

# Telescope Project

Chance Shepherd



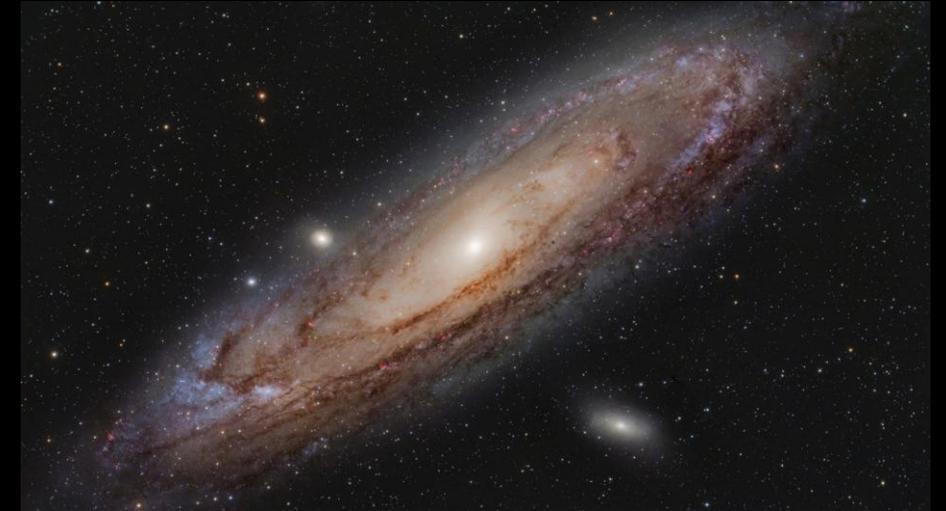
# Criteria and why?

## Criteria:

- Versatile, Transportable, Simple, and Inexpensive
- Large field of vision
- Good visibility of planets, galaxy long exposure photos, and nebulas

## Why?:

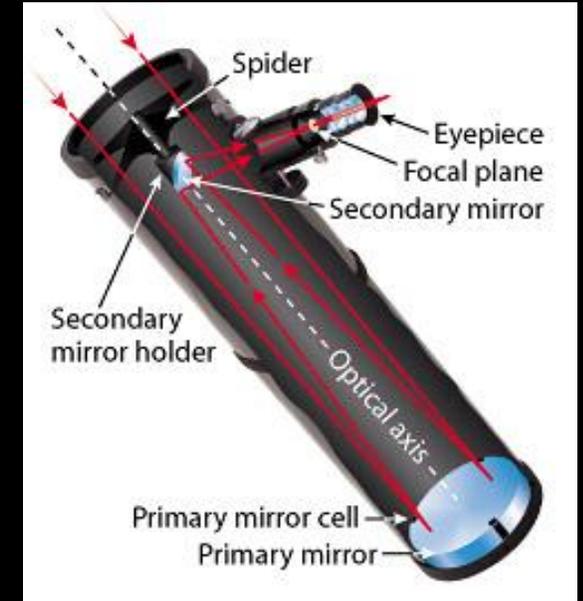
- Because telescope are awesome
- Display my engineering capabilities and skills
- Creativity over consumption
- Allow other people to experience a telescope



# Telescope Selection:

I chose a **Newtonian** style telescope:

- Simplicity
- Big aperture and fast focal ratio (f/5)
- Wide sky view and versatile
- Wide variety of information



# Telescope Selection:

## Components:

- Tube
- Primary and Secondary Mirror
- Primary Mirror Cell
- Secondary Mirror Cell
- Focuser
- Eyepieces
- Base (Dobsonian Style)

I think it will be important first to go over components to develop a general understanding of what goes into a Newtonian telescope

# Telescope Component Selection:

## Component:

- Tube

## Selection:

- 3D printed PLA

## Justification:

- Easy to manufacture
- Relatively cheap
- Never done before to this extent



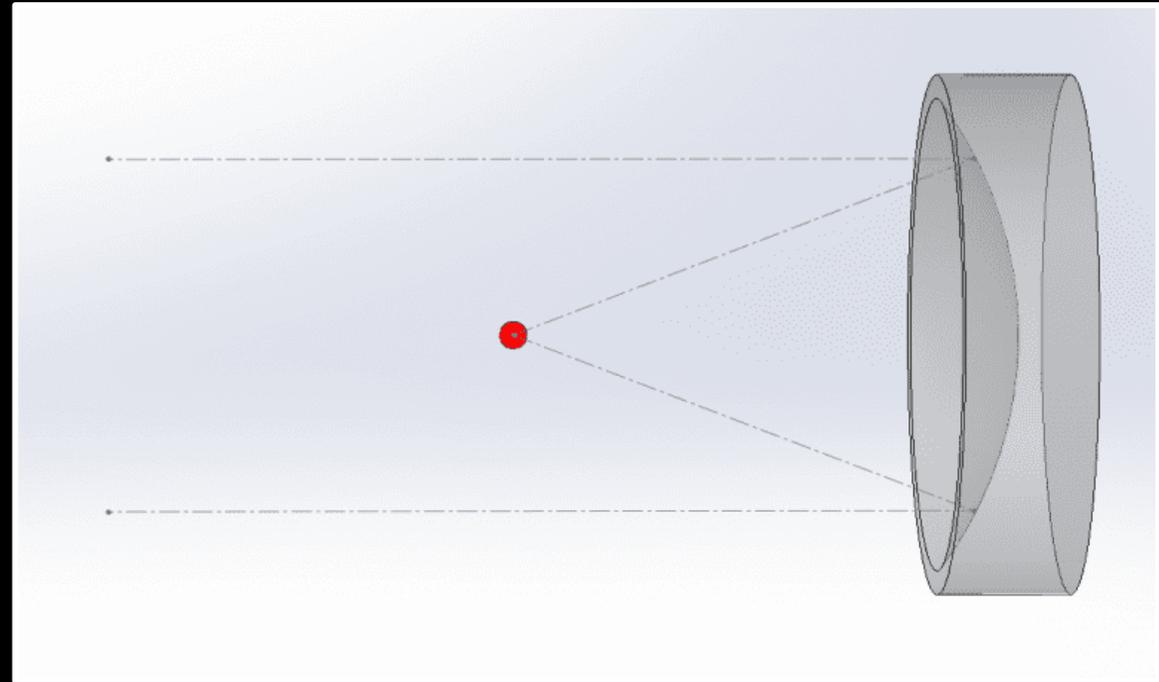
# Telescope Component Selection:

## Component:

- Primary Mirror/Secondary Mirror

## Selection:

- GSO 8" f/5 Parabolic Primary Mirror, 62.5mm Elliptical secondary mirror



Think of this mirror as a “parabola”, it directs any light that hits the mirror to a single point. The Focus point.

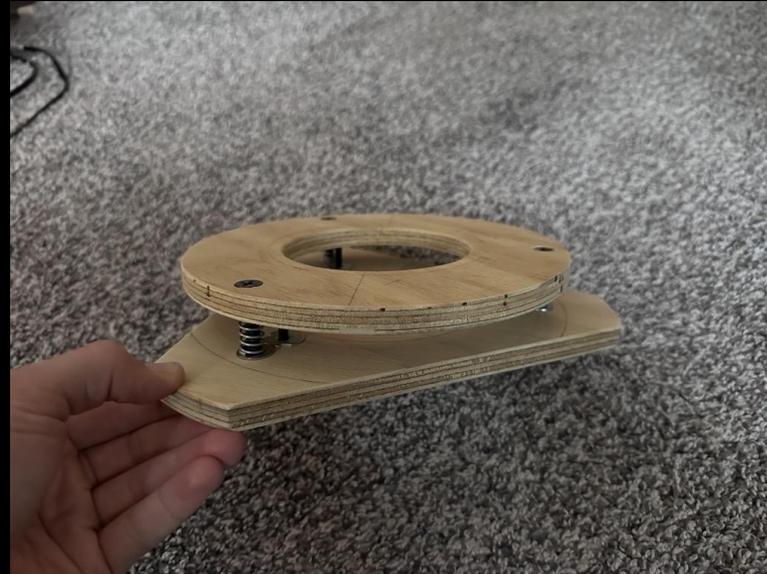
# Telescope Component Selection:

## Component:

- Primary Mirror Cell

## Selection:

- Custom 3-axis wood



## Justification:

- Made years before as a wood working project
- Integrated into scope design

# Telescope Component Selection:

Component:

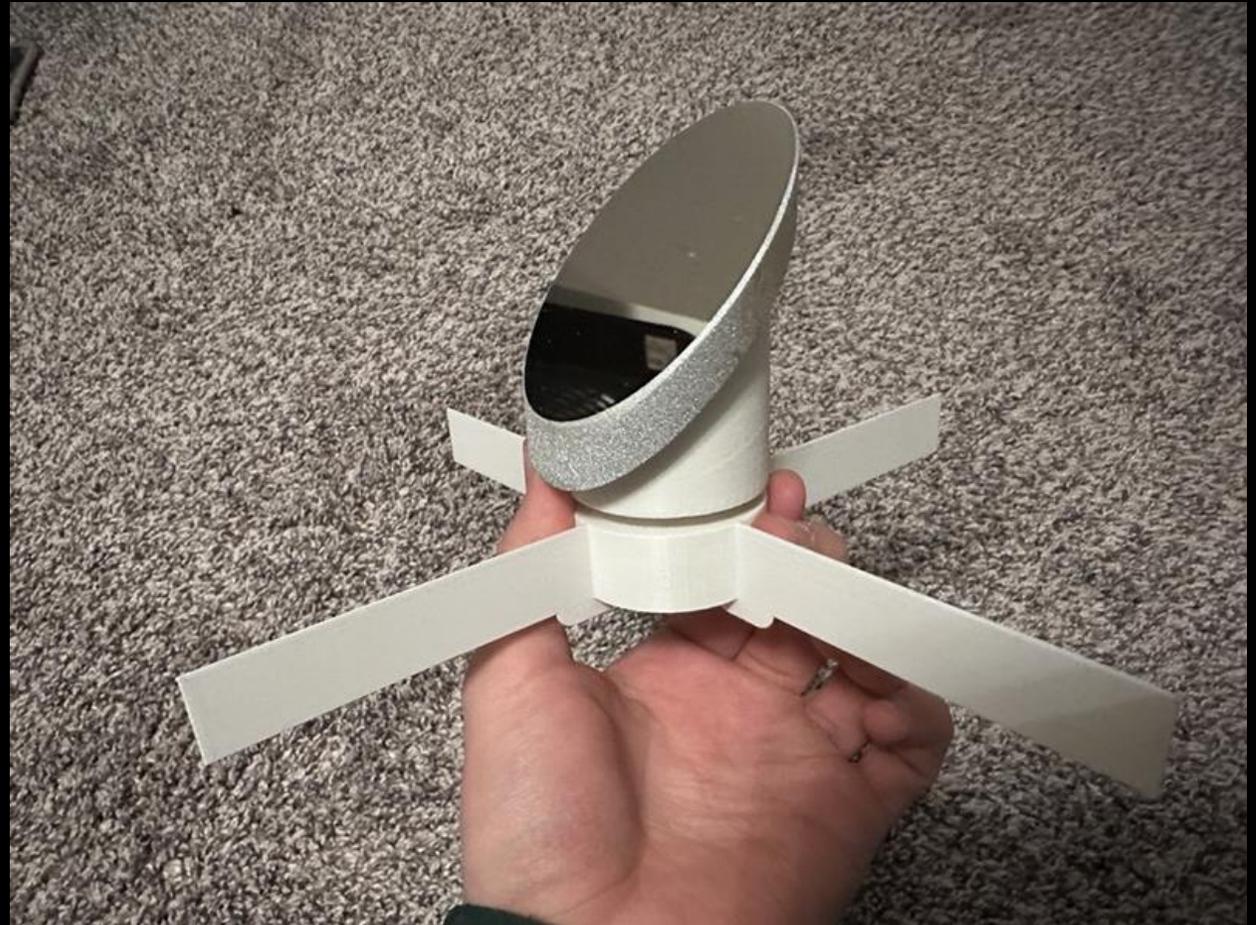
- Secondary Mirror Cell

Selection:

- 3D printed 4 vane system

Justification:

- Ease of iteration and design complexities



# Telescope Component Selection:

Component:

