Building the Fully* Printed Newtonian

Introduction

This document describes the process for selecting sizes and building the "Fully* Printed Newtonian" telescope, which built with only printer filament, mirrors, glue, and #6 screws. (Use of a purchased tube is also an option and is described below.)

The design philosophy and the reasons for certain design choices are detailed elsewhere, and this document focuses on preparing the materials, choosing the size, and assembling the telescope.

(The model files are available on Printables.com here and on GitHub here.)

Materials Required

The printed parts excluding the tube require roughly 250 g of filament (for a 114 mm mirror diameter), at ~100 for the primary mount, and ~50g each for the secondary mount, the viewport mount, and the tripod strap. A bit more will be needed for the various accessories. Black filament should be used to minimize stray light, although non-black filament may be okay if the telescope is used only at night.

The tube, if printed, requires about 800 g of filament for the variant with 114 mm diameter, 900 mm focal length. The filament requirement will be roughly proportional to diameter and length. As with the other parts, the tube should be printed with black filament, although it is also possible to paint the interior of the tube.

Excluding the mirror and tube, which are discussed in the next section, you will need:

- Screws: #6 sheet metal screws, 1/2" length, which I believe is equivalent to 3.5 mm sheet metal screws with 12 mm length (length is not critical). You will need at least 6 to install an eyepiece.
- Epoxy
- Tape (optional) for securing mirrors to mounts instead of epoxy

* Since the Fully* Printed Newtonian is not *literally, fully* printed, please do not refer to it as "Fully Printed Newtonian" or "FP Newtonian" or "FPN". Instead call it "Fully* Printed Newtonian" or "F*P Newtonian", or "F*PN".

Figure 1. Screws, epoxy, and tape

If you are building the tripod mount, you will need one ¼”-20 nut. (Quarter inch nominal size, 20 threads per inch.)

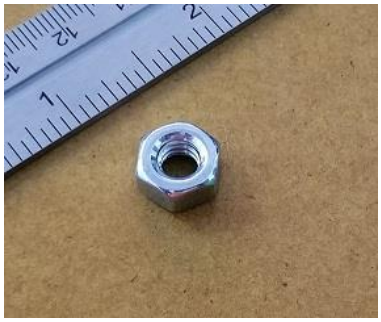

Figure 2. Quarter-20 nut for tripod mount

If you are purchasing a tube you will also need some sort of saw, a drill, and a step drill bit to make a 25 mm hole.

Figure 3. Saw and drill with 25 mm drill bit

Choice of Mirror and Tube

For a Newtonian style telescope to have ideal performance, there are two options: the primary mirror can be spherical with a relatively long focal ratio, or it must be parabolic. The options are summarized in Figure 4, where the green region represents the zone where spherical mirrors produce good image quality:

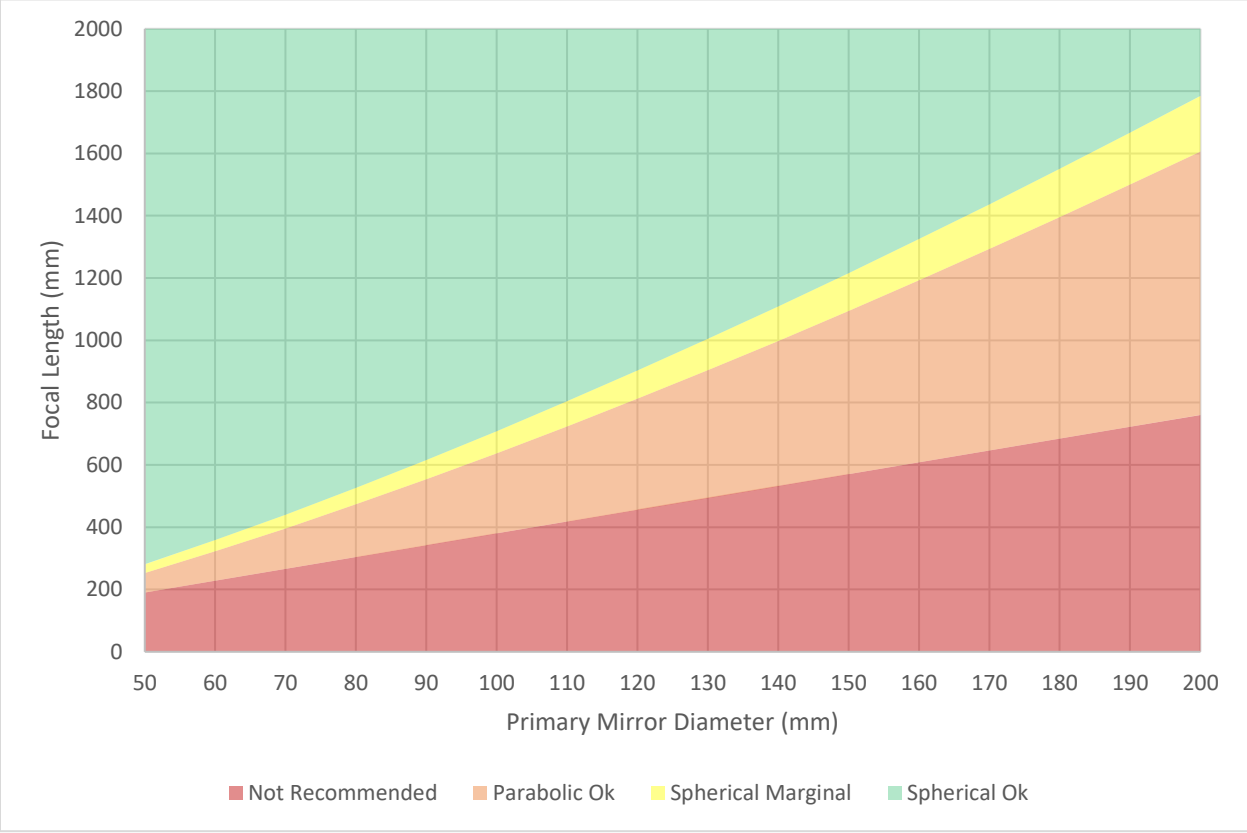

Figure 4. Cheaper spherical mirrors are permitted at longer focal ratios, while parabolic mirrors are required for shorter focal ratios.

Since spherical mirrors are much less expensive than parabolic mirrors, it is assumed that spherical mirrors with long focal lengths are usually going to be chosen, but parabolic mirrors are also permitted, except that very short focal lengths are not recommended, as illustrated by the red area in Figure 4.

For a printed tube, the outside diameter of the tube is about 25 mm larger than the mirror, and your printer must be able to accommodate this, plus an additional 6 mm for the various straps that clamp onto to the outside of the tube. So, for example, a 150 mm printable area would be able to accommodate a mirror size up to 119 mm.

If you purchase a tube, the recommended size for the inside diameter is between 15 mm and 40 mm larger than the mirror. The exact dimension is not critical, but too large or too small and the performance will suffer. The outside diameter of the tube must be at least 10 mm larger than the diameter of the mirror, or it will not assemble properly.

Given these guidelines, you may purchase a tube and cut it to length if you can find a compatible tube and mirror combination of appropriate sizes, or if you wish to use a mirror for which no appropriate tube can be found (or if you prefer not to use a saw and drill), then you may print a tube instead.

Constructing Telescope Body from Purchased Tube

Cut the tube such that the length L is

$$L = \text{focal length} - 77 - \frac{\text{tube outside diameter}}{2}$$

Cut the ends perpendicular and flat to the extent possible. (Note: do not assume the factory-cut end of PVC tube is cut square!) One way to get a square cut is to wrap a ribbon or some flat material like paper around the tube and use it as a guide to mark a line. Then cut the tube very slightly long and use a file or sandpaper to file the tube back to the line.

After cutting the tube to length, drill a hole in the side. This hole should be 25 mm in diameter and the center of the hole should be 37.5 mm from the end.

