8" Binocular Telescope

WVAS started discussions for a new project in the fall of 1998. After months of discussions and presentations, we decided to build an 8-inch binocular telescope.
Three major issues of design came up: The first was portability. Two 8" optical tube assemblies mounted permanently together would be quite bulky. Using two separate tubes that would be separated between uses and reattached for use might make the alignment problem (second issue) more difficult. We decided to make the tubes in sections with only the rear parts permanently attached in a box frame. The upper section includes a truss tube section to increase portability and decrease the needed storage space.
The second issue was alignment: With a binocular scope there has to be a way to adjust the distance between the eyepieces. The individual scopes are Newtonian reflectors, so when the light cone comes out of the side of the tube it is bounced off a star diagonal (the "tertiary") so that the light cones and eyepieces are parallel for viewing. With this set-up, the easiest way to vary the inter-ocular distance is to use a focuser at the normal Newtonian position to vary the distance from the telescope tube to the tertiary and eyepiece. The problem with that is that it changes the distance from the primary mirror to the eyepiece, so it changes the focus. Another focuser is placed after the teriary and holds the eyepiece. We wanted to build a scope that could be used at public events, and it has been our experience that the general public is often very timid about touching the controls on a scope, so having to adjust the first two focusers and then make a significant change with the other two focusers may be too much "fussing" for the general public.

Another option is to change the inter-ocular distance by moving one or both telescope tubes. The difficulty with this is that with the magnification, the tubes need to maintain their alignment to within about 1 arcminute (at high power, and especially in the vertical direction) for the eyes and brain to combine the two images into one. This is difficult to do given the size and weight of the full tubes. Several methods to do this have been tried by other people, and it is generally regarded as one of the most difficult parts of building such a telescope. We ultimately decided to suspend the lower sections of the tubes from pivots so the tubes would swing out away from each other to the needed inter-ocular distance (much like conventional binoculars, except that each tube will have its own pivot).

The third issue involved optics: As mentioned above, an extra diagonal is needed to aim the light cones and eyepieces in a parallel direction. This means more of the light path is past the secondary, so a larger secondary is required, and that will degrade the image. A possible cure for this is to install a Barlow lens in the side of the tube where the light cone exits the tube. This streches out the remainder of the cone so that a smaller secondary can be placed farther from the primary and still achieve focus at the eyepiece.

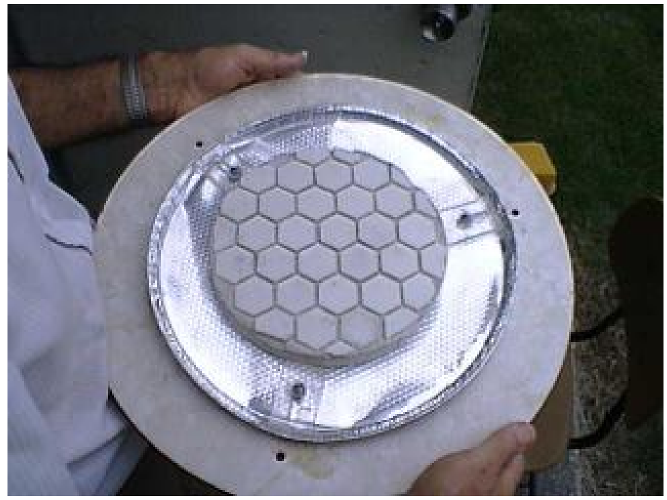
The drawback is that the scope operates at a high focal ratio, which means higher magnification, a correspondingly smaller field of view, and tighter alignment tolerance. In fact, since the light path bounces through the tertiary star diagonal before going to the eyepiece, a standard 2X Barlow will operate at about 3X. We used a "shorty" Barlow, with the Barlow tube itself acting as the extension tube between the side of the main tube and the tertiary. In our Barlow the cell holding the Barlow lens itself unscrews from the tube so it can be removed for low power viewing. There may be a bit of vignetting in this case since in choosing the secondary size, we compromised between the two options, but leaned toward the smaller size, leaving open the possibility of getting a larger second set of secondaries later for better low power viewing. The lower tube sections will have two sets of mounting holes for the primary mirror cells since the mirrors will have to be moved forward if the Barlow is not used.

It is common knowlege that using two eyes allows for easier viewing and usually provides a better view, but after reading about the extreme difficulty of the alignment problem, you may be wondering why we didn't just start with a single primary with twice the surface area and use a bino-viewer. After all, a larger primary is theoretically capable of producing higher resolution, right? There are several reasons we didn't take that route: first, the cheapest bino-viewers cost about as much as our entire budget for this project. Second, while a larger primary would achieve better resolution under perfect conditions, conditions are rarely good enough to get better resolution than an 8" mirror provides, and a larger mirror will actually be more affected by atmospheric turbulence on bad nights. Also (and not often recognized), since the two mirrors will be looking through different air masses, they will show two slightly different images, depending on how each is affected by the turbulence. When the brain gets two views of the same object, it is remarkably good at concentrating on the sharper image. Thus a true binocular scope provides good views almost twice as often as a single tube scope. Finally, another reason we made this particular type of scope (and not some other type of scope altogether) was that Jim Sattler had two 8" mirror blanks to donate to the project.

Work started on September 5, 1999. The mirror was given a rough shape using a curve generator.

Next we built the ceramic tile grinding tool.
The real work of grinding the glass is done by the grit that is kept on the surface. You can see the grit being pumped onto the surface in the picture below.


Rockwell



Those pathetic frozen pizzas have the perfect sized pans for making sure that the slurry formed by the grit and water would stay contained. While cleaning the turntable is not difficult, it could get messy if we did not constantly make sure the slurry was contained. Additionally, each time that we need to go to finer grit, we HAVE to get ALL of the old coarser grit out of the system. A single piece of old grit could mess up the mirror by causing deep scratches or pits that would have to be ground out starting with the coarser grit and then moving back toward the finer grit.

Next we had to clean up the grinding machine...

While getting the machine uncovered was the first chore, getting it cleaned up was the second. Although the machine would be getting dirty with the grinding grit, we needed to make sure that the grit was just what we put on the tool, not from old dirt falling onto the surface, which could cause serious scratches.

Jim (Mettler) and Jim (Sattler) found that the machine had been last used to grind a 6" mirror. This required that the stroker cam be adjusted. It needed to be adjusted so that the upper object would go about 1/3rd of the mirror's diameter past the edge of the lower object. This is the length of the standard grinding/polishing stroke.