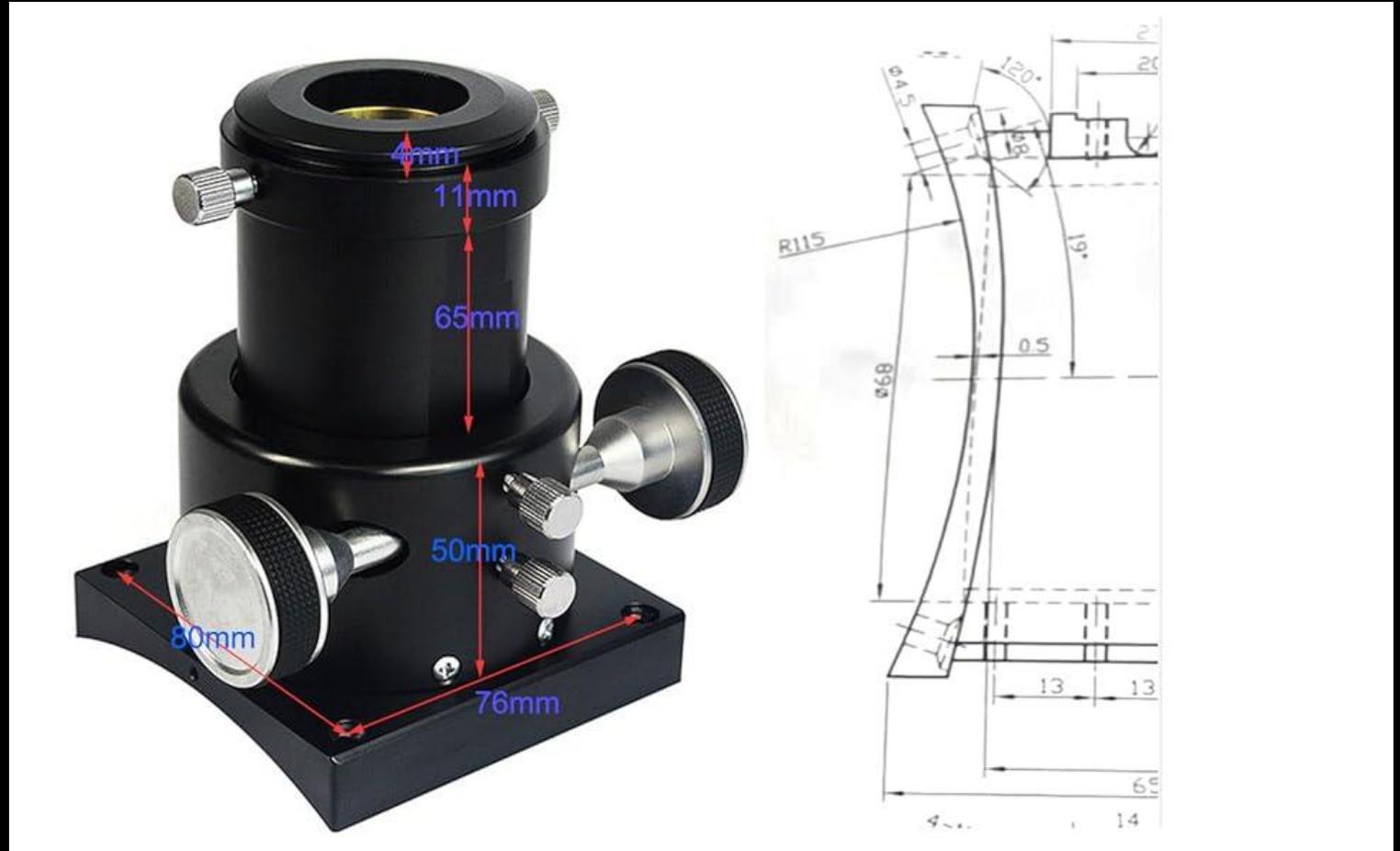
- Focuser

Selection:

- 2" Crawford Style

Justification:

- Cheap
- Well performing
- Matches my eyepieces



# Telescope Component Selection:

Component:

- Lenses

Selection:

- Celestron 2" Lense Kit

Justification:

- A gift to me
- Quality lens kit to work with



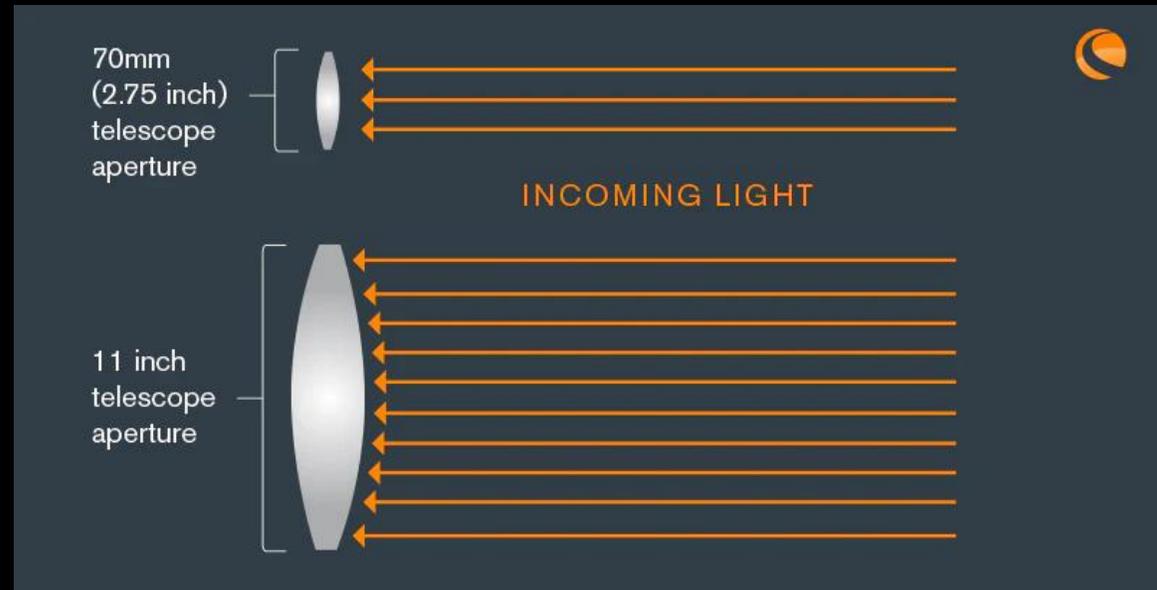
# Definitions

We need to understand some basic terms to dive into the design of the telescope.

# What does Aperture and F/5 Mean?:

Aperture is the diameter  
of the primary light  
collecting mirror

8" in our case



# What does Aperture and F/5 Mean?:

F/5 is referring to the Focal Ratio.

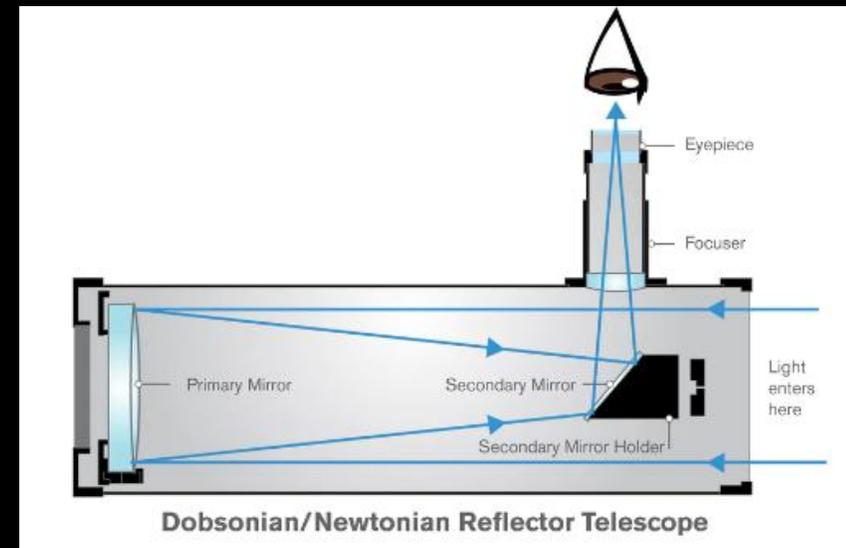
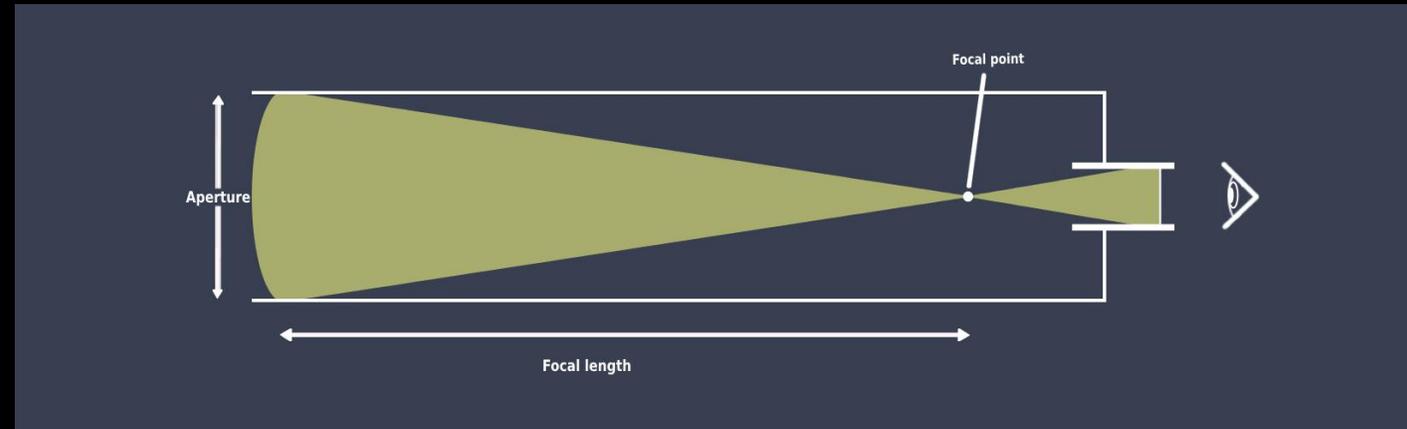
Focal Ratio is:

$$\frac{\text{Focal Length}}{\text{Aperture}} = F/5$$

We need to solve for Focal Length:  
 $\text{Focal Length} = 203\text{mm (8")} \times 5$

Focal length = 1015mm or 1.015m

Focal Length is important for finding  
tube length and secondary/eyepiece  
placement



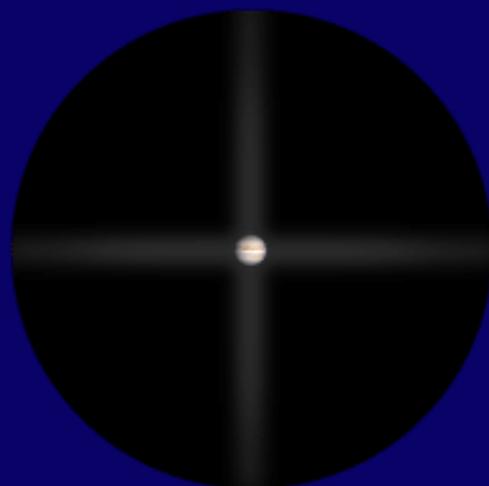
Design:

# Vane Design:

## Diffraction Spike Comparison

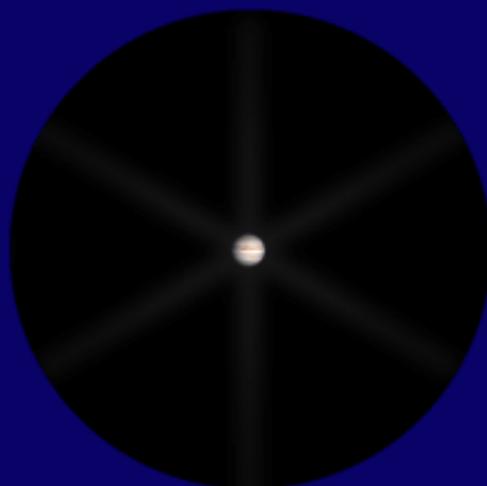
Simulated view of Jupiter at low magnification showing diffraction effects caused by the secondary support. (Diffraction brightness is exaggerated for clarity.)

4-vane spider



Eight radial diffraction spikes are created, but four overlap the other four. The result is the appearance of four bright spikes.

3-vane spider



Six radial diffraction spikes are created that are evenly spaced at 60° intervals. Each spike is half as bright as what a 4-vane spider produces.

180° arch support



No linear spikes are produced. The diffraction is spread symmetrically around bright field objects.