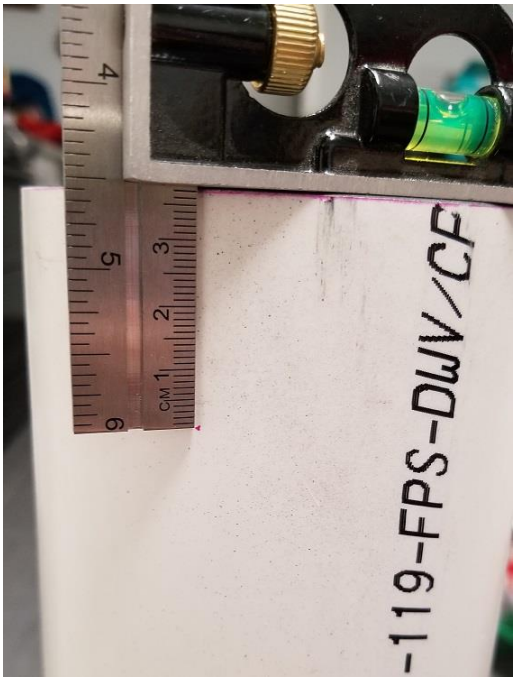

Figure 5. Side hole is 37 mm from end

The interior of the tube should be painted black, and the inside surface of the drilled hole should also be painted black, to minimize stray light contaminating the image.

Figure 6. Painted interior of tube and edge of hole

As an example, for a primary mirror with a diameter of 80 mm and a focal length of 800 mm, the recommended inside diameter is between 95 and 120 mm. A four-inch PVC tube has an inside diameter of approximately 106 mm, so it is suitable for the 80 mm mirror. The outer diameter of the 4" PVC pipe is about 113 mm, so the tube should be cut to a length of:

$$L = 800 - 77 - \frac{113}{2} = 666.5 \text{ mm length}$$

Irrespective of mirror or tube diameter or focal length, the hole in the side of the tube should be centered at 37.5 mm from the end, and the diameter should be 25 mm.

Printing and Assembling the Customized Tube

If an appropriate tube is difficult to find, or if it is expensive, then tubes can be printed. Even if an appropriate tube is available, using a printed tube requires only gluing, and avoids the need to cut it to length or drill holes, which might be an advantage depending on what tools are available.

The printed tube is printed in sections, with one 'bottom' segment serving as the first segment, to which the primary mirror is attached, and one 'top' segment, where the secondary mirror and viewing attachments are mounted. In between are some number of 'middle' segments. Usually there will be two middle segments, but the exact number will depend on the overall length of the final tube and the maximum Z capacity of your printer.

Black filament is recommended, to minimize stray light within the tube. If you are not using black filament, then you should plan on painting the interior surface black. This is even more important if you use the telescope for daytime terrestrial viewing.

Figure 7. Printed segments for 114 mm mirror with 900 mm focal length.

The assembly of the segments should be self-evident. Each tube segment has a concentric overlapping feature to assist gluing the segments straight and concentric. Perform a dry fit of all the pieces before gluing. Then apply epoxy to the mating surfaces and press together such that the layer of glue mostly squeezes out and the surfaces are bonded securely and straight. Allow plenty of time for the epoxy to set.

Figure 8. Segments after painting and assembled and glued together.
(Top segment replaced because painting was too messy.)

The remaining instructions are the same, regardless of whether the tube was purchased, cut, and drilled, or if it was printed in segments and glued together. The pictures will show a combination of 80 mm with purchased tube and 114 mm with printed tube.

Alignment

The purpose of aligning the mirrors is to ensure that the axis of the primary (and secondary) mirror is "looking" directly down the axis of the tube and not off to one side. If the mirrors are crooked, the telescope will still produce an image, but off-axis from perpendicular to the primary mirror. This creates optical aberration if the error is significant.

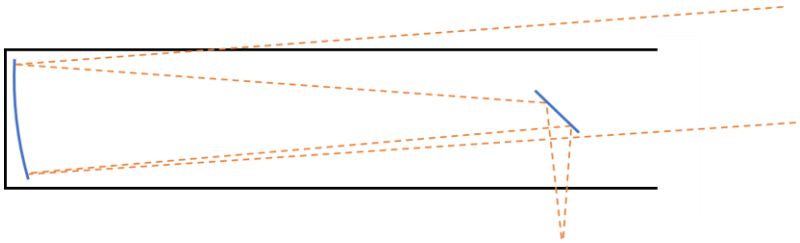

Figure 9. Severe misalignment will harm image quality. The primary mirror should be perpendicular to the axis of the tube.