The standard stroke normally requires that the upper object also be moved gradually side to side, about 1/3 the mirror diameter in either direction, so that the center of the upper object traces out a W shaped path over the center of the lower object. Also both the upper object and the stroke direction are occasionally rotated. In this case, the machine produces only slight side to side movement, but that is countered by the machine's constant rotation of the lower object and the more frequent rotation of the upper object. The upper object is <u>not</u> held firmly in place by the alligator. Instead, it literally bounces between four rubber bumpers. The looseness allows the

object to turn a bit at the end of each stroke. The relatively crude construction of the alligator also insures that the rotation of the upper object is not too consistent, which could introduce regular errors in the shape of the mirror due to the cyclic nature of the action. Randomness causes any errors to be distributed around the entire surface of the mirror and average out so a reasonably spherical shape will be formed.

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Finally it was time to begin rough grinding...

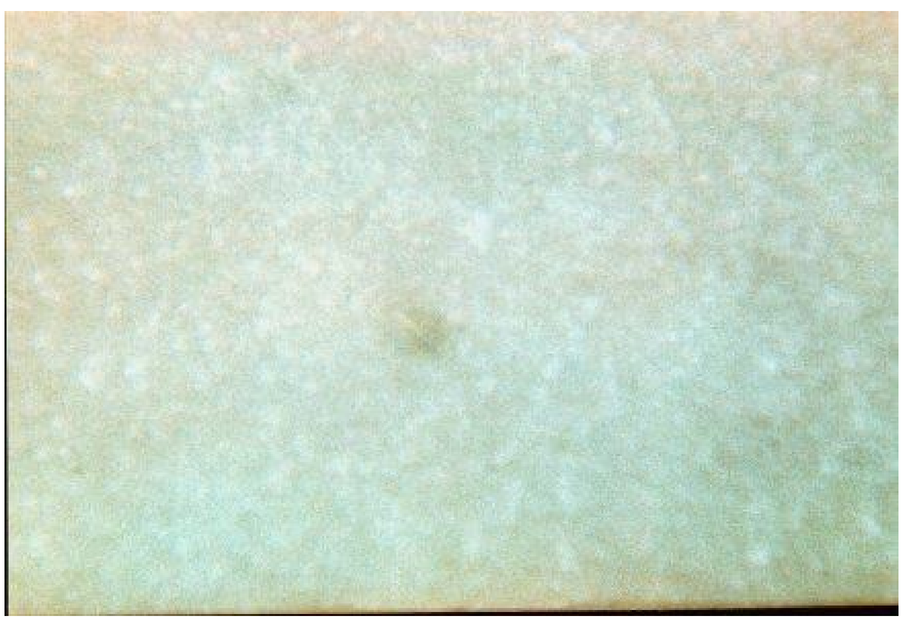
Patience is a virtue, or so they say. Unfortunately, if you wait for the simple weight of the mirror against the grit and tool to get rid of the radial lines, then death will come shortly before those lines are ground out. So we removed the alligator and applied a bit of muscle to put more pressure on the tool (now on top of the mirror, since we wanted less curvature at the point) while grinding. The machine turned the mirror and we all took turns manually moving the tool. Later we proved we were smarter than the machine by putting weights on top of the tool to increase the pressure and putting the alligator back on so the machine would move the tool. (or were we so smart? This approach nearly proved disastrous during the polishing phase.)

After we finished the rough grinding, we moved onto the fine grinding...

Since the grinding machine produces random motions, the resulting surface must be approximately spherical. This is simply because grinding removes any high spots and a spherical surface is the only surface that allows full contact regardless of the orientation of the surfaces (think of a small section of a ball-and-socket joint). As the grinding progressed, we needed to make sure the curvature was staying approximately correct. If the curvature was too shallow (longer focal length), we needed to deepen it (by working with the mirror on top). If it was getting too deep (shorter focal length), then we needed to make it more shallow (by working with the tool on top). Jim Sattler used his spherometer to measure the curvature. At one point early in the grinding process, it became obvious that one mirror was significantly shallower than the other, which would be difficult to correct with our current methods, so we went back to the curve generator stage with that mirror to correct it quickly. Our original target radius of curvature is 96 inches which will result in a focal length of 48 inches (f/6). (Note: Since it's hard to be sure we'd cleaned all the grit out of the spaces between the tiles of the tool when changing to a finer grit, as a precaution we worked with the tool on the bottom for all but the first 2 coarsest grits. That caused the radius to shrink, so over the course of grinding, the radius shrank to 88 inches (44" focal length, f/5.5).

George is looking at the surface of the mirror. At this point, we have started the first stage (#120 grit) of fine grinding.

In this stage of the grinding, the material is being removed by the grit 'rolling' over the surface of the mirror. This results in the grit fracturing the glass and causing pits in the glass. To help document this process, John Mahony used an "eyepiece projection minus telescope" set-up as a photomicroscope and took a close-up of the surface of the mirror. The dark spot in the center of the image is a pit left from the previous grade of grit. The rest of the image shows the finer surface texture resulting from the newer finer grit.

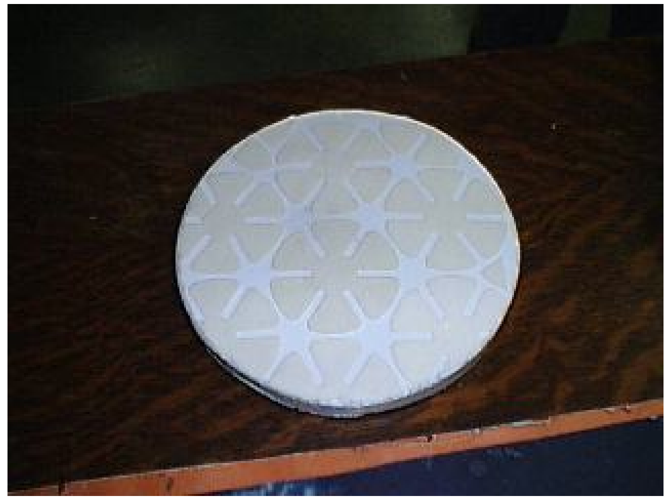


His setup...

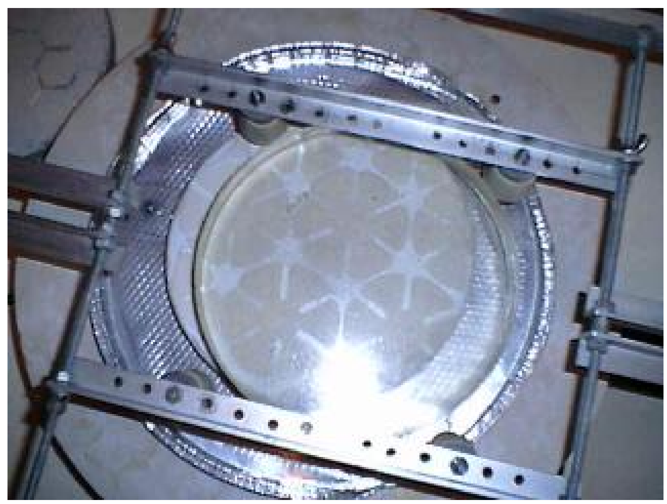
Of course, we all have to document the documenters....