No obstruction



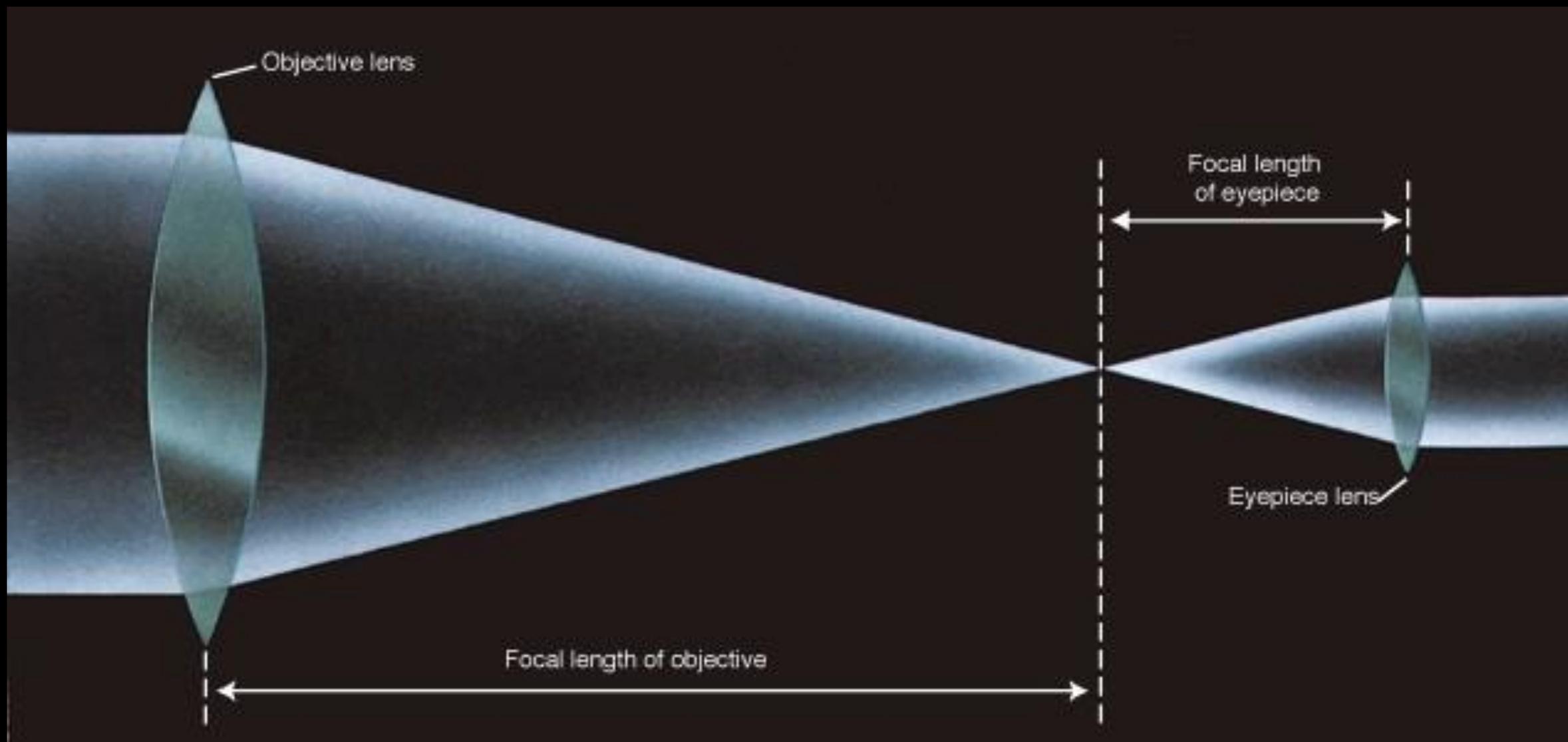
# Optics Layout Design:

# Matching Focal Planes:

To get a clear image, you must match the focal point of your primary mirror, to the focal point of your eyepieces.

On your eyepieces, you are given the distance to focal point





# Distance:

Our focuser has a change in distance ( $\Delta d_{focuser}$ ) of 60 mm total, extrusion of 10mm to 70mm.

Our lenses range of focal point lengths is from 26mm to 40mm

Difference of 14mm in change of focal point distance ( $\Delta d_{fp}$ )

35 mm drawn out focuser is middle distance, lets use this to set out distance to focal point convergence.

$$\frac{\Delta d_{focuser,max} - \Delta d_{focuser,min}}{2} = 35 \text{ mm}$$

# Distance:

If we take our 32 mm eyepiece.

That 32 mm is from the Principle Plane to the focal point.

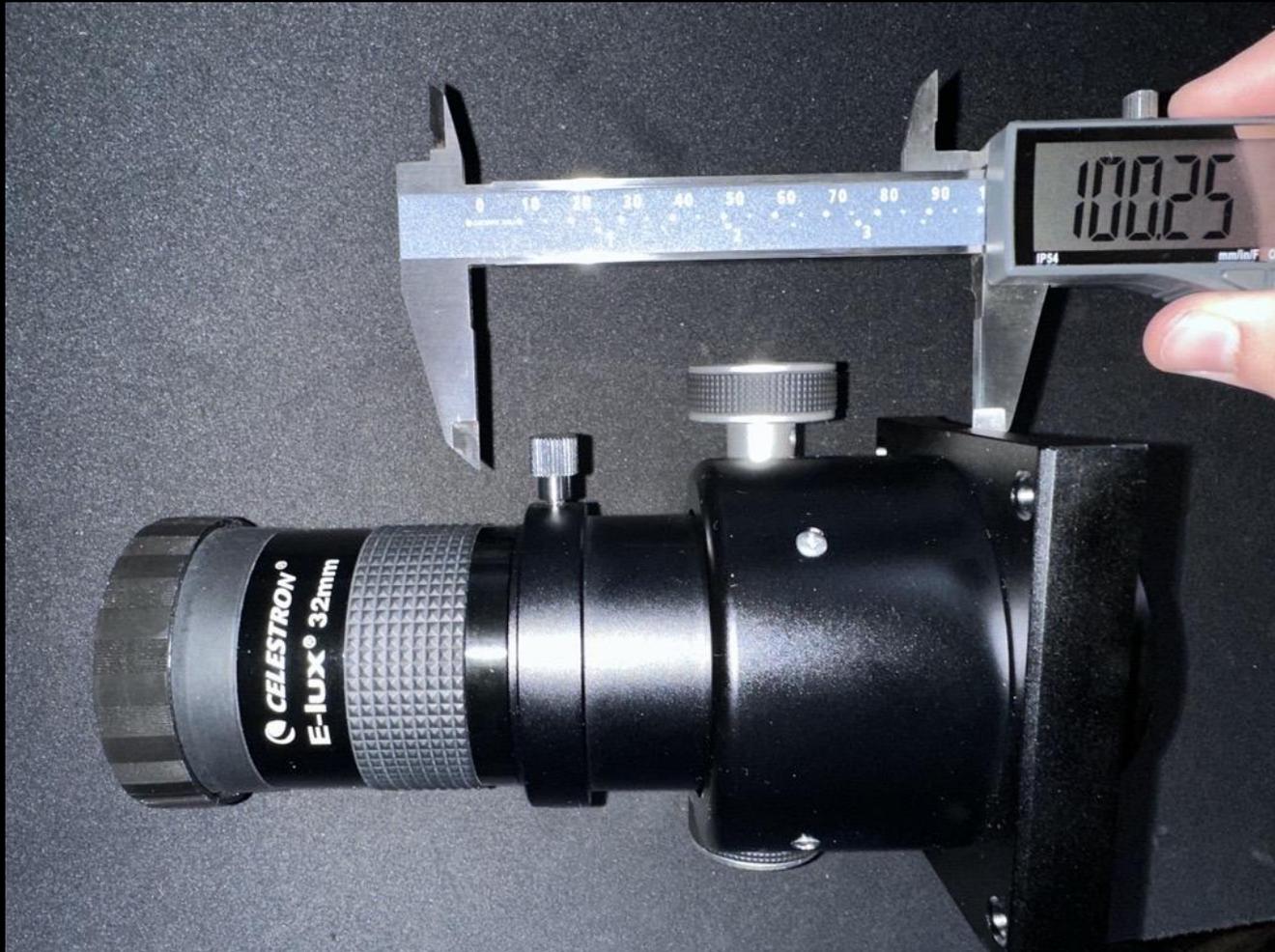
You can not just measure from the bottom of the eyepiece to the focal point.



Principle Plane

Focal Plane

# Distance:



Focus point of eyepiece is *roughly* 100 mm away from the edge of the tube.

100 mm + 12.85 mm (tube wall thickness) + 114.3 mm (distance from interior wall to center of secondary mirror) = 227.15 mm

$1015 - 227.15 = 787.85 \text{ mm}$

787.85 mm is the distance from primary mirror to secondary mirror reflective surfaces

# Distance:

When focuser is drawn out 35mm (our middle ground), principal plane (our measuring point) is barely outside of the eyepiece.

This means our focus point where our primary mirror and eyepiece converge will occur inside of the eyepiece/focuser.

*Now that we know this...* lets take our calculated 787.85 mm and set the height of the tube, secondary mirror location, and focuser location.

# Tube Design:

The first step in determining tube length is adding the primary mirror cell height, which is 45 mm. Then the height of our mirror, which is 27.4 mm (measured).

Therefore the primary mirror cell + mirror height = 72.5 mm

The height of our tube now includes  
 $72.5 + 787.85 = 860.35$  mm



# Tube Design:

Now that we have our 860.35 mm number, we need to create room for the secondary mirror cell and room to add a tube cap.

The secondary mirror cell height will be 70mm (mirror cell + height of the mirror itself). This is an arbitrary number I feel comfortable with to create the cell.

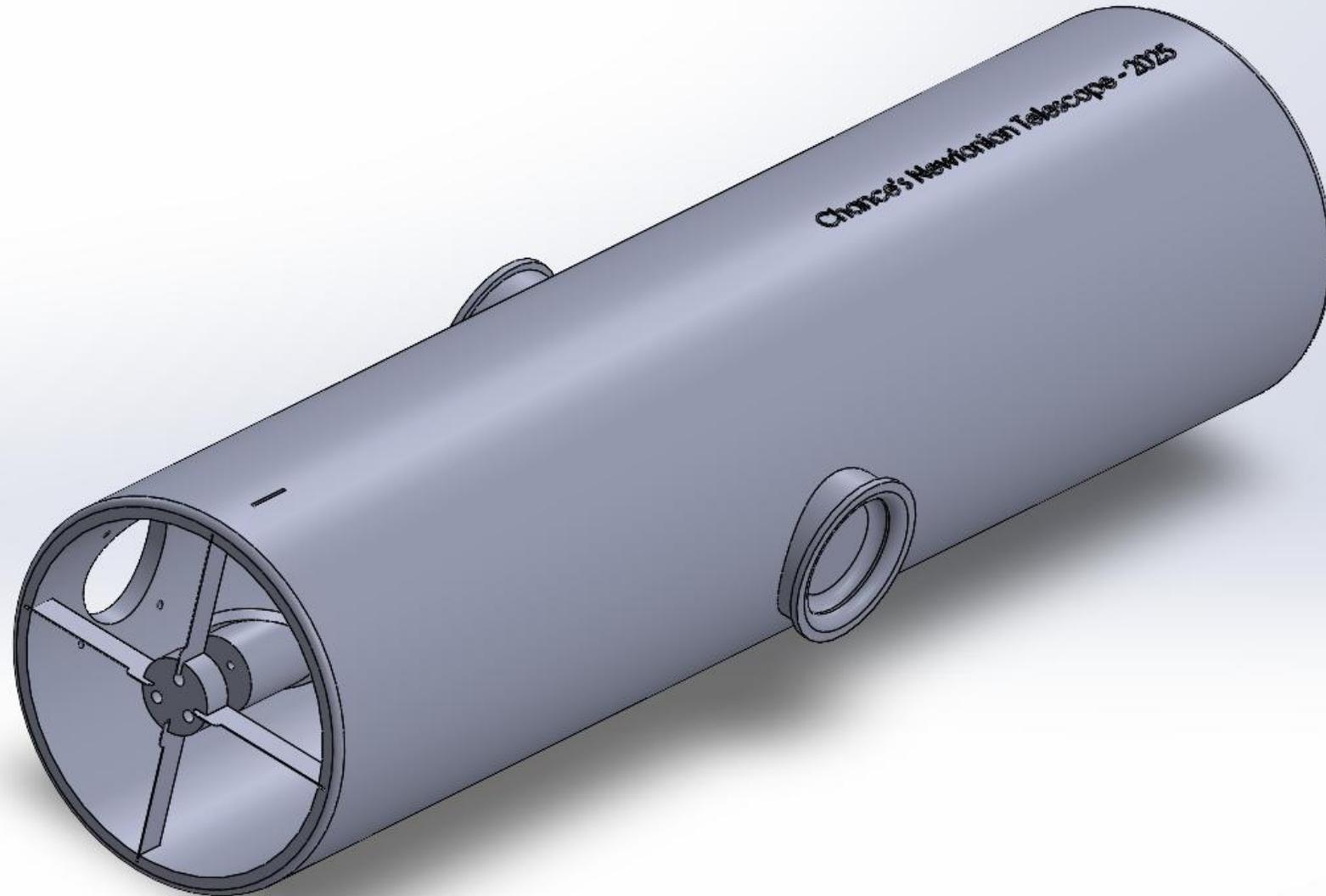
Add 10 mm for room to have a tube cap.

With this we arrive at our total tube length. Let's do the calculation in full.

