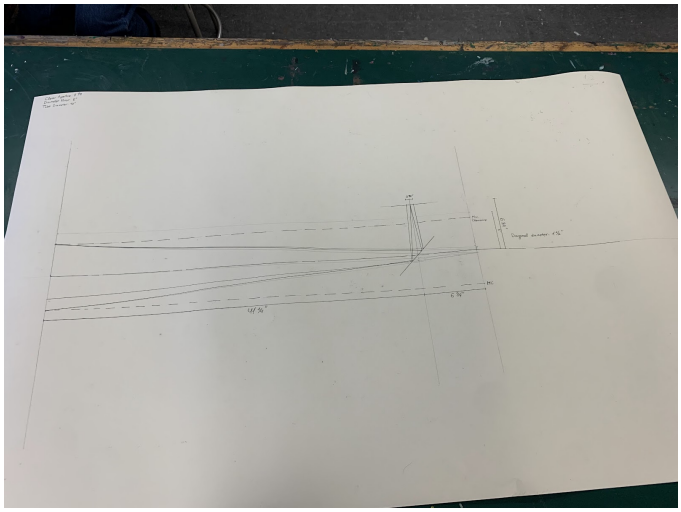
Jan 10, 2022

The January mirror class got canceled because of COVID-19. That means I won't be able to start fine grinding because I don't have any more grits to continue. This is a big bump on the road because, without being able to grind, the whole mirror grinding process is going to be slowed down at least a month. Hopefully the next class won't be canceled, that will mean that I will still be able to finish in time.

Because of this inconvenience I'm going to focus on assembling the tube and finishing the layout of the rays of light that hit the mirror so I can know the measurements of the tube, secondary mirror and focuser.

Jan 13, 2022

I finished the layout!! Huge thanks to Rafael Kelman for helping so much with measurements, sketching and for the materials he lent me. Here is a photo of it:



Thanks to this I will be able to order the secondary mirror and start building the actual tube!!
This has been a big point in my project because it seemed really difficult to be accurate about the sketching in such a big scale (1:2). It actually ended up being a lot easier than I thought and gave me a lot of confidence in the project.

Jan 17, 2022

I started to build some parts of the tube today. My host dad and I went to the hardware store to get a bunch of pieces and we started basically building the frame of the tube. This consisted in the lower box and the top part where the secondary mirror is going to be. To attach the tubes that will connect the top and bottom parts we thought we'll use dowels with electrical tape around them so the tubes are tight against the dowels and will stay still. Adding to that, we'll use rope going through eye hooks in each end and tighten it up so the tube is sturdy.



Feb 2, 2022

I started building the Mirror holder. I followed the instructions from a book I found in the library. This procedure was fairly easy, as I had instructions on how to do it and it isn't the hardest thing to build at all. Here are some photos:



Feb 8, 2022

The February class has been canceled again because of COVID-19. This is going to make finishing my mirror really hard time-wise. I emailed Katie, one of the organizers of Stellafane, asking for materials so I can at least finish grinding the mirror at home. She told me she will find me something and mail it to me. I hope that the package will arrive as early as possible.

Today I added the dowels and cut the tubes. Thanks to this, the project seems to start having a shape and this is giving me a lot of hope about the future of this project.


Feb 16, 2022

I got the grits from Katie!! Now I will be able to grind the whole mirror before the mirror class and start directly polishing then!!

I already started grinding with #220 grit. I will update when Im done grinding the whole mirror.

Mar 3, 2022

I finished grinding the mirror down!! The last grit I used was 5 micron, which is a really fine grit, sometimes some people don't grind that far because it has a higher risk of making scratches but I decided to go with it so polishing takes less time.

I found that there is a little problem. The focal length is actually a lot longer than I thought it was going to be. I think I measured the focal length wrong when I was first making the curvature of the mirror because I worked with the mirror on top of the tool while grinding, which is supposed to make the focal length shorter, so it doesn't make sense that I enlarged the focal length while grinding all the way from f/6 (48") to f/7.3 (59"). Anyways, this changes a couple things but is not really that difficult to fix with my telescope.

Because it's a tubeless telescope with just 4 tubes holding the secondary mirror holder, I have the advantage that I can just enlarge or shorten the whole thing adapting to the focal length. I will just have to enlarge the tubes adapting to the new focal length, around 53".

Mar 5, 2022

Today I went to a mirror class! Finally!! After two of them were canceled. It was a really productive class. I made the polisher by a really cool process of putting this petroleum-like liquid and waiting till it hardened enough to be solid but also to be shaped with the shape of the mirror by pressing both against each other so the mirror gets contact all over its surface. I talked with a guy named David Kelly who helped me a lot and he offered to help me finish the mirror at his place, where he has all sorts of machinery to do all that faster.

I will be polishing as much as I can before meeting with David so I can go to his place and basically start figuring so I can have the mirror finished before April so I can get it coated and finished before the middle of the month and be able to do a little star watching night with it at the academy.

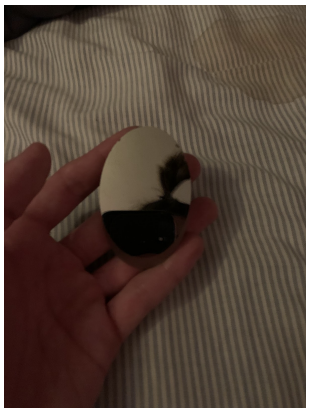



Mar 17, 2022

Yesterday I met with David. He showed me this machine that he has for polishing. This is going to make the whole process a lot easier and faster. He knows a lot about mirrors so I know its in good hands. He said he wanted to keep it to flatten the back part out and polish the back part so it is stronger and so I can see through the mirror how well the contact is.

David also gave me a flat (secondary mirror)! He found one that fit my measurements and thought he wasn't going to use it so he just gave it to me. This is incredibly helpful.

I also saw his huge telescope that he built. Is a 12" newtonian mainly made out of metal and is amazing



Apr 2, 2022

I finished the mirror!! I went one last time to David's house to finish figuring the mirror and we did it, and he says it's a good one!! We put it into a testing equipment he made which shot light from a point, it reflected in the mirror, reflected in a flat, back in the mirror and into a thin stick where the image was formed. With it we were able to see what the shape of the mirror was, though I still don't really know how the shape thing works really well. I have a video of it I more or less could take. In it you will see a ball of light and you will see how a shadow moves around the ball making it even disappear.

Here is the final look of the mirror:

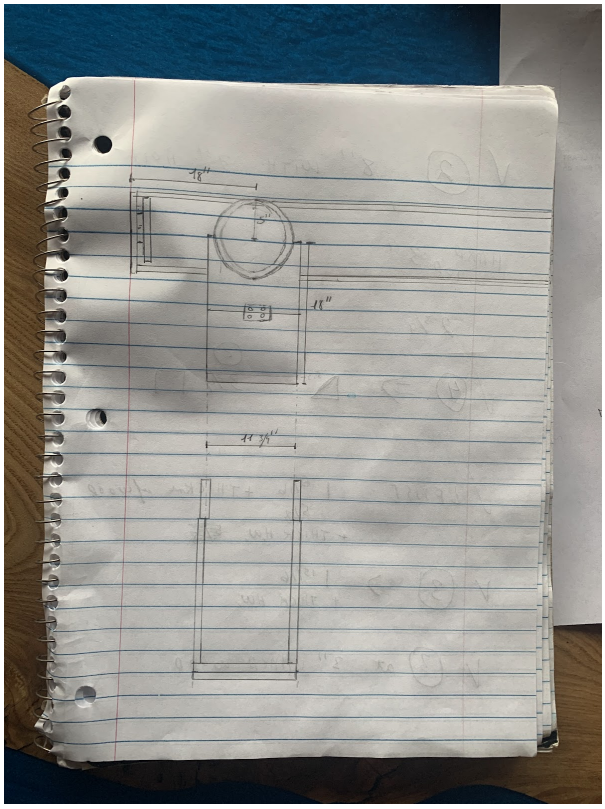
Apr 3, 2022

Once I finished the mirror, I used it to find the balance point of the tube by setting it on a pole and moving it back and forth till it basically stayed still.
I also had to make some changes to the tube, including changing its length and adding some support parts so the mirror doesn't fall out of the case.



Apr 9, 2022

Today I finished sketching the rocker box and its components (The moving part of the telescope) and I'll head later to home depot to get some materials. While thinking about it I realized that the pieces where going to be too big to make them all a box. So I decided to separate the two sides where the telescope lays down and make them the front part of the box when disassembled.



I also realized that, even though I shipped the mirror 6 days ago, the mirror is still in New York city which is quite far from California, where the mirror has to go to get coated. This is kind of a crisis point because the project is due the 22nd of this month and, if the mirror doesn't get back in time, I'm screwed. I think I'm going to call the labs where I'm sending the mirror to and ask to change the way the mirror is being shipped back so it can go by plane. Is probably going to cost a bunch but I don't think I have more options.

Apr 10, 2022

I have started working on the rocker box! I cut the azimuth-rotational circles and made the base and the side boards of the rocker box. The circles are not perfect but I think that when I add the formica it will be a pretty spherical shape.

Apr 16, 2022

Today I made a bunch of parts for the rocker box. It was a whole adventure because I couldn't find formica in reasonable amounts and prices nowhere and I realized that teflon blocks are not a common thing to buy, they normally just sell them in hobby shops. My host dad and I went to home depot and, in a burst of an idea, he realized that we could just take formica in free samples and just do that. Also, searching around the internet for teflon blocks, I realized that the hard plastic chair sliders are made out of teflon! So we also just bought those instead of going all around western mass trying to find a teflon block.

Now it was time to attach all the stuff together. I glued the formica to the circles and put some teflon chair sliders to the sideboard of the rocker box. Also, I realized that the shape that we gave to the last sideboard was wrong because, with the teflon stuff, the circle wouldn't be able to fit in the hole and therefore slide over it. So I changed the hole, instead of being whole semicircle i just cut from a lower part than the center of the circle, making it better to slide over.

I also put formica under the bottom board so I can make the ground board later.

Apr 17, 2022

The telescope is almost finished!! I attached the side boards and made the ground board and I put everything together and it moves smoothly and great!! I now just need to do the optical stuff like the focuser, finder etc. By the way, I received those the other day and it seems pretty easy to set up.

To attach the sideboards I glued them to the bottom board and nailed them. Then I put the upper sideboards (the ones were the rings will go on) on top off the bottom sideboards and nail a plate that unifies both. The result was really unstable and the distance between sideboards ended up being too thick. So I decided to ditch the idea of the plates (also because I tried to bend them and one of the bottom sideboards cracked) and I realized I could just screw the top sideboard to the bottom one from the inside. That would make the whole structure stronger and the distance between sideboards perfect for the tube to rest on it.
Then I made the holes for the bolts on the rings and on the tubes at 17” which is the balance point and I just added the rings on the sides with bolts and nuts. Then I mounted the tube and put everything in place and it worked!! I just needed to add a jar full of water to make the counterbalance that the mirror would make.

Now for the ground board. I cut the ground board the other day. Today I made a whole so that the ½” bolt could go through and be flushed and I ground down the top of the bolt so it wouldn’t stick out. Then I made a circle, more or less around the points where there was more formica under the bottom board and I nailed some chair sliders in a circle. I just put the ½” bolt through both the ground and bottom board and I put a washer and a nut at the end of the bolt. The result was a great horizontal movement.

Apr 18, 2022

Today I added the focuser. This was tricky because I needed to calculate how far I could put the focuser while being able carpentry-wise to attach it and also maintain the image position. I run out a couple of simple calculations for where I could attach the focuser (Focuser in travel (½”) + thickness of wood (½”) + diameter of tube (5”) = 7”) and I subtract that from the focal length (59-7 = 52”) which left me with the result that it was better to cut 1” from the tubes, and so I did. Then I just screwed the focuser to a wooden square and I screwed that to the outside of the top of the tube.

Apr 19, 2022

I got the piece that I needed for the finder and I screwed it to one of the sides of the top part of the tube. I also tried setting up the secondary mirror holder, which was going to be attached to a block screwed to a bent metal ruler but I broke the ruler so that is going to delay everything a day or two.

Apr 21, 2022

I finally attached the diagonal holder. It was tricky because I had to bend a metal ruler and it kept breaking but I finally figured out how to not make it break. Then I attached a 1” wood block to it and screwed the holder in it. Now I can say that the telescope is complete!! Except for the mirror that won’t come back till at least half a month more. But yay!!

4. Conclusion

Going into this project I didn’t know the amount of knowledge I would get. From carpentry, to drawing in scale and all the way up to learning how optics are made and tested; this project has had a huge variety of skill sets that I needed to learn in order to succeed.

While it is true that the product and what I have accomplished was really ambitious, I was even more ambitious in the beginning and I had to narrow down my project significantly. At first I was thinking about doing monthly night observations with the academy community, doing some astrophotography with the telescope, writing instructions on how to use the telescope at the academy (which I'm still thinking about doing) and even more! But I ended up narrowing down the project to just 1 observation night (or maybe 2 if conditions allow it) and no astrophotography.

A lot of the project time was spent on the mirror. The actual moving parts weren’t so time consuming though they did require more logistics because I was following my own design that I came up with.

The carpentry aspect has been some of the most satisfying part of my project, apart from the completion of the mirror, because of how tangible the outcome was.

5. Community Outreach - Observing with the Academy

This whole time I have been exploring at least a little bit the night sky, how it works, and how to identify constellations and other objects. This is something fascinating for me and something I have been really looking forward to share in the form of a class. Unfortunately because of the weather, COVID-19 and my own personal time constraints; I haven't been able to do the class but, now that the telescope is complete and the temperatures are going up, I'm feeling confident to at least start preparing for the night. I have prepared a little script on things to watch and to learn about.

Because of the fact that I don't have my own mirror yet, I'm going to have to ask for one and I won't be able to get it till the middle of May. Therefore, I'm planning on doing the class around those times.

At the times that I'm going to be able to do the class the planets are not going to be out at reasonable hours. That is a bummer because they are firmly the most beautiful object to watch for the unexpert eye. I have seen people develop at least a continuous curiosity about astronomy just because one day I showed them Saturn and its rings. So I'm limited to more faint objects like nebulae, galaxies or clusters; which are more than enough for me!

My plan is to divide the class in two parts: Part 1, without Telescope, to understand the night sky and to gain knowledge about how to navigate with the stars; and part 2, with the telescope, show the audience a couple galaxies and nebulae and clusters and explain their origins and stories.

For part 1 I decided I was going to explain: How to find the Big and little dipper and subsequently the north star (Which is part of the little dipper constellation. Explain why the north star is so important (it is right on top of the vertical axis of the earth, meaning that if you follow it you are traveling north and because the whole night sky rotates about that point)

The elliptic: First start with the Sun (it goes from east to west following a path that is called the elliptic and it changes height around the year), then move to the moon and the planets (they follow the same path as the sun, from east to west but throughout a certain time they don't just rotate around but they stop in one place and they go backwards in the elliptic) and then finally move to the zodiacal constellations, why they are important (they are on the elliptic so therefore they follow the same path as the sun throughout the night too) and actually explain why the zodiac signs so the people that like to talk about others' zodiac signs know what they are talking about. This all relate because they are all in the same plane as the sun and the earth. Finishing up with the no-telescope part I will explain how we can use the stars and the planets to guide ourselves towards a destination, using all the above.

Now with the Telescope part, it will be pretty simple. I will point at some object, explain their formation, what constellation they are from and maybe a story if the object has one. Here is a

brief list of objects I thought about looking at. This list may or may not get larger depending on how well I can study the night sky during this time of the year.

Telescope:

M109

Whirlpool galaxy (M51)

Owl nebula (M97)

Heart nebula (IC1805)

Soul nebula (IC 1848)

6. Self Evaluation

During the length of this project, I have learned about so many subjects. When I was getting into it, I didn't know it would involve so much information to make it and to understand how to make it. This project has involved carpentry, optics, stellar navigation, star gazing, material choice, drawing in scale and most importantly patience.

I would've never thought that carpentry would involve so many techniques, decisions and precision. I'm really glad that I got to work with my host dad and be able to learn from him, as he is a carpenter, but also learn with him. He normally works in houses or bigger structures and I have noticed that this project has been a little challenging for him, so we both had to put the best of ourselves in figuring out how things were going to work. About this subject, I think I'm pretty happy with the results and how the process of learning it was, I wouldn't change anything.

The mirror has definitely been a real big challenge for me in this project, but it was probably one of the parts that I enjoyed the most. Before I started the project I thought that all mirrors were made with really precise machines that have extremely exact cutting knives and, if someone would've told me that I would make a concave mirror by myself, I wouldn't have believed them. I really enjoyed the learning process of it and, while is true that I have been taught a lot by other people, I did a big amount of the research by myself because COVID-19 restrictions canceled the meetings that I had with other people. I'm really proud of myself for that. This is a highly technical field that I was exploring and one I could not mess a lot with. And I did the right choices and I put great

effort into this. Now that I'm remembering the whole process of working with it, I realized that it was a great amount of work, around 2 full days worth of working time, and if there is something I'm going to take away from this project, is the experience of being able to work on such precise matters for such an extended period and still do it correctly. This will for sure help me in future projects or jobs or any challenging situation that I will confront.

If there is something that I would have changed from the beginning was my attitude towards the final deadline. I feel like I didn't really start working with such a good pace till January and I think that, if I had started before, the overall project would look a lot more tidy, complete and strong. It is true that the first months I used them basically for research purposes, and I'm really glad that I did spend that time, but I think I could have pushed myself a little more in the beginning.

The part that has inspired the most my creativity has been the sketching/scale drawing part. I had a lot of fun thinking in my head about how different parts could match all together and then drawing them in scale and giving them measurements and finally finding out that all that works in real life, and things matched successfully. Also this will help me a lot as an engineer, as I mentioned before. I had mistakes too after things seemed to match in paper. Sometimes I would cut two pieces one off of each other and realize that they don't actually fit that well and, finding out new ways to overcome those problems has also been really enjoyable.

A big bump on the road that I faced was COVID-19. I went to the December telescope making class thinking that I could start with fine grinding. Turns out I couldn't and after grinding for an hour or so, the some of my teachers looked at my grinding tool and they realized that it was ground off. That left me unable to work on the december and then COVID-19 cases went straight up and both the January and February classes were canceled, so that left me with really little time to continue grinding the mirror. I think that, if I had tried harder, I could have had materials by February and therefore be able to finish sooner. Although that time did give me a little rest to figure out the new design of the telescope and come back stronger.

Overall I think I'm really proud of myself for this project and I think I had a good working pace and I'm really thankful for the huge learning stretch that this project gave me. I wouldn't have changed anything.

Here is the website where I will add updates on my telescope, photos etc.:

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