Once the fine grinding was done, a pre-polish step was taken...

What will happen now is that the grit will become embeded within the pads. Now the grit rather than playing boulder and rolling and forming pits, the grit will be embedded in the pads and perform more like sandpaper. Once the surface becomes 'smooth' enough, we will start the true polishing of the mirrors.



The prepolish tool was carefully watched during this phase since no one in the group had ever used these polishing pads before. We had several concerns.



They seem to have done well however. Members watched while the grinding continured and the glass got clearer. For the final part of this stage, we used polishing rouge on the felt pads rather than the 9 micron grit.

While we were finishing this, we prepared the pitch lap...

- The tool form was made from the rough ground mirror. Was the shape close enough to the target shape to correctly polish the entire surface of the mirror?

- Would the pads really stay stuck to the plaster tool?

- Plaster is a difficult surface for adhesives to stick to. If the pads came loose between the mirror and tool, bad things could happen. Would they really do anything useful?

Jim had taken some wood and built a jig to allow him to pour the melted pitch into strips.

Between room temperature and it's liquid state, it will turn into an almost taffy consistency and stickiness! Cutting it into its final shape is difficult. You need to warm it enough that it can be cut without shattering, but not warm enough to stick to your instruments. The compromise that was made was to warm it enough to just barely cut it. This resulted in a bit of a mess that needed to be cleaned up.

The concrete base of the tool was now covered with a thin layer of pitch. This helped make sure that no particles of concrete would come loose and scratch the mirror. It also provided the base that the squares of pitch would stick to.

A small amount of turpentine was applied to the back of the squares to help them adhere to the tool.

At this point, the lap is almost done. The remaining corners will be fitted with properly cut pitch. Note the channels visible between the tiles. The bright light is from a heat lamp that was used to soften the squares so that they would deform slightly to the curved shape of the tool and make them stickier for good contact.

John and Jim are applying a bit of correction to the tiles. Some of them had a bubble hole or two in them that needed to be filled. The channel edges are where the polishing actually occurs. The holes could cause uneven polishing of the surface.

After the basic lap was finished, a bee's wax mold is used to impress a pattern onto the surface of the tool. This will speed up the polishing because it will form an edge at each ridge. The edges are where the polishing occurs most. (We used this only in the early stages of polishing as the small facets and rapid polishing are thought to produce small-scale ripple and roughness in the surface.)

Remember with the rough grinding that the grit acted like boulders that smashed their way along the glass surface. We went to finer and finer grit. Since we are after a surface with an accuracy measured in fractions of a micron, we cannot find a grit (or even powder) that would be fine enough for the original boulder approach. Rather, the pitch will be covered in polishing rouge and the rouge will be used to scrape the surface smooth. Some theories suggest that the heat from the constant rubbing and scraping will cause the glass to flow at the molecular level and have the material from the peaks fill the valleys on the surface.

Finally we are ready to start polishing...

The standard polishing stroke is the same as the standard grinding stroke. Polishing takes a lot of patience. Unlike the grinding operation that can be done by machine, this stage is better done by hand. We had done some of the initial polishing with the machine, but the process started to seriously slow down as we progressed with the polishing. There is a *lot*of friction between the lap and the mirror once the mirror gets sufficiently smooth, and this led to a minor disaster when one of the rubber bumpers on the alligator couldn't take the stress and fell off which allowed the mirror to fall off the tool while weights were on top of it and while no one was looking as the machine did it's job and we were all in the other room and this led to a loud crashing sound which nearly led to four simultaneous heart attacks........ There was some damage to the lap and a few scratches on the mirror which we hoped we could polish out without having to go back a step or two....We decided to use the machine just as a rotating platform and do the polishing by hand.

John Mahony is using the machine as a rotating turntable for his hand polishing.

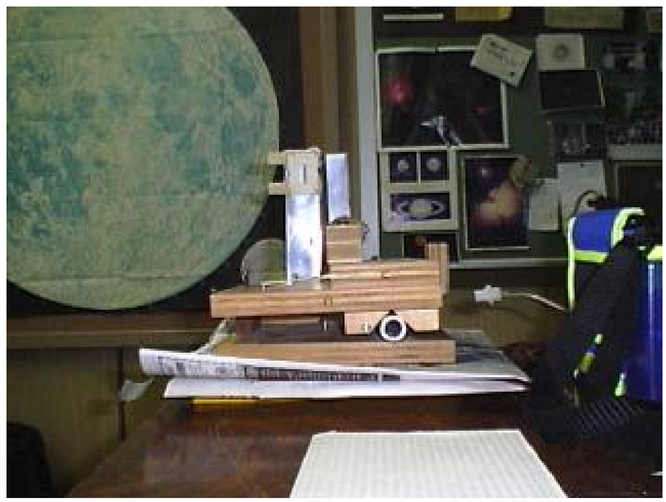
We also made a second tool and started polishing both mirrors at the same time. One on the machine and one clamped onto a desk. This will allow both mirrors to progress at the same time. After switching to hand polishing, we progressed as much in two weeks as the prior two months worth of machine polishing.

Ed Harfmann is shown taking a short turn at grinding. (He's usually trying to update these pages....)

These pictures were taken in the early stages of polishing when we were using white polishing rouge. We eventually ran out and switched to red rouge (slower, but better quality polishing). Red rouge is simply extremely fine particles of iron oxide, aka "rust". This is the same material used in cosmetic rouge. The universal staining effect of red rouge eventually caused our work area to be compared unfavorably to a slaughterhouse in appearance.

Once the mirrors started to become reflective we could check the accuracy and quality of the surface figure using a Foucault Tester...

The Foucault test is one of many different tests designed to test the focal length, smoothness, and accuracy of the surface figure of a mirror (most of the other tests are just elaborations of this basic set-up). A good description is given in Texereau's classic *How to Make a Telescope*, copyright Interscience Publishers, Inc. 1957. Newer editions are available, but the basic design has not changed.



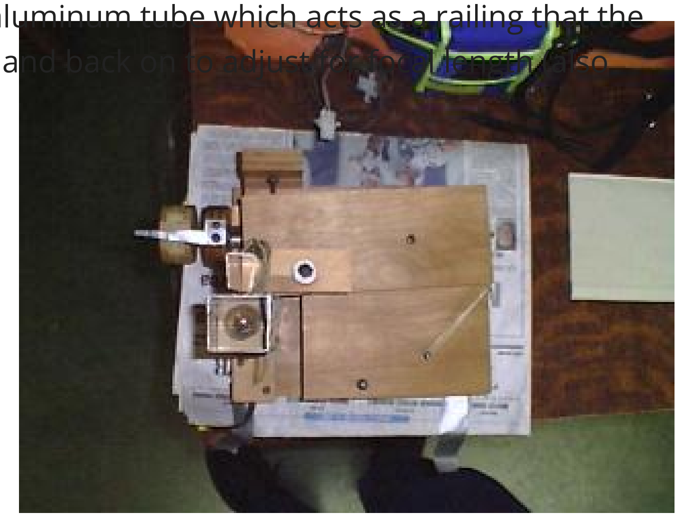
The screw at front adjusts the front-to-back tilt. Sideways adjustment is done by nudging the front or back of the rolling platform that the stand sits on. The mirror has to reflect light from the slit back to the knife edge.

Using the Foucault tester was by far my (JM) favorite part of making the mirrors. The idea that a contraption made out of- wood, basic hardware, scrap plastic, razor blades, rubber bands and a car's taillight bulb- could measure a mirror's surface to an accuracy of about 2 millionths of an inch- is nothing short of astounding to me.

Our tester was built sometime in the past by some unknown excellent woodworker, but needed some minor mechanical refurbishing, such as replacing rusty screws, adding bottle caps as knobs, and installing rubber bands. Then we were ready for the first test...

The larger shiny object holds a light which shines through a very narrow slit between two razor blades (seen taped at the top).
The smaller shiny object is a support for another razor blade which partially intercepts the light after it has bounced back off the mirror. This third blade is what gives this and related tests the nickname "knife edge test".

The vertical shiny object is a thick-walled aluminum tube which acts as a railing that the upper portion of the tester slides forward and back on to adjust for focal length (also seen in front view above). The large knob in back (also seen below) is graduated and turns a threaded rod which pushes the upper part. This gives a fine-scale adjustment and reading of the distance from the mirror.



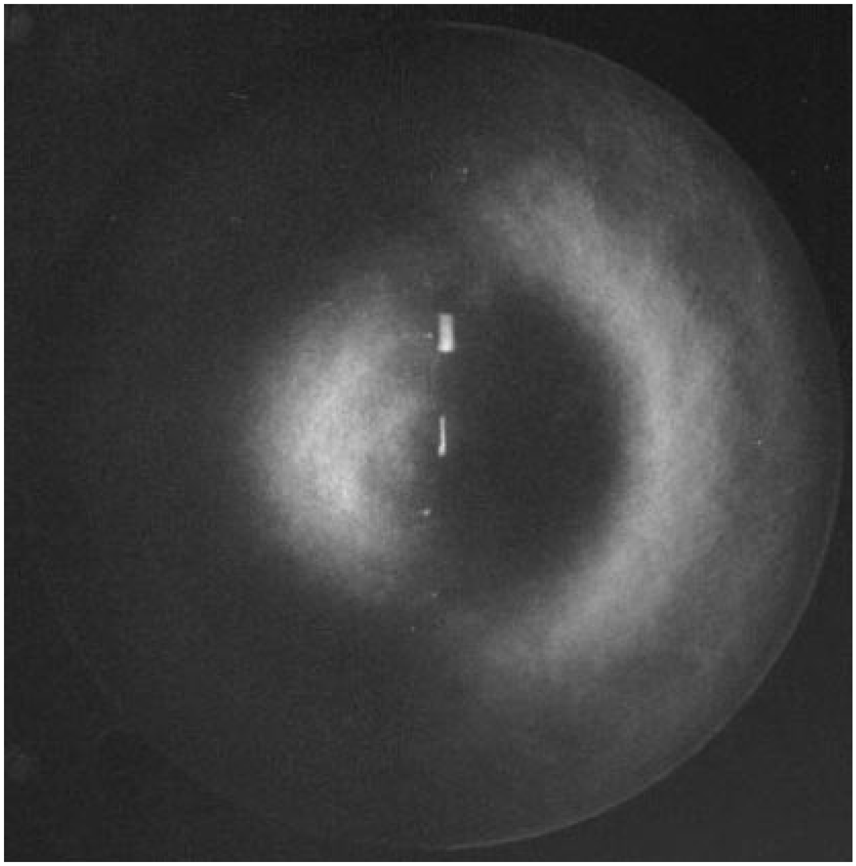
Here the upper platform has been tilted up a bit to show the tube-railing at the far side. The platform-angle screw is at top, lifted up. The screw normally slides on the lower (dark brown) block when the upper section moves forward or back. The block is polished wood, but was later covered with hard smooth plastic since the wood was dented from earlier use.

The upper wood block (aircraft-grade plywood) pivots on the upper right screw to move the intercepting razor blade (the "knife edge"). The rubber band maintains tension while the upper left screw adjusts the position so the blade is just at the interception point (no knob attached yet, but soda bottle caps worked well!). The center left bolt allows coarse adjustment. The lower center screw (also seen below) adjusts the tilt of the upper platform so the intercepting blade is parallel to the slit. The shiny part at upper left is the pointer for the large graduated knob.

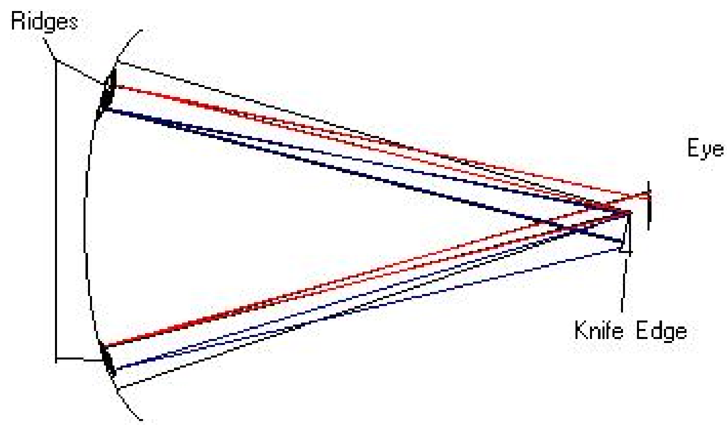
Usage of the Foucault tester started in February. While the mirror was not really ready for testing, it was satisfying to test the mirror and see a dim pattern in the expected form. The room is darkened since the image is quite dim. (Remember, it has not been aluminized yet!) We had to make sure to warn both Jim and John before the flash went off, since eyes need to be adapted to low light levels to see the reflected light.

Jim is seen trying to find the reflection of light from the slit on the Foucault tester.

John is seen adjusting the mirror stand up and down by adjusting the screw in the front of the holder. By moving the entire cart side to side and the adjustment screw up and down, the reflected image from the slit should be focused back to Jim and the knife edge.