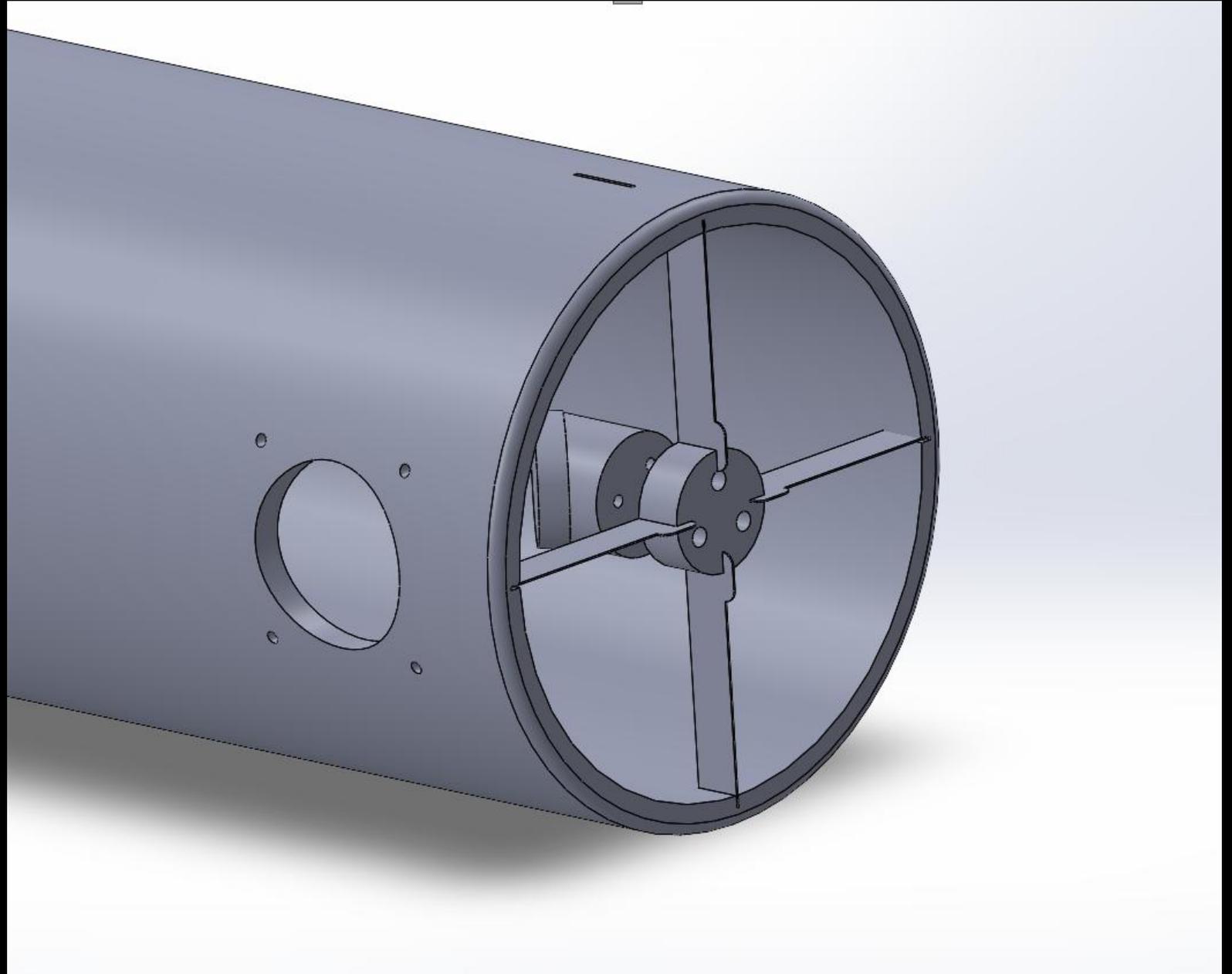
$$860.35 + 70 + 10 = 940.35 \text{ mm}$$

940.35 mm total tube length

# Tube CAD:



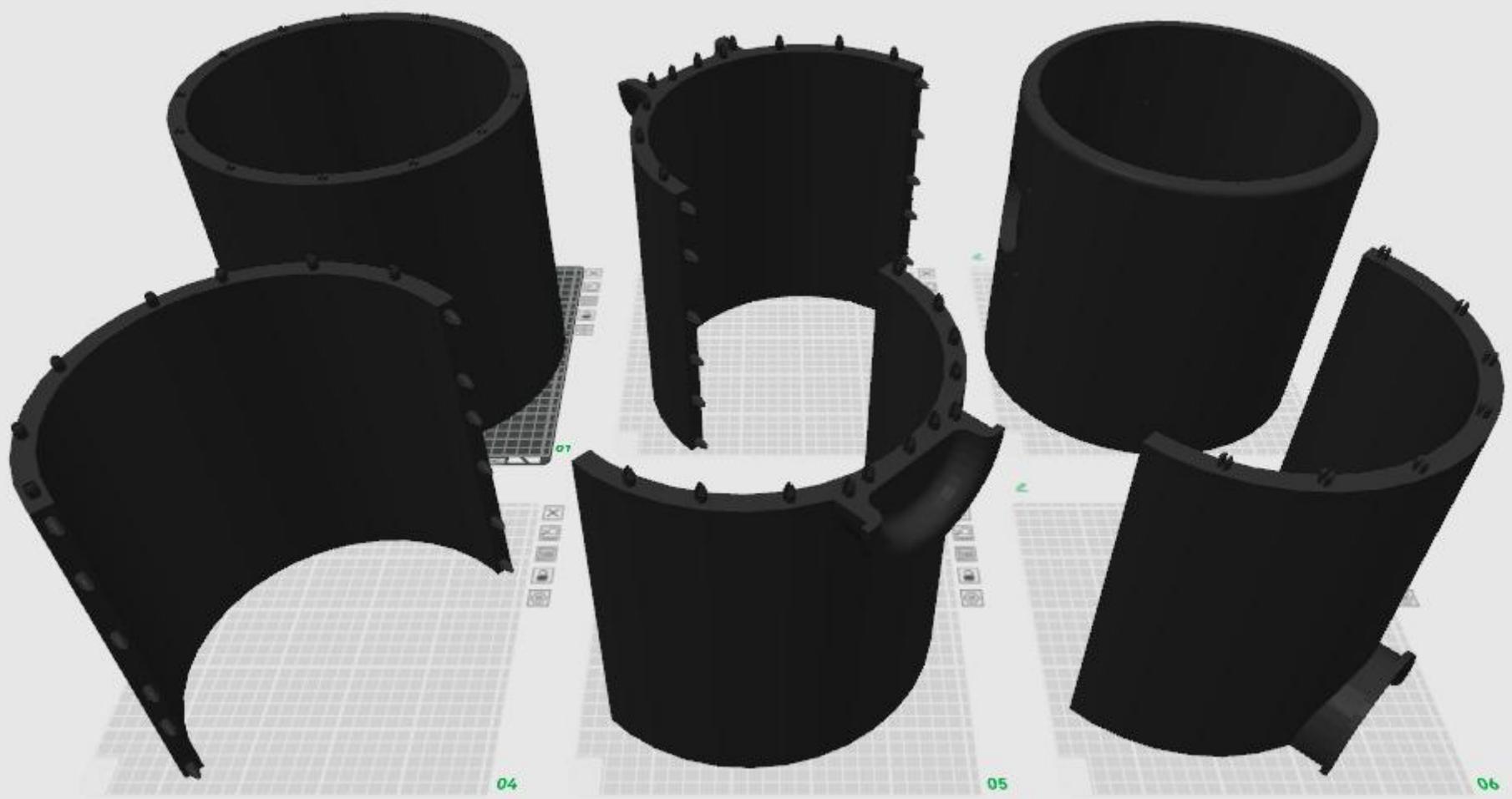
# Tube CAD:



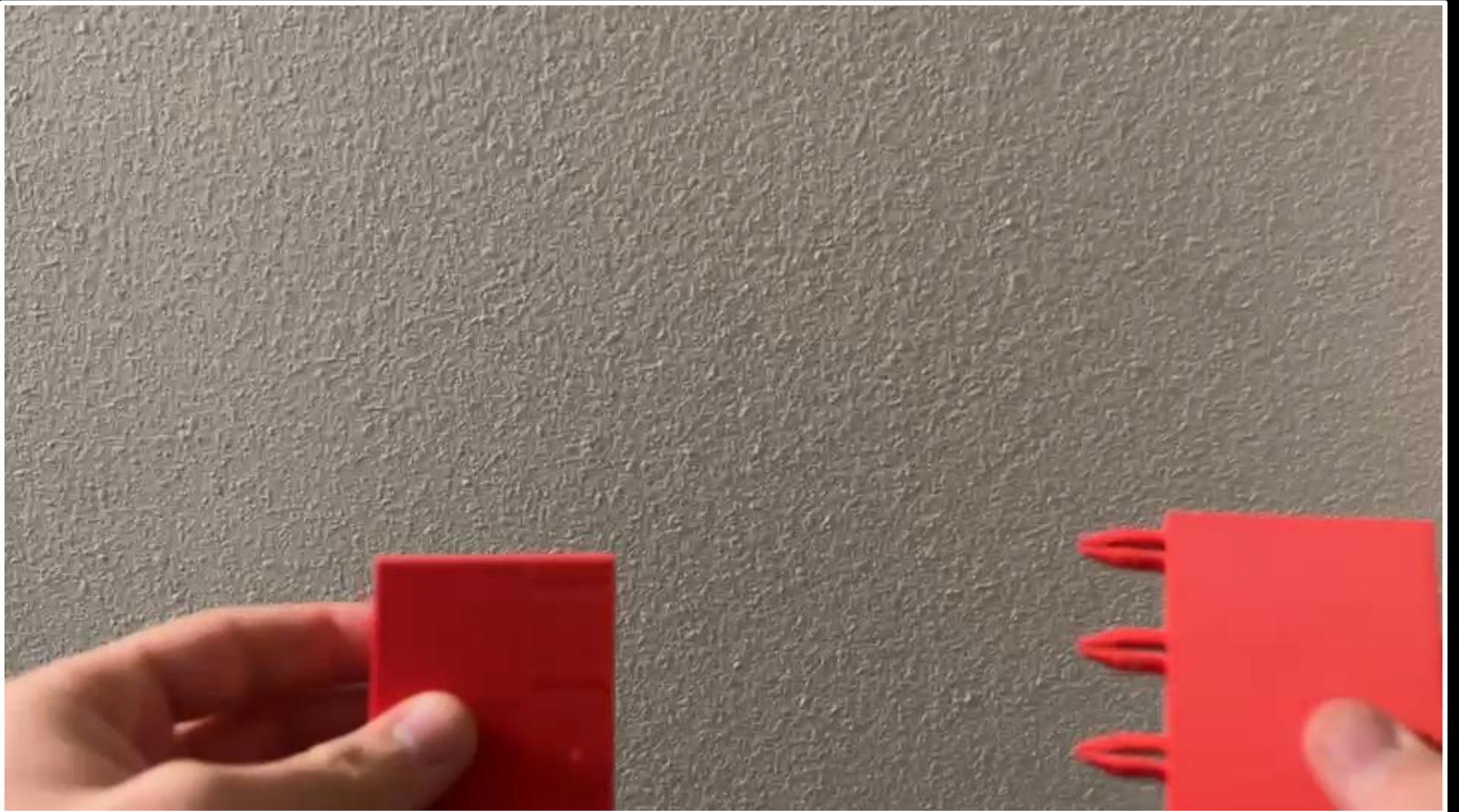
# Tube CAD:



# Printing:







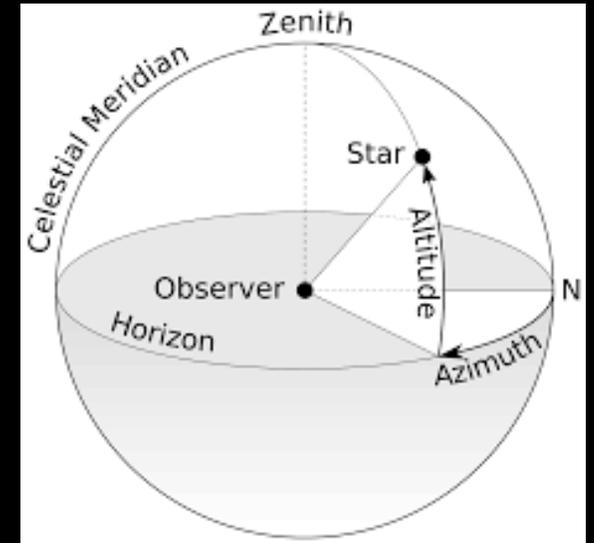
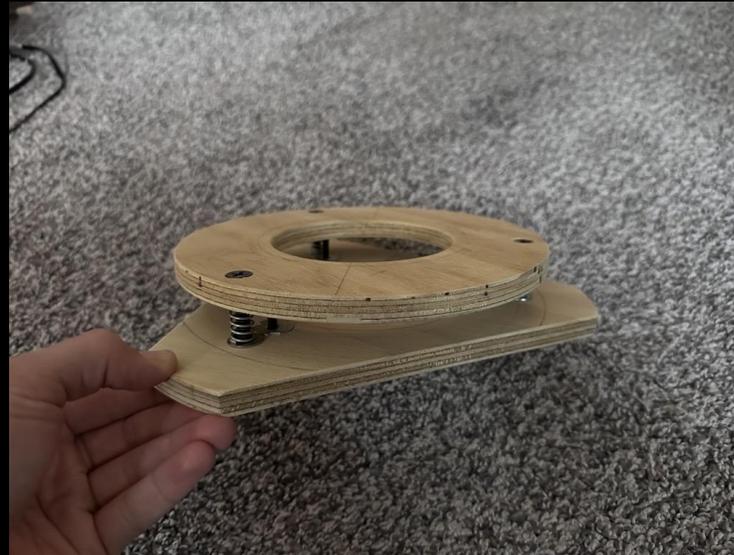
\*The bottom snap connector broke before the video

# Primary Mirror Cell Design:

A mirror cell serves two functions:

1. Hold the mirror
2. Be adjustable

That's it.