While the alignment will affect image quality, it does not need to be extremely precise. It should not take more than about 5 minutes to align the primary mirror reasonably well.

Mounting and Aligning the Primary

Before fixing the mirror in place, test fit the mirror mount onto the end of the tube. If it is the wrong size or if it can't be tightened for some reason, it's better to find out before the mirror is secured in place.

Note: if your mirror does not have a spot marked in the center, you will probably want to add one before mounting the mirror into the telescope. The "crosshairs" piece used for primary alignment also has a ring to assist locating the center of the primary mirror. Place it on the primary mirror such that the small gap is equal on all sides and then mark the center accordingly.

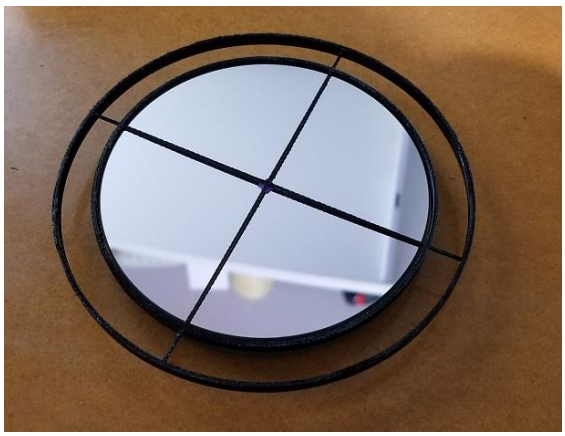

Figure 10. Use crosshairs piece to mark center of primary mirror.

The primary mirror is held to the mount by three spots of glue or tape, and the mount is clamped onto the end of the tube. Three optional adjustment screws allow spacing the mount slightly off of the end of the tube, to align the primary mirror, but I find it is easier to adjust without them.

After securing the mirror to the mount, use a screw to clamp the strap onto the end of the tube tight enough that it won't fall off, but loose enough so some movement is still possible. Make a mark in the center of the mirror, and with a temporary 'crosshairs' mounted on the front end of the tube, adjust the primary mirror until the crosshairs, center mark, and the reflection of the crosshairs appear collinear. This ensures that the center of the mirror is pointing at the center of the front end of the tube.

This is much easier to see visually than it is to photograph. A 10-second video illustration can be seen at https://www.youtube.com/watch?v=JBTcHePyMpQ.

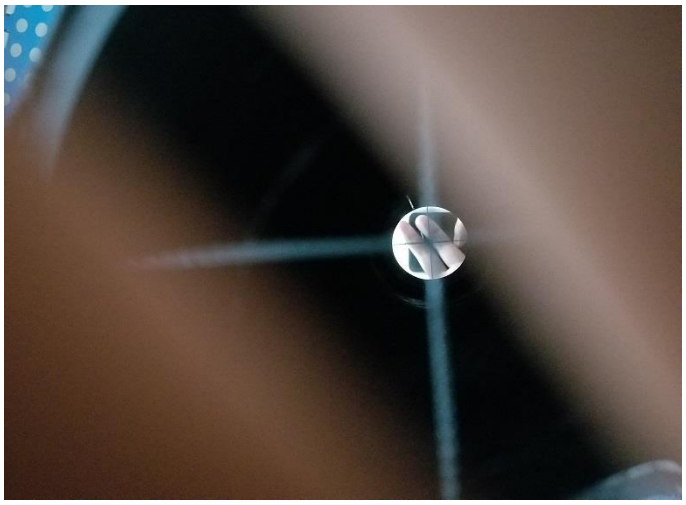

Figure 11. Camera, crosshairs, center of mirror, and reflection of crosshairs are all collinear.