Once the knife edge is properly placed, this is the image that was seen when looking through the tester. A spherical surface will appear flat. There is still some surface roughness left since the mirror is not yet fully polished. The raised ring is due to some problems with the curvature of the prepolishing tools. Fortunately, this is (very roughly) the general appearance that a paraboloid shows in the test, although it shouldn't be as extreme as in this appearance.   Notice that you see the inside of one ridge on the mirror and the outside of the other. The bright lines down the centerline of the image are actually reflections from the back of the mirror, we believe. If you look carefully at the image, you can barely see a pattern of spiral lines. These are from the periodic strokes of the grinding machine. Since this is early, this is of little concern. Later polishing should remove this error.


Ridges
Eye
Knife Edge

This turned edge resulted from the fact that the pre-polishing tool was cast from the mirror after curve generating and before much grinding had been done. Since the grinding had been done with the mirror mostly on top, the curvature increased, so by the time we got to pre-polishing, the pre-polish tool was too flat and wore the edge too much. This was noticable in the pre-polishing phase (the surface cleared in the center but not at the edge) but we hoped it would clear up in the polishing phase. No such luck. Although "anti-turned edge" polishing methods were used, this is a difficult defect to overcome, and in fact the turned edge seemed to only get worse. Later measurements of the error showed that it had increased to about 5 microns off from the desired shape in that region. This is a dramatic error. Fortunately we found some extremely fine 3 micron grinding powder (much finer than the original 9 micron powder). Given the severe error and the scratches, it was decided to take this mirror back to the pre-polish phase with a newly made prepolishing tool. After all the initial polishing the edge *had* finally polished smooth, but it was turned down, so when we went back to pre-polishing with a new correct-cuvature tool, it roughened everywhere *except* at the edge. After about 45 minutes, the mirror looked like this...

Notice that you can even see on this photo that the edge is still polished, since the 5 micron edge error is even larger than the 3 micron grit. Back to the polishing pads for a bit more time!

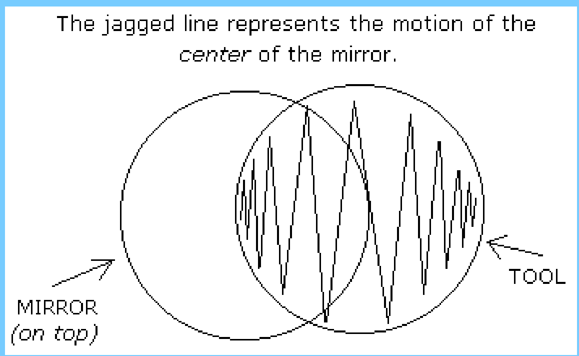
The left mirror didn't seem to have much of a problem with a turned edge, so we went on to figuring...

A new series of "focograms" further into the polishing phase showed that the (right) mirror is much smoother, but also has some scratches suffered in a near disaster in the early stages of the polishing phase. But another problem is that the mirror has a "turned down" edge. You can see this in the image below. Note the bright edge to the right and dark to the left. This means the edges are lower than the rest of the surface (relative to a sphere of a particular radius of curvature).

Figuring is the art/science of fine-tuning the shape of a polished optical surface. After grinding and basic polishing, the surface is usually nearly spherical, and depending on what kind of optical design you're making, you will want it to be either spherical (but to probably a higher degree of accuracy than it already is) or paraboloidal, ellipsoidal, or hyperboloidal (say that three times fast) or sometimes some other shape. The difference from the starting near-sphere to one of the other shapes is usually very slight, perhaps one light-wavelength or less (a half micron or about 2 hundred-thousandths of an inch) for typical amateur scope dimensions, with a preferred accuracy of 1/8 wavelength or better (2.5 millionths of an inch!). In this case (Newtonian reflector) we need a paraboloid.

The way in which a paraboloid varies from a sphere depends on the radius of the sphere you compare it to. Alternatively, if we start with the sphere obtained after grinding and polishing, the variation depends on what type of parabola we want. Simplified to 2 dimensions (with the vertex at the origin), a parabola has the equation $y=a*x^2$. Changing the value of *a* gives different parabolas. If we look for a paraboloid that matches our 8" f/5.5 sphere at the center and edge, the parabola will be higher than (a hypothetically perfect) sphere by up to 12 millionths of an inch in the intermediate zones. This means (in a sort of reversed sense) that we could obtain the parabola by polishing heavier in the center and edge of the sphere to remove (or at least redistribute) some of the glass there. But there are other options. Using a slightly different value of *a* we could have a parabola that matches the sphere at the center but gradually drops off as we move towards the edge (equivalently the parabola matches at the edge but rises in the center) . Alternatively, yet another value of *a* gives a parabola that matches the sphere in the center but rises as we go toward the edge (or equivalently matches at the edge but drops in the center).

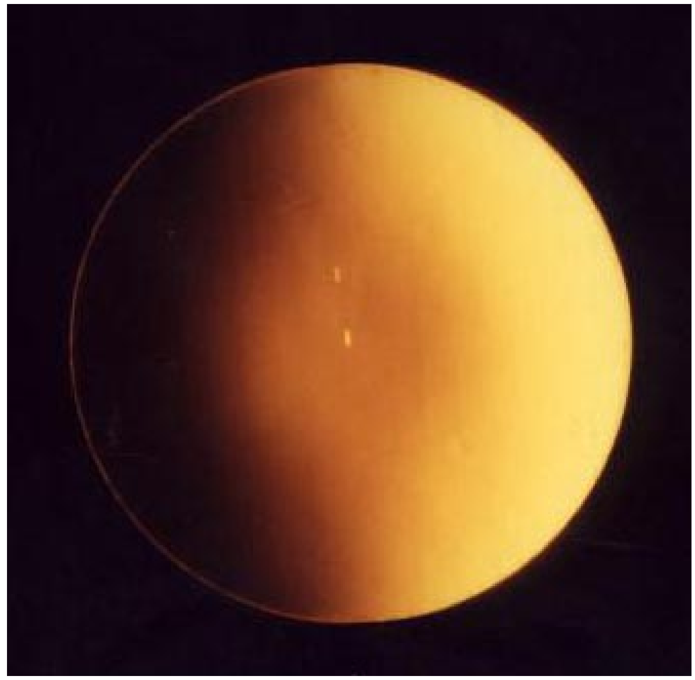
So to produce a parabola we need to alter our polishing method to find a way to lower the surface of the sphere at the edge, or at the center, or both. This is done using polishing strokes that concentrate the pressure and action in one part or another of the mirror. Here is an example (adapted from Texereau's classic *How to Make a Telescope*, copyright Interscience Publishers, Inc. 1957).



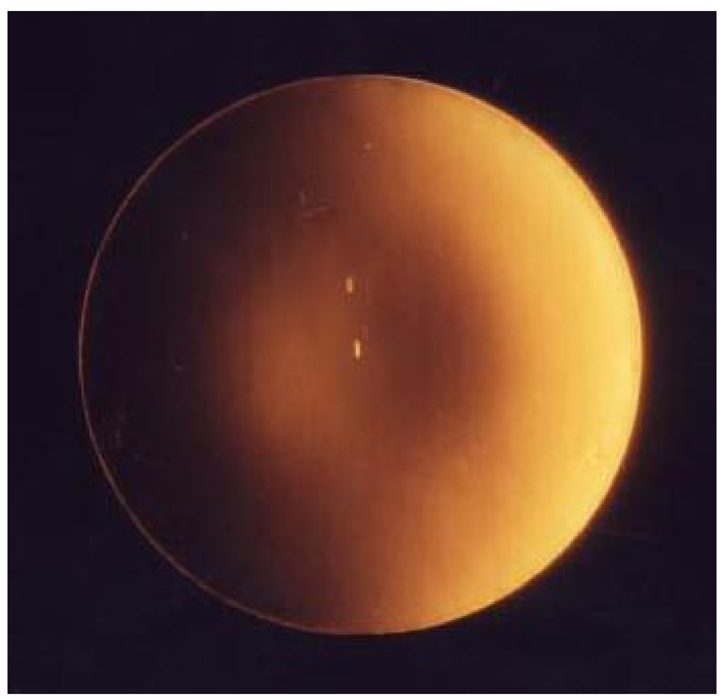
Here the action is concentrated when the mirror is near the edge of the tool. In that situation, the weight of the mirror is resting on its center, so the mirror gets worn away more there. Both the mirror and tool are rotated frequently so the action is evenly distributed (in terms of the angle, *but not the distance* from the center). Strokes that hollow out the center rather than lowering ("reducing") the edge seem to be more commonly used, probably because of the danger of getting a turned edge. This is one of the easier errors to get and one of the more difficult to cure. Using figuring strokes represents much of the *art* of figuring. Besides getting the right amount of effect on the right part of the mirror, the surface heights of different parts of the mirror need to be blended smoothly from one part to the next. Many variables can affect the efficiency of a given polishing stroke, such as the temperature, the hardness of the pitch lap, and the amount of water mixed into the polishing rouge. And before you can even start on parabolizing, you generally want to have the surface very nearly spherical, so other specialized strokes besides parabolizing strokes may be needed to make small corrections. Or sometimes it's better to just to use a steady standard polishing stroke to gradually reduce errors down to a spherical surface. Then when parabolizing you may get "nearly parabolic" with a small error somewhere, in which case you need to be able to get rid of that small error without interfering with the rest of the surface. And if that doesn't work and you get a distorted surface you need to know when to give up on parabolizing and temporarily go back to spherical. I (JM) was constantly amazed at how my inexperienced attemps would give unpredictable results, even giving different results if I tried the same thing twice, while WVAS' unofficial master optician Jim Sattler semed to get pretty close to the results he wanted most times.

Finally we can take a look at a nearly completed mirror...

Center Null



Below are the focogram images for the (nearly finished) left mirror. To the discerning eye (not mine yet!-EH), you will see that the mirror appears somewhat flat from about half to three quarters of the way from the center to the edge. This means that part of the mirror is still spherical and the mirror as a whole is still undercorrected (ie, it hasn't been changed all the way from a sphere to a paraboloid). (Note to experienced or potential opticians- the "zone numbers" shown below were used only for convenience and do not quantitatively match the standard zones).

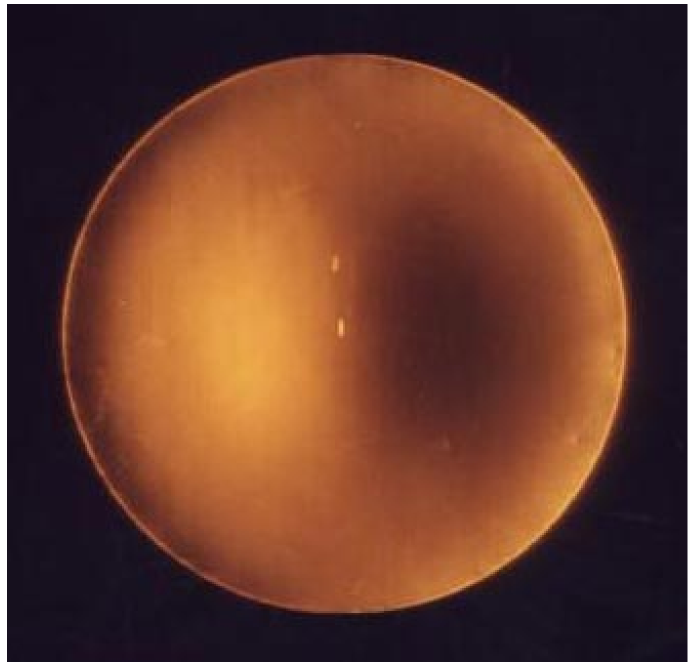


So how do you read these images? The knife edge was moved back a bit between each image (roughly 3 hundredths of an inch each time). As the Foucault test diagram showed, the test images show (nearly) an extremely exaggerated relief view of how high the surface is *relative to a given sphere*. When the knife edge is moved forward or back, you are changing the radius of the sphere you are comparing your surface to. Note that all of the pictures resemble the descriptions of what various parabolas look like relative to different spheres. Does this mean we have a parabola? Unfortunately not.

Hyperboloids and half of all ellipsoids also show qualitatively similar images. To be sure we have a parabola, we need to make some measurments of how certain parts of the images look depending on the position of the knife edge. There are a few ways to do this. The most common is to block or "mask" most of the surface so that you're only looking at areas at a given range of distance from the center. Now if you used the Foucault test on a perfect sphere, and if the knife edge was positioned just right (essentially at the center of curvature of the sphere), then all the light would reflect back exactly to the edge of the blade. Then if you moved the knife edge to the left or right, you would either be cutting the light off completely or uncovering it completely, so the image would get completely bright or completely dark, all at once. At other positions, the mirror will go dark from one side to the other. The idea of using a mask is that you move the knife edge forward and back, while simultaneously moving it left or right, until you find the right knife edge distance where the exposed parts of the surface go completely bright or completely dark, all at once when you move the blade sideways (this is what the word null refers to in the above picture labels, the "zones" refer to a particular range of distance from the center). This means the exposed parts of the surface have the same slope angle, and thus the same curvature, as a sphere whose radius corresponds to the knife edge position. Checking this at several distances from the center of the mirror to the edge can tell you if the surface is really a parabola. The details of the math are included in any good book on amateur telescope mirror making.

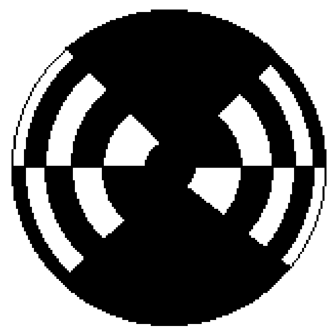
(approximate) zone mask used on our mirrors
This is actually a multiple-zone mask that can be used to check 5 zones rather than checking each zone with a separate mask.

The focograms show a few scratches. This was due to the fact that we streched the process over such a long period of time, generally working only a few hours each weekend. This allowed dust to build up in our work area, which contaminated the rouge and scratched the mirrors. The bright dashes in the center are reflections off the back surface of the mirror.



The bright thin line around the dark left edge in the images is a good sign: it is a diffraction effect that occurs only if the mirror doesn't have a turned edge.

Although the measuring and math involved in reading focograms are among the most scientific parts of the process of producing optics, reading focograms is also a bit of an art. The measurements can tell you the shape within the required 1/8 wave criterion (though often only barely with most amateur test equipment, and it strains your ability to detect differences in light/shading levels), but the 1/8 wave criterion is only part of the story. Overall smoothness is also very important. A mirror that has been fine-tuned to death in the figuring process will likely not be very smooth on a smaller scale.



The entire WVAS membership thank John, Jim and the others who have spent their time and shared their knowledge in polishing these mirrors.

The first step was to build the box frame to hold the two tubes. Jim Mettler took charge of this part. The frame was made from 3/4" square aluminum tube (1/8" wall thickness) held together with machined fittings press-fit into the ends. The fittings were made very slightly oversized, with the corners of the square pegs rounded to avoid splitting the square tubes.

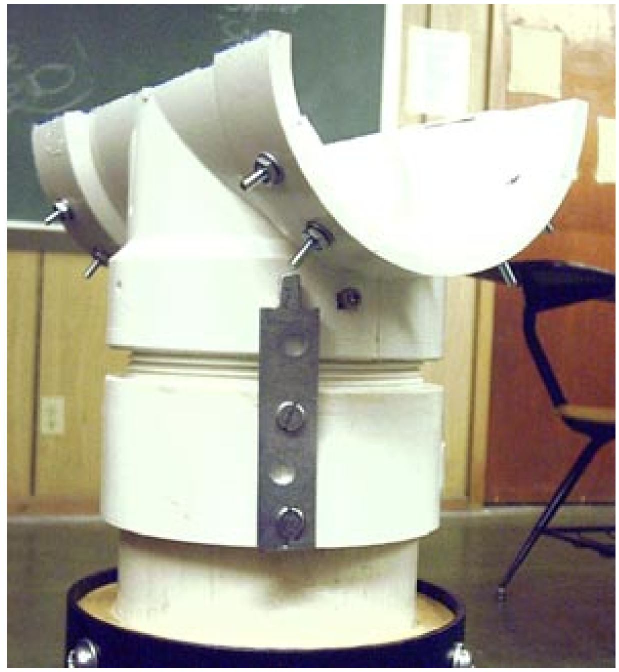
After a few hours of cutting aluminum tube lengths and pressing the fittings into them, the basic frame took shape. Then we added two 1/8" aluminum sheet plates to hold the altitude bearing, and since one section of the frame has to be left out so that the frame can be moved in altitude when on the pier, more 1/8'' aluminum sheet was used as a gusset in the back to keep the two sides from sagging towards each other.

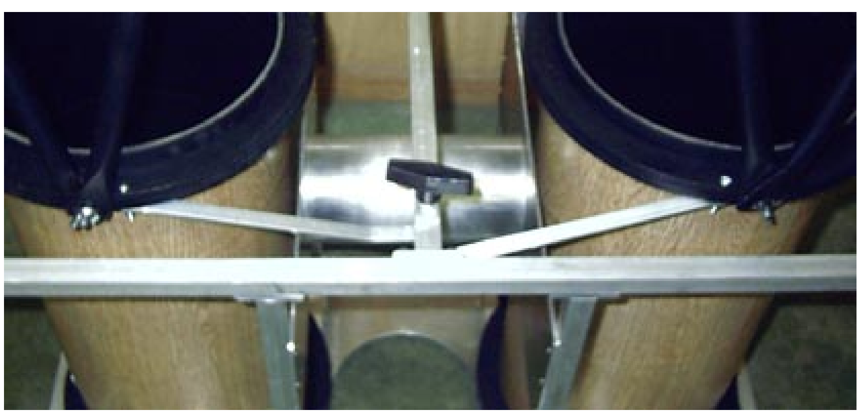
(Left) Jim Mettler uses his press to attach a fitting to a tube section.
(Above) A close-up of a corner fitting about to be pressed into a tube section.

After the frame was complete, the mount bearing was created.

For the altitude bearing, wooden disks made by George Gourko were pressed into the ends of the 4" diameter aluminum tube. These were drilled off-center (left) to allow a vertical adjustment for balancing the scope. But the off-center holes means there will be some torque on the tube, so sandpaper disks were glued to the disks (right) for better friction when the bearing is mounted between the side plates in the box frame. To allow for horizontal adjustments, slots rather than holes were cut in the side plates for mounting the bearing.

Finally, to finish the project, the inter-ocular adjustment system was added.





The following parts make up the bearings: At left is a section of 4" PVC pipe that slides into the pier. Two snug wooden spacer rings made by George Gourko provide a tight fit (only one is shown-the other is already in the pier). At the top of the pipe is a threaded adapter. In the center of the picture is a 4" PVC "T", sliced in half, that forms the heart of the mount (Jim Sattler's idea). The third ("stem of the T") opening is threaded, and screws on top of the pipe to form the azimuth bearing. Heavy grease is applied for smooth movement. At right is a 4" diameter aluminum tube that will be cradled in the top of the "T" to form the altitude bearing. This tube will be mounted in the box frame between the optical tubes, so it will be sort of an "inside out" version of a standard Dob mount.

Teflon pads were added to the T, and a stop was added to make sure the mount wasn't accidentally "unscrewed".

The nearly completed pier and bearings.

The handle in the middle rotates a part (below) that moves two struts attached to the upper mounting rings of the optical tubes, at a point roughly opposite their pivot points, so that the tubes swing apart.

Last, the pier was constructed.

The pier is from a 16" Meade Starfinder Newtonian. The pier is on semi-permanent loan from the Prairie Grass Observatory. (Cat included for scale :)

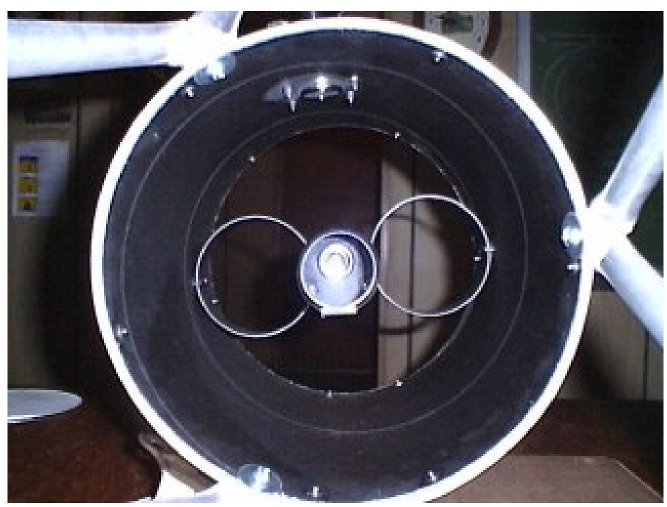
Here's a view of a completed optical tube assembly.

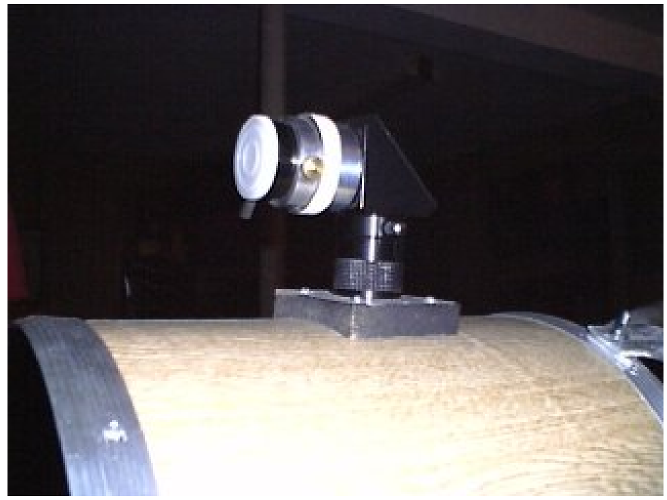
The secondary cage was made from a 12 1/4" piece of 10" ID Sonotube. (Sonotube for the whole project was donated by J&K Supply of Lafayette.) This section was made almost entirely by Jim Sattler.

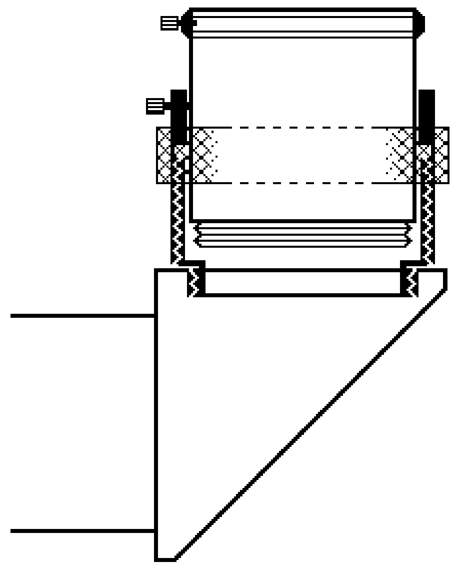
View from the top: The spider was made from 2 very short pieces of 4" aluminum pipe. The curved spider vanes eliminate the diffraction spikes caused by standard spider vanes.

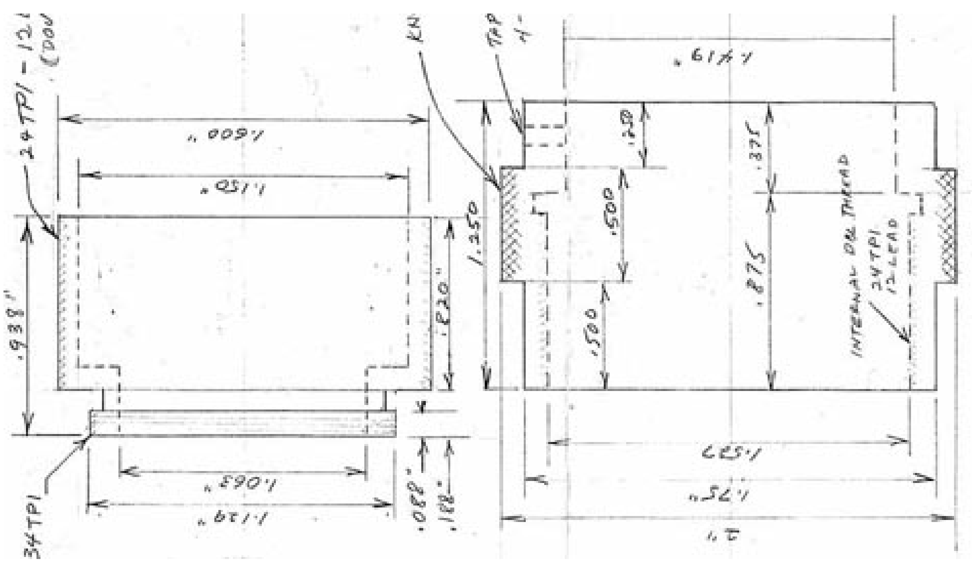
View from the bottom, showing the reflection of the built-in Barlow in the 2.14" secondary. The secondary holder was made from a piece of black PVC pipe.

Barlow, diagonal, and focuser: the Barlow tube acts as an extension tube. The Barlow lens cell unscrews from the Barlow tube for low power viewing.









Jim machined the helical focuser from two pieces of spare aluminum. The inner piece threads into the diagonal where the original eyepiece holder tube was. The inner piece is threaded on the outside. The outer piece then threads onto the inner piece for fine focusing. The upper inside of the outer piece is not threaded, rather the original eyepiece holder slides into it for coarse focusing. The outer piece has a knurled grip ring.

Next, the truss assembly was contructed.

John Mahony took charge of the truss tube section, with help from George Gourko and Jim Sattler. Once the tubes were cut and drilled, the ends were beaten into submission with a vise and a large hammer to fit them to the tube sections.

Lower tube construction was next.

Here's a view of a completed optical tube assembly.

George Gourko also made the mirror cells. Three sets of push screws and spring-loaded pull screws adjust the mirror. The plates are wood with ventilation holes. The mirror is held to the upper plate with 6 large drops of silicone rubber cement (aquarium glue), three on the bottom and three through holes (not visible in the image because they're filled with glue) in steel angle brackets that act as a back-up support in case the bottom silicone comes loose. The mirror was supported on coins on the upper plates until the glue dried, so it rests on the glue rather than the wood.