We need to adjust our mirror on all axis (specifically our angle  $\theta$  from xy plane to z ~ better known as altitude), to *collimate* our telescope.

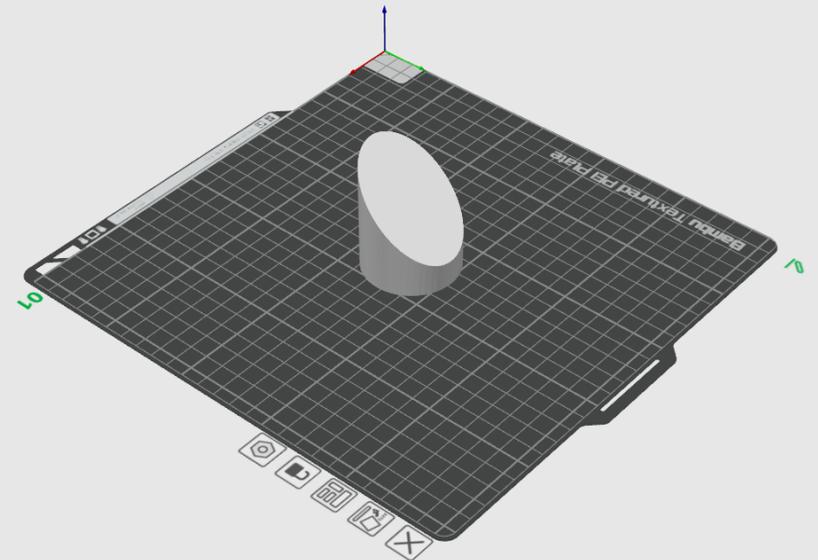
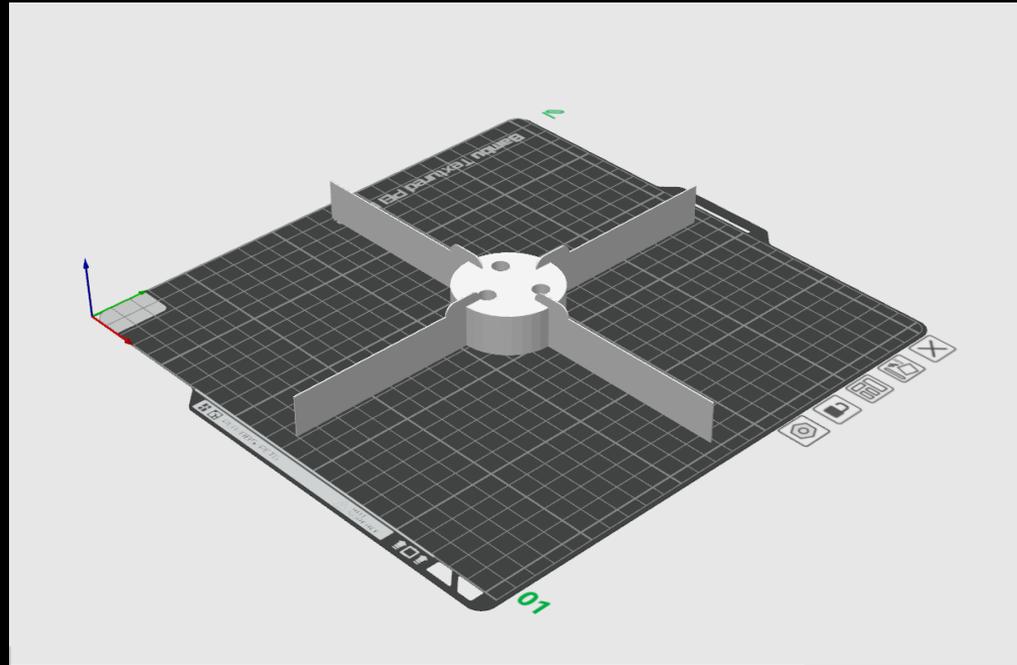
*Collimation* is aligning our telescope internal optical elements, to ensure optimal performance.

*Collimating* our telescope is necessary in order to provide clear visuals.

# Secondary Mirror Cell Design:

Our secondary mirror cell has the same purpose, but this time it is upside down.

No biggie, lets take advantage of gravity and have 3 screws with threaded heat press inserts to gain access to our 3 axis for collimation.



# Color choices:

Why I chose the colors I chose:

- Black absorbs color – making an excellent tube color (reduces noise)
- White reflects color – makes an excellent secondary mirror vanes? (reduces noise?)



# Modular Viewfinder:

I also added a small 2 mm slit to the top of the tube for a small iron sights style viewfinder.

This will help align the center of the scope with objects in the night sky visible with the naked eye.



Assembly:

# The glue debate:

If you research online the best ways to secure a primary mirror to the mirror cell, you will encounter a surprisingly heated debate.

Most claim that glueing will cause *astigmatism*, an optical effect where mirror's surface has different curvatures in perpendicular planes, causing a blurry image.

<https://www.telescope-optics.net/astigmatism1.htm>

## Mild Astigmatism

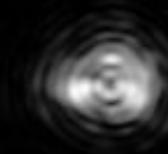
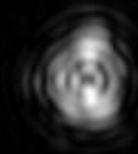
Inside

Outside

Slight Defocus



More Defocus

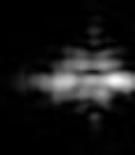


## Bad Astigmatism

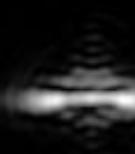
Inside

Outside

Slight Defocus



More Defocus



# The glue debate:

The glues curing process “could” in theory be enough to affect the mirror and cause astigmatism according to the internet.

But others claimed online it wasn't an issue.

This left me confused, so I decided to take matters into my own hands and work with the classic engineering First Principles Thinking.



Don't just follow the trend. You may have heard me say that it's good to think in terms of the physics approach of first principles. Which is, rather than reasoning by analogy, you boil things down to the most fundamental truths you can imagine and you reason up from there.

— *Elon Musk* —

AZ C

# The glue debate:

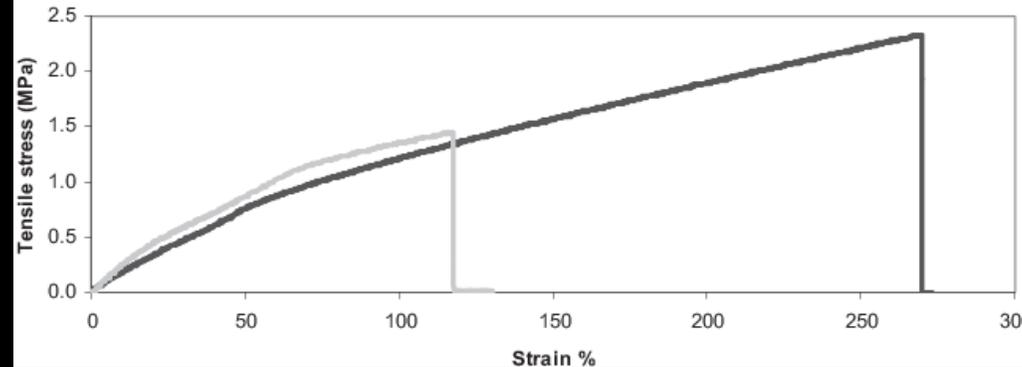
Three 10 mm × 1–2 mm RTV pads placed at 120 degrees of each other it will provide a *mechanically secure and optically safe* mounting method

- The adhesive shear capacity greatly exceeds the mirror's weight which means the mirror cannot slip or detach. (14x Factor of Safety) \*napkin math
- The pads are small (1–2 mm thick), which prevents the mirror from being distorted by curing or thermal stress, it basically “floats” on flexible supports.
  - In fact, the elastic modulus of Silicone RTV is MORE than the elastic modulus of our mirror, meaning the silicone will act as natural adjuster and won't warp our mirrors image.
- Using three evenly spaced pads gives a statically determinate system, minimizing optical deformation.



I used Automotive Primer on the wooden primary mirror cell to create a non-porous even adhesion surface.

Adhesive	Young Modulus E (MPa)	Tensile Strength (MPa)	Tensile Strain (%)
AS1805	2.63 ± 0.03	1.4 ± 0.01	120 ± 24
RTV106	1.60 ± 0.05	2.3 ± 0.02	270 ± 15



Coefficient of thermal expansion	$30 \times 10^{-9} \text{ m/m}^\circ\text{C}$
Thermal conductivity	1.46 W/m $^\circ\text{C}$
Specific heat	800 J/kg $^\circ\text{C}$
Density	2530 kg/m $^3$
Modulus of elasticity	$9.2 \times 10^{10} \text{ Pa}$
Poisson's ratio	0.24
Shear modulus	$3.71 \times 10^{10} \text{ Pa}$

# The glue debate:

Simply put, this means we are good to glue our primary mirror to our mirror cell.

I provided a full 48 hours of curing in order to ensure proper adhesion in a room temperature environment.

This method should be adequate for 20+ years, Silicone RTV is known to be a robust and reliable adhesion method.

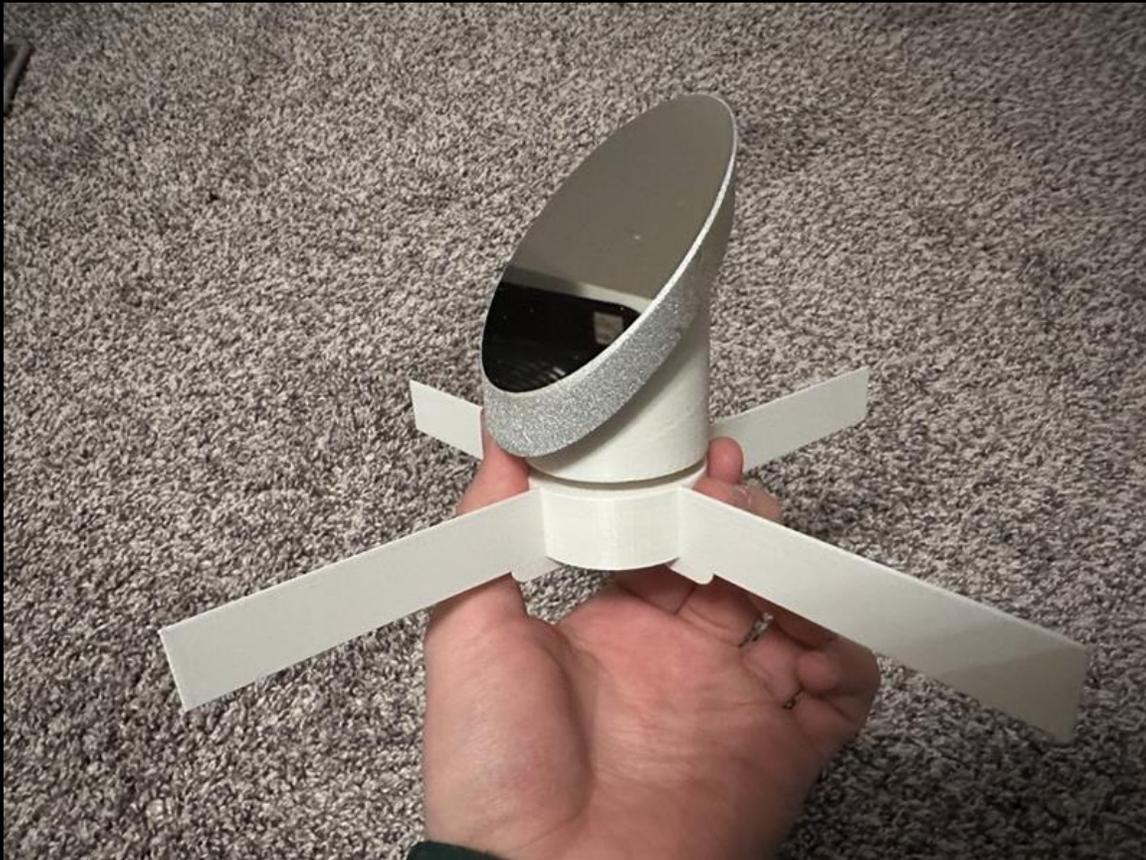
For reference, Silicone RTV is used to aquarium walls and has been used for 50+ years. (Think about the load and time under pressure)



# The glue debate:

Also, I went and assembled the secondary mirror cell and started the glue process with the same method.