There are three screw holes provided in the perimeter of the primary mirror mount that could be used for fine adjustment, but I found better success gently tapping the edge of the mirror mount to adjust it slightly on one side at a time.

After the adjustment, tighten the clamping screw to hold the mount securely in place, and after tightening, check again to validate that the alignment is still good.

Mounting and Aligning the Secondary

As with the primary, test fit the secondary mirror mount onto the front end of the tube before securing the mirror in place.

The central post on the secondary mirror mount is slightly "short" to accommodate the thickness of the secondary mirror, placing the front surface of the mirror at the appropriate place. Because of this offset, together with the angled mount, it can be a little tricky to properly center the mirror on the mount.

To properly center the mirror, place tape such that the edge of the tape is across the short axis of the mirror. The mirror post has two ridges on the sides. Place the mirror such that the tape is in line with the ribs on both sides. This will ensure that the center of the mirror is properly centered within the tube.

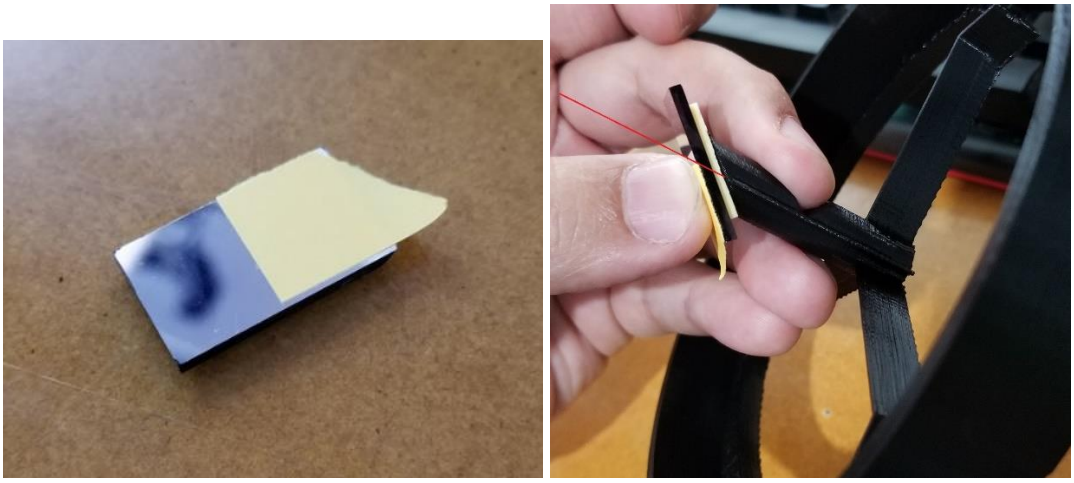

Figure 12. Tape on secondary mirror aligned axially with ribs on mount (illustrated with red line) to properly center

Use glue or tape to affix the secondary mirror onto the spider. If using glue, the mount has a feature to make it relatively easy to clamp the mirror in place while the glue sets.

After mounting the secondary onto the spider, mount the spider onto the front end of the telescope.

Orient the spider such that the secondary reflects out through the hole in the side. Gently tighten the clamping screw so the spider grips the front of the tube, but still allows adjustment.

Look through the hole in the side and make fine adjustments to the spider until you can see the reflection off the secondary, primary, and secondary again (and see your eye) in the reflection. As with the primary adjustment, there are holes for adjustment screws, but I found gently tapping the ring to be much easier. The spot in the center of the primary mirror should be coaxial with this view and it should be near the center of the hole.