Small 3 dots, equidistant from each other and equal in size.



# Tube Assembly:

Once all tubes were printed, I went and applied a small layer of our JB Weld plastic bonder, snapped together all of the connectors and let the tube cure for a few hours.



# Tube Assembly:

Here it is fully assembled and curing

If you look closely, you can see where the sections meet where it is snapped and glued together

I placed the glued mirror and secondary mirror assembly in the tube as well.





# Testing:

I couldn't resist, so collimated it and took the tube out that night to see if it worked.

I laid it down on the ground and pointed it at the moon near the horizon.

It focused!!



First light was a success, but the base still had to be made, and *I realized something about important about magnification.*

# What is “magnification”

*Magnification is the ability of a telescope to make an object appear larger.*

Magnification = Telescope Focal Length /  
Eyepiece Focal Length

I can't change my focal length, that is given to be with the mirrors I purchased. But I can change the lenses and add a Barlow lens (which can double, triple, or even quintuple your magnification.)

Smaller mm lens = larger magnification.

In our case, my telescope has a magnification range of 25.38x to 73.08x.... which is not much relatively.



Custom Scope - Celestron - E-Lux - 26mm - EP: 5.21mm - Mag: 39x

# Magnification

There is an excellent website titled “Astronomy Tools”, with a FOV calculator and imager. I would highly suggest looking at this website *before* purchasing primary and secondary mirrors.

My magnification is way lower than expected. For example, here is what Jupiter looks like with my smallest lens and 2x Barlow through the FOV calculator.

Its small!



Custom Scope - Celestron - E-Lux - 26mm & 2x Barlow - EP: 2.6mm - Mag: 78x

[https://astronomy.tools/calculators/field\\_of\\_view/](https://astronomy.tools/calculators/field_of_view/)

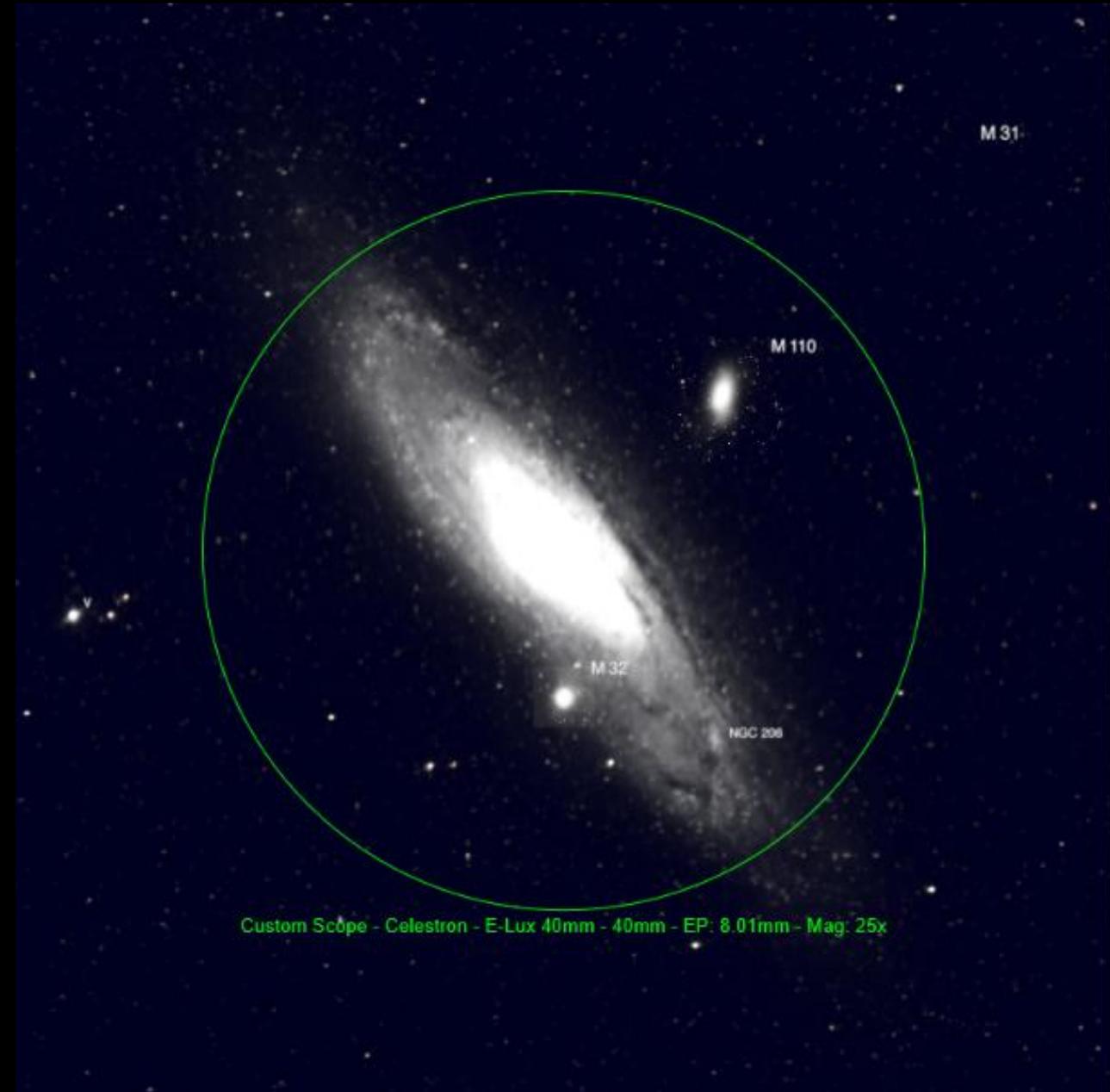
# Magnification

I can acquire smaller focal length lens or use this telescope for large FOV astrophotography... which was the goal.

Here is what my largest lens with no Barlow FOV looks like with the Andromeda Galaxy, our closest neighboring galaxy, and largest object in the night sky... perfect!

Although... this is *NOT* what it would look like through the telescope with the naked eye.

[https://astronomy.tools/calculators/field\\_of\\_view/](https://astronomy.tools/calculators/field_of_view/)



# Long Exposure

To see galaxies, you need to take long exposure photos.

Your eye cannot receive enough photons from these distant objects to make them visible.

Long exposure photos require an equatorial tracking mount, as long exposure photos create streaks of lines over time as objects move across the night sky relative to us on earth.



# Stacking photos

Distant objects, such as the Whirlpool galaxy don't move much relative to our FOV... but earth does.

Earths rotation is what makes viewing distant objects difficult. Closer objects like planets have their own movement through the night sky as well.

This is why tracking is important.



*Whirlpool galaxy image taken from Hubble*

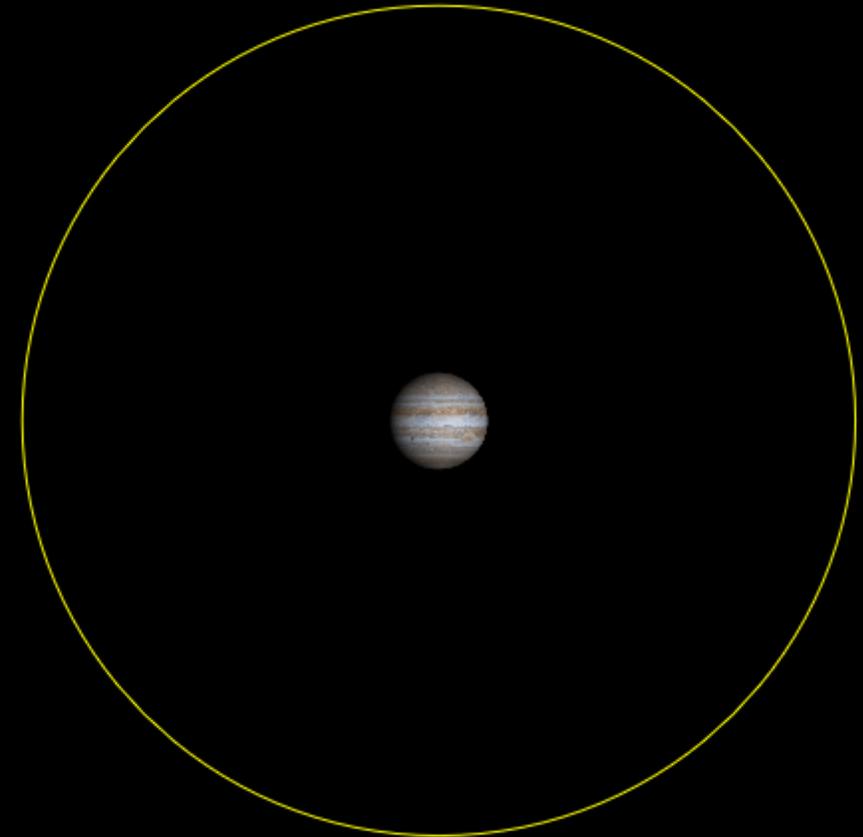
With tracking, you can take multiple long exposure photos and stack them together in post processing. This is precisely what every great telescope does including Hubble and JWST. This provides clearer images and is exactly what I will need to do with mine to achieve high quality photos.

# Magnification

I grabbed a kit of lens from an old telescope I had. It had as small as a 4mm lens.

Using this 4 mm lens, with a 2x Barlow. I can get up 508x magnification. This means Jupiter is massive! This is exactly what I was going for.

The real catch will be seeing how accurately this simulator aligns with real life.



Custom Scope - Custom Eyepiece & 2x Barlow - EP: 0.4mm - Mag: 508x

[https://astronomy.tools/calculators/field\\_of\\_view/](https://astronomy.tools/calculators/field_of_view/)

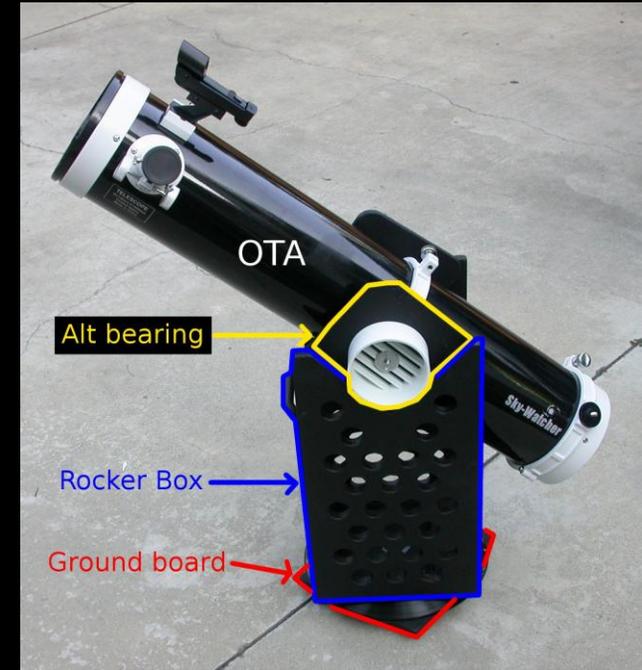
# Current setup

For now, I am going to finish making a regular mount without equatorial tracking. That will be a separate project and video.

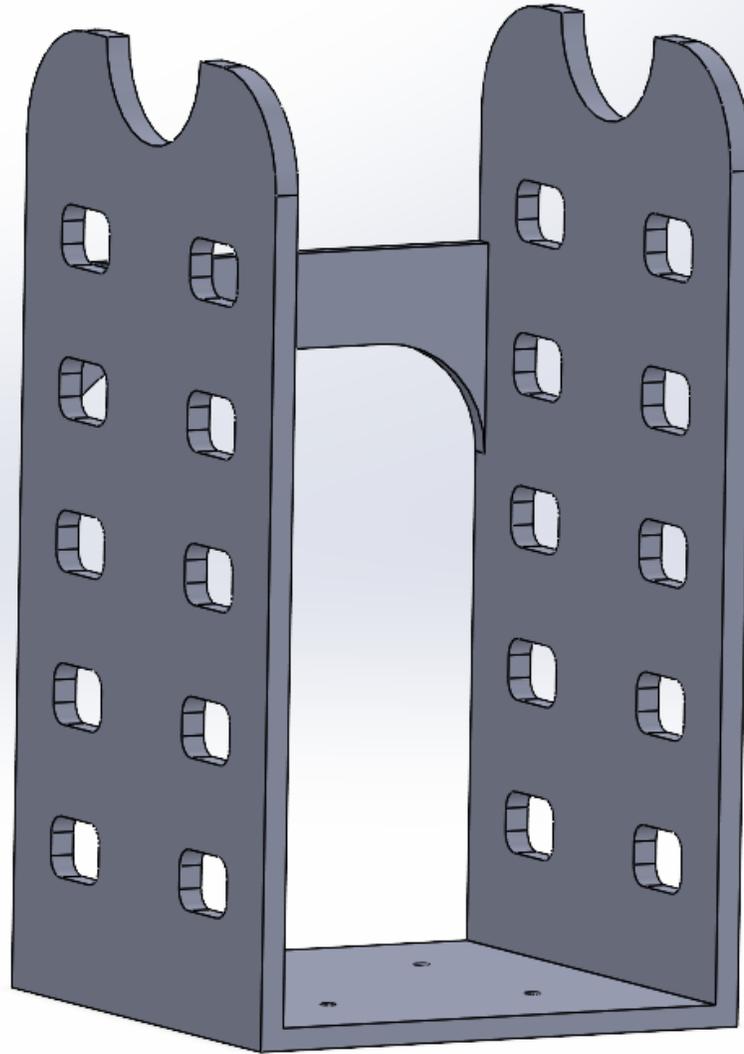
I will finish assembly of the mount and show the final product. As well as a few photos of objects I can see with the naked eye, without tracking capabilities.

# Dobsonian Base:

- The Dobsonian telescope base comes from John Dobson, who developed a simple, affordable alt-azimuth mount in the 1960s to hold large, homemade Newtonian reflector telescopes.
- I chose this style for its affordability, simple design, ease of use, and ability to hold a large aperture telescope for a low cost



Mount:



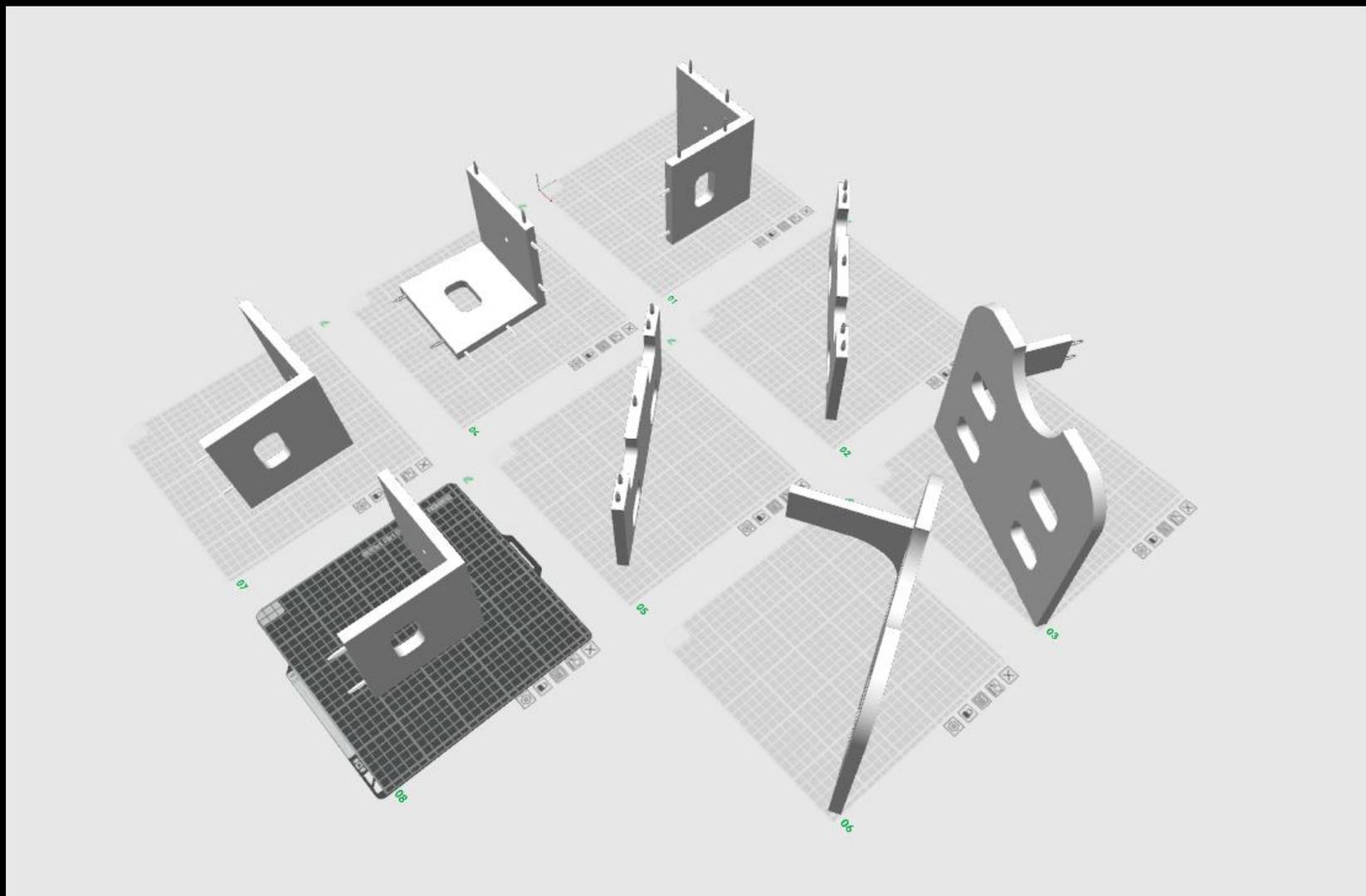
# Mount:

Filament	Model	Support	Total
■ 1	492.84 m	64.45 m	557.29 m
	1564.75 g	204.63 g	1769.37 g

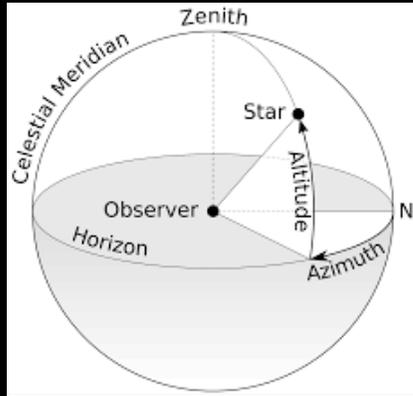
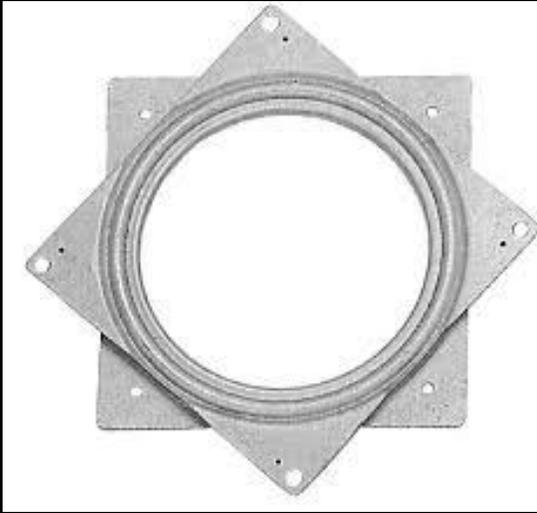
Total cost: 44.22

## Time Estimation

Plate 1	2h39m
Plate 2	2h26m
Plate 3	5h53m
Plate 4	2h30m
Plate 5	2h26m
Plate 6	5h51m
Plate 7	2h53m
Plate 8	2h40m
Total	1d3h17m



# Rotating Base:

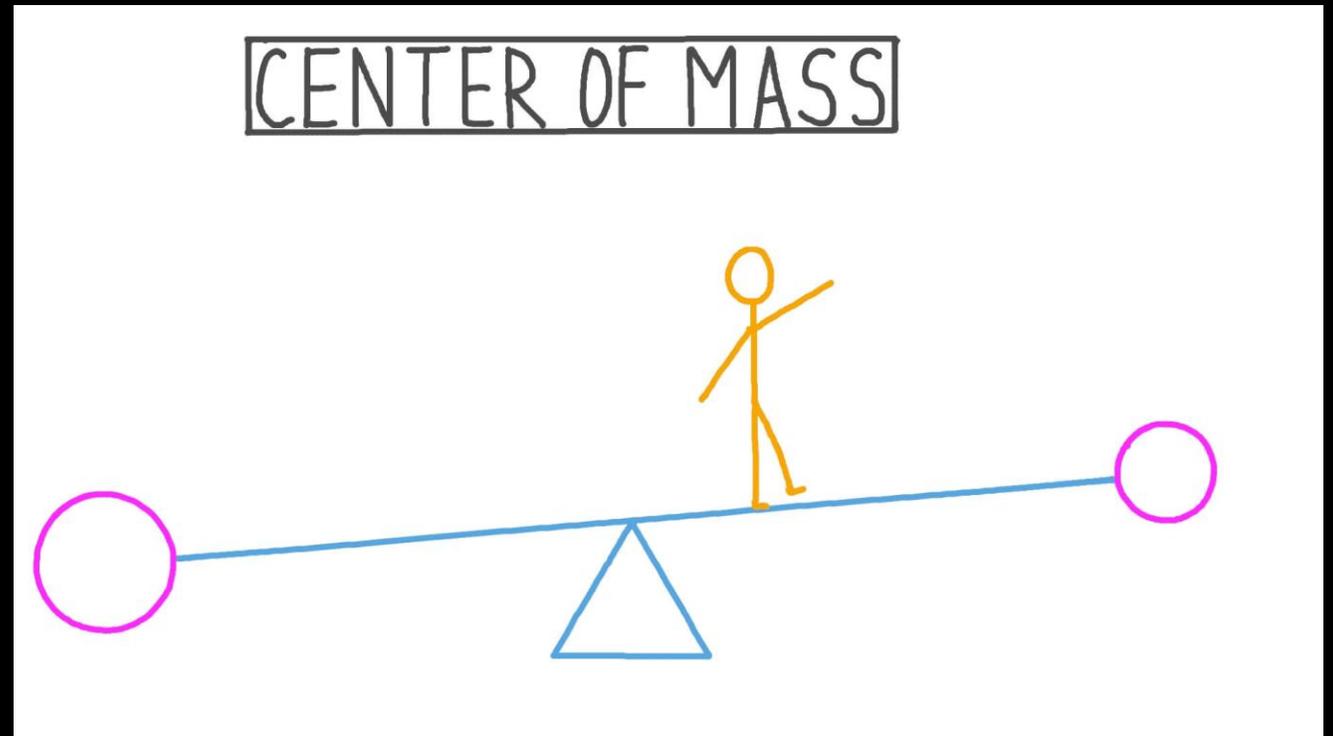


- Lazy Susan bearing sandwiched between the mount and a circular base to get full 360-degree rotation (can be called the azimuth angle in astronomy relative to true north)



# Weighting:

- A good telescope is weighted properly, to allow for easy adjustability
- I failed to properly predict the center of mass
- The center of mass creates a great position to pivot the telescope about
- This ensures the telescope does not rotate forward or backwards when trying to make minute adjustments



# Finding CM:

- Find the mass all of the objects in your telescope (mirrors, mirror cells, eyepiece, and lens)
- Find the distance of those objects using an arbitrary distance (choose the base of your telescope for simplicity).
- Multiply mass \* distance for each summation of item measuring
- Divide that value by sum of mass
- Create your pivot point with that given distance value calculated

$$X_{cm} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \dots}{m_1 + m_2 + m_3 + \dots}$$

# Weighting:

- I did not do this correctly
- Therefore, I had to weight my telescope using actual weights.
- I chose adhesive tire balancing weight
  - Cheap
  - Sticks directly to curvature of the tube
  - Adjustable