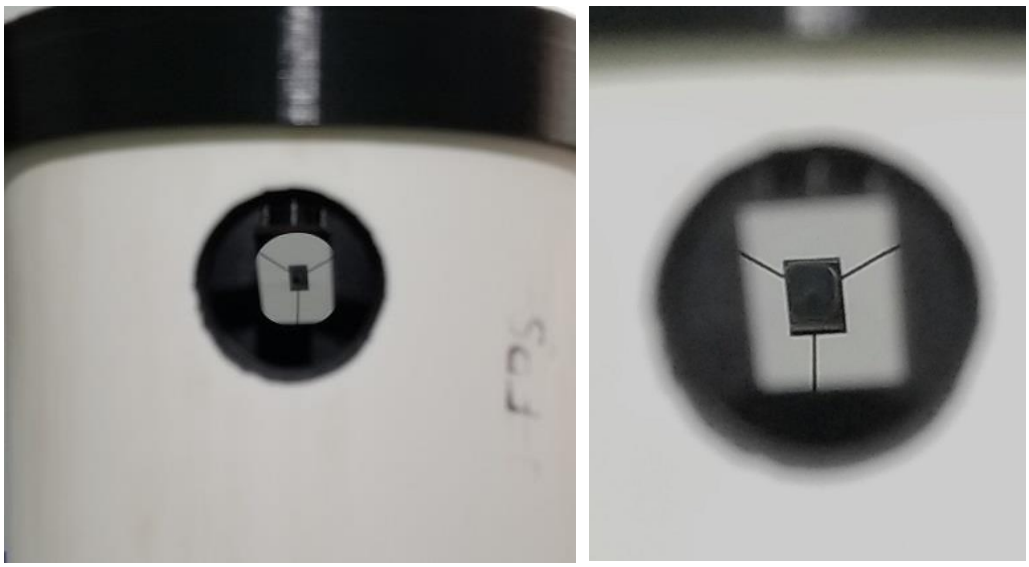

Figure 13. Alignment of secondary is complete when center of primary mirror appears coaxial with eye and center of hole

Tighten down the clamp on the spider, and after tightening, validate that the alignment is still good.

Tripod Mount

Note: The tripod mount is far from ideal, and it is not recommended if you have another option. (A camera tripod is generally not very heavy or stable, so it tends to vibrate, and it is hard to move in small increments.) If nothing else is available, it can be used temporarily until a better one is developed.

To assemble, apply epoxy to the interior wall of the hexagonal recess, and then insert the ¼"-20 nut. Apply a bit more epoxy around the outside of the nut. The "floor" between the nut and the tripod is relatively thin because some tripods have short bolts. The epoxy adds strength so that the telescope has more support than just that thin layer of plastic.

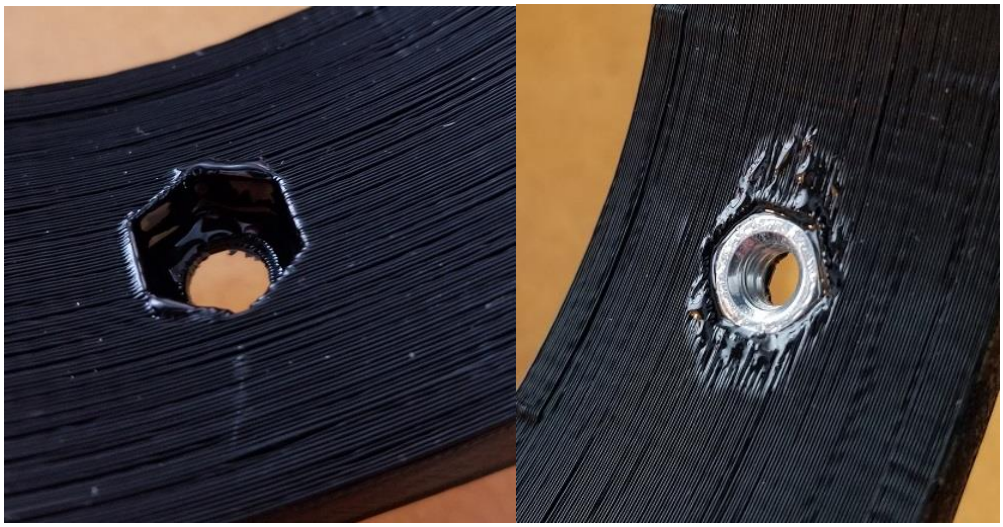

Figure 14. Epoxy secures nut to provide more strength than thin-wall plastic.
(A small amount will do; the amount shown is too much and made a mess.)

Note: the tripod screw is not usually rigid enough to prevent unthreading by turning the entire telescope to the left or right. Use care when rotating the telescope to avoid accidentally unthreading the telescope from the tripod.

Tip: I have found it is generally very hard to move the tripod in small increments. One trick that seems to work is to grab the tip of one of the feet where it meets the ground and move it slightly. This changes the orientation of the telescope only slightly.

After the epoxy has set, the strap should be flexible enough to stretch to fit over the primary mirror mount, so no disassembly is needed to add or remove the tripod mount.

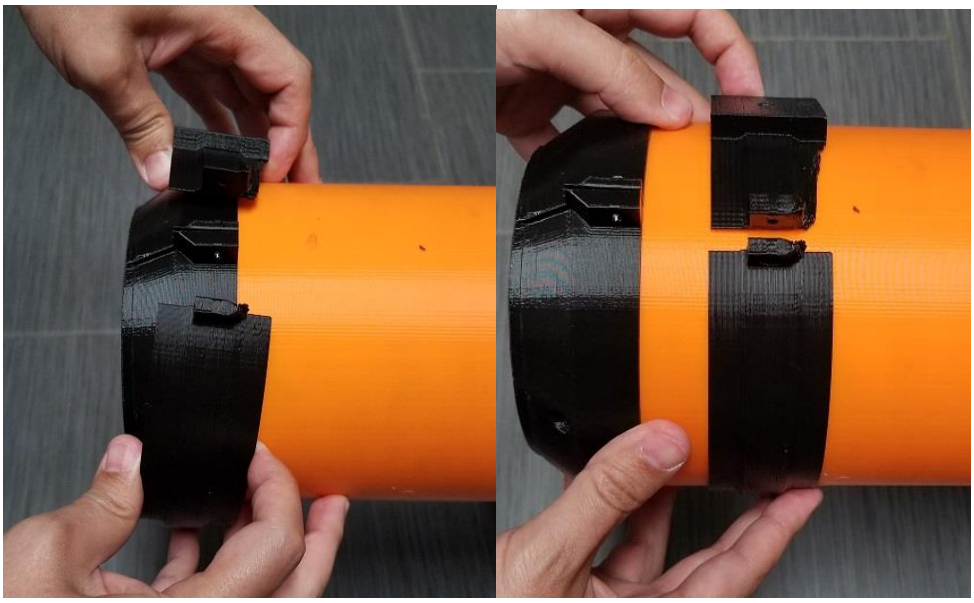

Figure 15. Stretch tripod mount strap to fit over the primary mirror mount.

Place the mount near the center of gravity of the telescope. Tighten down the clamp. Thread the tripod bolt into the trapped nut and secure.

Viewer Mount (For Eyepiece or Other Accessories)

The Viewer Mount is attached to the tube at the hole in the side and allows mounting various accessories. As an interface it offers a 1.25-inch boss, 10 mm in length, with a flange behind it.

To attach the Viewer Mount to the telescope, simply slide it over the end of the tube, align with the hole, and tighten down with a screw. It should be flexible enough that it can be installed or removed without removing the secondary mirror mount.

Figure 16. Viewer mount installed

Eyepiece Mount

The eyepiece mount is extremely simple. Clamp one end firmly onto the boss of the viewer mount, and the other end onto the eyepiece. Gently tighten the clamp on the eyepiece, leaving it loose enough to

allow movement by hand. Manually slide the eyepiece forward or back to get optimal focus, and then tighten the clamp on the eyepiece.

The length of the eyepiece mount is such that the image plane should be near the upper screw clamp, which is 72 mm away from the flange. However, small deviations in the assembly such as adjustments to align the primary or secondary mirror can influence the exact focus position.

Figure 17. Eyepiece mount and installed eyepiece

One Final Step

The last step is one of the most important: have fun! The image quality of this telescope will be as good or better than others of similar size, thanks to the somewhat fool-proof Newtonian configuration. Completing the project and exploring the night sky visually or through photography can be very rewarding. If you enjoy tinkering as much as astronomy, perhaps you can add an equatorial mount and clock drive. Maybe you can create a computerized tracking system or adapt an existing one.