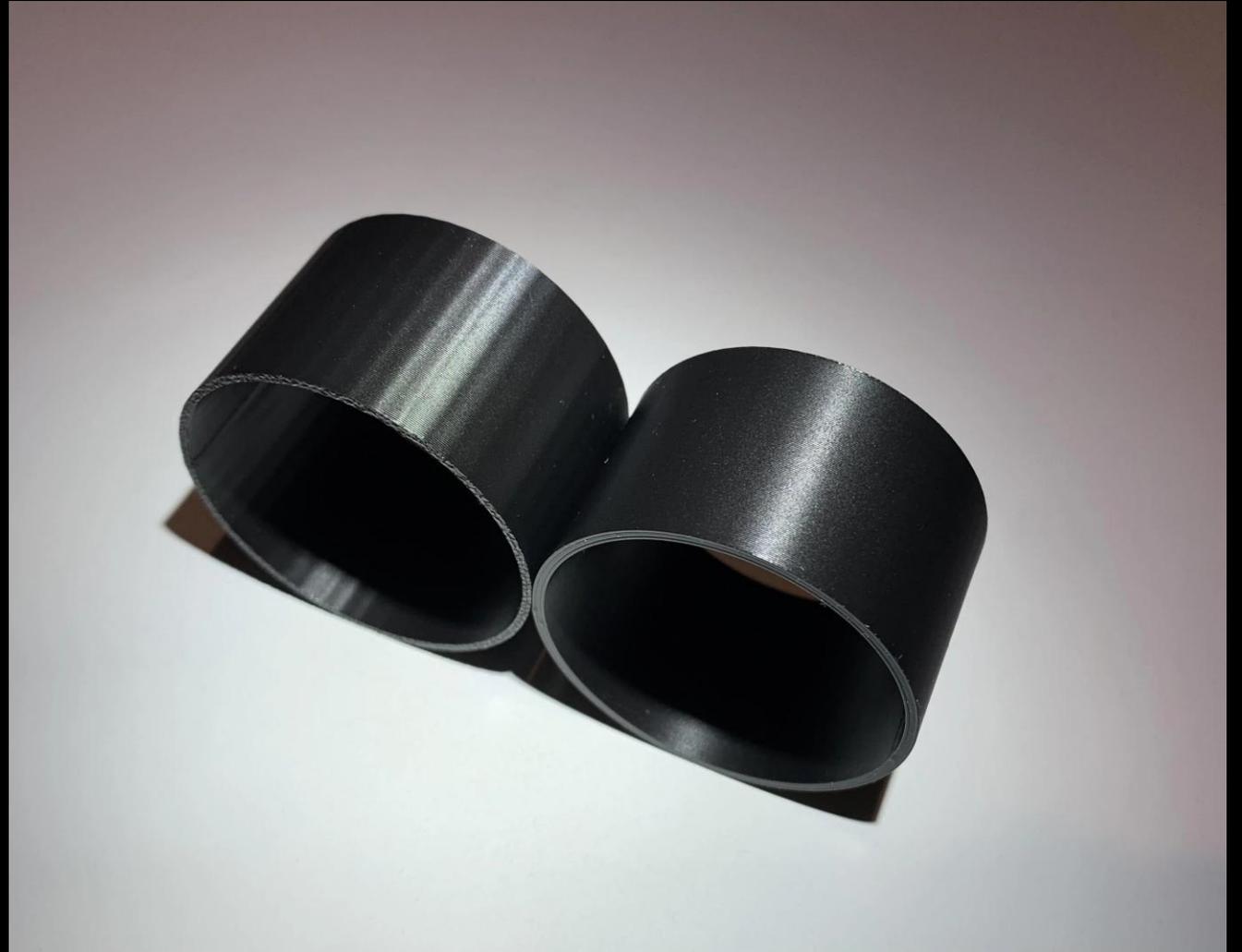
Finished Product



Things I would change

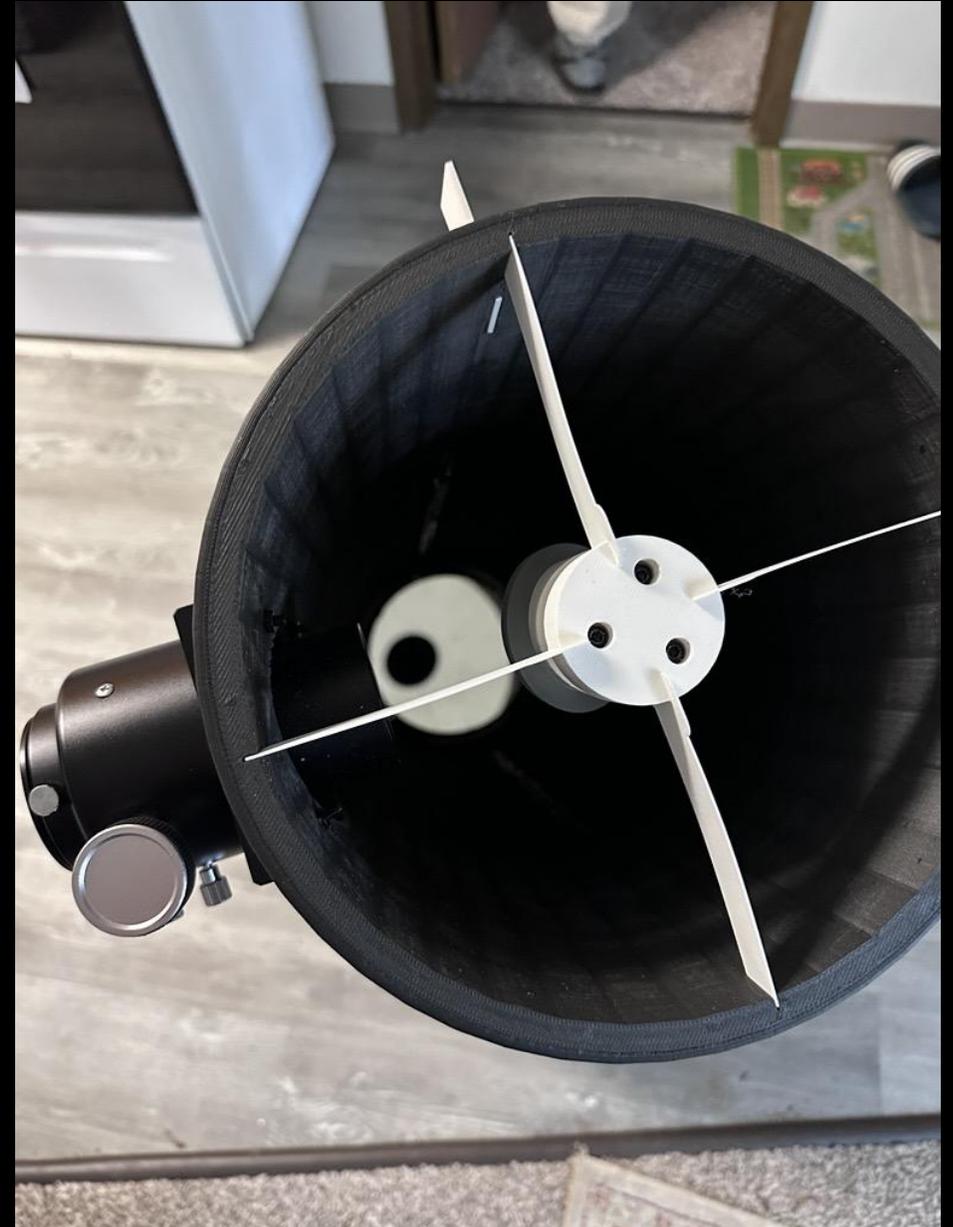
# Things I would change

- Using STEP files instead of STL files for the tube
  - Creates a smoother edge for tube



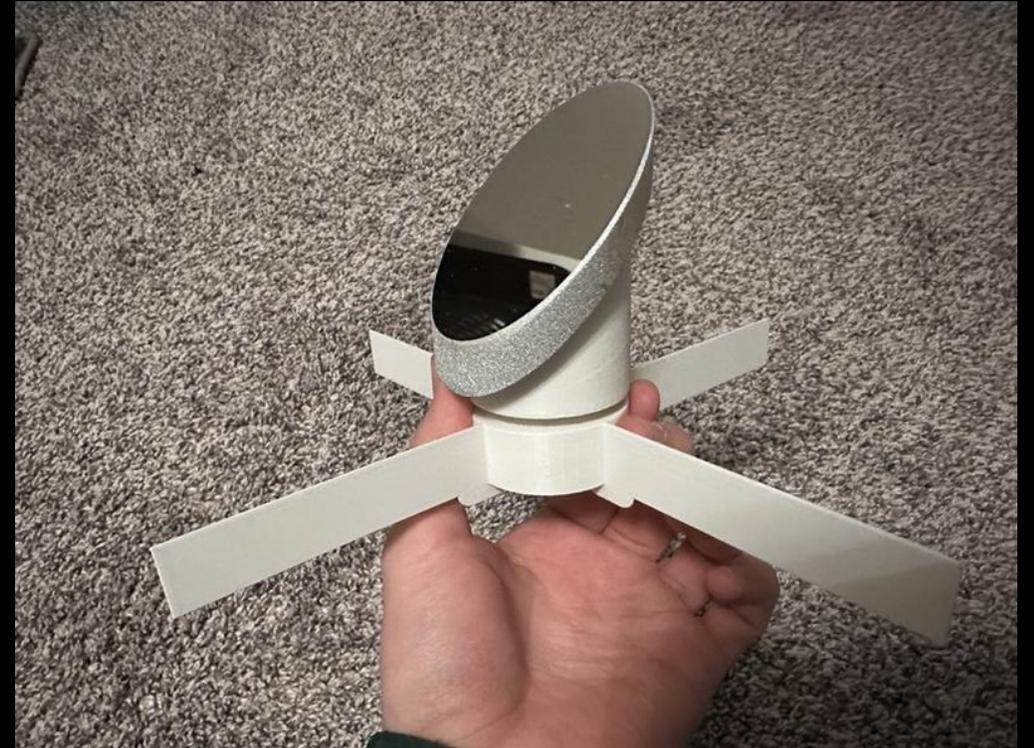
# Things I would change

- Thinner tube walls
  - 0.25" walls with 2 walls and 10% infill turned out very strong
  - Reduced size to save on filament



# Things I would change

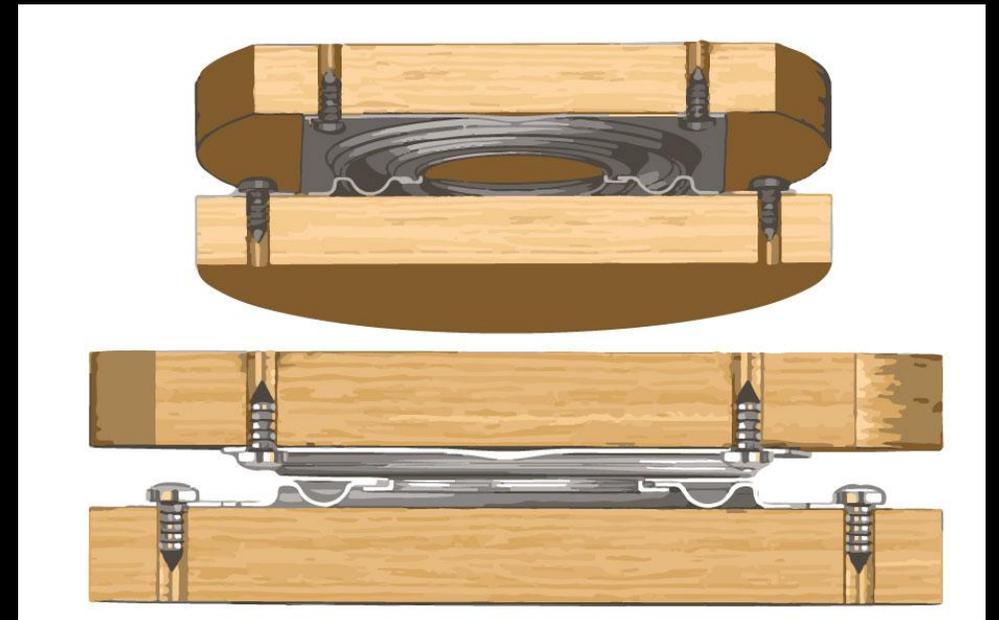
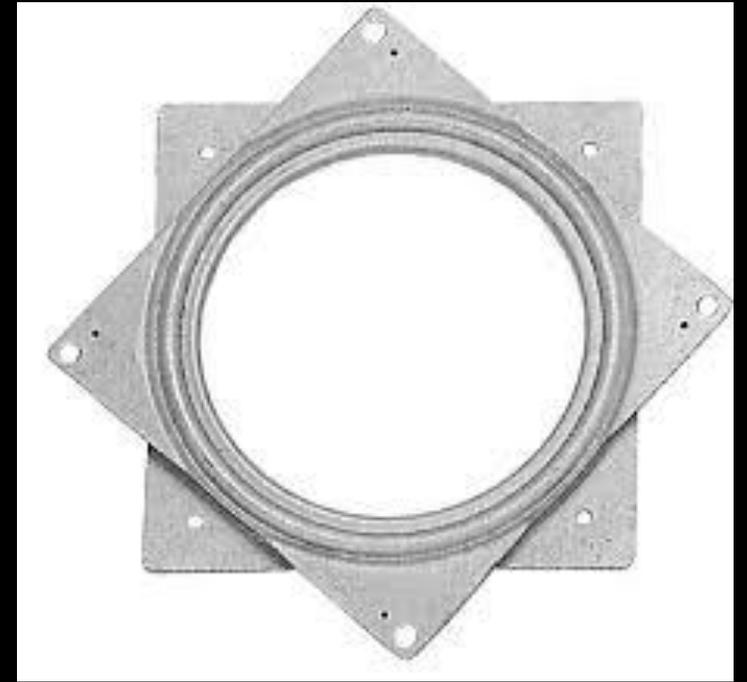
- Metal vanes for the secondary mirror holder
  - 3d printed vanes were tricky to print and are not very strong laterally
  - Send-cut-send metal vanes would be a better option
  - Easier to collimate



*SendCutSend*

# Wobbly Susan

- Our lazy Susan bearing is wobbly
- Consist of two tracks with ball bearings in-between
- My cheap lazy Susan allows for the plates to be separate and moved up and down easily
- Solution: don't buy the cheapest lazy Susan bearing online



Results: