Accessible Telescopes: Windows to the Universe for People Living with Disabilities

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Based in part on my unpublished fixed focal plane/accessible telescope material from previous years.
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Abstract: Many aspects of amateur astronomy can slip out of reach for people who have health issues or injuries that adversely influence endurance, lifting capacity, or mobility. This is partly because handicap access has not been an emphasis in the design of amateur astronomy equipment. One of the greatest barriers to accessibility is the position of the eyepiece when an astronomical telescope is pointed toward various parts of the sky. Often, the eyepiece is too high, too low, or at the wrong angle to be accessible by people living with certain disabilities; particularly by people using wheelchairs. When my health prevented using conventional amateur astronomy equipment in the 1980's, I invented a number of improvements that made astronomical observing and photography possible. While I invented these items purely out of necessity, the average healthy person found that the same items were more convenient to use than equivalent existing items. Making such items available to other amateur astronomers became the primary basis for founding Versacorp in 1983. Since then, I began to think of ways that a large aperture (but affordable) telescope might be configured to be more accessible to a person such as one with my progressive condition. More recently, knowing friends and acquaintances who use wheelchairs has increased the motivation to develop simple and cost effective concepts for affordable large aperture telescopes having an eyepiece position that can be accessed from a wheelchair or similar mobility device. Basic specifications for several specific "accessible telescope" designs are presented in this work. One of these telescopes has a large 56 cm aperture, and its design is applicable to even larger apertures. Such "accessible telescopes" would be useful at public viewing events, since they provide a way for most if not all handicapped people (who can get there) to participate. For many astronomical objects, there is no substitute for a direct, visual view through a telescope. If local skies are dark, a large aperture is very useful. An "accessible telescope" is also by definition a telescope that *anyone* can conveniently use from a seated position. Therefore, "accessible telescopes" are useful to a wide variety of people. This is a *"defensive publication"* that operates to prevent third party patenting of any patentable material herein. It is supported by numerous unpublished but verifiable priority documents dating back to the 1980's. Upon publication of this material, only that which is *patentable* may enter the public domain. All that is covered by *Copyright* (text, photos, artwork) shall *not* enter the public domain. All Rights Reserved.

Contents:

1.) Introduction: Accessible Telescopes: Their Necessity and Dual Applications.

When people have health issues or injuries that adversely influence endurance, lifting capacity, or mobility, many aspects of amateur astronomy can slip out of reach. This is in large part due to the design of commercial equipment that is marketed to amateur astronomers.

Throughout many decades, a number of people, including the late well known Russell W. Porter, have designed telescopes that accommodate less than optimum health conditions. Some of the related concepts, including fixed positions for the telescope focus, have made their way into many well known extremely large aperture telescopes that professional astronomers still use.

When I was bedridden for a few months in late 1979, I worked on concepts for telescopes that could be accessed when very weak, and even one with an eyepiece position that could be used from a bed. Since then, I emphasized simpler designs that have fixed indoor eyepieces, but that are not necessarily accessible from a bed. Some of these proved to be novel, and others did not.

Later, when my mobility was reduced to the point of often needing a walker, I began to think of ways that a large aperture (but affordable) telescope might be configured to be more accessible. More recently, knowing friends and acquaintances who live and work from wheelchairs has increased the motivation to come up with simple and cost effective concepts and designs for affordable (as in, affordable relative to the aperture considered) large aperture outdoor telescopes having eyepiece positions that are accessible from wheelchairs or similar mobility devices.

An "accessible telescope" would be extemely useful at public viewing events, since this would provide a way for most if not all handicapped people (who can get there) to participate. For many astronomical objects, there is no substitute for a direct, visual view through a telescope. And if local skies are dark, a large aperture is useful for observing deep sky objects.

An "accessible telescope" is also by definition a telescope that *anyone* can conveniently use from a seated position. Therefore, such a telescope is useful to a very wide variety of people.

1.1) Accessible Telescope Trade Space and Concepts (with Illustrations)

The trade space for an accessible telescope includes optical design, maximum practical aperture, physical size, eyepiece accessibility, and many other aspects. Basic requirements specific to large aperture *accessible* telescopes that are useful to people with a variety of disabilities include:

* Eyepiece position low enough to be accessible from a seated position, regardless of aperture.
* Eyepiece position low enough to be accessible by a seated person with severe scoliosis.
* Variable eyepiece angle that minimizes how much a person must move their head or neck.
* Variable eyepiece angle, also for the purpose of accommodating users of different heights.
* Clearance for a manual wheelchair, motorized wheelchair, or other common mobility device.
* Finger clearance for grip rings on a low cost wheelchair that lacks tilted wheels.
* Accessible focus control that can be operated with very little force.
* Ease of use, small enough to fit through interior doors or move in mini-van or smaller vehicle.
* Safety features to minimize risk to eyes from accidental operation of a motorized wheelchair.

There are many ways to implement (or modify) telescopes to provide accessible eyepiece positions. Each has its advantages and disadvantages, and each is associated with a maximum practical aperture, f/ratio, or field of view. Only a few concepts are compatible with providing a large aperture accessible telescope at relatively low cost. Some are novel, and some are not.

1.1.1) Small Telescope on Table or Overhanging Pier. The most basic approach is to simply place a small telescope on a table, then roll a wheelchair up to the table to use the telescope. In order to reduce the required range of head and neck motion, a variety of eyepiece angles (for viewing objects at different elevation angles) are provided by simply looking straight through the telescope, or by using diagonal mirrors or prisms that provide a variety of (or variable) eyepiece angles. Commonly available optical path deflection angles include 45, 60, and 90 degrees.

Two diagonal mirrors can be used together in series when a continuously variable eyepiece angle is desirable. A tabletop telescope imposes limits on aperture, so it is not covered in detail.

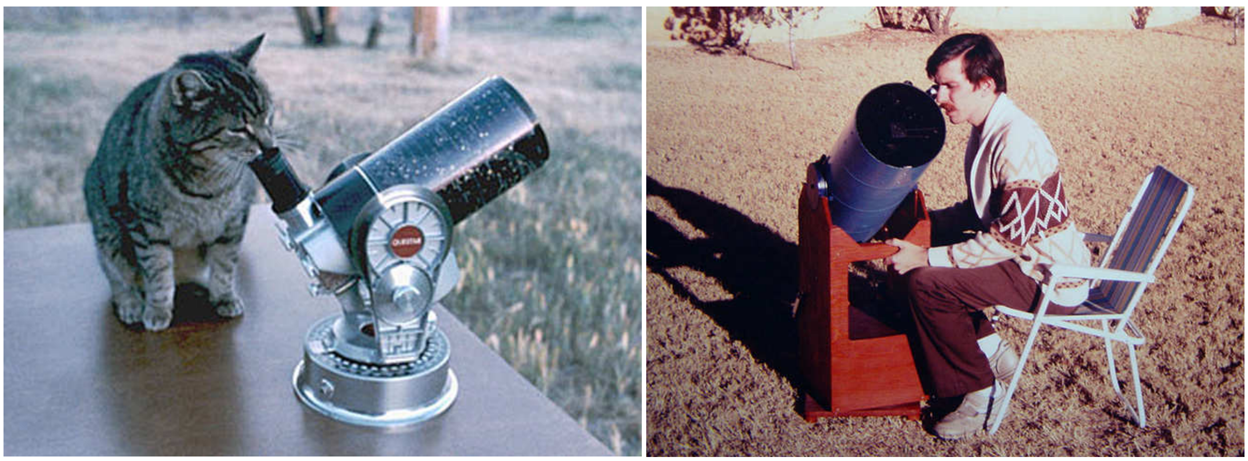


Figure 1.1.1A. Small telescope and cat on table; Telescope with low eyepiece position.
LEFT: When deployed on a table, this Questar 3.5 Maksutov-Cassegrain telescope is accessible to more than just people! This feline telescope user is birdwatching.
RIGHT: An accessible telescope requires an eyepiece that is low enough to access from a seated position. The shown eyepiece angle works at all elevation angles. However, this alone is not enough. A person in a wheelchair cannot get as close to the telescope mount as I am in this picture, since the wheelchair foot rest will be in the way. Also, some users of wheelchairs or other mobility devices cannot lean forward as much as shown here. I built this compact 20 cm f/3.6 telescope in 1989. It can be stored and transported in its mount, along with eyepieces and other accessories. It weighs only 13 kg including the mount.

1.1.2) Variable Angle Fold Mirror. A variable angle fold mirror is useful in conjunction with most concepts and designs in this work. The most useful range of angles are dependent on other aspects of the telescope. There is also more to it than just angle. For example, a variable angle fold mirror for a fast f/ratio modified Newtonian telescope (see 1.1.7), must be designed in a way that its front interface does not block the outer edge of an f/4 (or even faster) light bundle.

This imposes requirements that cannot be met by available dual angle or variable angle fold mirrors. For example, the simple practice of using two diagonal mirror assemblies in series adds two optical surfaces to the system for each region in which the optical path angle is varied, and two diagonal mirrors in series generally will not optimally accommodate an f/4 light bundle.

Another consideration is the precision with which the front interface, the mirror, and eyepiece holder (or relay lens assembly) must be aligned with respect to each other. The front and rear parts of the assembly must both move at equal angles with respect to the mirror, so that the mirror is effectively tilted half the angle at which the focal plane end of the assembly is tilted. Yet another consideration is that construction must be heavy enough to support the eyepieces (and possibly cameras) that are used where the light bundle exits the variable angle fold mirror.

Still another consideration is that the light path fold angle must be variable, not merely dual. This means that the mechanism must maintain alignment throughout the range of adjustment, as opposed to only at each end of the range. Two variable angle fold mirror assemblies are useful with a relay, since this provides a wide range of eyepiece positions and angles in 3-dimensional space. The angle of deviation for the light path is also important. Since a unique type of variable angle fold mirror is best suited to modified Newtonian telescopes shown in part 1.1.7, the shown version has fold angles between 58 and 105 degrees, which are well suited to the application.

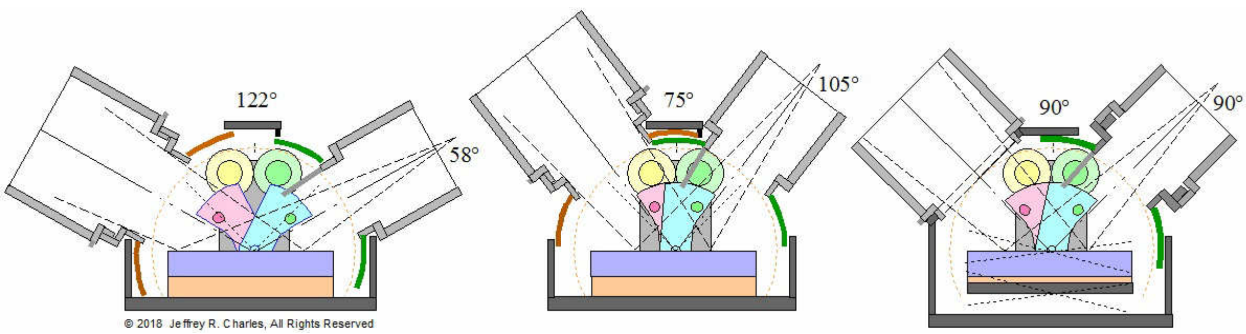


Figure 1.1.2A. Variable Angle Fold Mirror (VAFM): Version having 58 to 105 degree range. This variable angle fold mirror can deviate the light path to any angle between 58 and 105 degrees. The LEFT figure shows the fold mirror set for a 58 degree light path fold angle, and shows that the housing fully encloses the light path. The CENTER figure shows the fold mirror set for 105 degrees, and shows overlap between different housing parts. Shown front interface is T-thread since a 1.25" OD barrel can't accommodate the shown f/4 light bundle. The angle for each end of the housing is maintained relative to the mirror. Here, coaxial gear sectors are tied to each end (red sector for front, green for back), and mesh with two 2-stage idler gears tied to the mirror mount. For clarity, the mirror is shown tied to the baffled housing. RIGHT: In practice, the front is best part of the main housing. Simpler ways to synch. angles are to use cams, or a long screw that's fixed in reference to the mirror, with right hand threads on one end and left hand on the other. As the screw is turned, relative tilt for both ends of the unit change equally.

1.1.3) Long Refractor. Another accessible telescope concept is simply a refractor telescope having a tube long enough to provide an eyepiece position far enough from its pier or tripod that the eyepiece is accessible. A folded refractor with a fixed eyepiece near the polar axis assembly is another option. The maximum practical aperture of a good (affordable) refractor is limited.

1.1.4) Relay lens. One simple solution is to extend the back focus for conventional Cassegrain focus far enough out to provide adequate clearance. A relay lens can be used for this. *This design has been prototyped and tested.* (See below. Also see relay lens test results in part 3.3.)

Figure 1.1.4A. Relay lens prototype being tested on a Celestron 20.3 cm (8") f/10 SCT, 180818. These photos show testing of a simple relay lens assembly on a Celestron C8 Schmidt-Cassegrain telescope (SCT). The angle of the relay can be varied with respect to the telescope in order to provide the appropriate eyepiece height and angle needed for an accessible telescope, and can also be used on either side of the telescope. For example, in the LEFT image, the telescope is pointed well east of the southern meridian, and the eyepiece is at a low position, with the diagonal mirror at the end tilted up. This is suitable for an observer who can move their head and neck to some degree. If a person can't move their head much, the relay can swivel upward and the diagonal at the outer end can be rotated so that the eyepiece suits the observer. The RIGHT image shows the telescope pointed just west of the meridian. Here, the relay is positioned in a way that the eyepiece points horizontally, for access by a person who has a lower eye position relative to the ground. The eyepiece height is *variable* in most configurations. This is important for *accessible telescopes*, because an observer's *hair* is less likely to interfere with observing when the eyepiece is at or close to a *horizontal* orientation than when it is oriented vertically.

In order to be useful in providing an accessible eyepiece position for observers using wheelchairs and other mobility devices, a relatively long relay lens assembly is required to move the eyepiece position far enough from the telescope to provide good clearance between the telescope with its mount, and a wheelchair, etc. The pictured relay is only 46 cm (18") long, but can be lengthened simply by using extension tubes between the relay lenses, or by using longer focal length relay lenses. The latter is practical with slow f/ratio telescopes such as the pictured Celestron 8 SCT.

When such a long relay assembly is used on a telescope of this relatively small size, it must be supported by a wire or spring cable (etc.), and a counterweight (shown just right of the telescope) should be used in at least one location on the opposite side. The design works on an equatorially mounted telescope such as this one, but is better suited to altitude over azimuth mounted scopes, since the rear cell angle and position do not change as much with respect to the tripod.

1.1.5) Optical Path Through Altitude Axis. For more convenient access to the eyepiece, a Cassegrain or folded refractor telescope on an altitude over azimuth mount that has an optical path through the altitude axis can provide consistent and accessible eyepiece positions, provided the eyepiece is far enough from the telescope and mount. This used to be more common in commercial scopes than it is today. Now, such a telescope is expensive (an existing scope and mount must be modified), and it also has a limited field of view. This design is pictured below.

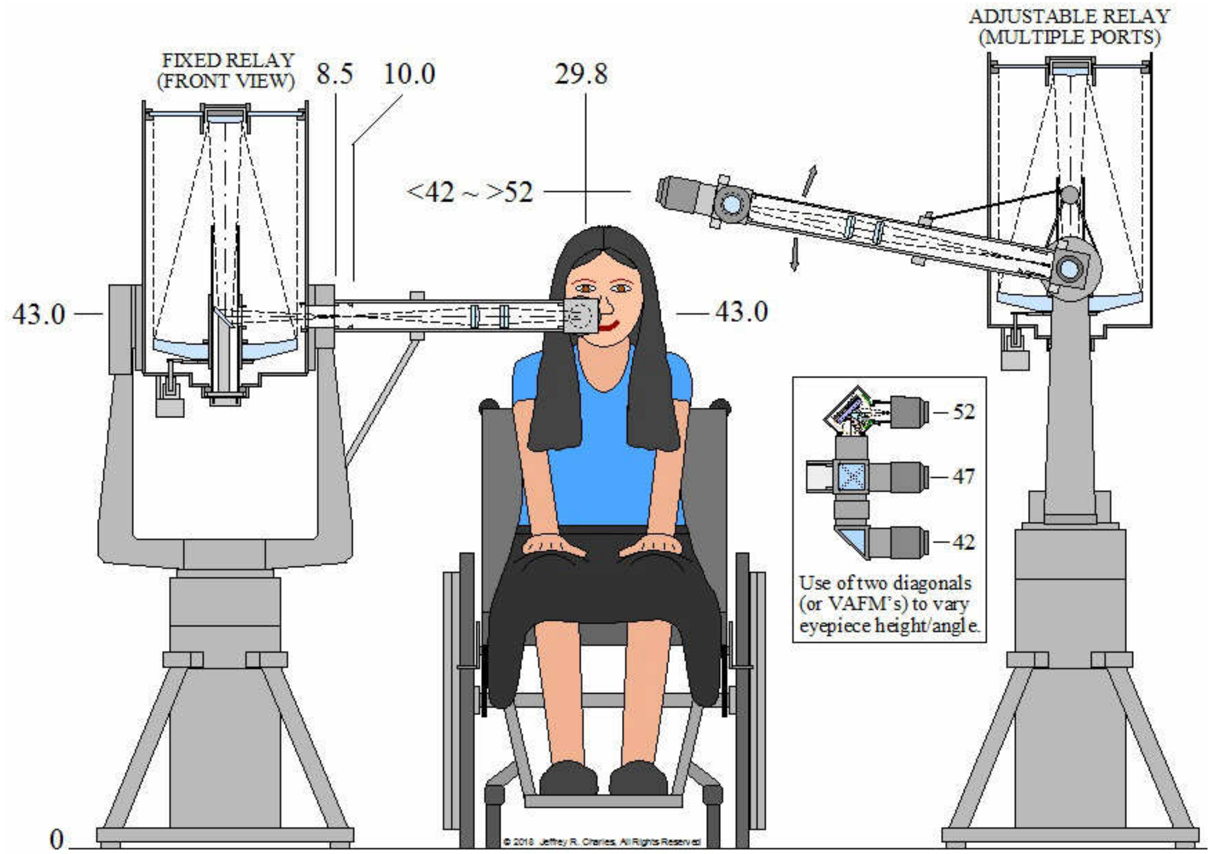


Figure 1.1.5A. Drawing of "accessible" 30.6 cm aperture f/10 portable SCT with relay lenses. By adding relay lenses to slower f/ratio telescopes such as this 30.6 cm f/10 Meade Schmidt-Cassegrain telescope (SCT), it is possible to accommodate both a seated position and clearance for a wheelchair or other mobility device. When the telescope is further modified as shown, to provide a light path through the elevation axis of its mount (and then used in alt-azimuth mode), the eyepiece can remain at a fixed height regardless of where the telescope is pointed in the sky. Multiple diagonals can be used in series at such slow f/ratios for flexibility. This design has many advantages for accessible astronomy. However, due to characteristics of an f/10 SCT, including the relatively small size of its primary baffle tube, field of view (FOV) is limited. Specifically, when using simple achromatic relay lenses, the useful FOV for a 20 cm f/10 SCT is only about 0.6 degrees, which translates to about 63x magnification with an average orthoscopic or Plossl eyepiece. Useful FOV decreases for larger apertures, to 0.5 degrees for a 25 cm SCT, and 0.4 degrees for a 30 cm SCT. Fortunately, FOV of a 25 cm or larger SCT can be increased by at least 50% if ED glass is used in the relay lenses, or if the relay optics are more complex. Here, a conventional SCT is modified to include an internal fold mirror to direct light out the elevation (altitude) axis. A relay lens assembly is used to provide clearance for an observer in a wheelchair, rollator, or other mobility device, while retaining a low eyepiece position. etc. It is moderately compact. A 20 cm version can be portable enough to transport in a compact car. This design provides an *accessible telescope* of moderate to large aperture, while providing good portability. The eyepiece height can be lower than 1.1 meters, regardless of where the telescope is pointed. The eyepiece height can be varied via the mount's tripod, by swiveling the relay tube, by using extension tubes between diagonal mirror(s) and eyepiece, or etc. There is clearance to allow use of either eye by observers, while still providing several inches of finger clearance between a conventional low cost wheelchair and the telescope mount or tripod. A 30 cm telescope is shown here, but the concept is applicable to smaller apertures, and to larger apertures up to at least 41 cm (largest available consumer SCT). Details are in the "Relay Lens" section of part 3, below.

1.1.6) Fixed Focal Plane. An "accessible telescope" that is set up in a way that the eyepiece is in a comfortable indoor or outdoor location is another way to provide good eyepiece access. A refractor is well suited to an indoor eyepiece because the objective can be closer to a feed mirror on the roof than is the case for reflector telescopes. This in turn reduces the required pointing mirror size versus the telescope aperture and unobstructed field of view. This design is described here, and also in a later chapter, though it is not emphasized as much as larger aperture designs.

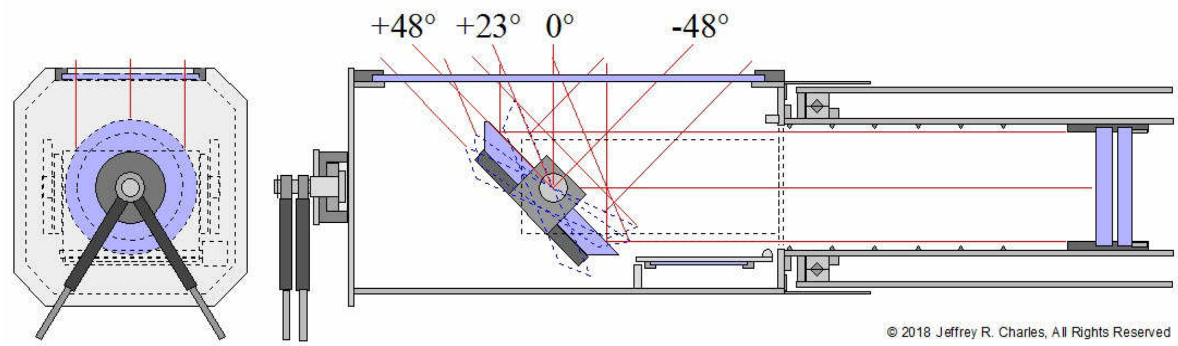


Figure 1.1.6A. Cross-section view of telescope built into building; feed mirror assembly detail. A telescope having an indoor eyepiece location is very convenient, but usually must be limited in terms of aperture. This drawing shows a pointing (feed) mirror assembly that is used on a roof, and that uses a flat steering mirror to effectively point the telescope. The LEFT drawing is a polar end view, while the RIGHT drawing is a side cross section. The optical axis of the refractor objective shown on the right points at the celestial pole, and the elliptical feed mirror is tilted to select declinations between +48 to -48 degrees. The entire assembly is rotated about the objective lens optical axis (via a ring bearing) to point and track in right ascension. For safety, a shutter with a solar filter in it is always closed unless remotely opened by an observer. The width of the shown housing is about 27 cm, and the tube passes through the roof just in front of the objective lens. The tube extends down into the habitable area, and has a double wall where it passes through an attic. The space between the tube walls can be temperature controlled to minimize tube currents. If the yard around a building is wide enough, a telescope with a similar mirror assembly could simply be positioned outside, so the eyepiece end fits through a masked window opening.

In 1989, I developed improvements that made fixed eyepieces practical for larger aperture indoor and outdoor telescopes. One version is an unobstructed off-axis Newtonian with a fixed primary mirror down low, and a flat pointing mirror on an elevated equatorial mount for pointing. It was designed in four sizes: 12.7 cm f/10.5, 18 cm f/10.7, 23 cm f/11.5, and 32 cm f/12.9. Small sizes are very portable. In any version, the primary mirror *can* (but need not) be in a separate housing that can sit on the ground, and have remote control motorized collimation that is operable from by the eyepiece. The taller baffled pointing mirror and eyepiece assembly is one to a few meters from the primary mirror, depending on focal length. The most portable version is a 12.7 cm f/9.6 off-axis Newtonian in which the primary and pointing mirrors are in the same compact 122 cm (4 foot) long unit (upper left, Fig. 1.1.6B). Another portable version is based on a folded refractor. Back then, the maximum aperture was 32 cm because the largest “affordable” blank I could find for a pointing flat was the Coulter 44.5 cm (17.5") blank. Large versions were / are intended to be compatible with indoor and outdoor focal plane locations. An alternate version of this design used a pointing flat with a small tapered and angled center hole to accommodate faster f/ratio primary mirrors that are not off-axis (right inset in Fig. 1.1.6B). In any design, two diagonal mirrors (and/or variable angle fold mirrors) can be used to vary eyepiece height and angle.

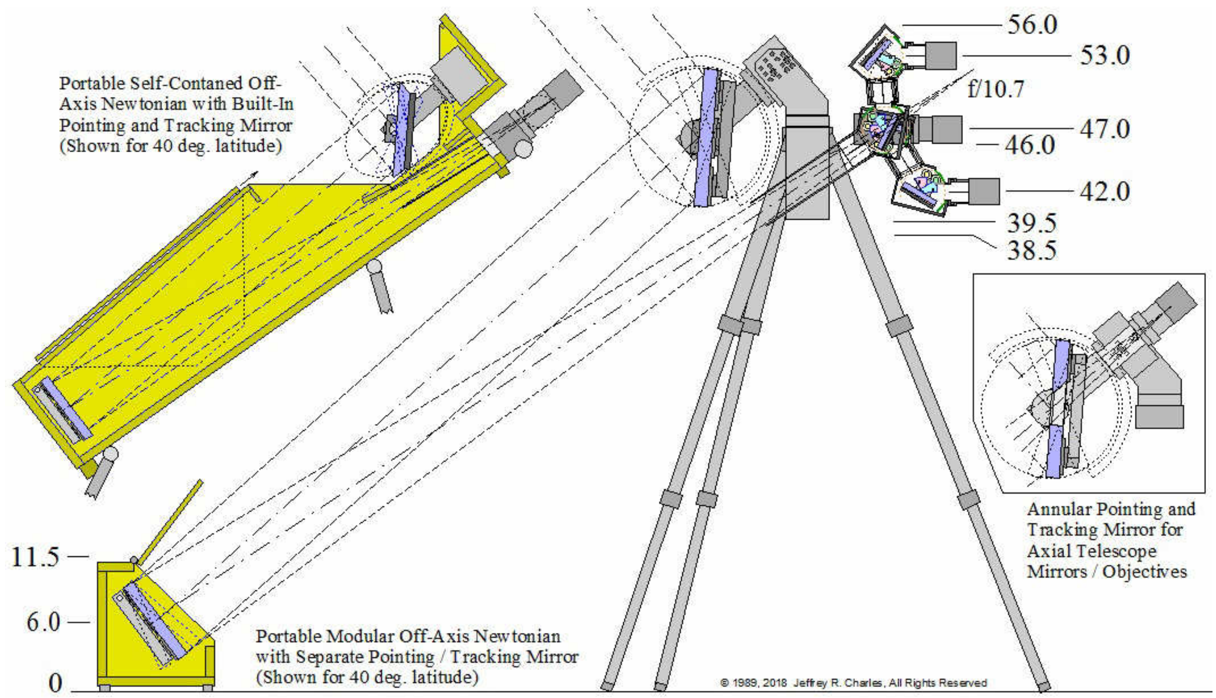


Figure 1.1.6B. Modular fixed eyepiece telescopes with latitude adjustment I designed in 1989. These off-axis Newtonian 'scopes use a fixed primary mirror, and a pointing flat on an equatorial mount. In the modular version, the primary mirror is in a separate housing on the ground and the pointing mirror and focal plane are in a taller assembly, one to a few meters away, depending on focal length. The shown 18 cm f/10.7 version works as an accessible telescope. Structure that supports the eyepiece and pointing flat spans an area wide enough for a wheelchair. Two VAFM's are added to the original version for more variation in eyepiece heights and angles. The self-contained 12.7 cm f/9.6 at upper left has enough back focus to use a diagonal to vary eyepiece angle. Lack of funds due to not being able to get medical care in prior years was the sole reason that one or more of these telescopes was not built way back in the 1980's.

Since these telescopes were designed, others independently designed a few similar items, and (fortunately) had funds to build them. One example is a large accessible telescope at a Texas university. One difference is that my annular pointing flat was on an equatorial mount (designed before alt-az tracking practical for amateur flats), but the Texas flat is on an alt-azimuth mount.

1.1.7) Modified Newtonian. The design emphasized most herein is a modified Newtonian telescope having an "accessible" eyepiece. This approach provides a larger aperture than most.

In some versions of the modified Newtonian design, the secondary mirror reflects light from the primary at an unconventional angle (or even a variable angle, at the expense of adding some complexity to tilt the secondary mirror at half the rate of the focal plane angle). This provides a relatively low eyepiece position, even when the telescope is pointed at high elevation angles. In addition, use of a second flat mirror near focus makes it possible to swivel the eyepiece position. In some cases, the eyepiece angle can be a bit odd at certain low to moderate elevation angles. However, the variable angle fold mirror mentioned above can normalize the eyepiece angles. The last major difference between a modified and conventional Newtonian is that the eyepiece position is well beyond half the width of a wheelchair from the telescope and mount, for better accessibility. The secondary can be smaller if a weak (-120 to -600 mm FL) Barlow lens is used.

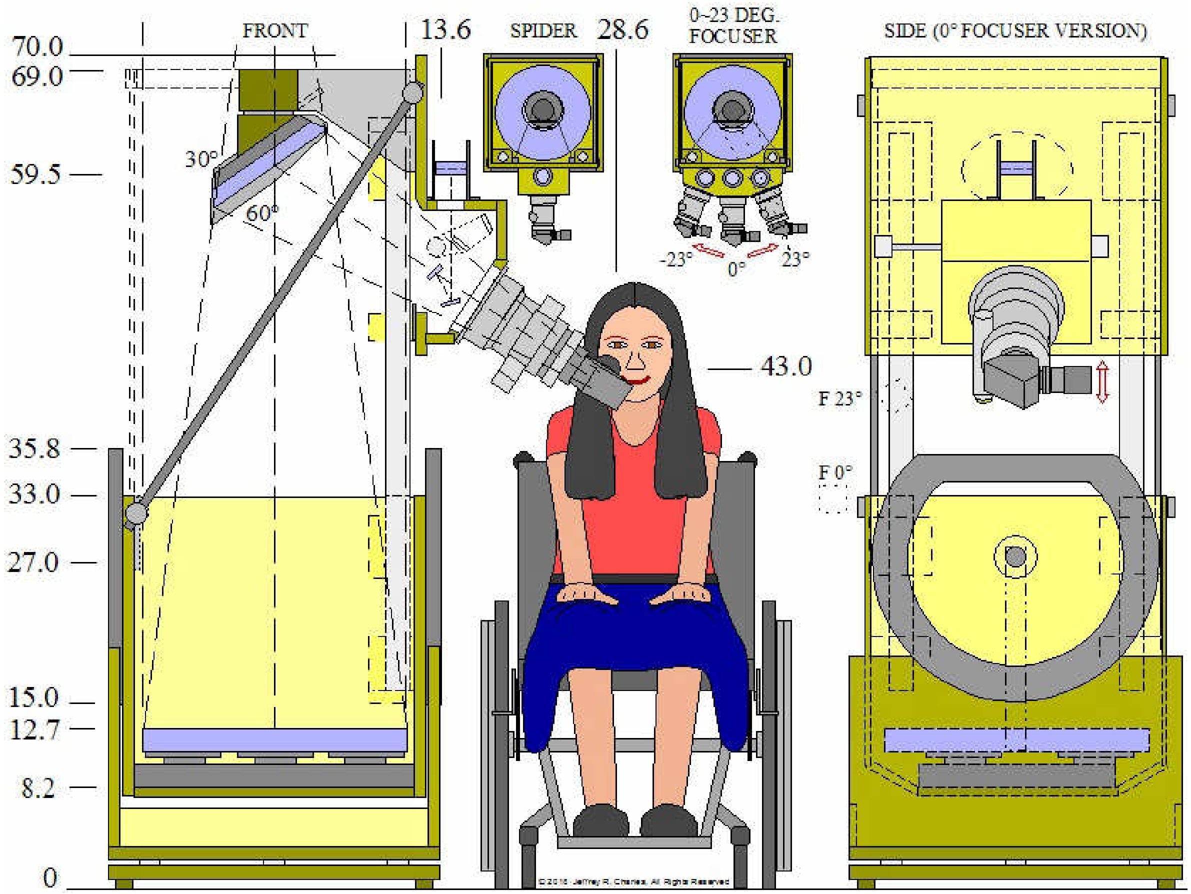


Figure 1.1.7A. Drawing of "accessible" 56 cm aperture f/3.7 modified Newtonian telescope (1.0) By using unconventional angles for the secondary mirror and focuser, a modified Newtonian design provides an *accessible telescope* having a large 56 cm (22") aperture, while also providing some degree of portability when used with a truss and/or dual mast tube design. The eyepiece can be as low as 43" above the ground when the telescope is pointed at zenith. The eyepiece also has good lateral clearance from the telescope structure, providing space for an observer in a wheelchair. There is enough clearance to accommodate use of either eye by the observer, while providing adequate finger clearance between the wheelchair and telescope. Focuser can rotate ±23° about primary mirror axis to provide better eyepiece heights at various elevation angles. Native eyepiece angle is not necessarily orthogonal to telescope at low to moderate elevation angles. However, a variable angle fold mirror (VAFM, shown by eyepiece) provides more intuitive orthogonal eyepiece positions. A 56 cm aperture telescope is shown here, but the concept is applicable to other apertures, depending on which parts are customized. In this embodiment, the rocker box and primary mirror assemblies are shallow and narrow enough to facilitate transport in a typical minivan, and (with focuser removed) rolling the telescope through a doorway as narrow as 2'-6". The primary mirror box is deep enough to facilitate storage of the entire secondary mirror and focuser base assembly. This telescope has a *very* large aperture, but at f/3.73, it requires a coma corrector and well corrected eyepieces. The side light path enclosure and focuser can be made from moderate cost refractor parts. In this version, a finder scope can be built-in as shown, with its image visible in the main eyepiece. Finder scope mirrors can slide or flip in as shown. Observers can choose between the finder image, main telescope image, or the finder image overlapped with the telescope image. Mirrors arranged as a pentaprism provide matching image orientation and can reside in area shaded by secondary. Twin truss poles are inspired by Jim Stevens' 1990's 17.5" f/4.5 Newtonian telescope that Thomas Bopp used to incidentally co-discover comet Hale-Bopp. Details about this and other scopes are in parts 2-3, below.

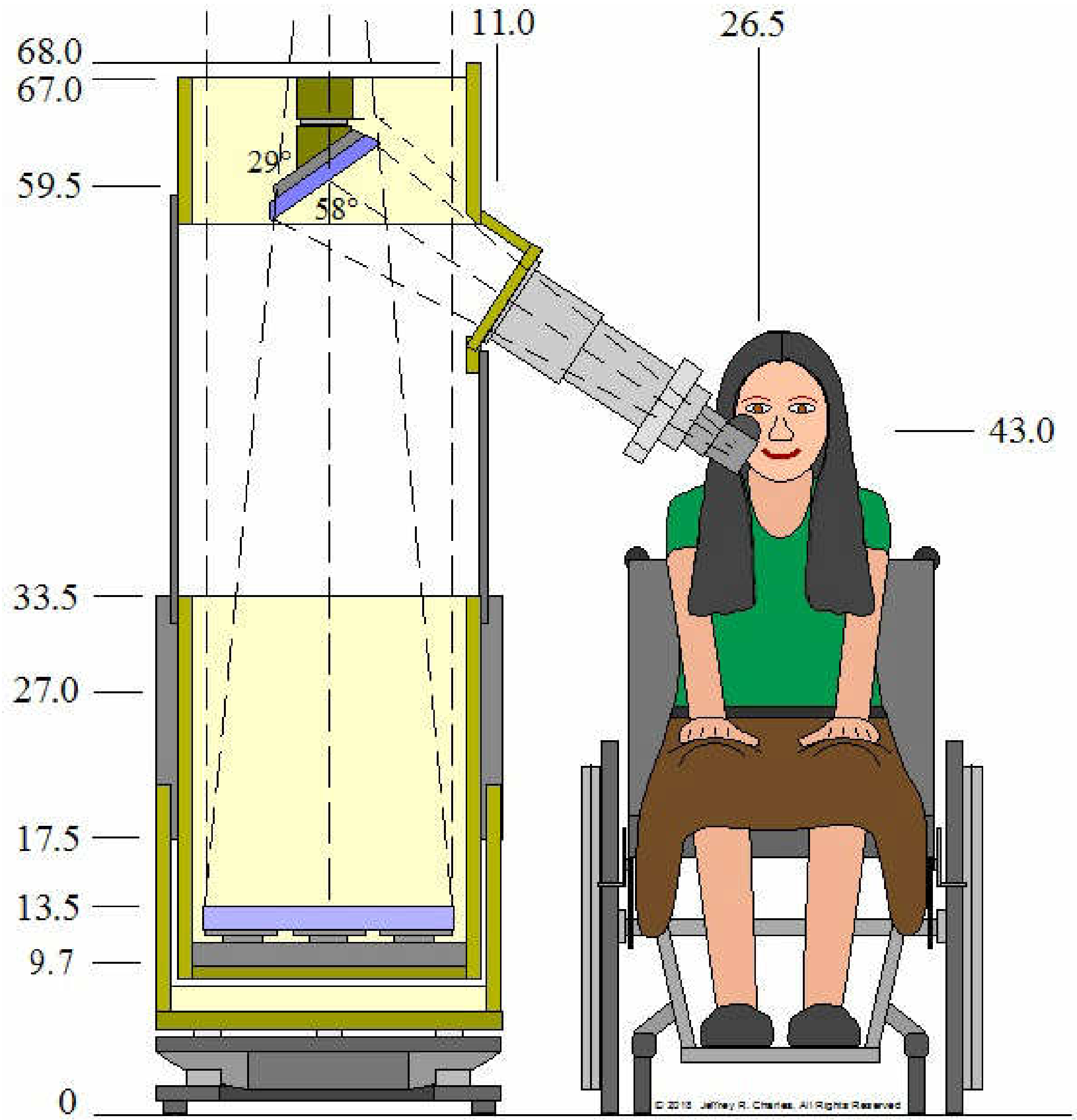


Figure 1.1.7B. Drawing of "accessible" 40 cm aperture f/5 modified Newtonian telescope (5.0). By again using unconventional angles for the secondary mirror and focuser, this modified Newtonian provides an *accessible telescope* having a large aperture, while also providing some degree of portability. The eyepiece can be as low as 43" above the ground when the telescope is pointed at the zenith. The eyepiece also has good lateral clearance from the telescope structure, providing space for an observer in a wheelchair. There is enough clearance to accommodate use of either eye by the observer, while still providing ample finger clearance between the wheelchair and the telescope. A wheelchair with slanted wheels will provide even more finger clearance. A 40 cm aperture telescope is shown here, but the concept is applicable to apertures up to at least 56 cm if more parts are customized. In this embodiment, the primary mirror box is deep enough to facilitate storage of the secondary mirror assembly. This version is preferred in some ways because it has high performance, and at f/5, it does not need highly corrected eyepieces. It can also be used with a tracking platform (shown at bottom) and still have a low eyepiece position. The side light path enclosure and focuser can be made from low cost refractor telescope parts. At lower elevation angles, versions with unusual secondary mirror angles are best used with a 60 deg. (or variable) diagonal Details for design of this and other scopes are in parts 2-3, below.

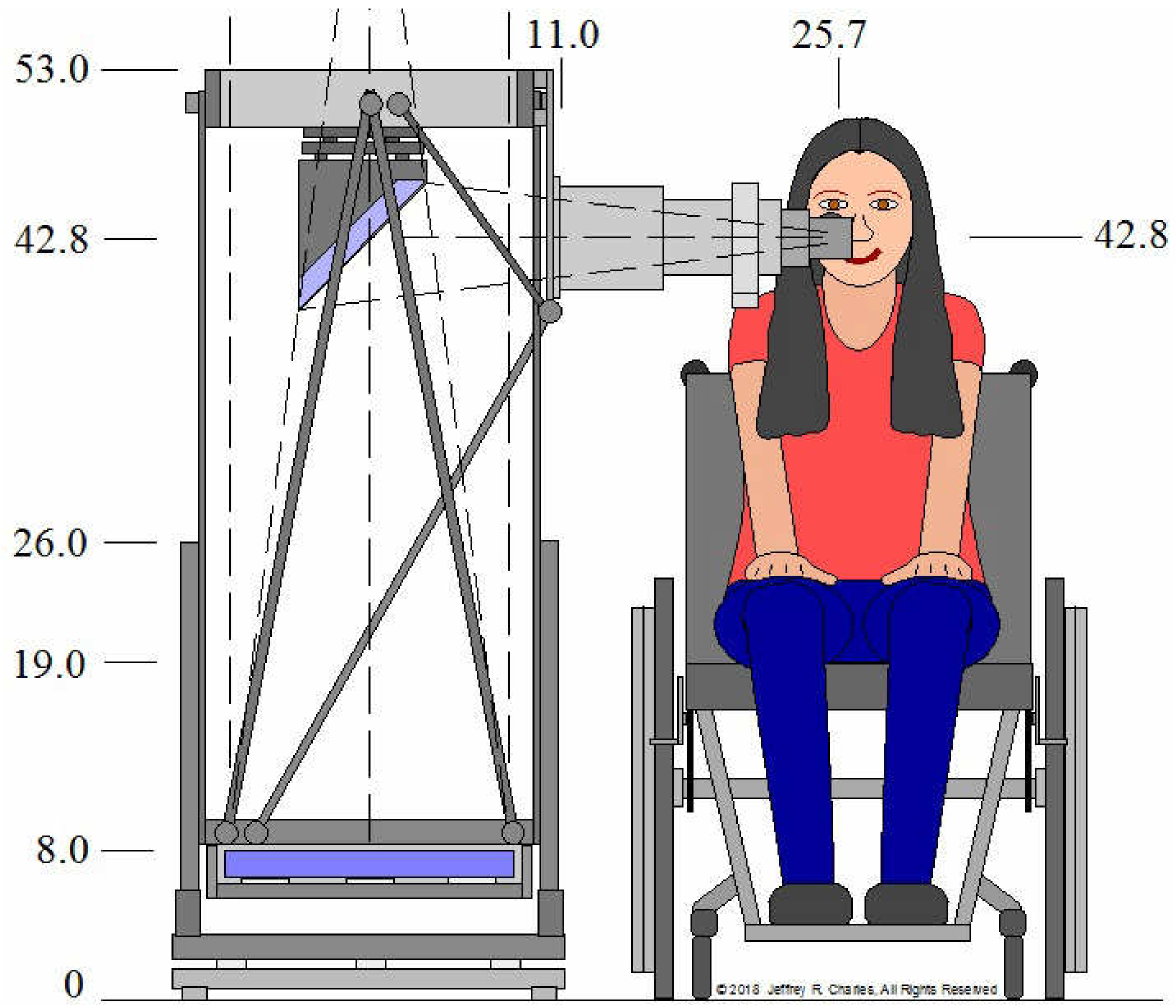


Figure 1.1.7C. Drawing of "accessible" 42 cm aperture f/3.96 modified Newtonian telescope. This telescope is optically more conventional, but mechanically less conventional. It is compact, but this is at the expense of some performance. Here, a conventional Newtonian telescope design is used in conjunction with a structure that *can be* derived partly from modifying a Hubble Optics mount and truss assembly (or using circa 1992 RTMC mast telescope concept). Unfortunately, a very large (45.5% dia.) secondary mirror is needed to provide clearance for observers in wheelchairs, rollators, or other similar size mobility devices. This design provides an *accessible telescope* with a large aperture, while providing better portability. The eyepiece can be as low as 42.8" when the telescope is pointed at the zenith, but the eyepiece also has 2 cm (3/4") less lateral clearance from the telescope mount. This still provides space for an observer in a wheelchair, but with less margin. There is clearance to accommodate use of either eye by the observer, while still providing about 1.7" (4 cm) finger clearance between conventional low cost wheelchairs and the telescope. A wheelchair with slanted wheels provides much more finger clearance. A wheel bumper near the bottom of the telescope mount (not shown) can further prevent pinched fingers. A 42 cm aperture telescope is shown here, but the concept is applicable to smaller apertures, and to apertures up to at least 56 cm if the secondary obstruction percentage is enlarged further or diagonal angle altered. This embodiment is more portable, but at f/3.96, it tends to need a coma corrector and well corrected eyepieces. If a long throw coma corrector (LTCC) is used with a 41 cm (16.0") primary mirror, an f/3.47 primary could be used with a 45% diameter secondary mirror, while also providing clearance for a tracking platform. Details for this and other telescope designs are in parts 2 - 3, below. This is the “4th Version”. An f/3.47 design with LTCC (next page) is “18th version”.

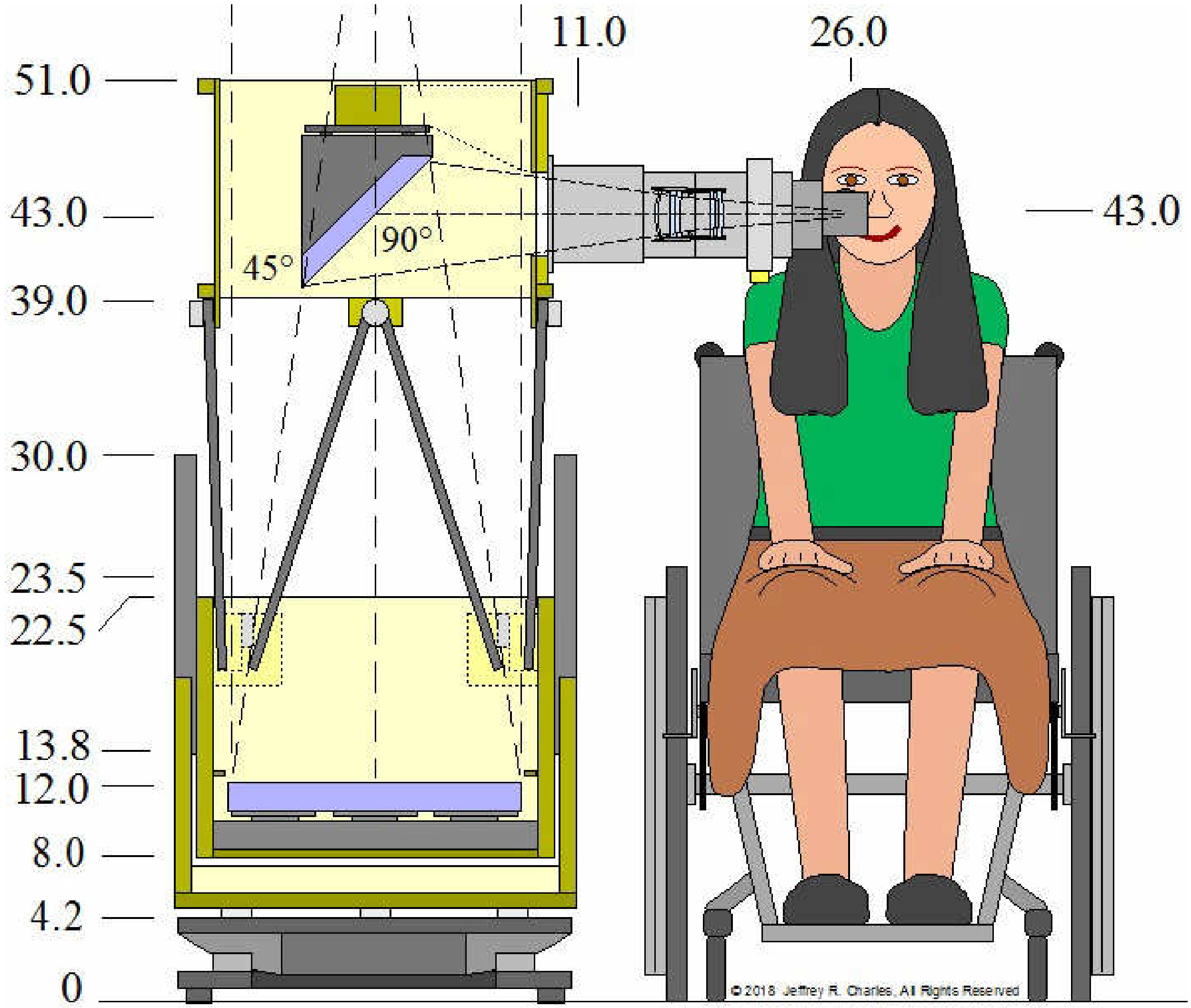


Figure 1.1.7D. Drawing of "accessible" 41 cm aperture f/3.47 modified Newtonian telescope. This telescope is optically less conventional, but mechanically more conventional. It is very compact, but this is at the expense of some performance due to the fast f/ratio primary mirror. This version uses a "Long Throw Coma Corrector" (LTCC), which also functions as a weak Barlow lens, field flattener, and back focus distance extender. The effective negative focal length of the LTCC can be very weak (on the order of -600mm in some versions) which allows it to be located up to, or even beyond, 30 cm from the focal plane. This places its mounting interface in front of the focuser, diagonal attachment, and eyepiece, where the optimum distance from the primary mirror can be maintained regardless of the focus setting. Another benefit of the LTCC is that it can add up to (or even more than) 109 mm of back focus to the system, while only increasing the focal length about 1.5x. This preserves relatively wide field viewing capability when 2" eyepieces are used. In the illustration here, the additional back focus provided by the LTCC permits use of a shorter focal length primary mirror, while also allowing use of a slightly smaller secondary mirror, and a shorter distance between the primary and secondary. The latter makes it possible to add a tracking platform under the telescope without significantly raising the eyepiece height above that shown in the previous figure (1.1.7C). An LTCC also facilitates further reduction in secondary mirror size if a tracking platform is not needed. If at least the front of the telescope structure can be rotated, it will provide a *variable* eyepiece height at most elevation angles. In any version, when clearance with or w/o diagonal permits, observer can be oriented so the wheelchair faces telescope. This is "18th version".

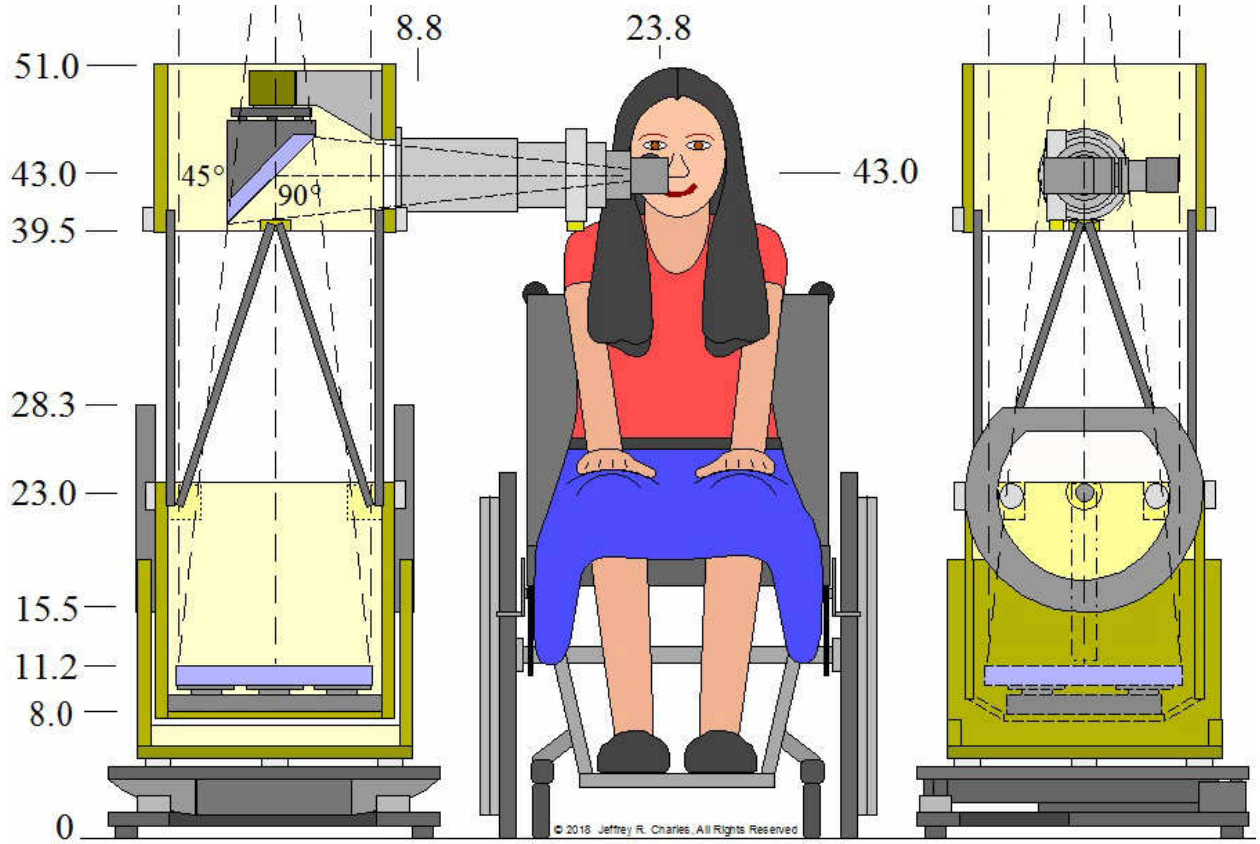


Figure 1.1.7E. Drawing of "accessible" 31.7 cm aperture f/4.55 portable Newtonian telescope. This telescope is optically more conventional, and also mechanically conventional. It is compact, but this is at the expense of considerable aperture. Here, a conventional Newtonian telescope design is used in conjunction with a conventional yet compact structure that *can* be based on conventional designs (or the “mast telescope” concept.) Unfortunately, a very large (46.0% diameter) secondary mirror is needed to provide clearance for observers in wheelchairs, rollators, or other similar size mobility devices, yet retain a low eyepiece position. In this version, a coma corrector may be used with a 38 mm amici prism in a 2" housing for wide field, and a regular diagonal can be used with or without a weak or strong Barlow lens for high magnification viewing. This design provides an *accessible telescope* with moderate aperture, while providing good portability. *This design also works with a separate tracking platform, as shown*. The eyepiece can be as low as 38.9" (42.9" with tracker) when the telescope is pointed at zenith, but the eyepiece also has 1.3 cm (1/2") less than optimum lateral clearance from the telescope mount. This still provides space for an observer in a wheelchair. There is clearance for the observer to use either eye, yet still providing about 2.0" (5 cm) finger clearance between a conventional low cost wheelchair and the telescope. A wheelchair with slanted wheels provides more finger clearance. A wheel bumper near the bottom of the mount (not shown) can protect both fingers and the ground level tracker. A 32 cm aperture telescope is shown here, but the concept is applicable to smaller apertures, and to apertures up to at least 56 cm if the secondary obstruction percentage is enlarged further. This version is moderately portable, and at f/4.55, it may not always need a coma corrector or well corrected eyepieces. The side f/4.55 light path enclosure and focuser can be made from low cost refractor parts. As in most versions, a finder scope can be built in (as in the 22"), with its image visible in the main eyepiece. A flip-in pentaprism (or mirrors arranged as a pentaprism) provide the same image orientation as the telescope, and reside in area shaded by secondary mirror. Details for this telescope design are in parts 2-3, below. It is Version 15A. *This is one of the most likely versions to be used in practice, since it can be used with a small tracker.*

1.2) Assumptions for Wheelchair Size, and Range of Wheelchair Observer Eye Heights

The purpose of this section is to compile dimensions for a few different types of mobility devices (namely, wheelchairs and rollators) and the distance above the ground that the eyes of various people may have when using such mobility devices. It is envisioned that, over time, assumptions below will be replaced by actual measurements of people with mobility related disabilities.

The assumed range of observer height for adults is 4 feet 10 inches to 6 feet 2 inches. The 4 foot 10 number is used because I was acquainted with several Central American adults of about this height who went to a church I once attended. In order to arrive at valid numbers, an additional reduction 3 inches is assumed for people who may have severe scoliosis or certain types of spinal fractures that have been fused. The objective is to arrive at the lowest eye height that is likely to be encountered. I will start with my own eye height measurements and then offset from there.

Assumptions for Wheelchair and Telescope User (Observer) Attributes:

The basic assumptions shown below are used to arrive at a minimum required lateral clearance from the telescope mount structure, and the range of eye heights that may be encountered.

Assumptions for Eye Heights of Various People; Full Height vs Seated Height:

Tallest: 6 feet 2 inches (74"), eye height is 32-33" above rigid seat.
Myself: 5 feet 8.5 inches (69"), eye height is 30~31" above rigid seat.
Shortest: 4 feet, 10 inches (58"), eye height is 26-27" above rigid seat.
Shortest with severe scoliosis: (58"), eye height is 24" above rigid seat.
Conclusion: Range of eye heights for different seated people is about 9 inches.

Assumptions for Minimum Lateral Observer Clearance Requirement of 14.75" to 15.50":

* Typical wheelchair or rollator width: 26.0" (Observed range is 24.5 to 26.5)
* Wheelchair wheel grip rim finger clearance, minimum: +2.0" (if wheels not slanted)
* Wheelchair user eye preference offset: +1.25 (half of inter-ocular distance) (16.25" half width)
* Typical wheelchair and rollator seat width: 17.0" (range is 17.0 to 18.0)
* Typical maximum side bias for seated person: -1.5" (16.25" - 1.5" allows 14.75" half width)
* Results above impose a minimum lateral eye to telescope clearance of: 14.75"
* Some designs assume a larger minimum eye to telescope clearance of 15.5".

Other mobility device dimensions that are applicable, since clearance must be allowed:

* Typical wheelchair wheel grip ring diameter: 21.0"
* Typical wheelchair wheel diameter: 24.0"
* Typical wheelchair seat height: 19.0" (slightly higher than test wheelchair)
* Typical wheelchair arm rest height (for wheelchairs having arm rests): 30.0"
* Typical wheelchair push handle height: 36.0"
* Typical rollator push handle height for good posture with average to tall user: 37.0"

Note: Push handles are the most likely parts of a mobility device to get caught on a telescope focuser (or relay, if used), especially when a telescope is pointed at low to moderate elevation angles. Therefore, it is best to slowly roll up to the eyepiece, use the telescope, then back directly away from the eyepiece a little, and after that, turn to one side while leaving the immediate area.

Assumptions Driving the Requirement for the Lowest (43 inch) Zenith Eyepiece Height:

* Shortest test camp stool or chair height (flexible seat): 14" (many are at least 1" higher)
* My *lowest* eye height when seated with back straight on test camp stool or chair: 43.0"
* Lowest and highest eye heights for people on short test camp stool or chair: 37", 45".

* Test wheelchair flexible seat height: 18.0~18.5", but many seats are a little higher.
* My eye height when seated with back straight in test wheelchair: 50.0"
* Lowest and highest eye heights for people on test wheelchair: 43", 52". (ADA ref: 43" to 51")

* Test rollator rigid seat height: 21.0", but many rollator seats are lower.
* My eye height when seated with back straight on test rollator: 52.0"
* Lowest and highest eye heights for people on test rollator: 45", 54".

* Estimated minimum user eye height when on wheelchair: 43.0" (Also minimum per ADA ref.)
* Estimated typical user eye height when on wheelchair: 47.0" (5'-3" person, 19" seat height)
* Estimated maximum user eye height when on wheelchair: 52.0" (Max. is 51" per an ADA ref.)
* Estimated minimum adult eye height that should be accommodated: 43.0"
* Estimated minimum eyepiece height, with margin for uneven ground: 42.0"

2.) Accessible Telescopes: Basic Descriptions of Two Families of Telescope Designs

The sections that follow cover two specific strawman designs for accessible telescopes. The purpose of this exercise is to show that it is possible to make such telescopes. In fact, if I could still use machine and other power tools, I probably would have built one long ago.

2.1) Description of Large Aperture Accessible Modified Newtonian Telescope

The emphasis of this design is to provide a large aperture telescope having an eyepiece that is accessible from a wheelchair, while also requiring a minimum of head and neck motion. A significant emphasis is to achieve the lowest appropriate eyepiece position possible (down to as low as 42 or 43"), since a person in a wheelchair usually can’t raise their eye height. There are many simple and obvious ways to *raise* the eyepiece position for taller observers when necessary.

The purpose of an "accessible telescope" is to make it possible for handicapped people in wheelchairs (or other mobility devices) to view deep sky and other objects through even a large aperture telescope, without having to transfer to another chair or tip their head very much. Such a telescope would be useful at public viewing events, and maybe some can own one. People using wheelchairs could then access large aperture telescopes having wide fields of view, just like everyone else. By definition, a wheelchair accessible telescope is *also* a telescope that almost <u>*anyone*</u> can use from a seated position, no matter where the scope is pointed in the sky.

As of early 2018, the concept for this type of telescope had matured enough that I approached a well known telescope mirror manufacturer about quoting on the primary and secondary mirrors. I also informed them about what the mirrors would be used for, but never heard back from them.

After some brief research and a few calculations, I determined that the maximum practical size for an *affordable* "accessible telescope" is probably in the 40 cm (16 inch) aperture range. The reason for this is that 40 cm is close to the largest aperture for which a *conventional* “Dobsonian” ground board and rocker box can fit through a 2 foot 6 inch door (assumed 27.75" clearance), and it is also the largest aperture for which a suitable secondary mirror is readily available.

A 40 cm aperture is in the sweet spot for striking a balance between fixed distances such as the required lateral eyepiece clearance, and design requirements that include the maximum allowable eyepiece height versus the maximum secondary mirror size, versus available secondary mirrors, and controlling cost. It is possible to achieve a 56 cm aperture and still fit through a 2 foot 6 inch door, but many aspects of the design have to less conventional, which increases cost.

In order to provide good eyepiece clearance from the telescope *without* using a Barlow lens that would limit the field of view, the present design has a large maximum secondary mirror diameter of about 44 percent of the telescope aperture. This is a relatively large obstruction, but it is not unprecedented. It is roughly equivalent to the obstruction percentage for some commercial telescopes, including the vintage Meade 4 inch f/10 Schmidt-Cassegrain Telescope (SCT).

If a custom larger secondary mirror is used in conjunction with a custom lower profile mirror cell and rocker box assembly (similar to certain parts of my design for an 8 inch f/3.6 Newtonian telescope I built in 1989) then it would be possible to push the aperture up to 56 cm (22").

However, since I can no longer fabricate major telescope components myself, the aperture emphasized here will be about 40 cm, as this makes it possible to build the telescope from mostly conventional components that multiple vendors can provide; or even from second hand parts.

In practice, *the <u>most likely</u> aperture to be implemented first may be in the 32 cm range*, and the secondary obstruction diameter may be up to 47 percent of the telescope aperture. Telescopes in this aperture range that also have large obstructions tend to have simple designs, and can be used with separate low profile *star tracking units* that are used between the telescope and the ground.

Even a 40 cm class aperture is well below the "knee" for the aperture size at which galaxies begin to visually look almost as good as 1970's era deep sky photographs. This knee for such views of galaxies is in the 56 to 61 cm (22 to 24") aperture range. However, many other deep sky objects, including globular star clusters, will look excellent in a 40 cm aperture telescope.

Conventional telescopes up to 42 cm aperture that are made by Starmaster (TM) have a 66 cm (26 inch) square rocker box, and a similar size ground board at the bottom. This does not include wheel supports, which would add 2~8 cm to the width. Other brands have 69.2 cm (27.25") rocker boxes, including protrusions. Unconventional designs such as the Hubble Optics 40 cm telescope are more compact, having a smaller 55.9 cm (22") rocker assembly and base width.

2.1.1) The Present Design for a circa 40 cm Class Modified Newtonian Reflector Telescope

The present design for a large aperture accessible telescope is a 40 cm class modified Newtonian configuration. The bottom part of the telescope may be like or similar to any other Newtonian in a Dobsonian style altitude over azimuth mount (and thus be compatible with third party tracking systems), but some design variations are less conventional from the secondary mirror onward.

In higher performance embodiments, the secondary mirror tilt angle is unconventional, so it reflects light path downward at about 30 to 32 degrees (this narrow range of angles appears to be optimum this far), when compared to a normal right angle secondary mirror configuration.

The angle is intended to reduce the height of the eyepiece position, including when the telescope is pointed at a high elevation angle. One or more additional flat mirrors, which may each consist of a conventional "star diagonal" mirror attachment or a variable angle fold mirror (VAFM), may be also used by the focal surface in order to provide a comfortable and adjustable eyepiece angle.

When the telescope is pointed at the zenith and a diagonal mirror is used near focus, the eyepiece height for a 40 cm f/5 telescope can be lower than 1 meter (and can obviously be higher), when the eyepiece is oriented horizontally so the user can look straight ahead to see into the telescope.

Eyepiece height is relatively consistent for subjects above 40 degrees elevation angle. At 30 deg. elevation angle, eyepiece height may be as high as 88 cm with a diagonal, and can be lower if needed. It can also be higher (>105 cm) in some versions for low elev. angles. (Fig. 1.1.7A, etc).

The eyepiece position gets still lower as the elevation angle decreases for viewing objects near the horizon, but the center of the diagonal never gets below about 63 cm, and the diagonal can be angled upward to compensate. After the length of a typical high eye relief eyepiece is added, the worst case low eyepiece height becomes ~76 cm, and observers can look down a moderate angle to see into it. If the telescope (or at least the secondary mirror and focuser) can rotate about the primary mirror optical axis (or be angled), eyepiece height will be variable, and can be higher..

Another difference from an ordinary Newtonian telescope is that the secondary mirror minor axis is relatively large, being up to roughly 44 percent of the telescope aperture. The maximum commonly available secondary mirror size (about 18 cm minor axis) is another situation that limits the maximum practical (when it must be affordable) telescope aperture to about 40 cm.

The large secondary mirror is used to provide at least 37.5 cm (14.75") of lateral clearance between an observer's eye and the telescope rocker box, without resorting to a Barlow lens to increase back focus distance. This preserves the wide field capabilities of a standard Newtonian telescope. This distance provides clearance for a wheelchair and the observer's fingers, while also accounting for each person's eye preference. The design is optimized to minimize required neck motion, since many with spinal cord injuries may be unable to tip or turn their head much.

To use the telescope, the observer's wheelchair (or other mobility device) is rolled up next to the telescope rocker box, facing more or less toward the azimuth of the telescope's optical axis. A diagonal mirror and eyepiece are then positioned directly in front of the observer's eye.

It is never necessary to look upward when using the telescope, but its use is enhanced for objects at low to moderate elevation angles if an observer is able to look downward up to 30 degrees, and even more so if it is possible for an observer to lean forward a little. A fold mirror and weak Barlow lens (to provide more back focus) can be used when an observer can't look downward.

A telescope design having an optical path that passes right through the elevation axis would be easier to use, because the eyepiece height remains constant regardless of the elevation angle. However, this is not very practical with a Newtonian telescope. It is practical (and was once more common) with Cassegrain telescopes (see 1.1.5), but a Cassegrain of similar aperture costs more, weighs more (wood construction is less common), and has a much smaller field of view.

Owing to the large secondary mirror, planetary performance of the described embodiment of an accessible 40 cm class Newtonian telescope may often be similar to that of an unobstructed 16.5 to 18 cm (6.5 to 7 inch) aperture telescope, due to a large amount of energy being in the first diffraction ring, because of the larger secondary obstruction. However, deep sky performance with the 40 cm telescope will be superior to telescopes having considerably smaller apertures.

In terms of weight, if the mount and structure for a 40 cm telescope are of *conventional* design, and made from wood (including if made by a company such as Starmaster), it may weigh only slightly more than their standard 42 cm (16.5") f/3.7 FX series telescope. The components are beyond my own lifting capacity, but not beyond the lifting capacity of most people. Specifically:

* Rocker box and ground board weight: 14.5 kg (32 lbs)
* Mirror box weight: 14 kg (31 lbs)
* Mirror and cell weight: 17.3 kg (38 lbs)
* Mirror transport box weight: 5.5 kg (12 lbs; not part of scope, not in total)
* Secondary cage assembly: 5 kg (11 lbs) 7.2 kg (16 lbs) for accessible version)
* And for the accessible version: Side light path and focuser assembly: 2.7 kg (6 lbs)
* Total weight: 55.7 kg (123 pounds), which is similar to weight of a C14 and mount, w/o tripod.

Comment: Weight can be reduced by over 30 percent by using standard light-weighting methods.

Regarding dimensions, the estimated telescope tube or truss assembly *length* ranges from 109 cm (43 inches) to 152 cm (60"), and the envelope of the entire assembled 40 cm f/5 telescope and mount (when pointed at zenith) measures roughly 170 x 66 x 66 cm (67 x 26 x 26"). This is based on conventional design. An f/4 or faster version may be as short as 129 cm (51").

The assembled f/5 telescope envelope can be reduced to as little as 165 x 53 x 53 cm (65 x 21 x 21") if more unconventional parts are used. The design most likely to be implemented uses a few unconventional parts to reduce the rocker box and ground board widths to about 56 cm (22"). The telescope can also be lighter than a conventional design by using thinner material or having cutouts in key places. Details, including basic specifications, follow the next subsection.

Many of the concepts and details discussed in this document can be scaled with aperture. For example, the physical size (and observer clearance) for a larger or smaller aperture telescope will be influenced by the same attributes that are discussed in light of a 40 cm aperture instrument.

2.2) Accessible Telescope with Fixed Eyepiece Inside of a House or Other Structure.

My own design for a “built-in telescope” design has remained relatively unchanged in concept for decades, but a few specifics have recently become more defined. One detail that imposed limitations on the maximum affordable aperture was the cost of *ring bearings* to support the rotating quasi heliostat (or other feed mirror) assembly, and the maximum size of lathes that are plentiful enough to contribute to lower ring bearing interface fabrication costs.

Specifically, the inside diameter of *affordable* crossed roller ring bearings is in the 150 mm to 160 mm range. Since a wall thickness of at least 6 mm (nearly 1/4 inch) is needed for the tube where it runs through the bearing (if it is to support the weight of the feed mirror and its enclosure), the maximum aperture is limited to between 12.7 cm and 14 cm (5.0 and 5.5").

The reason the recommended aperture is limited this much is because the inside of the telescope tube forward of the objective must also provide some clearance for off-axis parts of the light path, plus light baffles. This additional clearance is needed to reduce the effects of boundary layer currents at the tube walls and light baffles.

This means that the best available objective will likely be a 5 inch f/25, but a 15 cm f/20 could work if stopped down to 14 cm (f/21.8). Details about this are in part 3.2, below.

Maximum sizes for a ring bearing versus two aperture sizes have been evaluated. In reality, it is likely that the larger 160 mm ring bearing (only affordable second hand) would be used even for a 12.7 cm (5") objective, since this would better reduce boundary layer effects in the tube. A minor axis of 16.5 cm (6.5") should still be adequate for the feed mirror, and this sightly smaller mirror should take less time to adjust to different temperatures. Spring loaded shock absorbers can be used at the upper polar end of the assembly (as in Figure 1.1.6A) to reduce oscillation.

3.) Accessible Telescopes: Strawman and Baseline Designs.

The sections that follow cover specific strawman designs for accessible telescopes. The purpose of this exercise is to show that such telescopes are possible. In fact, if I could still use machine tools, I would have built one long ago. Most details in the following sections are not in metric units. Additional information, including vendor data for selected parts, are in the Appendices.

Accessibility is determined by a number of factors. Many are accommodated at the expense of other attributes, including the size of the secondary obstruction. Details to consider include:

* Eyepiece *height* is one of the most important considerations. Must accommodate down to 43".
* Eyepiece *angle* is important for observers having numerous fused vertebrae that limit motion.
* Means of tracking, whether integrated into the mount (expensive), or via a tracking platform.
* Width of rocker box. For a 16" telescope, this can vary from 21" to 27.25". Smaller is better.
* Physical size and weight, including fitting through doorways; fitting in vehicles, on walker, etc.
* Ease of setup, time to set up, and physical capabilities or knowledge needed to set up telescope.
* General access and safety features, including eye safety for people in motorized wheelchairs.

3.1) Accessible Large Aperture (40 cm Class) Modified Newtonian Reflector: Versions

Methods of Accessibility for Large Aperture Modified Newtonian telescope include:
* Modified Newtonian having large secondary mirror, and long focuser extension on side.
* Folded light path with large secondary mirror, second flat mirror even lower on side.

3.1.1) SPECIFICATION (Example, based on version 5, and iteration 5.0, from below):

Version 5.0: 44% Secondary Obstruction, Tilted 29 Deg., with 16.0" f/5.00 Primary Mirror.
* 16.0" f/5.00 primary mirror: 80.00" (2032 mm) focal length.
* Tolerance for primary mirror f/ratio is from f/4.95 to f/5.02.
* 7.0" secondary mirror minor axis, optimized for 58 degree reflection.
* 2" diagonal mirror attachment used by eyepiece (so no need to turn head).
* Ground board and rocker box width shall not exceed 22.0"
* Lateral clearance between user's eye and rocker box is at least 15.5"
* Maximum aperture: 16.0~16.5" (Baseline for this design is 16.0")
* Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
* Half width of telescope assembly (custom parts used): 11.0"
* Half width plus larger 15.5" lateral user clearance (11+15.5) = 26.50"
* Fastest f/ratio based on secondary size alone: (26.50/6.8) = f/3.90
* Fastest f/ratio if add diagonal (1.25+2.75"): (29.25/6.8) = f/4.30
* Adjust for optical path direction: 1/COS32 ([26.50]*1.179) = 31.24"
* Additional optical path distance from 2nd diagonal to eyepiece: 2.75"
* New f/ratio after account for angle: (31.24+2.75=33.99)/6.8 = f/5.00
* Required focal length after diagonal added: 80.00" (2032 mm)
* Optical distance from primary to secondary: (80.00-33.99) = 46.01"
* Optical path distance from secondary to diagonal: 31.24" (26.50 lateral)
* Height reduction due to 58 deg. reflection: 31.24*SIN32 (.53) = 16.55
* Eyepiece distance above primary when at zenith: (46.00-16.55) = 29.45"
* Primary is realistic 12.55~13.55" above ground for 42-43" eyepiece height.
* Maximum tube assembly length (estimated): 58" (147 cm)
* Maximum telescope envelope when pointed at zenith: 67 x 22 x 22" (170 x 56 x 56 cm)
* Minimum / Maximum elevation axis height (estimated): 26.0" (66 cm)
* Primary mirror height above ground (min.) 12.55" (conventional slightly higher)
* Maximum eyepiece height at zenith (eyepiece horizontal): 42.0"
* Estimated weight if design mostly conventional: 123 lbs (55.7 kg)
* Estimated weight if design mostly unconventional: 74 lbs (33.6 kg)

Remarks: This design can be tweaked to work with a 16.5" f/4.87 mirror, but at the expense of a slightly higher eyepiece position, or by reducing the lateral user clearance from 15.5" to 14.75". This is shown in version 5.1 below. Likewise, the telescope envelope can be reduced slightly (by about an inch in length) by using a 16" f/4.87 primary mirror.

Conclusion:
* The design above IS feasible with secondary obstruction of 44%, and no Barlow is needed.

3.1.2) BASIS FOR SPECIFICATION (User Attributes, plus Several Versions):

In this subsection, a few design versions will be shown to illustrate why certain approaches are practical, while others are not. One version will show that a secondary as small as that in a conventional Newtonian telescope is not practical. An additional version will show that the simplest approach, including a fast primary and a large but conventional 45 degree secondary mirror tilt, do not provide adequate clearance from the telescope without making the secondary mirror larger than what is desirable. Units for most dimensions below are *not* metric in order to be consistent with the units used by most domestic telescope manufacturers.

Assumptions for Wheelchair and Rollator Attributes:
* Typical wheelchair or rollator width: 26.0" (13" half width)
* Wheelchair grip rim finger clearance, minimum: +2.0" (requires 15" half width)
* Wheelchair user eye preference offset: +1.25 (16.25" half width)
* Typical maximum side bias for seated person: -1.5" (allows 14.75" half width)
* Results above impose a minimum lateral eye to telescope clearance of: 14.75"
* Some designs assume a larger minimum eye to telescope clearance of 15.5".
* Test wheelchair seat height: 18.0", but many wheelchair seats are higher.
* Estimated typical user eye height: 47.0" (for 5' 3" person)
* Estimated worst case low eye height (shorter person with scoliosis, etc.) 43.0"

Assumptions for Most Basic Telescope Specifications:
* Useful clear aperture of primary and secondary mirrors is 5 mm less than substrate size.
* Full width of 40.64 cm primary substrate assumed for light bundle, to prevent clipping.
* Primary mirror is up to 44.5 mm thick, and of either flat or meniscus type.
* Max. half width of telescope ground board is 13". Smaller half widths (down to 11") possible.
* Secondary mirror having a minor axis no larger than what is commonly available: 18 cm (7").
* Telescope components small and light enough for average person without disabilities to handle.
* Barlow lens is not required to provide adequate clearance, since a Barlow reduces field of view.
* Telescope "go to" capability (if a scope has it) is *disabled* in order to provide better eye safety.

3.1.3) Design Versions and Iterations

Even though a conventional Newtonian design is *not* practical for an accessible telescope *with a small secondary obstruction* (while also not using a Barlow lens, since it limits FOV), certain versions with secondary obstructions *larger* than 40 percent are workable. A few versions for conventional designs are shown to illustrate this point. One important consideration is keeping the secondary obstruction to a reasonable size, even though it is a larger than conventional size.

The secondary must be large with any accessible configuration that does not use a Barlow lens, but the secondary obstruction must be kept well below 50 percent of the telescope aperture in order to prevent serious reduction in performance due to diffraction, plus exit pupil anomalies.

A maximum secondary minor axis of 44 percent was ultimately specified. Another consideration is that the largest commonly available secondary mirrors have a minor axis of only about 18 cm.

The simplest approach for an accessible Newtonian telescope may at first *seem* to be a fast f/ratio primary mirror (between f/3 and f/4.2), combined with a relatively large diameter secondary mirror. However, as shown below, this does *not* work as well as an unconventional design.

Specifically, the minimum lateral clearance distance required from the eye of a person in a wheelchair, including allowing for eye preference and wheelchair finger clearance, is 14.75", and 15.5" is better. The base and rocker box width for a *conventional* 16 inch Dobsonian is about 26". Rocker box width remains 10" wider than primary mirror for moderately larger apertures.

This means that, for a *conventional* design 16" telescope, the lateral distance from the center of the telescope to the observer's eye is 13 + 14.75", or 27.75" from the optical axis. Adding a diagonal mirror near the eyepiece (necessary so the wheelchair can be sideways, next to the telescope) increases this distance by *at least* another 2.75", for a total of 30.5" (27.75 + 2.75).

It must also be kept in mind that the *maximum* eyepiece height goal is 43", and 42" is preferred in order to allow for uneven ground by the telescope. In a *conventional* design, the primary mirror surface is up to *12"* above the ground, to provide clearance between the back of the mirror cell and the mount base when the scope is pointed in various directions. This means the maximum primary to secondary distance is limited to 30" (42" eyepiece height - 12" mirror height).

Working backwards to arrive at a viable focal length, we see that the optimum focal length is the 30" maximum allowable mirror spacing, plus the 30.5" observer clearance from the optical axis. This results in a focal length of 60.5" (1537 mm). For a 16" mirror, the resulting f/ratio is f/3.78. Unfortunately, when we divide the 30.5" observer clearance by the 3.78 focal ratio, we arrive at a secondary mirror minor axis of 8.07". This exceeds 50 percent of the primary mirror diameter!

If the primary mirror f/ratio is slowed to work with a 44 percent secondary mirror diameter (7.0" substrate, with 6.8" being useful as a mirror surface), the f/ratio becomes f/4.49 (30.5/6.8). This results in a primary mirror focal length of 71.84". When the 30.5" distance from the secondary to focus is subtracted, we see that the distance between the primary and secondary must be 41.34". But there is more. The primary mirror is 12" above the ground. Adding 12" to the 41.34" mirror spacing results in an eyepiece height of 41.34 + 12", or 53.34". This much eyepiece height is out of reach for almost any short to average height person in a wheelchair. My own eye height in a test wheelchair is up to 50", and I am near average height and can also sit up straight.

The secondary obstruction can be *smaller* if the rocker box *width* is reduced, and if the *distance* between the ground and primary mirror is reduced. Achieving *both* requires an *unconventional* telescope structure that may provide less protection for the primary mirror. In this example, we will assume use of a Hubble Optics telescope frame, or similar. It is ~22" wide, and the primary mirror is about 8" above the ground. The changes reduce the observer clearance to 28.5" optical distance from the optical axis, and the allowed primary to secondary spacing becomes 34" (42-8"). This results in a focal length of 62.5" (28.5 + 34), and an f/ratio of f/3.91. When we divide the 28.5" user clearance by the f/3.91 f/ratio, we arrive at a secondary mirror minor axis of 7.29". This requires a 7.5" secondary substrate. The obstruction is 47 percent. Therefore, a *conventional* Newtonian telescope design is not quite optimum for a large aperture accessible telescope.

One *solution* is to use an *unconventional* secondary mirror tilt angle of about 29 to 30 degrees. This reflects the light path down 30~32 degrees, compared to the usual right angle reflection in a Newtonian telescope. This provides a better ratio between the allowed primary to secondary spacing, and observer clearance from the optical axis. This design works with a 16" f/5 mirror.

Even though a circa 40 cm aperture telescope is the emphasis, other apertures will be shown to illustrate that the concepts and designs can be scaled, if appropriate variables are accounted for. To set the stage, the following table shows the range of rocker box widths for different apertures.

Aperture:	Conventional	Small Rocker Box	Unconventional	Primary M. Height
20 cm (8.0")	14.5"	12.0"	11.5"	6.5~9.5"
25 cm (10.0")	17.5"	14.5"	14.0"	6.8~10.0"
32 cm (12.5")	20.5"	17.5~18.0"	17.0"	7.0~10.5"
37 cm (14.5")	22.5"	19.5~20.0"	19.0"	7.7~12.0"
38 cm (15.0")	23.0~25.0"	20.0" (Tscope m8.5)	19.5"	7.9~12.5"
41 cm (16.0")	24.5~27.25"	21.0"	20.5"	8.0~13.5"
46 cm (18.0")	28.0~29.25"	23.5"	23.0"	9.9~15.4"
51 cm (20.0")	30.0~31.25"	25.5"	25.0"	10.8~17.2"
56 cm (22.0")	32.0~33.25"	28.0"	27.25"	12.7~19.1"
61 cm (24.0")	34.0~35.25"	30.0"	29.5"	14.5~21.0"

To evaluate different designs, we will start with the largest practical telescope (22" with compact but unconventional mount) and then progress to smaller apertures, but emphasize a 16" aperture.

Version 1.0: 43.2% Sec. Obst., 30 Deg. (22.0" f/3.69 primary; coma corrector) (*Backup 6*)
Maximum aperture: 22.0" (Baseline for this design is 22.0") f/3.685.
Tolerance for primary mirror f/ratio is from f/3.67 to f/3.71.
Maximum secondary obstruction (43.2%): 9.5" (9.3 useful, for 22.0") (8.3ca=38.6%,f/3.6 49.4sp)
Half width of *unconventional compact* telescope assembly (custom parts used): 13.6"
Half width plus slightly larger 15.0" lat. user clear (13.6+15.0) = 28.60" phys (-1.5cc) 27.10" opt.
Fastest f/ratio based on secondary size alone: (27.10/9.3) = f/2.914
Fastest f/ratio if add diagonal (1.25+2.75"): (29.85/9.3) = f/3.210
Required focal length after diagonal added: 70.62" (1794 mm)
Distance from primary to secondary (for conventional Newtonian): (70.62-29.85) = 40.77"
Adjust for 1/COS30 ([28.60phys]*1.155) = 33.02" (Note: 2x 29d. = 58; 90-58=32 deg. f/perpen.)
New f/ratio after account for angle (33.02-1.5 coma cor=31.52); (31.52+2.75=34.27)/9.3=f/3.685
Required focal length after diagonal and angle added: 81.07" (2059 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (81.07-34.27 opt) = 46.80"
Eyepiece height reduction due to 60 deg. reflection: 33.02*SIN30 (0.50) = 16.51"
Eyepiece distance above primary when at zenith: (46.80-16.51) = 30.29"
Allows primary to be 11.71~12.71" above ground for 42-43" eyepiece height. (Tracker *won't* fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 12.7"
Primary to secondary distance plus mirror height: 42.99" eyepiece height. (*Barely meets* req'mt.)
Design *is feasible* with 43.2% secondary obstruction, no Barlow. But must use *Alt-Az tracking*.
Remarks: Purpose of this version is to show if 22.0" aperture practical for accessible telescopes.

Version 1A: 42.5% Sec. Obst., 30 Deg. (20.0" f/4.02 primary; coma corrector)
Maximum aperture: 20.0" (Baseline for this design is 20.0") f/4.019 (f/3.791.if 8.8 ca sec.38.1eh)
Tolerance for primary mirror f/ratio is from f/4.00 to f/4.03.
Maximum secondary obstruction (42.5%): 8.5" (8.3 useful, for 20.0") (if sec. 8.8 useful: f/3.791)
Half width of *unconventional compact* telescope assembly (custom parts used): 12.8"
Half width plus slightly larger 15.0" lat. user clear (12.8+15.0) = 27.80" phys (-1.5cc) 26.30" opt.
Fastest f/ratio based on secondary size alone: (26.30/8.3) = f/3.169 (7.8 sec = f./3.724 w/diag)
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (29.05/8.3) = f/3.500 (8.8 sec = f/3.301 w/diag)
Required focal length after diagonal added: <u>70.00</u>" (1778 mm) (8.8 sec = 66.02"; 9.3 = 62.47")
Distance from primary to secondary (for conventional Newtonian): (70.00-29.05) = <u>40.95</u>"
Adjust for 1/COS30 ([27.80phys]*1.155) = 32.11" (Note: 2x 30d. = 60; 90-60=30 deg. f/vert.)
New f/ratio after account for angle (32.11-1.5 coma cor=30.61); (30.61+2.75=33.36)/8.3=<u>f/4.019</u>
Required focal length after diagonal and angle added: <u>80.39</u>" (2042 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (80.39-33.36 opt) = <u>47.03</u>" (8.8 sec = 75.82"; 42.16")
Eyepiece height reduction due to 60 deg. reflection: 32.11*SIN30 (0.50) = 16.05"
Eyepiece distance above primary when at zenith: (47.03-16.05) = <u>30.98</u>" (*8.8 sec = 26.11 trkr fit*)
Allows primary to be 11.02~12.02" above ground for <u>42-43</u>" eyepiece height. (Tracker *won't* fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 12.0"
Primary to secondary distance plus mirror height: <u>42.98</u>" eyepiece height. (*Barely meets* min.)
Design *is feasible* with 43.2% secondary obstruction, no Barlow. But must use *Alt-Az tracking*.
Remarks: Purpose of this version is to show if 20.0" aperture practical for accessible telescopes.

Version 1B: 43.1% Sec. Obst., 30 Deg. (18.0" f/4.29 primary; coma corrector)
Maximum aperture: 18.0" (Baseline for this design is 18.0") f/4.293 (f/4.411.if 7.3 ca sec 42.7eh)
Tolerance for primary mirror f/ratio is from f/4.28 to f/4.31. (f/4.128.if 7.8 ca sec. 37.6eh)
Maximum secondary obstruction (43.2%): 7.75" (7.5 useful, for 18.0")
Half width of *unconventional compact* telescope assembly (custom parts used): 11.8"
Half width plus slightly larger 15.0" lat. user clear (11.8+15.0) = 26.80" phys (-1.5cc) 25.30" opt.
Fastest f/ratio based on secondary size alone: (25.30/7.5) = f/3.373 (7.3sec=f/3.842w/d;fn79.38)
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (28.05/7.5) = f/3.740 (7.8sec=f/3.591w/d;fn74.31)
Required focal length after diagonal added: <u>67.32</u>" (1701 mm) (7.8 sec = 64.73"; Fin. FL:74.31)
Distance from primary to secondary (for conventional Newtonian): (67.32-28.05) = <u>39.27</u>"
Adjust for 1/COS30 ([26.80phys]*1.155) = 30.95" (Note: 2x 30d. = 60; 90-60=30 deg. f/perpen.)
New f/ratio after account for angle (30.95-1.5 coma cor=29.45); (29.45+2.75=32.20)/7.5=<u>f/4.293</u>
Required focal length after diagonal and angle added: <u>77.28</u>" (1963 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (77.28-32.20 opt) = <u>45.08</u>" (7.8 sec = 74.31"; 42.11")
Eyepiece height reduction due to 60 deg. reflection: 30.95*SIN30 (0.50) = 15.48" (4.411;79.39)
Eyepiece distance above primary when at zenith: (45.08-15.48) = <u>29.60</u>" (*7.8 sec = 26.63 trkr fit*)
Allows primary to be 12.40~13.40" above ground for <u>42-43</u>" eyepiece height. (Tracker *won't* fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 11.0"
Primary to secondary distance plus mirror height: <u>40.60</u>" eyepiece height. (*Easily meets* min.)
Design *is feasible* with 43.2% secondary obstruction, no Barlow. But must use *Alt-Az tracking*.
Remarks: Purpose of this version is to show if 18.0" aperture practical for accessible telescopes.
1C: Coulter 17.5" f/4.5 mirror can be used in this configuration. Max. eyepiece height is 42.13".

2nd Version: Small 35% Secondary Obstruction, 45 Deg. (16" f/5.55 primary mirror):
Maximum aperture (see below): 16.0~16.5" (Baseline for this design is 16.0")
Maximum secondary obstruction (35%): 5.5" (5.3 useful, for 16.0")
Half width of telescope assembly: 13.0"
Half width plus minimum user clearance (13+14.75) = 27.75"
Fastest f/ratio based on secondary size: (27.75/5.5) = f/5.05
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (30.5/5.5) = f/5.55
Minimum focal length with diagonal added: 88.80"
Distance from primary to secondary: (88.80-30.5) = 58.30"
Primary to secondary distance exceeds maximum allowable eyepiece height. Therefore:
Design NOT feasible if secondary obstruction is 35%, and no Barlow. (Eyepiece too high.)

Version 2A: 44% Secondary Obstruction, 45 Deg. (16" f/4.4 primary mirror, std. mount):
Maximum aperture (see below): 16.0~16.5" (Baseline for this design is 16.0")
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of telescope assembly: 13.0"
Half width plus minimum user clearance (13+14.75) = 27.75"
Fastest f/ratio based on secondary size: (27.75/7.0) = f/3.96
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (30.5/7.0) = f/4.36
Focal length with diagonal added: 69.71"
Distance from primary to secondary: (69.71-30.5) = 39.21"
Primary to secondary distance plus mirror height *exceeds maximum allowable eyepiece height*:
Design is NOT feasible if sec. obstruction 44% or less, and no Barlow. (Eyepiece too high.)

3rd Version: 44% Secondary Obstruction, 45 Deg. (16" f/4.19 primary; compact mount)
Maximum aperture (see below): 16.0~16.5" (Baseline for this design is 16.0")
Maximum secondary obstruction (47%): 7.0" (6.8 useful, for 16.0")
Half width of *unconventional compact* telescope mount assembly: 11.0"
Half width plus minimum user clearance (11+14.75) = 25.75"
Fastest f/ratio based on secondary size: (25.75/6.8) = f/3.79
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (28.5/6.8) = f/4.19
Focal length with diagonal added (f/4.19): 67.04" (1703 mm)
Distance from primary to secondary (and eyepiece height above primary); 67.04-30.5 = 36.54"
Primary mirror height when using low profile base and altitude axis (Hubble Optics): 8.0"
Primary to secondary distance plus mirror height: 44.54" (Exceeds Min. Eyepiece Height)
Design <u>*barely*</u> is NOT feasible if sec. obstruct. 44% or less, and no Barlow. (Eyepiece too high.)

4th Version: 45.5% Sec. Obst., 45 Deg. (16.5" f/3.96 primary; compact mount) (<u>*Backup 1*</u>)
Maximum aperture (see below): 16.0~16.5" (Baseline for this design is 16.5")
Maximum secondary obstruction (45.5%): 7.5" (7.2 useful, for 16.5")
Half width of *unconventional compact* telescope mount assembly: 11.0"
Half width plus minimum lateral user clearance (11+14.75) = 25.75"
Fastest f/ratio based on secondary size alone: (25.75/7.2) = f/3.60
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (28.5/7.2) = <u>f/3.96</u> (16.0" would be f/4.08; 7.25 sec.)
Focal length with diagonal attachment added (f/3.96): <u>65.34</u>" (1657 mm)

Distance from primary to secondary (and eyepiece height above primary); 65.34-30.5 = 34.84"
Primary mirror height when using low profile base and altitude sector (Hubble Optics): 8.0"
Primary to secondary distance plus mirror height: 42.84" (Barely Meets Min. Eyepiece Height)
Design ***IS just barely feasible*** if secondary obstruction enlarged to 45.5%. No Barlow needed.

5th Version (Ver. 5.0): 44% Sec. Obstruction, 29 Deg. (16" f/5 primary) (*Original Baseline*)
Maximum aperture: 16.0~16.5" (Baseline for this design is 16.0") f/5.00.
Tolerance for primary mirror f/ratio is from f/4.91 to f/5.00.
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of telescope assembly (custom parts used): 11.0" (10.5 unconv. structure for f/4.91)
Half width plus larger 15.5" lateral user clearance (11+15.5) = 26.50"
Fastest f/ratio based on secondary size alone: (26.50/6.8) = f/3.90
Fastest f/ratio if add diagonal (1.25+2.75"): (29.25/6.8) = f/4.30
Adjust for 1/COS32 ([26.50]*1.179) = 31.24" (Note: 2x 29 deg. = 58 deg.; 90 - 58 = 32 deg.)
New f/ratio after account for angle: (31.24+2.75=33.99)/6.8 = f/5.00
Required focal length after diagonal and angle added: 80.00" (2032 mm)
Distance from primary to secondary: (80.00-33.99) = 46.01" (circa 46.00)
Height reduction due to 58 deg. reflection: 31.24*SIN32 (.53) = 16.55
Eyepiece distance above primary when at zenith: (46.00-16.55) = 29.45"
Allows primary to be realistic 12.55~13.55" above ground for 42 - 43" eyepiece height at zenith.
Design IS feasible with secondary obstruction of 44%, and no Barlow. (*Tracker fits* w/low pr mt)
Remarks: Design can work with 16" or 16.5" f/4.87 mirror if eyepiece slightly higher. See V5.1.

Version 5.1: 42.5% Secondary Obstruction, 29 Deg. (16.5" f/4.87 primary) (*Backup 5*)
Maximum aperture: 16.0~16.5" (Baseline for this design is 16.5") f/4.87.
Tolerance for primary mirror f/ratio is from f/4.86 to f/4.91.
Maximum secondary obstruction (42.5%): 7.0" (6.8 useful, for 16.5")
Half width of telescope assembly (custom parts used): 11.0"
Half width plus larger 14.75" lateral user clearance (11+14.75) = 25.75"
Fastest f/ratio based on secondary size alone: (25.75/6.8) = f/3.79
Fastest f/ratio if add diagonal (1.25+2.75"): (28.50/6.8) = f/4.19
Adjust for 1/COS32 ([25.75]*1.179) = 30.36"
New f/ratio after account for angle: (30.36+2.75=33.11)/6.8 = f/4.87
Required focal length after diagonal and angle added: 80.36" (2041 mm)
Distance from primary to secondary: (80.36-33.11) = 47.25" (circa 47.25)
Height reduction due to 58 deg. reflection: 30.36*SIN32 (.53) = 16.09
Eyepiece distance above primary when at zenith: (47.25-16.09) = 31.16"
Allows primary to be realistic but tight 11.84" above ground for 43.0" eyepiece height.
Design IS feasible w/secondary obstruction of 42.5%, and no Barlow. (Tracker firs w/low pr. mt)

Version 5.2: 44% Secondary Obstruction, 30 Deg (16" f/5.12 primary)
Maximum aperture (see below): 16.0~16.5" (Baseline is 16.0) f/5.12.
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of telescope assembly: 13.0"
Half width plus minimum 14.75" lateral user clearance (13+14.75) = 27.75"
Fastest f/ratio based on secondary size: (27.75/6.8) = f/4.08
Fastest f/ratio if add diagonal (1.25+2.75"): (30.5/6.8) = f/4.49
Adjust for 1/COS30 ([27.75]*1.155) = 32.05"
New f/ratio after account for angle: (32.05+2.75=34.80)/6.8 = f/5.12
Required focal length after diagonal added: 81.92" (2081mm)
Distance from primary to secondary: (81.92-34.80) = 47.12" (~47.10) P-S
Reduction due to 60 deg. reflection: 32.05*SIN30 = 16.02
Eyepiece distance above primary when at zenith: 31.10"
Design allows primary mirror to be up to realistic 8.9" above ground.
Design IS feasible with secondary obstruction of 44%, and no Barlow.
However, this design is less favorable than V. 5.0, since eyepiece is higher.

Version 5.3: 44% Secondary Obstruction, 30 Deg. (16" f/4.91 primary)
Maximum aperture (see below): 16.0~16.5" (Baseline is 16.0)
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of telescope assembly: 11.0"
Half width plus larger 15.5" lateral user clearance (11+15.5) = 26.50"
Fastest f/ratio based on secondary size: (26.50/6.8) = f/3.90
Fastest f/ratio if add diagonal (1.25+2.75"): (29.25/6.8) = f/4.30
Adjust for 1/COS30 ([26.50]*1.155) = 30.61"
New f/ratio after account for angle: (30.61+2.75=33.36)/6.8 = f/4.91
Required focal length after diagonal added: 78.56" (1995 mm)
Distance from primary to secondary: (78.56-33.36) = 45.20" (~45.20) P-S
Maximum primary to secondary distance IF f/5.0 (1.44 longer FL): 46.60 Nom
* If f/5, focus is 33.36 to 34.00 from secondary. Dist. = (46.00-46.60) !
Reduction due to 60 deg. reflection: 30.61*SIN30 = 15.30
Eyepiece distance above primary when at zenith: 29.90"
Design allows primary mirror to be up to realistic 10.10" above ground.
Design IS feasible with secondary obstruction of 44%, and no Barlow.
However, this design is less favorable than V. 5.0, since eyepiece is higher.

Version 5.4: 44% Secondary Obstruction, 30 Deg. (16" f/4.78 primary) (smallest 5x version)
Maximum aperture (see below): 16.0~16.5" (Baseline is 16.0)
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of telescope assembly: 11.0"
Half width plus minimum 14.75 lateral user clearance (11+14.75) = 25.75"
Fastest f/ratio based on secondary size: (25.75/6.8) = f/3.79
Fastest f/ratio if add diagonal (1.25+2.75"): (28.5/6.8) = f/4.19
Adjust for 1/COS30 ([25.75]*1.155) = 29.74"
New f/ratio after account for angle: (29.74+2.75=32.50)/6.8 = f/4.78

Required focal length after diagonal added: 76.45" (1942 mm)
Distance from primary to secondary: (76.45-32.50) = 43.95" (~44.00) P-S
Maximum primary to secondary distance IF f/5.0 (3.55 longer FL):
* If f/5, focus is 32.50 to 34.00 from secondary. Dist. = 46.0 to 47.5
Reduction due to 60 deg. reflection: 29.74*SIN30 = 14.87
Eyepiece distance above primary when at zenith: 29.08"
Design allows primary mirror to be up to realistic 10.92" above ground.
Design IS feasible with secondary obstruction of 44%, and no Barlow.
However, this design is less favorable than V. 5.0, since it has less user clearance.

6th Version: 42% Secondary Obstruction, 30 Deg. (16.5" f/5.12 primary)
Maximum aperture (see below): 16.0~16.5" (Baseline is 16.5)
Maximum secondary obstruction (42%): 7.0" (6.8 useful, for 16.5")
Half width of telescope assembly: 13.0"
Half width plus minimum lateral user clearance (13+14.75) = 27.75"
Fastest f/ratio based on secondary size: (27.75/6.8) = f/4.08
Fastest f/ratio if add diagonal (1.25+2.75"): (30.5/6.8) = f/4.49
Adjust for 1/COS30 ([27.75]*1.155) = 32.05"
New f/ratio after account for angle: (32.05+2.75=34.80)/6.8 = f/5.12
Required focal length after diagonal added: 81.92" (2081 mm)
Distance from primary to secondary: (84.48-34.80) = 49.68" (49.70)
Reduction due to 60 deg. reflection: 32.05*SIN30 = 16.02
Eyepiece distance above primary when at zenith: 33.66"
Design allows primary mirror to be up to 7.34" above ground.
Design barely NOT feasible if secondary obstruction 42%, and no Barlow.
Design is feasible with 44% obstruction, but would require a custom secondary size.

7th Version: 40.0% Secondary Obstruction, 30 Deg., (17.5/16.5 f/4.5/4.78 primary)
* Assumption is low profile 22" rocker box width:
Maximum aperture (see below): 16.0~17.5" (Baseline is 17.5)
Maximum secondary obstruction (40%): 7.0" (6.8 useful)
Half width of telescope assembly: 11.0"
Half width plus minimum 14.75 lateral user clearance (11+14.75) = 25.75"
Fastest f/ratio based on secondary size: (25.75/6.8) = f/3.79
Fastest f/ratio if add diagonal (1.25+2.75"): (28.5/6.8) = f/4.19
Adjust for 1/COS30 ([25.75]*1.155) = 29.74"
New f/ratio after account for angle: (29.74+2.75=32.50)/6.8 = f/4.78
* Amount of 17.5" f/4.5 primary mirror utilized at f/4.78: 16.48"
Required focal length after diagonal added: 78.75" (2000 mm)
Distance from primary to secondary: (77.75-32.50) = 45.25" (~45.30) P-S
Reduction due to 60 deg. reflection: 29.74*SIN30 = 14.87
Eyepiece distance above primary when at zenith: 30.38"
Design allows primary mirror to be up to marginal 9.62" above ground.
Design IS feasible with secondary obstruction of 44%, and no Barlow.
This design is less favorable than V. 5.0, since the primary mirror weighs more.

8th Version: 44.0% Sec. Obst., 34.5 Deg. (16.0" f/4.52 primary; compact mount) (*low cost*)
Maximum aperture: 16.0~16.5" (Baseline for this design is 16.0") f/4.52.
Tolerance for primary mirror f/ratio is from f/4.48 to f/4.52.
Maximum secondary obstruction (44%): 7.0" (6.8 useful, for 16.0")
Half width of *unconventional compact* telescope assembly (custom parts used): 11.0" (std 12.25)
Half width plus slightly larger 15.0" lateral user clearance (11+15.0) = 26.00"
Fastest f/ratio based on secondary size alone: (26.00/6.8) = f/3.82 (7.2 sec: f/3.61)
Fastest f/ratio if add diagonal (1.25+2.75"): (28.75/6.8) = 6.8: f/4.23 (7.2 sec: f/3.99)
Adjust for 1/COS21 ([26.00]*1.071) = 27.85" (Note: 2x 34.5 deg. = 69 deg.; 90 - 69 = 21 deg.)
New f/ratio after account for angle: (27.85+2.75=30.60)/6.8 = f/4.50
Required focal length after diagonal and angle added: 72.00" (1829 mm)
Distance from primary to secondary: (72.00-30.60) = 41.40"
Height reduction due to 69 deg. reflection: 30.60*SIN21 (.36) = 10.97"
Eyepiece distance above primary when at zenith: (41.40-10.97) = 30.43"
Allows primary to be tight 11.57~12.57" above ground for 42 - 43" eyepiece height.
Primary mirror height when using standard profile base and altitude sector: 12.5~13.0
Primary to secondary distance plus std. mirror height: 42.93" (Barely meets min. eyepiece height)
Design *IS just barely feasible* with secondary obstruction of 44%, and no Barlow.
Design better allows for std. 12.25" half width structure w/7.5" secondary (47% obs); see 9th iter.
Remarks: 16" (40.6 cm) f/4.5 mirrors may be less expensive because many are on used market.
The purpose of this version is to show if a 16" f/4.5 mirror is practical for accessible telescopes.

Eyepiece heights for alternate versions having conventional secondary mirror angles:
f/4.0 eyepiece height if 7.0" (6.8) secondary mirror (44%) at 45 deg: (64.0 - 30.6) + 12.5 = 45.9"
f/4.0 eyepiece height if 7.5" (7.2) secondary mirror (47%) at 45 deg: (64.0 - 32.4) + 12.5 = 44.1"
f/4.5 eyepiece height if 7.5" (7.2) secondary mirror (47%) at 45 deg: (72.0 - 32.4) + 12.5 = 52.1"

9th Version: 47.0% Sec. Obst., 29 Deg. (16.0" f/4.52 primary; compact mount) (*Backup 4*)
Maximum aperture: Baseline for this design is 16.0" f/4.52 (w/coma cor., on 6" EQ platform)
Tolerance for primary mirror f/ratio is from f/4.48 to f/4.52.
Maximum secondary obstruction (47%): 7.5" (7.2 useful, for 16.0") [27.25 lat clearance. needed]
Half width of *conventional compact* telescope assembly (custom parts used): 12.25"
Half width plus slightly larger 15.0" lateral user clear (12.25+15.0) = 27.25" (-1.5 cc) 25.75" opt.
Fastest f/ratio based on secondary size alone: (25.75 opt /7.2) = f/3.58 (6.8 sec: f/3.71)
Fastest f/ratio if add diagonal (1.25+2.75"): (28.50 opt /7.2) = 6.8: f/3.96 (6.8 sec: f/4.19)
Adjust for 1/COS29 ([27.25phys]*1.143) = 31.15" (Note: 2x30.5d.=61; 90-61=29 deg. f/perpen.)
New f/ratio after account for angle (subtracting 1.5 coma cor): (28.65+2.75=32.40)/7.2 = f/4.50
Required focal length after diagonal and angle added: 72.00" (1829 mm)
Distance from primary to secondary: (72.00-32.40 opt) = 39.60"
Height reduction due to 68 deg. reflection: 31.15*SIN29 (.485) = 15.10"
Eyepiece distance above primary when at zenith: (39.60-15.10) = 24.50"
Allows primary to be realistic 12.50" (18.5 w/eq. plat.) above ground: 37 - 43" eyepiece height.
Primary mirror height when using standard profile base and altitude sector: 12.5 (*18.5 if eq. plat.*)
Primary to secondary distance plus std. mirror height: 43.00" (Barely meets min. eyepiece height)
Design *IS feasible* with secondary obstruction of 44%, and no Barlow. *Compatible w/Tracker.*

10th Version: 43.3% Sec. Obst., 45 Deg. (15.0" f/4.50 primary; compact mount) (“TScope”)
Comment: *Original* telescope mirror height is 8.5", eyepiece at 64"; Mirror separation is ~55.5".
Maximum aperture: 15.0" (Baseline for this design is 15.0") f/4.50. (Orig. scope circa 72" tall.)
Tolerance for primary mirror f/ratio is from f/4.46 to f/4.51. (Note: 35% 5.25" sec only 12.5" clr)
Maximum secondary obstruction (43.3%): 6.5" (6.3 useful, for 15.0")
Half width of *conventional but compact* telescope assembly (custom parts NOT used): 10.0"
Half width plus slightly larger 15.0" lateral user clearance (10+15.0) = 25.00"
Fastest f/ratio based on secondary size alone: (25.00/6.2) = f/4.03
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (27.75/6.2) = f/4.48
Required focal length after diagonal added: <u>67.20</u>" (1707 mm)
Distance from primary to secondary (and EP height above primary): (67.20-27.75) = <u>39.45</u>"
Allows primary to be *impossible* 2.55~3.55" above ground for <u>42 - 43</u>" eyepiece height.
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 8.5"
Primary to sec. distance plus mirror height: <u>47.95</u>" (Way *above* min. EP height) (50.5" w/35% s)
Design is *NOT feasible* (by a wide margin) with secondary obstruction of 43.3%, and no Barlow.
Remarks: 14.5_15.0" aperture is largest aperture for which compact ver. ship costs reasonable.
The purpose of this version is to show if 15" aperture f/4.5 is practical for accessible telescopes.
Notes: Base is 20.0" wide and mirror box is 18.0" square, not counting elevation axis sectors.
Trade space for 15.0" includes if tracking vs cost better with this or with modified 12-14" SCT.

11th Version: 46.7% Sec. Obst., 45 Deg. (15.0" f/4.50 primary; coma corrector) (“TScope”)
Maximum aperture: 15.0" (Baseline for this design is 15.0") f/4.50.
Tolerance for primary mirror f/ratio is from f/4.46 to f/4.51.
Maximum secondary obstruction (46.7%): 7.0" (6.7 useful, for 15.0")
Half width of *conventional but compact* telescope assembly (custom parts NOT used): 10.0"
Half width plus slightly larger 15.0" lateral user clear (10.0+15.0) = 25.00" (-1.5 cc) 23.50" opt.
Fastest f/ratio based on secondary size alone: (23.50/6.7) = f/3.51
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (26.25/6.7) = f/3.92 (But 4.5x6.7=30.15 (20" clear.))
Required focal length after diagonal added (assumes f/4.5): <u>67.50</u>" (1715 mm)
Distance from primary to secondary (and EP height above primary): (67.50-30.15) = <u>37.35</u>"
Allows primary to be 4.65~5.65" above ground for <u>42 - 43</u>" eyepiece height. (Tracker won’t fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 8.5"
Primary to secondary distance plus mirror height: <u>45.85</u>" (Does *NOT* meet min. eyepiece height)
Design is *NOT feasible* (by almost 3") with secondary obstruction of 46.7%, and no Barlow.
Existing TScope 15" f/4.5 can work if secondary at unconventional angle, but *major* modif. req.
Remarks: 14.5-15.0" (36.8 cm) aperture is largest aperture for which shipping costs reasonable.
The purpose of this version is to show if a 15.0" aperture is practical for accessible telescopes.

Version 11A: 45.0% Sec. Obst., 45 Deg. (15.0" f/4.04 primary; coma cor., compact mount)
Same as Version 11, except has faster primary mirror and odd size 6.75" (6.5" useful) secondary.
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (26.25/6.5) = f/4.04. FL: 60.57" (1539 mm)
Distance from primary to secondary (and EP height above primary): (60..57-26.25) = <u>34.32</u>"
Allows primary to be 7.68~8.68" above ground for <u>42 - 43</u>" eyepiece height. (Tracker *won’t* fit.)
Notes: Base is 20.0" wide and mirror box is ~18.0" square, not counting elevation axis sectors.
Trade space for 15.0" includes if tracking vs cost better with this or with modified 12-14" SCT.

12th Version: 45.0% Sec. Obst., 45 Deg. (14.5" f/4.41 primary; compact mount)
Maximum aperture: 14.0~14.5" (Baseline for this design is 14.5") f/4.41.
Tolerance for primary mirror f/ratio is from f/4.39 to f/4.42.
Maximum secondary obstruction (45%): 6.5" (6.3 useful, for 14.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 10.0"
Half width plus slightly larger 15.0" lateral user clearance (10+15.0) = 25.00"
Fastest f/ratio based on secondary size alone: (25.00/6.3) = f/3.97
Fastest f/ratio if add diagonal (1.25+2.75"): (27.75/6.3) = f/4.41
Required focal length after diagonal added: 63.95" (1624 mm)
Distance from primary to secondary (and EP height above primary): (63.95-27.75) = 36.20"
Allows primary to be tight 5.80~6.80" above ground for 42 - 43" eyepiece height.
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 7.5"
Primary to secondary distance plus mirror height: 43.70" (Slightly above min. eyepiece height)
Design is *just barely NOT feasible* with secondary obstruction of 45%, and no Barlow.
Remarks: 14.5" (36.8 cm) aperture is largest aperture for which shipping costs reasonable.
The purpose of this version is to show if a 14.5" aperture is practical for accessible telescopes.
(f/4.5 epc. height with 6.5" (6.2) sec. mir. (45%) at 45 deg: (65.25-27.90) = 37.35"(+7.5)= 44.85)
Notes: Base is 19.7" wide and mirror box is 17.5" square, not counting elevation axis sectors.
Trade space for 14.5" includes if tracking vs cost better with this or with modified 12-14" SCT.

13th Version: 45.0% Sec. Obst., 45 Deg. (14.5" f/4.17 primary; coma corrector)
Maximum aperture: 14.0~14.5" (Baseline for this design is 14.5") f/4.17.
Tolerance for primary mirror f/ratio is from f/4.15 to f/4.20.
Maximum secondary obstruction (45%): 6.5" (6.3 useful, for 14.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 10.0"
Half width plus slightly larger 15.0" lateral user clear (10.0+15.0) = 25.00" (-1.5 cc) 23.50" opt.
Fastest f/ratio based on secondary size alone: (23.50/6.3) = f/3.97
Fastest f/ratio if add diagonal (1.25+2.75"): (26.25/6.3) = f/4.17
Required focal length after diagonal added: 60.42" (1535 mm)
Distance from primary to secondary (and EP height above primary): (60.42-26.25) = 34.17"
Allows primary to be 7.83~8.83" above ground for 42 - 43" eyepiece height. (Tracker won't fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 7.5"
Primary to secondary distance plus mirror height: 41.67" (Easily meets min. eyepiece height)
Design *is feasible* with secondary obstruction of 45%, and no Barlow. (But tracker won't fit.)
Remarks: 14.5" (36.8 cm) aperture is largest aperture for which shipping costs reasonable.
The purpose of this version is to show if a 14.5" aperture is practical for accessible telescopes.
(f/4.5 epc. height with 6.5" (6.2) sec. mir. (45%) at 45 deg: (65.25-27.90) = 37.35"(+7.5)= 44.85)

Version 13A: 46.6% Sec. Obst., 45 Deg. (14.5" f/4.04 primary; coma cor., compact mount)
Same as Version 11, except has faster primary, odd size 6.75" (6.5 useful) secondary. (*Backup 3*)
Fastest f/ratio if add diagonal (1.25+2.75"): (26.25/6.5) = f/4.04. FL: 58.56" (1487 mm)
Distance from primary to secondary (and EP height above primary): (58.56-26.25) = 32.31"
Allows primary to be 9.69~10.69" above ground for 42 - 43" eyepiece height. (Tracker *might* fit.)
Notes: Base is ~19.6" wide and mirror box is 17.5" square, not counting elevation axis sectors.
Trade space for 14.5" includes if tracking vs cost better with this or with modified 12-14" SCT.

14th Version: 44.0% Sec. Obst., 45 Deg. (12.5" f/5.01 primary; compact mount)
Maximum aperture: 12.0~12.5" (Baseline for this design is 12.5") f/5.00.
Tolerance for primary mirror f/ratio is from f/4.98 to f/5.02.
Maximum secondary obstruction (45%): 5.5" (5.3 useful, for 12.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 8.8"
Half width plus slightly larger 15.0" lateral user clearance (8.8+15.0) = 23.80"
Fastest f/ratio based on secondary size alone: (23.80/5.3) = f/4.49
Fastest f/ratio if add diagonal (1.25+2.75"): (26.55/5.3) = f/5.01
Required focal length after diagonal added: 62.62" (1590 mm)
Distance from primary to secondary (and EP height above primary): (62.62-26.55) = 35.97"
Allows primary to be tight 6.03~7.03" above ground for 42 - 43" eyepiece height.
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 7.0"
Primary to secondary distance plus mirror height: 42.97" (Barely meets min. eyepiece height)
Design *is just barely feasible* with secondary obstruction of 44%, and no Barlow. (Trkr won't fit)
Remarks: 12.5" (31.7 cm) aperture is largest aperture for which mount can fit on walker seat.
The purpose of this version is to show if a 12.5" aperture is practical for accessible telescopes.
Notes: Base is 17.0" wide and mirror box is ≤15.4" square, not counting elevation axis sectors.
Trade space for 12.5" includes if tracking vs cost better with this or with Meade 12" LX200 SCT.

15th Version: 44.0% Sec. Obst., 45 Deg. (12.5" f/4.73 primary; coma cor., compact mount)
Maximum aperture: 12.0~12.5" (Baseline for this design is 12.5") f/4.73
Tolerance for primary mirror f/ratio is from f/4.71 to f/4.75.
Maximum secondary obstruction (45%): 5.5" (5.3 useful, for 12.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 8.8"
Half width plus slightly larger 15.0" lateral user clear (8.8+15.0) = 23.80" (-1.5 cc) 22.30" opt.
Fastest f/ratio based on secondary size alone: (22.30/5.3) = f/4.21
Fastest f/ratio if add diagonal (1.25+2.75"): (25.05/5.3) = f/4.73
Required focal length after diagonal added: 59.08" (1501 mm)
Distance from primary to secondary (and EP height above primary): (59.08-25.05) = 34.03"
Allows primary to be 7.97~8.97" above ground for 42 - 43" eyepiece height. (Tracker won't fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 7.0"
Primary to secondary distance plus mirror height: 41.03" (Easily meets min. eyepiece height)
Design *is feasible* with secondary obstruction of 44%, and no Barlow. (But tracker won't fit.)
Remarks: 12.5" (31.7 cm) aperture is largest aperture for which mount can fit on walker seat.
The purpose of this version is to show if a 12.5" aperture is practical for accessible telescopes.

Version 15A: 46.0% Sec. Obst., 45 Deg. (12.5" f/4.55 primary; coma cor., compact mount)
Same as Version 13, except has faster primary, odd size 5.75" (5.5 useful) secondary. (*Backup 2*)
Fastest f/ratio if add diagonal (1.25+2.75"):(25.05/5.5)= f/4.55. FL:56.93" (1446 mm) [*13=f4.37*]
Distance from primary to secondary (and EP height above primary): (56.93-25.05) = 31.88"
Allows primary to be 10.12~11.12" above ground for 42-43" eyepiece height. (*TSO tracker fit*s.)
Comment: 13" f/4.38 should also work, if used with 6.0" (46%; 5.72" utilized) secondary mirror.
Notes: Base is ≤17.0" wide and mirror box is ≤15.4" square, not counting elevation axis sectors.
Trade space for 12.5" includes if tracking vs cost better with this or with Meade 12" LX200 SCT

16th Version: 44.6% Sec. Obst.; 29 deg. (11.2" f/6.75 primary; compact mount) (used mir.)
Maximum aperture: 10.0~11.2" (Baseline for this design is 11.2") f/6.75 (75.6" FL)
Tolerance for primary mirror f/ratio is from f/6.70 to f/6/80.
Maximum secondary obstruction (40.0%): 5.0" (4.7 useful, for 11.2")
Half width of *unconventional compact* telescope assembly (custom parts used): 8.00"
Half width plus slightly larger 15.0" lateral user clearance (8.00+15.0) = 23.00"
Fastest f/ratio based on secondary size alone: (23.00/4.7) = f/4.89
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (25.75/4.7) = f/5.48
Adjust for 1/COS37 ([23.00]*1.252) = 28.80" (Note: 2x 26.5 deg.=53; 90-53=37 deg. f/perpen.)
New f/ratio after account for angle: (28.80+2.75=31.55)/4.7 = f/6.713
Required focal length after diagonal and angle added: <u>75.19</u>" (1910 mm)
Distance from primary to secondary: (75.19-31.55) = <u>43.64</u>"
Height reduction due to 53 deg. reflection: 23.00*SIN37 (.602) = 13.84"
Eyepiece distance above primary when at zenith: (43.64-13.84) = <u>29.80</u>"
Allows primary to be generous 12.2-13.2" above ground for <u>42 - 43</u>" eyepiece height.
Primary mirror height with low profile base, altitude sector (MastTel.Con.) / Tracker: 7.0 / 13.0"
Primary to secondary distance plus mirror height: 36.80 / <u>42.80</u>" (Below min. eyepiece height)
Design *is feasible* with secondary obstruction of 44.6%, and no Barlow. *Compatible w/Tracker*.
Remarks: 11.2" (28.5 cm). Sec. mir. tilted 26.5 deg. 5.5" round secondary (49%) barely works.
The purpose of this version is to show if an 11.2" aperture is practical for accessible telescopes.
Notes: Base is 16.0" wide and mirror box is 14.0" square, not counting elevation axis sectors.
Trade space for 10.0" includes if tracking vs cost better with this or with modified 11-12" SCT.

17th Version: 45.0% Sec. Obst., 45 Deg. (10.0" f/<u>5.95</u> primary; compact mount)
Maximum aperture: 10.0~11.2" (Baseline for this design is 10.0") f/6.00 (60.0" FL)
Tolerance for primary mirror f/ratio is from f/5.93 to f/6.01..
Maximum secondary obstruction (45.0%): 4.5" (4.2 useful, for 10.0")
Half width of *unconventional compact* telescope assembly (custom parts used): 7.25"
Half width plus slightly larger 15.0" lateral user clearance (7.25+15.0) = 22.25"
Fastest f/ratio based on secondary size alone: (22.25/4.2) = f/5.30
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (25.00/4.2) = f/5.95
Required focal length after diagonal added: <u>59.95</u>" (1512 mm)
Distance from primary to secondary (and EP height above primary): (59.95-25.00) = <u>34.95</u>"
Allows primary to be tight 7.05~8.05" above ground for <u>42 - 43</u>" eyepiece height.
Primary mirror height when using low profile base and altitude sector (Mast Tel. Concept): 7.0"
Primary to secondary distance plus mirror height: <u>41.95</u>" (Slightly below min. eyepiece height)
Design *is feasible* with secondary obstruction of 45%, and no Barlow. (But tracker won't fit.)
Remarks: 10.0" (25.4 cm) aperture is largest aperture for which transport by 1 person is practical.
The purpose of this version is to show if a 10.0" aperture is practical for accessible telescopes.
Notes: Base is 14.5" wide and mirror box is 12.5" square, not counting elevation axis sectors.
Tracker probably will fit under a 10" f/5.0 telescope and achieve eyepiece height at or below 43".
Trade space for 10.0" includes if tracking vs cost better with this or with modified 8~11" SCT.

Telescopes with "Long Throw" Tunable Coma Corrector / Weak Barlow Lens (LTCC)
The following examples show how use of a "long throw" coma corrector (LTCC) that has a weak Barlow effect (1.5x or less) makes it possible to reduce the size of the secondary mirror. For these examples, a tunable combined coma corrector and 1.5x Barlow lens with a negative 600mm focal length is used at a distance of 300 mm from the focal surface. Including index of refraction effects, this adds 109 mm of back focal distance, which in turn permits use of a smaller secondary mirror. This makes it practical to use a 45 degree secondary mirror. Tuning in the lens is not merely compensating for the back focus of various eyepieces and cameras. Here, tuning also provides a way to vary the distance between the long throw optical elements in a way that corrects coma at one extreme, and restores a diffraction limited on-axis performance at the other. No commercial optical system like this currently exists, so it would have to be manufactured.

18th Version: 45.3% Sec. Obst., 45 Deg. (16.0" f/3.47; long throw coma cor., compact mt.)
Maximum aperture: 16.0~16.5" (Baseline for this design is 16.0") f/3.47
Tolerance for primary mirror f/ratio is from f/3.45 to f/3.48.
Maximum secondary obstruction (45.3%): 7.25" (7.05 useful, for 16.0")
Half width of *unconventional compact* telescope assembly (custom parts used): 11.0"
Half width plus slightly larger 15.0" lateral user clear (11.0+15.0) = 26.00" (-4.3 ltcc) 21.70" opt.
Fastest f/ratio based on secondary size alone: (21.70/7.05) = f/3.078 {42.4%=f/3.6, 59.33, 44.2"}
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (24.45/7.05) = f/3.468 {40.9%=f/3.76, 62.1", 46.95h)
Required focal length after diagonal added: <u>55.49</u>" (1409 mm) [LTCC FL is 83.23" (2114 mm)]
Distance from primary to secondary (and EP height above primary): (55.49-24.45) = <u>31.04</u>"
Allows primary to be 10.96~11.96" above ground for <u>42-43</u>" eyepiece height. (Tracker may fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): +9.3"
Primary to secondary distance plus mirror height: <u>40.34</u>" (Easily meets min. eyepiece height)
Design *is easily feasible* with secondary obstruction of 45%, and LTCC. *(And tracker fits!)*
Purpose of this version is to show if 16.0" w/LTCC practical for accessible telescope w/tracker.

19th Version: 44.0% Sec. Obst., 45 Deg. (12.5" f/4.24; long throw coma cor., compact mt.)
Maximum aperture: 12.0~12.5" (Baseline for this design is 12.5") f/4.24
Tolerance for primary mirror f/ratio is from f/4.21 to f/4.26.
Maximum secondary obstruction (44%): 5.50" (5.25 useful, for 12.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 8.8"
Half width plus slightly larger 15.0" lateral user clear (8.8+15.0) = 23.80" (-4.3 ltcc) 19.50" opt.
Fastest f/ratio based on secondary size alone: (19.50/5.25) = f/3.714
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (22.25/5.25) = f/4.238 {42%=f/4.41, 55.074", 39.8"}
Required focal length after diagonal added: <u>52.976</u>" (1346 mm) [LTCC FL is 79.46" (2018 mm)]
Distance from primary to secondary (and EP height above primary): (52.98-22.25) = <u>30.73</u>"
Allows primary to be 11.27~12.27" above ground for <u>42-43</u>" eyepiece height. (Tracker fits.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): +7.0"
Primary to secondary distance plus mirror height: <u>37.73</u>" (Easily meets min. eyepiece height.)
Design *is feasible* with secondary obstruction of 44%, and LTCC. (Low prof. tracker fits.)
Purpose of this version is to show if 12.5" w/LTCC practical for accessible telescope w/tracker.
Version 19A: 42.3% Sec. Obst.; TScope structure: (13.0" f/4.20, LTCC): Pri. f/4.19-4.22 OK
Sec. Obs. 5.5" (5.3 useful); 22.25/5.30=f/4.198 (54.58" 1386mm)-22.25=32.33 (10.67cl) 39.33ep

3.1.3.1) Applying Similar Design Principles to Larger (not always accessible) Telescopes:

This section shows how unconventional secondary mirror angles can be used to lower the focal plane and eyepiece position in even *larger* telescopes. In apertures over 28", this may *not* always result in a low enough focal plane for an *accessible telescope* without excessively increasing the secondary size. For *other* observers, it may make the difference between *standing on the ground* or having to use a *tall ladder* to use the telescope. Examples here are for a 36" f/4 Newtonian. The first example (V20) shows the eyepiece height (which is too high) when lateral clearance is enough for a wheelchair. The next example (V21) is one having conventional lateral clearance. The third (V22) is a 3-mirror system, but Version 22A <u>is</u> *accessible*, thanks to a *reflective* relay.

20th Version: 44.4% Sec. Obst., 20 deg. 36.0" f/4.00 (3.94~4.01) primary; coma corrector.
Maximum secondary obstruction (44.4%): 16" (15.5 useful, for 36") Secondary is *round*.
Half width of conventional "Star Splitter" telescope assembly (no custom parts used): 23.0" (est.)
Half width + slightly larger 15.5" lat. user clr (23+15.5)=<u>38.50</u>" phys (-1.5cc) <u>37.0</u>" optical dist.
Fastest f/ratio if add diagonal (1.25+<u>2.75</u>"): (<u>39.75</u>/15.5) = f/2.565. Req'd FL: <u>92.32</u>" (2345 mm)
Distance from primary to secondary (for conventional Newtonian): (92.32 - 39.75) = 52.57"
Adjust for 1/COS50 ([38.50phys]*1.556) = <u>59.91</u>" (Note: 2x20d.= 40; 90-40=50 deg.f/perpend)
New f/ratio after acct f/angle (59.91-1.5comacor = 58.41); (58.41+2.75= <u>61.16</u>)/15.5 = f/<u>3.946</u>
Required FL after diagonal and angle added: <u>142.04</u>" (3608 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (142.04 - 61.16 sec-FP optical distance) = <u>80.88</u>"
Eyepiece *height reduction* due to 40 deg. reflection: 59.91*SIN50 (0.6428) = 38.51"
Eyepiece distance above primary when at zenith: (80.88-38.51) = <u>42.37</u>"
Allows primary to be only 0.63" above ground for 42-43" EP height. (Not "accessible" height.)
Primary mirror height, using standard "Star Splitter" base and alt. sectors (estimate): 22.0"
Primary to eyepc. dist. (42.37) + pri. mir. height (22.0): <u>64.37</u>" eyepiece height (exceeds ac. min)
Is NOT "accessible" w/44.4% sec. no Brlw. <u>Needs step stool but not ladder</u>. No eq. plat. w/o lad.
Purpose of version to show if 36" aperture practical for *"no ladder" and* accessible telescopes.

21st Version: 44.4% Sec. Obst., 15 deg. 36.0" f/4.00 (3.94~4.01) primary; w/coma corrector.
Maximum secondary obstruction (44.4%): 16" (15.5 useful, for 36") Secondary is *round*.
Half width of conventional "Star Splitter" telescope assembly (no custom parts used): 23.0" (est.)
Half width + too small (for accessible) 7" lat. clr (23+7.0)=<u>30.00</u>"phys (-1.5cc) <u>28.5</u>" optical dist.
Fastest f/ratio with diag. (1.25+<u>2.75</u>")+<u>28.5</u>: (<u>31.25</u>/15.5) = f/2.016. Req'd FL: <u>72.58</u>" (1844 mm)
Distance from primary to secondary (for conventional Newtonian): (72.58 - 31.25) = 41.33"
Adjust for 1/COS60 ([30.00phys]*2.000) = <u>60.00</u>" (Note: 2x15d.= 30; 90-30=60 deg.f/perpend)
New f/ratio after acct f/angle (60.00-1.5comacor = 58.50); (58.50+2.75= <u>61.25</u>)/15.5 = f/<u>3.952</u>
Required FL after diagonal and angle added: <u>142.26</u>" (3613 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (142.26 - 61.25 sec-FP optical distance) = <u>81.01</u>"
Eyepiece *height reduction* due to 30 deg. reflection: 60.00*SIN60 (0.8660) = 51.96"
Eyepiece distance above primary when at zenith: (80.01-51.96) = <u>29.05</u>" (<u>Only 7" lat. clearance</u>.)
Allows primary to be 12.95~13.95" above ground for 42-43" EP height. (Tracker won't fit.)
Primary mirror height, using standard "Star Splitter" base and alt. sectors (estimate): 22.0"
Primary to eyepc. dist. (29.05) + pri. mir. height (22.0): <u>51.05</u>" eyepiece height (exceeds ac. min)
Design NOT "accessible" w/44.4% sec, no Brlw. <u>Needs no ladder/stl</u>. Eq. plat. tight w/o step stl.
Remarks: Purpose of version only to show if 36" aperture practical for "*no ladder*" telescopes.

One version below folds the light path down to just above the altitude axis, then out the side via a fold mirror. This provides a focuser position that is close to the structure and orthogonal with the OTA. The fold mirror near the focuser can be flipped out of the way so a second optical path below it can be used to provide an *accessible telescope* via a folded reflective relay that does not introduce false color. A large secondary obstruction is compatible with an axial reflective relay. The secondary mirror can (but need not) be a thin annular one that is supported by its center hole.

22nd Version: 44.4% Sec. Obst., 10 deg. 36.0" f/4.00 (3.98~4.03) primary; coma corrector.
Maximum secondary obstruction (44.4%): 16" (15.65 useful, for 36") Secondary is *round*.
Half width of conventional “Star Splitter” telescope assembly (no custom parts used): 23.0" (est.)
Half width + too small (for access.) -3.3" lat. clr (23-3.3)=<u>19.70</u>"phys (-1.5cc) <u>18.2</u>" optical dist.
Fastest f/ratio with 70 deg. fold mirror, focuser, 2" bf (2.0m+4.5fb")+18.2: (<u>24.7</u>/15.65) = f/1.578
Required focal length after diagonal added: <u>56.82</u>" (1443 mm)
Distance from primary to secondary (for conventional Newtonian): (56.82 - 24.70) = 32.12"
Adjust for 1/COS70 ([19.70phys]*2.924) = <u>57.60</u>" (Note: 2x10d.= 20; 90-20=70 deg.f/perpend)
New f/ratio after acct f/angle (57.60-1.5 comacor = 56.10); (56.10+6.50= <u>62.60</u>)/15.65 = f/<u>4.000</u>
Required FL after diagonal and angle added: <u>144.00</u>" (3658 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (144.00 - 62.60 sec-FP optical distance) = <u>81.40</u>"
Eyepiece *height reduction* due to 20 deg. reflection: 57.60*SIN70 (0.9397) = <u>54.13</u>"
Eyepiece distance above primary when at zenith: (81.40-54.13) = <u>27.27</u>" (<u>Has 3" lat. clearance</u>.)
Allows primary to be 14.73~15.73" above ground for 42-43" EP height. (Tracker won’t fit.)
Primary mirror height, using standard “Star Splitter” base and alt. sectors (estimate): 22.0"
Primary to EP vert. dist. (27.27) + pri. mir. height (22.0): <u>49.27</u>" eyepc. height (exceeds ac. min)
Design NOT “accessible” w/44.4% sec, no Brlw. <u>Needs no ladder/stl</u>. Eq. plat. tight w/o step stl.
22A: *<u>Accessible if</u>*: Swap 70d mir, f/>18x4.5" (folded) reflective relay: EP height= (37.3~)39.97
Remarks: Purpose is to show if 36" aperture practical for “*no ladder*” *and* accessible telescopes.

23rd Version: 46.4% Sec. Obst., 30 deg. 28.0" f/3.01 (2..98~3.02) primary; coma corrector.
Maximum secondary obstruction (44.4%): 13.0" (12.7 useful, for 28") Secondary is *elliptical*.
Half width of unconventional compact telescope assembly (no custom parts used): 17.0"
Half width + slightly larger 15.0 lat. clr (17+15.0)=<u>32.00</u>" phys (-1.5cc) <u>30.50</u>" optical dist.
Fastest f/ratio with diag. (1.25+<u>2.75</u>")+<u>30.5</u>: (<u>33.25</u>/12.7) = f/2.618. Req’d FL: <u>73.31</u>" (1862 mm)
Distance from primary to secondary (for conventional Newtonian): (73.31 - 33.25) = 40.06"
Adjust for 1/COS30 ([32.00phys]*1.155) = <u>36.95</u>" (Note: 2x30d.= 60; 90-60=30 deg.f/perpend)
New f/ratio after acct f/angle (36.95-1.5comacor = 35.45); (35.45+2.75= <u>38.20</u>)/12.7 = f/<u>3.008</u>
Required FL after diagonal and angle added: <u>84.22</u>" (2139 mm) (w/o re-optim. spacing)
New distance from primary to secondary: (84.22 - 36.95 sec-FP optical distance) = <u>45.47</u>"
Eyepiece *height reduction* due to 30 deg. reflection: 36.95*SIN30 (0.500) = 18.47"
Eyepiece distance above primary when at zenith: (45.47-18.47) = <u>27.00</u>" (<u>Has 15" lat. clearance</u>.)
Allows primary to be 15.00~16.00" above ground for 42-43" EP height.
Primary mirror height, using compact low profile base and alt. sectors: 18.0"
Primary to EP vert. dist. (27.00) + pri. mir. height (18.0): <u>45.00</u>" eyepc. height (exceeds ac. min)
Design *NOT quite accessible* w/46.4% sec, no Brlw. Needs no ladder. Eq. plat. fits w/o step stl.
23A: But design *IS accessible* (42.2" eyepiece height) <u>if</u>: “Long Throw Coma Corrector” used.
Remarks: Purpose is to show if 28" aperture practical for “*no ladder*” *and* accessible telescopes.

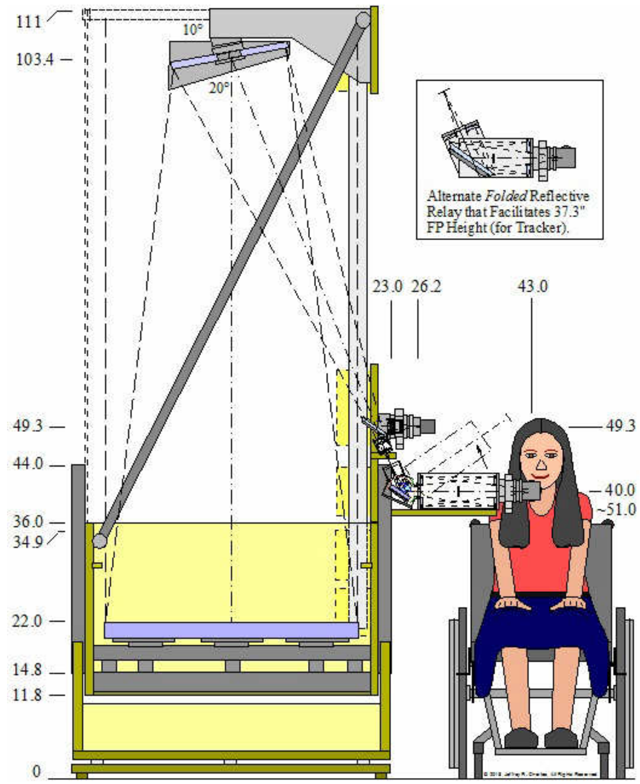


Figure 3.1.3.1A. Drawing of 91.4 cm (36") aperture f/4 modified Newtonian 'scope (V22, 22A) By using a more extreme unconventional angle for the secondary mirror, a larger modified Newtonian design provides focal plane and eyepiece positions low enough to permit use without a ladder (such as would normally be needed with a 36" Newtonian), but the telescope is not "accessible" to people with disabilities *unless* a few other measures are taken. The eyepiece at the *standard* focus position can tilt, and be as low as 49.3" above the ground when the telescope is pointed at zenith. The large secondary mirror is shown as a thin annular mirror that is supported by its center, but more conventional round flats can be used instead. As shown, the secondary mirror is tilted only 10 degrees. Another mirror (or roof mirror) near the focuser can be tilted to reflect light straight out the side of the telescope. This lets the focuser have a conventional orthogonal orientation with respect to the telescope OTA. However, the eyepiece does not have enough lateral clearance from the telescope to provide space for an observer in a wheelchair. Fortunately, additional improvements can make even a 36 inch Newtonian *and "accessible telescope"*. For example, the mirror nearest the focuser can be flipped out of the way, so that the light path can travel down closer to the ground, where ancillary optics can enable the focal plane to be low enough *and* have enough clearance to make the telescope *accessible*. The large secondary obstruction makes it practical to use the shown *reflective* relay system that uses annular mirrors and does not introduce false color to the image. A VAFM facilitates tilting the relay tilt to provide variable eyepiece heights and angles. A Long Throw Coma Corrrector (LTCC) can be used in addition to or instead of the relay to enhance accessibility. With these additions, there is enough clearance to accommodate use of either eye by an observer in a wheelchair, while still providing adequate finger clearance between the wheelchair and telescope. A second variable angle fold mirror (VAFM) provides more intuitive eyepiece positions at the "accessible" port, even if the shown relay is not used. A large 91 cm f/4 telescope is shown here, but the concept is applicable to other apertures and f/ratios, depending on which parts are customized. In this embodiment, the rocker box and primary mirror assemblies are conventional "Star Splitter" items, but shallower and narrower structures will enhance performance. At f/4, this telescope requires a coma corrector and fairly well corrected eyepieces for wide field observing. Details about this telescope are in part 3.3.1 (above) and details about other scopes are in parts 2 and 3, including all of 3.3.

This next and final version shows that a conventional Newtonian, including one faster than f/4, and that has a customary (smaller) secondary obstruction, can be used with a *reflective* relay “attachment” that simply fits the telescope focuser. The relay has means to connect an eyepiece or diagonal with eyepiece at the opposite end, to facilitate the clearance to provide an *accessible telescope*. A reflective relay works best when there is no fold mirror inside (as in the alternate in Fig. 3.1.3.1A), since any fold mirror inside the relay is subject to a *triple* pass by the light path.

24th Version: 32.0% Sec. Obst., 45 deg. 14.5" f/3.60 primary; reflective relay and coma cor.
Maximum aperture: 12.0~12.5" (Baseline for this design is 12.5") f/3.60 (Tolerance 3.58~3.63)
Maximum secondary obstruction (24%): 4.0" (3.8 useful, for 12.5")
Half width of *unconventional compact* telescope assembly (custom parts used): 8.7~8.8"
LW sec. cell w/shallow focuser; off-axis distance: Cell: 7.25; Focuser: 9.75 Focus: <u>10.5</u> Off Ax.
Focus clears lower structure by 1.7" (10.5-8.8). 14.8" needed for 15.5" lateral observer clearance.
Fastest f/ratio: direct / diag / diag+c.cor: 10.5/3.7: f/2.84 / 13.25/3.7: f/3.581 / 11.75/3.7: 3.176.
Required focal length after diagonal added: <u>44.76</u>" (1137 mm) Specification is f/3.6; <u>45.00</u>")
Distance from primary to secondary (and EP height above primary): (45.00-10.50) = <u>34.50</u>"
Allows primary to be 7.5~8.5" above ground for <u>42 - 43</u>" eyepiece height. (Tracker won’t fit.)
Primary mirror height when using low profile base and altitude sector (Mast Tel Concept): 7.7"
Primary mirror height when using low profile base and altitude sector (With Tracker): 11.2"
Primary to secondary distance (34.5) plus 7.7 ~ 11.2 mirror height: <u>42.20</u> ~ <u>45.70</u>" (Track not fit)
However, eyepiece height with tracker becomes <u>42.95</u> (11.2 + 45.0-13.25) if focus 13.25 off ax.
Lateral clearance with reflective relay (13.25 focus + 14.0 relay + 1.25 diag = 28.5 [-8.7]) = 19.8"
Design *is feasible* with secondary obstruction of 32%, and no Barlow. (But tracker barely fits)
Purpose of this version is to show if a 12.5" f/3.6 with relay practical for accessible telescopes.

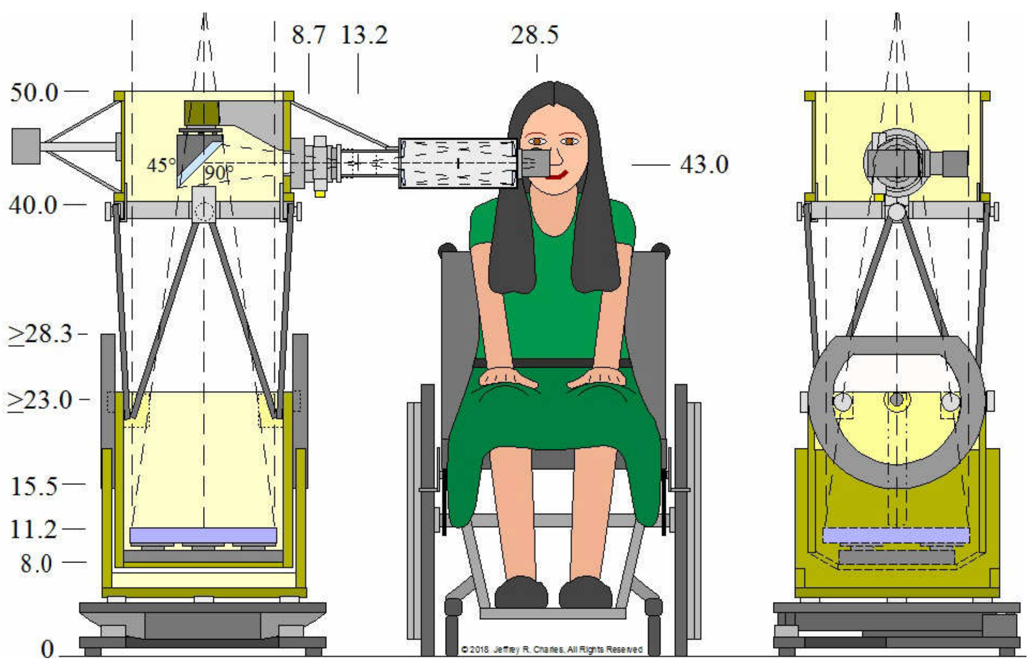


Figure 3.1.3.1B. Drawing of 31.7 cm (12.5") f/3.6 Newtonian telescope w/reflective relay (V24)
This conventional Newtonian makes use of a reflective relay *attachment* to provide accessibility. The front end of the telescope is counterbalanced, and rotates to provide variable eyepiece heights. A VAFM (shown in right view) provides variable eyepiece angles when needed. This is the “24th version”.

3.1.4) Results from Development of the above Telescope Versions:

The exercises above from which several telescope designs are derived provide a set of guidelines that should result in an appropriate maximum *accessible* eyepiece height range for telescopes of different configurations. The precise theoretical formula for each type would result in a smooth curve if plotted in a graph for optimum f/ratio versus aperture. However, since larger standard (and less expensive) secondary mirrors are often available only in 6.35 mm (1/4 inch) increments for the minor axis, real world values will deviate slightly from an exact match for the optimized f/ratio that would be represented by a smooth curve. The tables and lists below show real world values (those closest to optimized value) for several of the designs that have been considered.

3.1.4.1) Emphasized designs for Newtonian and modified Newtonian accessible telescopes:

* Conventional Newtonian, but with larger than usual right angle secondary mirror.
* Modified Newtonian having an unconventional secondary mirror reflection angle.
* Either telescope type, but with a coma corrector that increases back focus by about 4 cm.
* Either telescope type, but with Long Throw Coma Corrector, for ≥11 cm additional back focus.
* Any of the above telescope types, but with a tracking platform added under the telescope.

- The table below shows optimum f/ratio and focal length vs aperture for selected configurations.

Table 3.1.4.1A. Telescope Configuration (top row) vs optimum f/ratio and secondary size:

Aperture **Std. Newt / Central // Mod. Newt / Cent. //**
Inches (cm) / f/No / FL" / Obs% // f/No / FL" / Obs% // Comments (Std w/LTCC)
* 8.0 (20cm) / f/7.50 / 60.0 / 47% // NA / NA / NA // Mod. Newt: less benefit in small size
* 10.0" (25) / f/5.95 / 59.5 / 45% // f/6.50 / 65.0 / 44% // Standard Newt. is Version 17
* 12.5" (32) / f/4.55 / 56.9 / 46% // NA / NA / NA // Standard Newt. is Version 15A
* 13.0" (33) / f/4.37 / 56.8 / 45% // NA / NA / NA // Std is V 19A. TScope if <17/3" wide
* 14.5" (37) / f/4.04 / 58.6 / 47% // NA / NA / NA // Standard Newt. is Version 13A
* 15.0" (38) / f/4.04 / 60.6 / 45% // NA / NA / NA // Standard Newt. is Version 11A
* 16.0" (41) / f/4.00 / 64.0 / 47% // f/5.00 / 80.0 / 44% // Mod Newt is V5; f/4.5 OK at 30 deg.
* 16.5" (42) / f/3.96 / 65.3 / 45% // f/4.87 / 80.4 / 45% // Version 4, f/4.5 OK at 30 deg.
* 18.0" (46) / f/3.31 / 59.6 / 49% // f/4.29 / 77.3 / 43% // Modified Newt. is Version 1B
* 20.0" (51) / f/2.99 / 59.8 / 49% // f/4.02 / 80.4 / 43% // Modified Newt. is Version 1A
* 22.0" (56) / NA / NA / NA // f/3.69 / 81.1 / 43% // Mod Newt is V1 (f/4.12 FL too long)
* 24.0" (61) / NA / NA / NA // f/3.40 / 81.6 / 44% // Base too wide for res. interior doors.

Note 1: Focal length must be about 8 cm shorter to use tracking mount under std. tel. structure.

3.1.4.2) Fixed Eyepiece Telescopes.

Fixed eyepiece telescope, indoor focal plane refractor w/pm: 12.7 cm (5") f/25 largest cost effect.
Fixed eyepiece, outdoor off-axis reflector w/pt.mir: 18 cm f/10.7 best for high lat; 23 cm f/low lt
Fixed eyepiece scope, outdoor axial reflector w/pm 25 cm f/8 best for high lat; 32 cm f/low lat.
Fixed eyepiece, indoor ax/off-ax reflector w/pt.mit. 32 cm f/8~12.9 may be largest cost effective

3.1.4.3) Relay Lenses. (Recommended lenses vs. accessible telescope / relay lens application)
Part No. / Diameter / Focal L. / Back F.L. / CtrThk / EThk / Vendor / Notes (2 lenses/relay)
AC254-250-A / 25.4 / 250.000 / 246.700 / 6.00 / 5.20 / Thorlabs / Compact for f/12~15 high mag
L-AOC044 / 31.500 / 250.000 / 246.490 / 7.22 / 6.20 / Ross Optical / Compact for f/10 relay
L-AOC234 / 40.000 / 249.100 / 244.190 / 8.80 / 6.90 / Ross Optical / Best univ. (f/6.5 or slower)
L-AOC237 / 40.000 / 350.000 / 347.490 / 7.30 / 5.90 / Ross Optical / Best img/clearance w/f/10

3.2) Accessible Long Focal Length Refractor Telescope (focal plane inside building, etc.)

SPECIFICATIONS FOR BASELINE 12.7 cm (5.0") APERTURE DESIGN:
* 5.0" f/25 achromatic doublet objective lens.
* 6.5" minor axis mirror (9.19 major axis; fully illuminates to +24 dec.).
* Fold mirror is enclosed in 11 x 11 inch octagonal housing, TBD" long.
* 150 mm x 210 mm x 25 mm (NEW) IKO cross roller bearing to support feed mirror.
* Hollow shaft for optical path from mirror is 5.51" (140 mm) ID, 150 mm OD.
* Small north bearing at end of mirror housing supported by pneumatic pistons.
* Main telescope tube has OD of 6.0". Inside lined with fiberglass sheet.
* Outer tube (in part through attic) has OD of about 9".
* Part of telescope tube below ceiling has OD of 3.0 to 3.5 inches.
* Focuser is Unitron or modified Orion focuser with inner draw tube.
* Front aperture side of mirror housing has 6.5" wide plate glass window.
* Window is 5.5" from optical axis, and parallel to optical axis.
* To fully illuminate down to -35 declination, window south height must be:
** (5.5*Tan35)+(2.75*[1/COS35]) or: (3.85+3.36) = 7.2" (2.75=S. opt. path rad)
* To fully illuminate up to +40 declination, window north height must be:
** (5.5*Tan40)+(2.5*[1/COS40]) or: (4.62+3.26) = 7.88" (2.5=N. opt. path rad.)
** Therefore, window clear aperture shall be at least: 6.0 x 16.0"
** Window substrate shall be between 6.5 x 16.5" and 7.0 x 17.5".
** Allowance for bearing interfaces shall be 2.0" to south, 1.0" to north.
* Feed mirror housing length shall be approximately: 20.0 to 21.5" long (may vary w/details).
** North bearing shaft and its weather-proofing shall add an additional 2".
** Clearance from 4/12 roof at 40 lat shall be >4" (Housing base CL is 8" beyond roof)
* Total housing + path length including roof clearance, north bearing: 31.5" (may vary).
* Housing has built-in deployable solar filter by front of ring bearing, for safety and solar obs.

SPECIFICATIONS FOR ALTERNATE 14 cm (5.5") APERTURE DESIGN:
* 6.0" f/20 (stopped down to 5.5" f/21.8) achromatic doublet lens.
* 7.0" minor axis (9.90 major axis; fully illuminates to +22 dec.)
* Fold mirror is enclosed in 11 x 11 inch octagonal housing, TBD" long.
* 160 mm x 220 mm x 25 mm (USED) THK cross roller bearing to support feed mirror.
* Hollow shaft for optical path from mirror is 5.80" (147.5 mm) ID, 160 mm OD.
* Main telescope tube has OD of 7.0". Inside lined with fiberglass sheet.
* Outer tube (in part through attic) has OD of 9" to 10".
* Window clear aperture shall be at least: 6.3 x 17.0"
* Window substrate shall be between 7.0 x 17.5" and 7.5 x 18.5".
* Feed mirror housing length shall be approximately: 20.0 to 21.5" long (may vary w/details).
* Total housing + path length including roof clearance, north bearing: 32.5" (may vary).
* Other specifications are same as for baseline design.

Additional information, including vendor data for selected parts, is in Appendix D.

3.3) Relay Lenses to Increase Observer Clearance with Existing Telescopes

Several relay lens tests were performed with real optical hardware to obtain empirical results. Empirical tests were also performed because I don't currently have access to optical design software (that I know how to use), and because I already had a good idea of what was practical. Tests were performed with an Intes MN61 (15 cm f/6) Maksutov Newtonian telescope that has excellent optics, and with a Celestron 20 cm f/10 SCT having good optics. Moving and setting up either telescope was not trivial, given my condition. Several types of tests were emphasized:

* Determine minimum focal length for an achromatic relay that provides adequate performance.
* Determine maximum useful field of view (FOV) that can be obtained vs telescope type / f/ratio.
* Determine the optimum (simple) achromatic relay lens configuration for planetary viewing.
* Determine if reducing, unity, or magnifying relay lenses work for both deep sky and planets.

An iris was included in the relay lens assembly to provide a way to simulate different telescope f/ratios. The prototypes and test results are summarized below, and followed by conclusions.

Figure 3.3A. Relay lens prototype on Intes MN61 (150mm f/6) Maksutov Newtonian telescope. LEFT: Prototype "Unity Magnification" relay lens assembly (described below), shown on a 15 cm f/6 Maksutov Newtonian telescope. RIGHT: The relay provides enough lateral clearance from the telescope and tripod to accommodate a wheelchair or similar size mobility device, including the rollator pictured here. The eyepiece height and angle are variable by rotating the telescope, swiveling the diagonal mirror by the eyepiece, or varying the height of the tripod or telescope mount. The diagonal can also be used at different distances from the end of the relay assembly, which in turn permits some of the extension tube length to be between the diagonal and eyepiece. A variable angle fold mirror (VAFM) can also be used.

Figure 3.3B. Design and Construction of Unity Magnification Relay Assembly Prototype. Since I can't use machine tools, the prototype had to be made from optics and hardware I had on hand or could purchase. The top picture shows the assembly at its minimum length. The bottom one shows the unit disassembled. A camera coupling (or a flip mirror with one) can be substituted for diagonal at right.

3.3.1) Test 1: High Magnification (2:1) Relay Lens Assembly Prototype:

* First lens is a 100 mm x 31 mm (working at 29 mm) achromatic finder scope objective.
* Second lens is Ross Optical 200 x 40 mm achromat, reduced to 35 mm, working at 29 mm.
* Iris diaphragm is BETWEEN lenses.

3.3.1.1) Test Results for High (2:1) Magnification Relay Lens Set:

* Acceptable planetary images at f/8 or slower *original* telescope aperture.
* Acceptable full diameter lunar image at f/8 original telescope aperture.
* Acceptable 16 mm Nagler eyepiece field at f/10 or slower original telescope aperture.
* System has significant coma at wider apertures (e.g. f/6)
* Optical system limited telescope to about f/6.9 (200/29; due to working diameter of 100 mm).

3.3.2) Test 2: Strong De-Magnifying (1:2 Focal Reducer) Relay Lens Assembly Prototype:

* First lens is Ross Optical 200 mm x 40 mm achromat, reduced to 35 mm, working at 29 mm.
* Second lens is a 100 mm x 31 mm (working at 29 mm) achromatic finder scope objective.

* Iris diaphragm is BETWEEN lenses. (This is the high magnification assembly used in reverse.)

3.3.2.1) Test Results for Strong (1:2) De-Magnifying Relay Lens Set:

* Acceptable planetary images only at f/10 or slower *original* telescope aperture.
* Acceptable full diameter lunar image at f/12 original telescope aperture.
* Acceptable 16 mm Nagler field ONLY at f/15 or slower original telescope aperture.
* System has SEVERE coma, due to short 100 mm focal length achromatic lens.
* Optical system limited telescope to about f/7.5.
* This much focal length reduction with simple achromatic lenses is impractical for wide field.

3.3.3) Test 3: Moderate Magnification (1.25:1) Relay Lens Assembly Prototype:

* First lens is Ross Optical 200 mm x 40 mm, reduced to 35 mm, working at 32 mm.
* Second lens is Thorlabs 250 mm x 50 mm, working at 32 mm (limited by Ross 200 mm)
* Iris diaphragm is IN FRONT OF First lens (Ross 200 mm)

3.3.3.1) Test Results for Moderate (1.25:1) Magnification Relay Lens Set:

* Acceptable planetary images at f/7 or slower *original* telescope aperture.
* Acceptable full diameter lunar image at f/6 original telescope aperture.
* Acceptable 16 mm Nagler eyepiece field with f/7 or slower original telescope aperture.
* System allowed telescope to operate at almost full aperture (200/32 = f/6.25).

3.3.4) Test 4: Weak De-Magnifying (1:1.25 Focal Reducer) Relay Lens Assembly Prototype:

* First lens is Thorlabs 250 mm x 50 mm, working at 32 mm (limited by Ross 200 mm)
* Second lens is Ross Optical 200 mm x 40 mm, reduced to 35 mm, working at 32 mm.
* Iris diaphragm is BEHIND Second lens (Ross 200 mm)

3.3.4.1) Test Results for Weak (1:1.25) De-Magnifying Relay Lens Set:

* Acceptable planetary images at f/8.5 or slower *original* telescope aperture.
* Acceptable full diameter lunar image at f/8.5 original telescope aperture.
* Acceptable 16 mm Nagler field with f/10 and slower original telescope aperture.
* Optical system limited telescope to about f/7.8 (due to 32 mm working diameter of 250 mm).

3.3.5) Test 5: Unity Magnification (1:1) Relay Lens Assembly Prototype:

* Both lenses are Meade 210 mm x 31 mm (working at 29 mm) finder scope objectives.
* 25 mm aperture iris diaphragm is BETWEEN lenses. (Front sides of lenses face each other.)
* Maximum 25 mm aperture of iris limits all tested telescopes to working f/ratio of f/8.4.
* Unity magnification system was tested on both Intes MN61 Mak. Newt. and Celestron 8 SCT.

3.3.5.1) Test Results for Unity (1:1) Magnification Relay Lens Assembly (180818):

* Acceptable planet images at f/8.4 or slower *orig.* scope aperture (limit is relay assembly iris).
* Excellent planet images at f/10.7 or slower orig. scope aperture (aperture adjusted w/relay stop)
* Acceptable full diameter lunar image at f/8.4 orig. telescope aperture (limit is relay assem. iris).
* Very good full diameter lunar image at f/10.0 orig. telescope aperture (f/ratio of Celestron 8).
* Excellent full diameter lunar image at f/10.7 orig. telescope aperture (limit is relay iris setting).
* Acceptable 16 mm Nagler field with f/10.7 and slower orig. aperture. Some field curvature.
* Optical system limits fast telescope to about f/8.4 (due to 25 mm wkg. dia. of 210 mm lenses).
* Field curvature evident at f/10.7 or faster. (Add simple field flattener to one end of assembly.)
* Slight fringing in outer half of 16 mm Nagler field, due partly to low cost finder scope lenses.

Figure 3.3.5.1A. Results with Celestron 8 telescope & unity magnification relay lens prototype. These results with a prototype relay lens assembly on a Celestron 8 SCT show that little if any observable image quality is lost when using an appropriate relay lens assembly to provide camera or eyepiece accessibility for a slow f/ratio telescope. The LEFT image of the moon is close to full frame in an APS format Fuji X-T10 digital camera. The two UPPER RIGHT images are 50% crops from left image. LOWER RIGHT is a 200% (2x original size) crop of Saturn (just a single photo; not a stack).

3.3.6) Conclusions from Relay Lens Test Results

Conclusions below address both optical attributes and application to *accessible telescopes*.

3.3.6.1) Conclusions Related to Relay Lens Optical Attributes:

* Best images were obtained with unity magnification relay or slightly magnifying (25%) relay.
* All versions of unity magnification relay lens systems had moderate curvature of field.
* All versions of de-magnifying relay lenses had curvature of field and severe coma.
* f/8 is fastest original telescope aperture for best relay lens results vs simplicity.
* Unity relay lens results were almost indistinguishable from original scope at f/10.7 or slower.
* Relay system on C8 impractical for wide field 2" eyepieces due to weight and complexity.
* Working relay lens aperture of at least 31 mm needed for good 1.25" eyepiece edge brightness.
* Working achromatic relay lens paraxial f/ratio of f/7 or slower needed for good image quality.
* Working relay lens paraxial f/ratio of f/8 or slower needed for very good image quality.
* Working relay lens paraxial f/ratio of f/10~10.7 or slower needed for excellent image quality.
* Simple (2 element) field flattener recommended for one end of all tested relay lens assemblies.
* If field flattening lenses used at only one end, should be at end with shortest FL relay lens.
* Relay lenses of 250 mm focal length will have less field curvature than 210 mm FL test lenses.
* Best relay doublet is *250 mm FL, 35~40 mm dia. achromatic lens* (to control lens thickness).
* Excellent results should be possible at f/9.0 with 250 mm focal length achromatic relay lenses.
* High performance with greater clearance possible at f/9.2 with 350 mm FL achro. relay lenses.
* Lenses should be made to resolve close to theoretical limit (finder scope lens not good enough).
* Original telescope f/ratio of 8 or slower will limit paraxial f/ratio of >31 mm CA relay lens.
* Due to simple relay lenses having slow f/ratio, sys. impractical for most Newtonian telescopes.
* Relay lens system works best with f/8 RC or f/10 SCT telescopes, and slower Mak (etc) scopes.
* Housing ends may be made from T-thread extension tubes, Thorlabs 30 mm tubes, or other.

3.3.6.2) Conclusions Related to Relay Enabling or Enhancing Handicap Accessibility:

* Lateral extensions of 50 cm (20") or even more are feasible with an f/8 or slower telescope.
* Lateral extension is adequate to facilitate handicap access to appropriately mounted telescopes.
* Due to weight, it is best to size relay lens systems for 1.25" or smaller eyepiece barrels.
* Maximum well illuminated field of view with Intes MN61 and relay was about 1 deg. in tests.
* Minimum test magnification having good Intes MN61 relay results was 45x (16 mm Nagler).
* Maximum FOV with Celestron 8 SCT and 2x 210/25 relay was 0.55~0.6 deg. (1.1x lunar dia).
* Minimum practical magnification with Celestron 8 SCT is about 63x (32 mm otho or plossl).
* Maximum field of view with Meade 12" (305 mm) f/10 SCT and relay will be 0.4 degrees.
* Minimum practical magnification with Meade 12 will be about 94x (32 mm ortho or plossl).
* Maximum practical FOV for large SCT can be increased 50%, but at considerably more cost.
* Intes MN61 with relay can provide adequate public viewing of moon, if relay limits to f/8.4.
* Maximum practical aperture for public viewing of entire moon at once is 8" (C8 or equiv.).
* Folded Newtonian design (uses very large secondary) may be practical with or without relay.
* Best telescope to use with relay for planets may be 180 mm f/15 Mak, *only if properly baffled*.
* Best handicap access telescope to use with relay for deep sky / other obs. is C8 or larger SCT.

4.0) Conclusions:

* It *IS* feasible to design and build *accessible telescopes*. Rarity may be due to lack of interest.
* Since accessible telescopes are more convenient for average users than conventional designs, the market for such telescopes may be many times larger than the disability community itself.
* A variable angle fold mirror that works with f/4 or faster telescopes can enable more flexibility.

4.1) Conclusions for Accessible Large Aperture Modified Newtonian Reflector:

* Accessible modified Newtonian telescopes ranging up to / beyond 56 cm aperture are feasible.
* Implementation cost is only slightly higher than conventional designs. Most additional cost is in a larger secondary mirror, and the extension needed between the secondary mirror and focuser.
* If a commercial vendor makes such telescopes, emphasizing *convenience* may widen market.
* Design benefits from low magnification, long throw Barlow / corrector up to *neg*. 600 mm FL.
* Implementation possible as new build telescopes, or by modifying front of existing telescopes.
* In telescopes with unstable collimation, collimation controls should be accessible from front.
* Additional modified Newtonian conclusions are noted in part 3.1, above.

4.2) Conclusions for Refractor having Fixed Indoor FP, Eyepiece, Eyepiece Turret, etc.:

* 140 mm (5.5") is largest feasible aperture vs cost, but 12.7 cm is easier to accommodate.
* Ring bearing size/cost and outer tube size versus common machinist lathe size are cost drivers.
* Larger apertures are possible, but are expensive compared to conventional *outdoor* telescopes.
* Coverage from -29 to +29 degrees declination is the bare minimum requirement.
* Coverage from -35 deg to +40 deg desirable for upper latitudes.
* Coverage from at least -48 deg to +48 deg desirable for lower latitude. (BASELINE)
** Effective aperture is only 5.0 x 2.2" *at +48 deg*. with 6.5" minor axis / 9.2" major axis mirror.
* Optical window shall accommodate unobstructed optical path from -48 deg. to +48 deg. dec.
* Mechanical feed mirror motion shall accommodate from at least -48 to + 48 deg. declination.
* Feed mirror housing on roof should be as small as possible, since is unusual item for a roof.
* Feed mirror housing shall be weather proof, to protect the feed mirror and internal mechanisms.

4.3) Conclusions for Using Relay Lenses with Conventional or Modified Telescopes:

* Relay lenses provide one of the easiest ways to facilitate accessibility with existing telescopes.
* Empirical tests show it *IS* feasible to use *simple* relay lenses with f/8 and slower telescopes.
* Two facing relay lenses providing unity or slightly increased magnification work best vs cost.
* Precision achromatic lenses (as opposed to finder scope objectives) provide better results.
* Relay lens focal length of about 250 mm is close to optimum for slow f/ratio (f/10) telescopes.
* Faster f/ratios can be accommodated with ED or APO relay optics (Borg 45 mm, for example).
* Some eye protection (in case of accidental operation of motorized wheelchair) can be provided by suspending a relay assembly from two points, then using break-away fitting at telescope end.
* Eyepiece position may be easier to adjust if variable angle fold mirror(s) used with relay lenses.
* For planetary viewing, it is important to use a properly designed telescope (see Appendix A).
* Additional relay lens conclusions are summarized in part 3.3.6, above.

5.0) Claims Disclosure, Scope, Disclaimer, Remarks, and Appendices:

This section includes a disclosure of certain aspects, and is more or less written like patent claims (but may not be as formal or constrained as patent claims), plus a statement about the scope of this work as a *defensive publication*. A disclaimer and various appendices are also included.

5.1) Claims Disclosure: This material covers several concepts, designs, and improvements that can provide practical *access* to telescopes for people with disabilities, and more convenient access for the general population. What is claimed are but a few of many enabling attributes:

1.) An optical system comprising: a housing and least two achromatic, ED, or apochromatic lens groups and/or concave mirrors that are oriented with their front sides facing each other (or a triplet relay lens instead of two facing lens groups), further comprising appropriate interfaces and parts, whereby one end of the optical system receives light from the focal surface of a telescope or similar article, and forms a real (relayed) image of said focal surface at its opposite end.
2.) Apparatus according to claim 1, further comprising one or more fold mirrors (as needed), and an eyepiece, camera, or similar article to observe the image formed by the relay lens assembly.
3.) Apparatus according to claim 1, further comprising two variable angle fold mirrors (one at or near each end) that can also be rotated about the optical axis of the original or folded light path, said fold mirrors providing a wide range of eyepiece positions and angles in 3-dimensional space.
4.) Apparatus according to claim 1, further comprising a flip mirror, eyepiece turret, or both.
5.) Apparatus according to claim 1, where the real image is formed at a sufficient distance from a telescope or similar article that said image can be observed by a person, including a person in a wheelchair or other mobility device, by means of an eyepiece, camera, or similar article.
6.) Apparatus according to claim 1 or 5, having means to insert extension tubes between the relay lens groups to increase the physical clearance provided by the optical system.
7.) Apparatus according to claim 1, further comprising an iris diaphragm to control the aperture.
8.) Apparatus according to claim 1, further comprising user interchangeable relay lens groups.
9.) Apparatus according to claim 1, further comprising one or more field flatteners, as needed.
10.) Apparatus according to claim 1, further comprising a field stop, finder objective, flip mirror and reticle that can assist with subject acquisition and focusing of a telescope or similar article.
11.) Apparatus according to claim 1, further comprising a telescope and an altitude over azimuth mount, wherein the optical path passes through the mount's elevation axis to reach the relay lens.
12.) Apparatus according to claim 1, further comprising means to suspend the weight of the relay optical system and its enclosure, also comprising a break away junction near the telescope that will separate if excess pressure is applied to the eyepiece, for purposes including reducing risk of eye injury if a person in a motorized mobility device accidentally moves their device forward.
13.) Apparatus according to claim 1, further comprising remote control focus mechanism that can be operated by an observer, including an observer in a mobility device.

14.) A telescope comprising: a flat feed mirror that rotates about an axis parallel to earth's polar axis and tilts about an axis perpendicular to the polar axis, further comprising a support structure, a telescope objective lens or mirror, an optical path baffle or enclosure, a focuser, and means to observe the image formed by the objective at the focal surface by means of eyepiece, camera, etc.
15.) Apparatus according to claim 14, wherein feed mirror assembly is enclosed, weatherproofed, and located on the roof of a habitable structure, further comprising shock absorbers at polar end.

16.) Apparatus according to claim 14, wherein the optical path enclosure is double walled, insulated, and air conditioned to reduce the thermal gradient along the enclosed optical path.
17.) Apparatus according to claim 14, wherein the focal plane is located in a habitable structure.
18.) Apparatus according to claim 14, wherein the telescope eyepiece overhangs an observing area enough that the image is observable by an observer in a wheelchair or other mobility device.
19.) Apparatus according to claim 14, wherein the eyepiece angle is variable in height and angle.
20.) Apparatus according to claim 14, 18, or 19, wherein the pointing feed mirror and telescope objective are in separate portable modules that are set up at prescribed distances from each other.
21.) Apparatus according to claim 14 or 20, wherein the feed mirror has a hole in its center to provide a light path for light from a telescope objective or mirror in front, to a focal plane behind.
22.) Apparatus according to claim 20 or 21, where focal plane is located in a habitable structure.
23.) Apparatus according to claim 14 or 21, with objective and feed mirror in one portable unit.

24.) A telescope comprising: a Newtonian primary mirror with its support, a secondary mirror with its support, a structure, a mount, a focuser, an extension between the telescope structure and focal surface, and means to observe the focal surface via an eyepiece, camera, or similar article.
25.) Apparatus according to claim 24, further comprising an articulated extension and focuser that tilts about the secondary mirror, said secondary mirror tilting at half the rate of the focuser.
26.) Apparatus according to claim 24, further comprising a flip mirror, eyepiece turret, or both.
27.) Apparatus according to claim 24, wherein said extension between the telescope structure and focus is long enough that the focal surface is far enough from the bulk of the telescope (etc.) that the image at focus can be observed by a person in a wheelchair or other mobility device.
28.) Apparatus according to claim 27, wherein the secondary mirror is large enough to reflect the entire converging light bundle from the primary mirror to the center of the focal surface.
29.) Apparatus according to claim 24, wherein the secondary mirror is oriented at an angle other than 45 degrees, so it reflects the light bundle at an angle biased toward the back of the telescope.
30.) Apparatus according to claim 24, further comprising at least one variable angle fold mirror that is capable of providing eyepiece angles orthogonal with reference to the telescope, even when the telescope secondary mirror is oriented according to claim 29.
31.) Apparatus according to claim 24, further comprising a weak negative achromatic or APO lens (Barlow) that is located less than 0.6 times its focal length from the focal surface, whereby back focus is increased (yet secondary mirror can be smaller) without excessively reducing FOV.
32.) Apparatus according to claim 24, further comprising a coma corrector.
33.) Apparatus according to claim 32, where the coma corrector also acts as a Barlow lens (including, but not limited to, the Barlow lens in claim 31) to increase back focus distance.
34.) Apparatus according to claims 32 or 33, wherein corrector lenses are switchable, or tunable in spacing, to adjust between full coma correction and a normal diffraction limited central image.

35.) A mirror assembly comprising: A housing, a tilting mirror, an articulated eyepiece holder with camera interface, and a synchronizing mechanism, whereby the mirror tilts at half the rate of the articulated eyepiece holder, thereby providing a continuous range of optical path fold angles.
36.) Apparatus according to claim 35, wherein optical path fold angles encompass a continuous range of at least 58 to 105 degrees, and/or wherein the eyepiece holder has means to adjust focus.
37.) Apparatus according to claim 35, wherein the tilting mirror is a roof mirror having two front reflecting surfaces that provide reflection characteristics of a 90 degree Amici roof prism, that is also (by virtue of being a mirror rather than a prism) compatible with a variable eyepiece angle.

38.) Apparatus according to claim 37, wherein the front and rear housing interfaces are offset so that the axial light bundle does not intersect the 90 degree corner where both mirrors meet.
39.) Apparatus according to claim 35, having a front aperture, mirror size, and optical path length that is compatible with (i.e. does not obstruct) a light bundle as fast (e.g. convergent) as f/3.6.
40.) Apparatus according to claim 35, wherein the articulated eyepiece section includes a light baffle that blocks illumination of an eyepiece field by light that is not reflected from the mirror.
41.) Apparatus according to claim 35, wherein the front interface can attach directly to industry standard hardware. (For example, interface can be T-thread or another standard interface.)
42.) Apparatus according to claim 35, wherein the eyepiece holder attaches via industry standard threads. (For example, Leica M39 thread permits use of Leica M and other mirrorless cameras.)

5.2) Scope:

This disclosure is considered as illustrative of the principles of one or more inventions. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention(s) to the exact construction, operation, and appearance as shown and described, and accordingly all suitable modifications and equivalents my be resorted to without thereby departing from the basic principles of the invention(s). It will be further understood that the invention(s) are susceptible of embodiment in many various forms, some of which are illustrated in the accompanying drawings and photos, and that structural details and modes of fabrication herein set forth may be varied, interchanged, and combined to suit particular purposes and still remain within the author's inventive concepts. The foregoing also applies to any associated communications, including communications for the purpose of obtaining parts or cost estimates for various elements. Upon public disclosure that may include formal publication, this document is a *"defensive publication"* that operates to prevent third party patenting of any patentable material herein. It provides enabling descriptions for a variety of novel items, and is supported by several unpublished but verifiable priority documents dating back to the 1980's. On publication, only that herein which is *patentable* may enter the public domain. All that is covered by *Copyright* (text, photos, artwork) shall *not* enter the public domain. All Rights Reserved.

5.3) Disclaimer:

All information in this document and any and all of its attachments, appendices, or related communications are based on my own experiences and/or creative work and/or second hand knowledge about designs published by others, and is provided without warranty as to its value or accuracy for any purpose. Concepts and designs disclosed herein were developed with emphasis on a certain range of eyepiece heights and angles, and do not address any aspects of the ADA or other disability related regulations. Nothing herein is asserted to be ADA compliant. Applicable disability, safety, etc. regulations, must be consulted when providing public access to a telescope, including any and all essential or ancillary aspects required to access where a telescope is set up. A patent search was not done in association with this material. Accordingly, it cannot be asserted that any given design, or aspect of a design, is in the public domain rather than being part of a prior, active, patent. Readers are advised to conduct a reasonable patent search before "making, using, or selling" anything described herein This is not a medical, legal, or ADA document, nor is it written by anyone with such experience. It must not be used as a medical, legal, or accessibility reference. This document is not intended to be a substitute for professional regulatory, legal, or medical advice. Never disregard or delay seeking such advice because of anything read in, or inferred from, this document or any related communications or appendices. The Author shall be held harmless with regard to all real or imagined damages perceived to be related to this material. This document contains a lot of information and is not asserted to be free of inadvertent error.

5.4) Remarks:

This document is *not* intended to provide all of the answers concerning *accessible telescopes*. Instead, it is intended to be a starting point from which others can make further improvements, with such improvements being part of a *Creative Commons* (as opposed to being patented) that can help lower the cost of *accessible telescopes* for all who would benefit from them.

It is hoped that in the near term, *accessible telescopes* will be something that astronomical societies in various cities can afford to acquire, modify, or build, then temporarily or permanently make such telescopes available to members of the disability community during at least public viewing nights, or at star parties held at accessible locations. It is further hoped that the cost of some accessible telescopes will become low enough that individuals living with disabilities who want an accessible telescope will be able to afford one of at least small to moderate aperture.

It is also hoped that those working to provide accessible telescopes, and those of us in the disability community that may use them, will work together in a spirit of unity. For example, initial versions of *accessible telescopes* may by necessity be limited to a "best effort" that may not necessarily be ADA compliant. From these initial efforts, more can be learned about the range of *eye heights and angles* within the disability community that it is desirable and practical to accommodate. From here, further improvements can be made. At the same time, those of us in the disability community should not "carry around rulers" in order to try and impose every detail of ADA rules on good faith efforts by many to provide accessible telescopes. To do so would remove all incentive for people to work toward making *accessible telescopes* available.

This document is further intended to show that some things benefitting the disability community can originate *within* the disability community. There is no "us and them" dividing people living with disabilities from those without disabilities, but there is a difference in the *life experience* of each population. Many of us who live with disabilities have fixed incomes, or have had logistical difficulties with ADL's or transportation that the general population probably cannot fully grasp.

Many products that are made for the disability community are disproportionately expensive, and beyond the financial reach of many with disabilities who lack significant financial assistance. Some products for people with disabilities seem to cost the proverbial arm and a leg - an arm and a leg that some in the disability community may not have. However, *if the market for disability related products is open to more manufacturers*, it may help *lower* the cost of products useful to people with disabilities. A few things may improve chances for bringing this about. Namely:

Patents (to protect inventions) have long been *too expensive* and exacting to be prosecuted by the vast majority of *individual people*. This severely limits the percentage of the population that has incentive to put time or resources into inventing. Since individuals can rarely afford patents any more, it is large *corporations* that often end up with patents for things that *individuals* may have *already* invented, *<u>unless</u> we as individuals render our own intellectual property <u>unpatentable</u>* via *defensive publication* or other means. Only *preventing a monopoly on patentable IP by large corporations* can allow costs to be controlled. This makes it possible for *small* companies *(even those that can't afford patents)* to *compete* in providing products to the disability community.

Here's one example of high patent fees: In 2005, a comprehensive patent application I'd filed earlier - was abandoned *solely* because patent fees were too high. I had formalized 525 drawing figures and several hundred pages of text, to make it formal enough for a patent, but could not afford radically increased fees. Patent fees totaling more than $8,000 would have been required with the response to the Patent and Trademark Office (PTO) in order for it to be accepted. I had been awarded 9 patents up to that time, but by 2005, already high patent fees had climbed out of sight. Patents are even less obtainable for people on a fixed income, which is my situation now.

Therefore, one purpose of this document is to *bypass the patent system* altogether, and place that herein which is *patentable* into the *public domain*. This should make it possible for *more* manufacturers to *compete* in providing *accessible* telescopes. Upon publication, *only* that herein which is *patentable* may enter the public domain. All that is covered by *Copyright* (text, photos, artwork) shall *not* enter the public domain. All Rights Reserved. Using telescopes is a relatively peripheral and *low priority* activity for most with disabilities, since amateur astronomy requires some of what little time and endurance is left after taking care of *essentials* such as ADL's.

However, others within and without the disability community may have ideas for improvements in areas that are essential to *daily life*, and that thereby have a *wider market*. If these ideas are also made available through *defensive publication* or other means, it can potentially *lower the cost* of the resulting product by keeping multinational corporations from *cornering the market*.

What is needed is a <u>*creative commons*</u> that is by and for the disability community. It is *we* who bear the brunt of *high prices when too few companies can compete* because of patents obtained by large corporations and multinational conglomerates. (Only they can afford patents any more.)

If concepts, ideas, and inventions for items that are useful to the disability community are *made available to <u>all</u>* via defensive publication and other means, it *prevents* patenting of the disclosed material, and thereby helps make it possible for *smaller* cottage industries to produce products that large corporations may not want to bother with unless they can charge exorbitant prices. That's my soapbox on the matter of inventions that originate within the disability community, and that may also be useful to people within the disability community and maybe beyond.

This document represents only some of the concepts and designs I developed over time, and that may be applicable to *accessible telescopes*. Much of my material was developed in the 1980's, but most was never built or brought to market, due mostly to an ongoing lack of funds. (I won't be able to make or market the related equipment now either, for this plus medical reasons.)

Additional astronomical telescope material from the 1980's (and since) may be added later. If any want to donate toward further effort in making such material public, I may set up a PayPal button at some point. Disclosing such material via defensive publication would *not* be for profit, but I won't be setting up a nonprofit organization either, owing to the effort and costs involved.

Most telescopes herein are too large to be transported or set up by a person using a wheelchair. A goal is to refine smaller scopes so one in a wheelchair can set up and use them w/o assistance.

Clear skies, Jeffrey R. Charles

6.0) Appendices

6.1) APPENDIX A: Types of Telescopes, Review Link, Sample Lunar / Planetary Images

There are three basic types of telescopes, but a myriad of variations within each type. Each type was considered as a candidate for an *accessible telescope* prototype. The three basic types are:

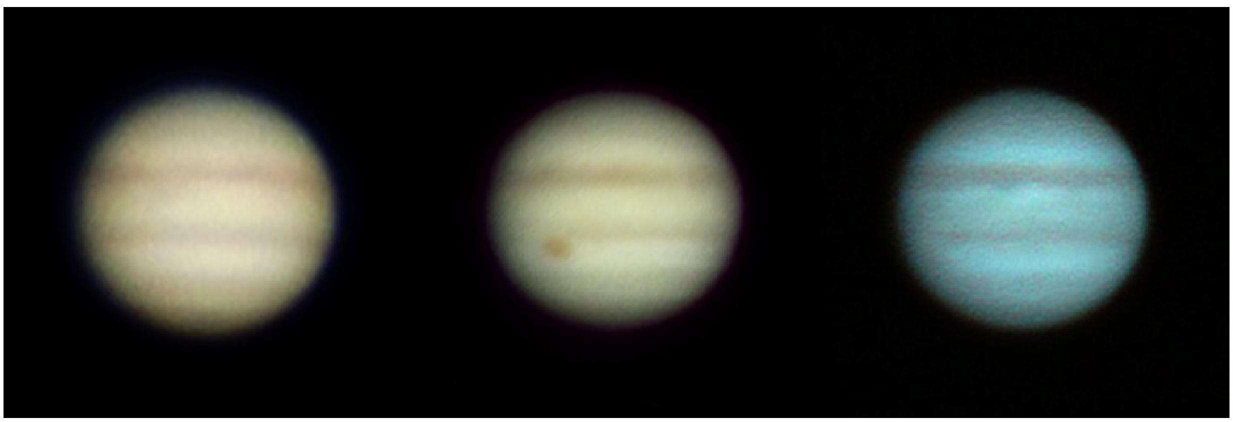
* **Refractor**. A refractor telescope consists of a lens (two or more elements) at the front, a lens cell, a tube or other support structure, a focuser, baffles, and an eyepiece and/or camera interface. A diagonal mirror or prism is often used to provide a more comfortable viewing angle for the eyepiece. Variations of refractors include types of glass used in the lens, whether or not the light path is folded, and whether or not field flattening lenses are used for wide field astrophotography.
* **Newtonian**. A Newtonian telescope is one of the most elegant telescope designs. It consists of a concave primary mirror with a paraboloidal optical figure, a flat secondary mirror to direct the light path to one side, and a support structure for the optics. Variations of the Newtonian include whether a spherical primary mirror is used in conjunction with a corrector lens (the corrector is usually at the front), and whether or not coma correcting, etc., lenses are used relatively near the focal surface. Some variations in this document utilize unconventional secondary mirror angles.
* **Cassegrain**. A Cassegrain telescope consists of a concave primary mirror at the back, a convex secondary mirror at the front, and a support structure. The primary mirror usually has a hole in its center to permit light that is reflected from the secondary mirror to exit the rear of the telescope. Variations include optical figures of the primary and secondary mirrors, and whether spherical mirrors are used with a front or rear refracting spherical aberration correction optics. The latter is usually called a catadioptric telescope. Most catadioptrics have a Maksutov or Schmidt corrector at the front. (Larger Schmidt tested better.) Other scopes have a concave secondary mirror, and others (including one shown in this material) fold the light path in front of the primary mirror.

The Cassegrain design is one of the most difficult to implement properly, because there are more optical and mechanical details to consider. Some of the most frequent design errors made in commercial Cassegrain telescopes are related to the light baffles. In a proper light baffle design, the back of the secondary baffle, front of primary baffle, and any retaining flange on the front of the primary mirror, will all appear to be close to the same size when viewed from the focal plane.

In a catadioptric Cassegrain telescope having a front corrector lens, it is usually bneficial if the primary mirror is slightly oversized, and if the primary light baffle OD (as seen from the center of the focal plane) appears to be *slightly smaller* than the other light baffles, while the inner and outer edges of the secondary baffle should appear to be slightly larger than other baffle elements. These details ensure that, for the axial image, the entrance pupil is defined by the aperture stop in the corrector lens cell, plus the outer boundary of the secondary light baffle. This minimizes longitudinal distortion of the exit pupil when a long focal length (low power) eyepiece is used.

Sadly, only a small percentage of Cassegrain telescopes are properly baffled. This is covered in some of my telescope reviews at this link: http://www.versacorp.com/vlink/jcreview/telerevw.pdf
In the linked reviews, the importance of proper light baffle design in a Cassegrain telescope will become evident. This is because improper baffle design can impair performance of a telescope, even if the optics are excellent. The appendix to the linked reviews covers this in more detail. The next two pages are lunar and planetary images that were taken through various telescopes. Specifically, images taken with telescopes that, in general, are designed and built properly.

Mars. Imaged with different telescopes. LEFT: Mars, 10 Aug. 2003, Vernonscope 94 mm f/7 refractor. Afocal image, taken by pointing camera and lens into eyepiece. CENTER: Mars, through Intes MN61 150 mm f/6 Mak-Newtonian with Barlow, mounted on photo tripod (no sidereal drive used) in 8/2018. RIGHT: Afocal picture taken though a 1.5 meter telescope at Mount Wilson, CA on 16 Aug. 2003.



Jupiter. LEFT: Imaged with TeleVue 60 mm f/6 ED refractor telescope in 7/2018. CENTER: Taken with Questar 3.5 Maksutov-Cassegrain telescope in 6/2018. RIGHT: Afocal image through Celestron 8 Schmidt-Cass. telescope in 7/2006. Has most detail, but noise from older camera. These are not fancy "stacked" images. Visually, planets usually look about twice as sharp as the photos from each telescope.

Saturn. LEFT: Imaged with compact TeleVue 60 mm ED refractor telescope in 7/2018. CENTER: Imaged with Celestron 8 SCT via relay lenses in 8/2018. RIGHT: Imaged with Celestron 8 SCT, circa 12/2003, on a night when atmospheric seeing conditions were a little better than average for my area.

6.1.1) Baffled by Telescope Light Baffles? So Are Some Telescope Manufacturers!

Is the ultimate "planet killer" telescope an expensive Maksutov-Cassegrain telescope? You may be surprised to find that it may not be. Some *larger* Mak-Cass telescopes that enjoy a reputation for excellent planetary images may, in reality, provide planetary images that are *inferior* to far less expensive Schmidt-Cassegrain telescopes (SCT's) of similar aperture. The reason for this? It is often *poor light baffle design* in the Mak telescopes. Several examples of poor baffle design were encountered when I inspected a relatively wide array of catadioptric telescopes over time.

But people have been getting good planetary images with these Maksutov-Cassegrain telescopes, haven't they?" Perhaps. However, this may be partly because people who *think* they have a good "planetary" telescope will use their telescope for planetary imaging. Other people may in fact have *better* telescopes for planetary observation and imaging, yet seldom use them for that purpose because they *don't think* they have a telescope with good planetary performance.

In reality, if you have a *USA-made* 8" Schmidt Cassegrain telescope (SCT), you may very well have a planetary telescope that is *superior* to *imported* Maksutov Cassegrain telescopes of similar to slightly smaller aperture that many use for planetary observation. A Celestron 8 or similar SCT has a central obstruction that is 34 percent of the aperture width. And so do many Mak-Cass telescopes! The Mak-Cass specs just *don't admit it.* As we will see, some large, expensive Mak-Cass telescopes may, in terms of percentage, have larger central obstructions than 8" SCT's.

We will start with the state of telescope light baffles when I first got into amateur astronomy decades ago. Back then, few if any telescopes were imported from China. For consumer catadioptric telescopes, there were a fewer choices than there are today, but *quality* was better. (In the context of this material, "catadioptrics" are reflector telescopes with refracting correctors.)

Early on, there was Celestron, with its recently introduced C90 Mak-Cass and its well established line of SCT's, in apertures of 5, 8, and 14 inches. The C11 was then about to become the new kid on the block. Another company, Criterion, made Dynamax SCT's in 6 and 8 inch apertures.

There was of course Questar, with their precision 3.5 and 7 inch Maksutov-Cassegrain telescopes (12" was not out yet), and the newly formed Optical Techniques (OTI), which made the Quantum 4 and 6 inch Maksutov-Cassegrain telescopes, and also had an 8" telescope in their brochure.

Other than these, there was the Ad-Astra III, a 78 mm Maksutov-Cassegrain, a few imported Cassegrain telescopes that were made in Russia (then the Soviet Union), and a few others.

A good percentage of the available catadioptric telescopes that I was able to see in person were *not* baffled properly. But a few were also *good* examples of light baffling. The Questar 3.5, the Quantum 6, and the Celestron 8 telescopes were almost textbook quality in terms of the diameter and length of their internal light baffles. In most of these, the interior surfaces of the light baffles lacked adequate knife edge stops, so they were not by any means baffled to perfection.

Other telescopes had light baffle flaws, but most were not as serious as flaws in later telescopes:

* The original Celestron 90 Mak-Cass has a primary baffle tube that does not extend very far in front of the primary mirror. At its front, there is a flat ring that serves to block some of the direct light that can get past the edges of the secondary baffle on the back of the Maksutov corrector. Unfortunately, a flat ring at the front of a short primary baffle tube is not an optimized design, and stray light entering from around the secondary baffle can flood the edges of the frame when a 35mm camera was used to take pictures. In addition, stray light reflected from the inside surface of the primary baffle tube caused obvious flare terrestrial photos. This was intolerable for my applications, so I extended the baffle forward by adding a conical section about 2.5 cm long that was made from sheet metal and epoxy, then painted black. This greatly reduced flare in my C90.

* The OTI Quantum 4 has a 100 mm aperture, and is noted for having a small 33 mm central obstruction. However, if you looked into the telescope from the focal plane at the back (while holding a transparent ruler across the front) it was obvious that the obstruction was really 36 mm, and that the front end of the primary baffle tube was causing the enlarged obstruction. Given the diameter of the front end of the primary baffle tube, it was too close to the secondary mirror spot on the back of the Maksutov corrector. This caused its reflection in the secondary mirror spot to occupy more than 1/3 of the telescope aperture width. The exit pupil had seemed odd when using a Quantum 4, so I checked and found the baffle tube issue. It causes some longitudinal distortion in the exit pupil, since the image of the telescope aperture is not on the same plane in the pupil as the image of the central obstruction. The Quantum 6 does not share this minor flaw.

So, at the time, light baffle issues were comparatively minor. This would change in later years.

A short time later, Meade introduced an 8" Schmidt-Cassegrain telescope (SCT), the 2080, then followed with a 10" SCT. The primary mirror in the 2080 was advertised to be almost 2 percent larger than the primary mirror in the Celestron 8. But there were *other* changes. The primary baffle tube was shorter and the secondary baffle was larger. This gave the Meade 2080 a central obstruction of almost 37 percent, while the Celestron 8 obstruction was only about 34.4 percent. This was not a big deal for most observers, but it deviated from the comparatively optimized design of the Celestron 8 light baffles. The *big* light baffle changes were still many years away.

In the 1990's, Meade introduced the ETX series of telescopes. The ETX 105 was a well baffled telescope, but in the smaller ETX 90, the secondary baffle was too small. This clipped the outer part of the light bundle from the primary mirror, reducing the aperture used for the axial image by more than 5 mm. Other telescopes from various manufacturers would follow in the same decade, but their light baffle flaws still were not huge in terms of percentage.

After 2000, telescopes from China began to be more common. Some people said they were good telescopes and some said they were bad. I did not have an opinion one way or the other until I bought a Chinese Mak-Cass in 2018. After that, I had an opinion, and it wasn't a favorable one!

I found that the Chinese-made Mak-Cass telescope produced poor images for several reasons. Later, I bought another Chinese Mak, then finally another. These too were flawed, and their light baffles were among the most significant flaws. At this point, I was through with Chinese Maks. It is here that our adventure of exploring "acceptable" to even "poorly made" telescopes begins!

In order to help others avoid the same pitfalls when looking for a telescope, some design flaws that I encountered are addressed in this section. I can't say if other telescopes of the same brand are as *poor* as my samples. However, to purchase 3 Chinese-made telescopes, then find that *all 3 have significant defects*, may speak volumes about Chinese Cassegrain telescopes in general.

The flaws of each Chinese-made Mak-Cass telescope I acquired during and after early 2018 are described below. The magnitude of some of the flaws may blow your mind. Some of the most significant flaws are related to *light baffles*, but one also had major optical flaws. Some baffle flaws can be corrected; others cannot. Think that imported Mak is a planet killer? It may not be!

Here are three real world examples of Chinese Mak-Cass telescopes that I inspected in the last year. The three examples are pictured below, then described in more detail after the photos.

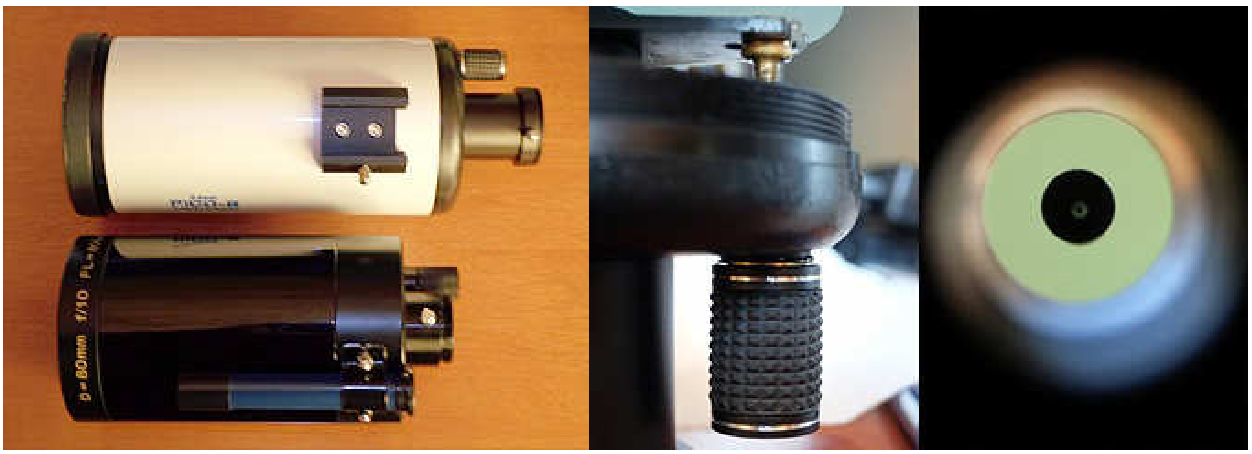


Figure 6.1.1A. The Kasai Pico-8 I bought in 2018 has *many* significant flaws. Where do I start?
LEFT: This Kasai Pico-8 was made in China. It is not as small as the 20 year old B&L 800 mm below it, and it is not as sharp either. However, it <u>*could*</u> have been a better telescope *if it had been made properly*. It has some of the most elementary design and build flaws I've ever seen.
CENTER: The focus knob had over 0.5 mm of end play, for very sloppy focus, and there is no adjustment for focus knob play, while there is in the B&L. I made a brass washer to correct this.
RIGHT: Bright reflections in primary light baffle tube cause obvious flare, even on the moon. Primary baffle is also too close to the secondary, effectively increasing central obstruction size.

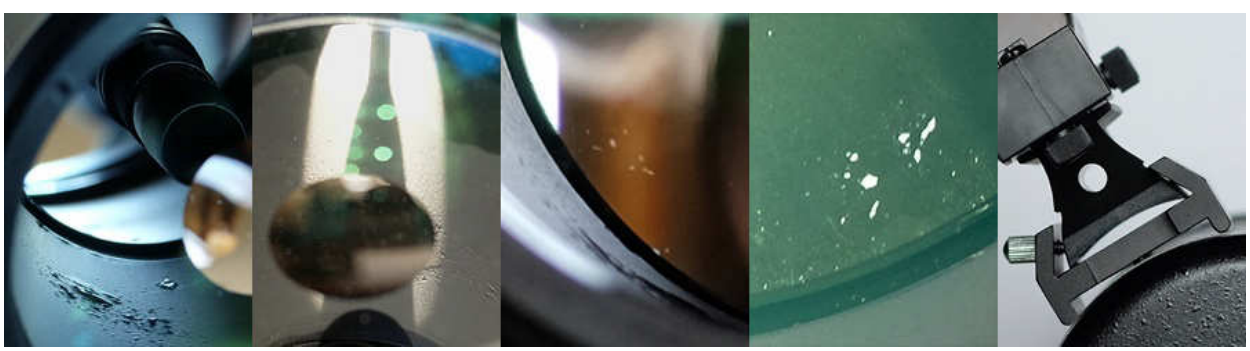


Figure 6.1.1B. Kasai Pico-8 flaws... But wait, there's more!
LEFT: Badly blistered paint *inside* the optical tube. And this is a "brand NEW" telescope!

SECOND FROM LEFT: More blistered paint, and dark stains toward front (top sides of image). CENTER: Pictured white spots are HOLES in the primary mirror coating, not spots on surface. SECOND FROM RIGHT: Detail of *holes* in primary mirror coating, along with possible surface roughness. The mirror, as seen through the holes in the mirror coating, appears to be white, as though mirror was not fully polished before it was coated. On top of this, the mirror has a turned down edge that causes the telescope to have a spot size larger than an *arc minute!* Planetary viewing wasn't even possible until the outer few millimeters of the primary mirror were masked off. Even then, the Pico-8 does not perform as well as some photographic mirror lenses. RIGHT: The red dot finder dovetail does not properly fit the telescope, because its side gusset gets in the way. The finder is then tilted so much that the dot can't be adjusted to match the telescope. It was fixed by filing the shown notches in the gusset so it can clear dovetail fitting on the scope. Small telescopes can be accessible, but it may be good to *avoid scopes like this one!*

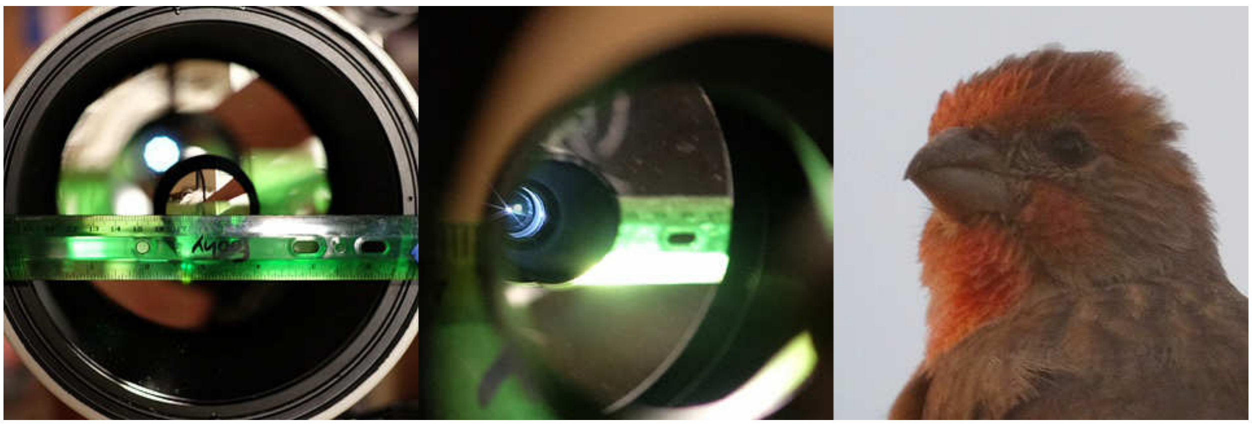


Figure 6.1.1C. Preparing to Measure Light Baffles; Bird After Modifying SW 180 Mak Baffle. The simple setup shown here is used to measure the effective aperture and central obstruction size of the pictured Sky Watcher (SW) 180 mm f/15 Maksutov-Cassegrain and other telescopes. LEFT: To measure the real world aperture and the light baffles, a transparent ruler is placed in front of the telescope, then the aperture is observed under moderate magnification (but with a small pupil lens) from the focal plane. Tested telescopes are focused to infinity prior to making measurements. Results of these tests for two telescopes are shown in the next figure (6.1.1D). CENTER: Testing the secondary baffle of the Sky Watcher (SW) 180mm f/15 Mak-Cass. This photo is taken from about 5 mm inward from the left outer edge of the Maksutov corrector at the front of the telescope. It shows the secondary mirror spot, as reflected from the primary mirror. The small spot of bright light at the left is at the center of the focal plane. The spot of light is beginning to be blocked by the tapered secondary baffle, and is extinguished when viewed from another millimeter toward the outer edge of the front aperture. This indicates that the secondary baffle (which is too small where it meets the secondary mirror spot) limits the aperture (as seen from the center of the focal plane, *which is what counts*) to 172 mm. The outer aperture visible to the left of the bright spot (just left of baffle reflection) is not being used. This blocks 9 percent of the aperture. This conclusion is confirmed below, by other methods of testing for the problem. RIGHT: Sharpened crop of small bird, photographed from just over 20 meters, after the SW 180 light baffles were modified to reduce flare and slightly reduce the size of the central obstruction. Original *SW 180* images are all a little soft due to presumed primary mirror surface roughness, but *spherical aberration correction* appears to be *better than average* for a Chinese-made Mak.

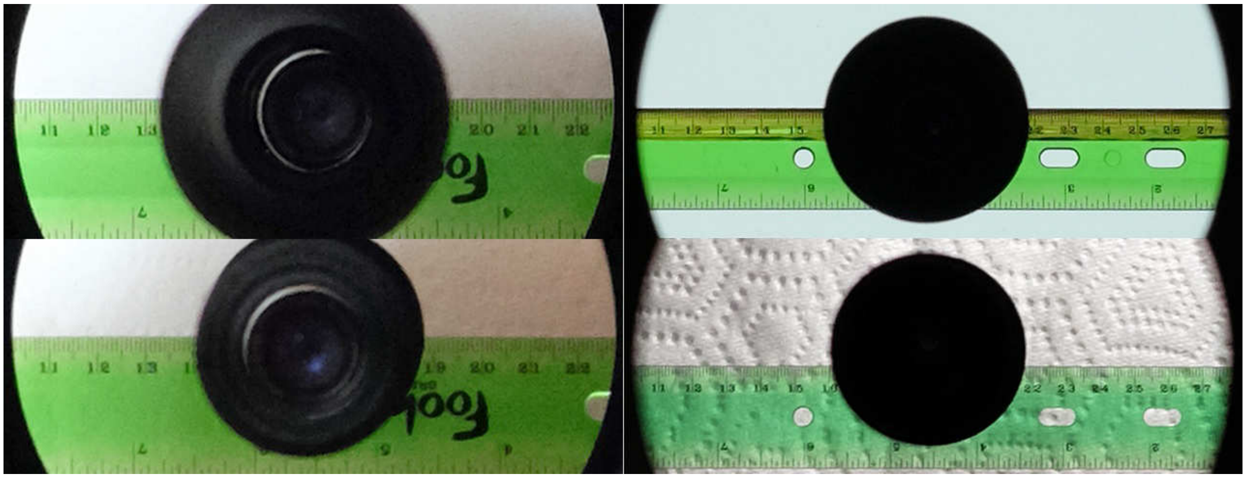


Figure 6.1.1D. Before and after measurements of *Mystery Mak* and Sky Watcher 180 apertures. These telescope entrance pupil images were taken from the center of the focal plane, at a back focus distance that is equivalent to using a typical 2" diagonal mirror attachment at the back. A small aperture is used in the camera lens to get enough depth of field to identify components that define the aperture and central obstruction in each telescope.

UPPER LEFT: The primary light baffle in this un-branded 130 mm f/15.4 Mak-Cass telescope is so long (and large at the front) that it defines the central obstruction, making it excessively large. It obscures fully 61 mm (49 percent!) of the real world telescope aperture diameter. Its effect is compounded by the fact that the *true* aperture of the telescope (as shown by the ruler) is only 125 mm, *not* the 130 mm shown on the telescope bezel. *(Each picture is scaled so the aperture will go to the edges of each image IF it meets manufacturer specifications).* LOWER LEFT: After replacing the huge primary light baffle tube with a more appropriate one, the central obstruction is reduced to only 46 mm, or about 37 percent. This *significantly* improved image quality. But the smaller obstruction by the primary baffle betrays that the primary mirror is not coaxial with either its mirror thimble or the baffle tube, evidenced by the oval shape of the central obstruction after the telescope is collimated. This is a weakness of many Chinese-made Mak telescopes.

UPPER RIGHT: This Sky Watcher 180 mm f/15 Maksutov-Cassegrain telescope has *two* design flaws in its light baffles. As with the "Mystery Mak", the front end of the primary baffle tube is too close to the secondary baffle, given its front diameter. This results in an effective central obstruction of 59 mm. The second design issue is that the secondary baffle is too small where it is cemented to the secondary mirror spot. This limits the real world aperture to only 172 mm. Unfortunately, this second problem cannot be corrected, because the edges of the secondary spot probably would not survive removing the secondary baffle in order to modify or replace it. In light of the working 172 mm aperture, the central obstruction width is 34.3 percent (59/172) of the aperture, which is the *same percentage* as the central obstruction of a Celestron 8 SCT!

LOWER RIGHT: After modifying the front end of the primary baffle tube, the effective central obstruction is reduced to about 56 mm. Not a huge difference, but it brings the linear obstruction percentage down to about 32.5. More importantly, replacing the front 20 mm of the SW primary baffle tube with a slightly shorter and thinner wall tube that also has a smaller inside diameter reduces flare from stray light, compared to the original primary light baffle configuration. The primary mirror of the Sky Watcher 180 mm is not quite co-aligned with its mirror thimble or the primary baffle tube, but the error is not as bad as that of the "Mystery Mak" noted above.

6.1.1.1) Kasai Pico-8, 80 mm f/11.2 Mak-Cass. The Worst Telescope I Have Ever Owned.

Details: The Kasai Pico-8 is without a doubt the worst telescope I've ever owned. It is incapable of producing a spot smaller than about 2 arc minutes (yes, 2 arc minutes!) in diameter. It also has very poor light baffles. The primary baffle has no visible threading or stops on the inside of its front half, and it has no secondary baffle at all. This causes serious veiling flare. The minimum focus distance is way out at 8 meters, which is very distant for a telescope of this small size.

The cause of the huge 2 arc minute spot? *A turned down edge on the primary mirror!* A mistake that people rarely made even when some made their own mirrors at home. In all, the outer 4 mm of the primary mirror (8 mm of its diameter) is severely affected. The telescope won't produce an acceptable APS format photo unless stopped down to 76 mm, and planetary images are awash in spherical aberration unless the Pico-8 is stopped down to 74 mm or less; preferably to 72 mm. Even when the Pico-8 is stopped down, its image is still washed out from the light baffle flaws. The turned down edge on the primary mirror is the tallest tent pole, but not the only tent pole.

What about that so-called "small" secondary obstruction in the Kasai Pico-8? Not so small when you consider the USEFUL aperture of the telescope! The obstruction measures 29 mm, as seen from the focal plane, and measured via a transparent ruler right at the front of the telescope. But given that the useful aperture is only 72 mm to 74 mm, the obstruction is a relatively large 39 percent (29/74). That's as large as the obstruction in some photographic mirror lenses.

And there is more. The black paint inside the tube is badly blistered, as though painted by a child in grade school. (Who knows, being made in China, maybe it was!) In addition, the primary mirror has small holes in its reflective coating. The glass where the coating holes are looks white rather than clear, as though it is not fully polished. The plastic rear cell also lets the primary mirror assembly ring like a tuning fork whenever a camera having a mechanical shutter is used, so it has often been impossible to get good photos through the Pico-8 with such a camera.

I bought the Pico-8 telescope new through a dealer, rather than get a lower cost no-name version of this Chinese scope online. I *thought* that if a Japanese trading company put their name on a scope, QC may be better. But this experience shows maybe this is not so. I provided feedback to Kasai via the dealer, but there was no response. Ironically, when I ordered the Pico-8, it was one of the few times I gave a dealer a *"heads up"* that I was *reviewing the telescope*. Image quality of the Pico-8 is so poor that I can't sell it, so it's quite literally being used as a *paperweight!*

6.1.1.2) *Mystery Mak*, a 130 mm f/15.4 Maksutov-Cassegrain with no Brand Name.

This nameless telescope is referred to as the "Mystery Mak". It was acquired used, and looks like most of the Chinese Mak telescopes in the same aperture class. I bought it partly because I thought it might be a prototype or pre-production model (so it would be an interesting piece), and it was also fairly inexpensive. Due to its severe light baffle flaws, I really *do* hope that it is a *prototype*, and that the manufacturer *learned* some lessons from *before* going into production!

Mechanically, the *Mystery Mak* it is built like a tank, but it is clearly a Chinese telescope because the rounded rear cell is exactly like that on some other Chinese Maks in the same aperture class.

The tube wall is about 2 mm thick, and the cells at each end are metal. Its minimum focus is a very distant 30 meters (unusually distant), which would reinforce the *prototype* theory.

The *Mystery Mak* has some spherical aberration that is obvious when comparing star images inside and outside of focus, but aberration is not so bad as to keep it from producing an Airy disk with clearly defined and fairly symmetrical diffraction rings in the *in-focus* image. However, its aperture is not really 130 mm. The front cell has an aperture of only 127 mm, and the back side of the cell limits the aperture to 125 mm (due to refraction by the Maksutov corrector), so it is really a 125 mm telescope. A telescope can't have more aperture than what its front cell admits.

But it was the light baffles that were its undoing. The primary light baffle tube is very large in comparison to the aperture of the telescope, and it does not taper down much toward the front. Given its outer diameter, the primary baffle tube is almost *three times* longer than it should be!

Specifically, as seen from the focal plane, the reflection of the front end of the primary baffle tube in the secondary mirror spot causes the effective central obstruction to be a huge 61 mm in diameter. The secondary baffle is a lot smaller than this, but *the size of the secondary baffle is irrelevant when something else blocks the view of its edge from the focal plane*. Given the actual 125 mm aperture of the telescope, the 61 mm central obstruction is a whopping 49 percent! I can only hope that this was a prototype, because if this light baffle flaw was in *production* telescopes, people would be very disappointed in the image quality, especially compared to what it could be.

It was possible to correct the primary baffle tube problem in terms of its effect on the central obstruction. This reduced the working central obstruction to just under 46 mm, or 37 percent by diameter. However, since I can't use machine tools now, I can't make a proper baffle tube to replace the existing one, so I opted for a marginal baffle like that in a C90, by adding a flat ring with a center hole of the appropriate size as a stop gap. I kept the original baffle tube intact because it is close to the most extreme example of an excessively long primary baffle tube I have seen in person. It provides *a good example of a bad baffle design*.

6.1.1.3) Sky Watcher 180 mm f/15 Maksutov-Cassegrain. A "Wannabe" Planet Killer.

Planetary images in my Celestron 8 SCT looked really good during nights with good seeing, but also looked fairly bad on nights with bad seeing. In the latter case, smaller apertures, and more particularly, smaller central obstructions, seemed to help with the seeing was poor. An Intes MN61, a 150mm f/6 Mak-Newtonian, with a tiny 19 percent (diameter) central obstruction, has been my "gold standard" for planetary viewing, frequently providing sharp images north of 400x. But it is heavy, and I have to use a Barlow lens to get enough back focus to use an Atmospheric Dispersion Corrector (ADC). Thus began the search for a telescope with more back focus, yet also having a small obstruction. Thus began the search for a so-called "planet killer" telescope.

The Sky Watcher 180 mm Mak-Cass does not seem to have a spec. for its central obstruction, but a similar telescope by Orion is said to have a relatively small 41 mm (23 percent by diameter) central obstruction. I went for the Sky Watcher over the Orion because Sky Watcher telescopes have not had the rear cell O-ring problems that I've read people have had with other brands.

I really wanted to like the 180mm Sky Watcher Maksutov-Cassegrain scope. Unfortunately, it has *two* of the three most common light baffle design errors. Only one of these can be corrected in an existing telescope. The most common three Cassegrain light baffle design errors are:

A.) Secondary baffle is too small, and limits the aperture of the telescope. For example, in the B&L 800, the secondary baffle clips the aperture to 72 mm, rather than the claimed 80 mm. In the Meade ETX 90, the secondary baffle clips the working aperture of the scope to about 84 mm.

B.) Primary baffle tube is too short, and allows light in from around the secondary baffle. The original f/11 version of the Celestron 90 Maksutov-Cassegrain telescope has this design flaw.

C.) Primary baffle tube is too long, so its reflection in the secondary mirror causes it to *define the boundary of the central obstruction*. This may make the obstruction larger than a manufacturer's specifications. For example the Quantum 4 primary baffle caused the central obstruction to be 36 percent rather than 33 percent. The "Mystery Mak" noted above *had* this problem in spades.

6.1.1.3.1) Two Light Baffle Design Errors in Sky Watcher 180 mm Mak: Errors A & C:

The extent of design error A is significant, partly because it compounds the problem caused by the other design error (C). Specifically, the secondary baffle is about 2 mm too small where it meets the secondary mirror spot. This makes it impossible for the outer 4 mm of the telescope aperture radius (8 mm of the diameter) to contribute to the central spot. This flaw is easy to see if looking into the front of the telescope while a short focal length eyepiece and a diagonal are on the back, and when the telescope is focused to infinity. You can't look backwards into outer edge of the aperture and see a reflection of any light from the eyepiece. If you start a cm or two closer to the center of the telescope aperture, then move so that light from the eyepiece is viewed from closer and closer to the outer edge of the front aperture, the eyepiece image will disappear when you reach 4 mm to 5 mm from the edge of the aperture. (Pictures of this test are in Fig. 6.1.1C.) The end result is that the benefit of *9 percent of the front aperture area is lost!* It is functionally only a 172 mm telescope on-axis, yet you have to carry around the weight of a 180 mm telescope.

The second problem is design error C. The primary baffle tube is about 20 mm too long, in light of its relatively large outer diameter at the front. The baffle tube does not step or taper down much toward the front, and it extends too far forward. The result is that the primary baffle tube (viewed from the focal plane, as reflected in the secondary mirror spot, with a transparent ruler at the front of the telescope to take measurements) causes an effective cental obstruction of 59 mm, which is larger than the optical size that even the tapered secondary baffle would appear to be.

Think that 180 mm Mak is a “planet killer” in comparison to a 203 mm SCT? Think again! I've done side by side comparisons, and even on planets, the C8 beats the 180 mm Mak hands down.

The reason the Mak images are *inferior* to the C8 is obvious when you consider the above light baffle design flaws. Remember the loss of the outer 8 mm of aperture from design flaw A? This sample of a 180 mm Mak is really a 172 mm scope! *The size of the front aperture doesn't matter if something else prevents seeing the edge of the aperture from the center of the focal plane.*

Now, let's look at that 59 mm central obstruction, caused by the excessively long (considering its outside diameter) primary baffle tube. In terms of percentage, the central obstruction of the 180 mm Sky Watcher Mak must be calculated based on the *actual* working aperture of 172 mm. Therefore, 59/172 = 34.30 percent central obstruction. This is virtually indistinguishable from the 34.37 percent obstruction in a Celestron 8 SCT! So, for all practical purposes, the "planet killer" Mak does <u>*not*</u> have a smaller central obstruction than a C8. And it has 23 mm (actually 31 mm) less aperture than a C8 SCT! (I don't know if this applies to *all* Chinese 180 mm Maks, but if you see one in person, you can inspect it in much the same way as I did mine <u>*before*</u> you buy.)

The Sky Watcher Mak tube wall is also fairly thin, and the Vixen dovetail is only attached in two places. This flexes the tube and results in vibration. If the dovetail had the wider footprint of the dovetail base plate of the "Mystery Mak" above, then the thin tube wall would not be an issue. The minimum focus distance of the Sky Watcher 180 mm (really 172 mm) Mak-Cass is about 20 meters. This is somewhat distant when compared to the 11 meter close focus distance of a C8.

It was possible to correct the problem of the primary baffle tube being too long by simply cutting off the front, filing it to have a tapered front end, then adding a smaller diameter front section. This reduced the real world central obstruction to just under 56 mm. The new, smaller, central obstruction is now defined by the secondary baffle and/or primary mirror retaining flange. The new obstruction is about 32.5 percent (56/172). Not a huge difference, but every little bit helps.

It was <u>*not*</u> possible to correct the problem of the secondary baffle being too small, partly because the cement used to hold the secondary baffle in place probably prevents removing the secondary baffle (to modify it) without spoiling the mirror coating in the area where the baffle is attached. The secondary baffle is *flawed*, and turns the Sky Watcher 180 mm into a 172 mm telescope.

6.1.1.4) But there's More: A "Glaring" Problem with the Primary Mirrors!

There is more. All three Chinese Maks evaluated above have glare over and around the planetary images they form. This reduces contrast. The glare is at least 4 times brighter, and significantly wider in extent, than any glare around the planetary images of either C8 SCT that I compared to the Maks. Glare in the Chinese Maks is even greater when compared to a Newtonian telescope.

The cause of this glare is not known for sure, but I would not be surprised if it is from failure to adequately *fine polish* the primary mirror before coating it. This impression is supported by the appearance of the Kasai Pico-8 primary mirror in the area occupied by coating holes, and the "frosted" look that strong lighting causes the other Chinese primary mirrors to have. The primary mirrors in my SCT's do NOT have this "frosted" look under similar lighting conditions, and the coatings in my SCT's are 30 years old! The glare problem in Chinese Maks that have it (which is *all* of them I've seen) cannot be corrected. True "planet killers" don't have this much glare.

Another thing the Chinese Maks have given up is stability. One of the selling points for a Mak *used to be* that you never had to collimate it. The primary mirrors used to be accurately fixtured when attached to the mirror thimble, so Maks were stable in terms of collimation. Mirror mounts were also robust, and did not oscillate enough to adversely influence observations and photos.

But the Chinese made Maks cantilever the primary baffle tube and primary mirror out in front of relatively thin collimating plates. This sacrifices the collimation stability that was formerly associated with Maks, and also increases susceptibility to vibration. And it's a *needless* sacrifice. Because of this, you can feel some Chinese Mak OTA's vibrate for a fraction of a second after tapping them. This vibration also happens when a camera with a mechanical shutter is used!

Also, when the primary mirror optical axis is not accurately fixtured to be coaxial with, or at least parallel to, the primary baffle tube, the baffle tube will point at a slight angle toward one side when the telescope is properly collimated. This requires margin in the baffle design, making the baffle a little less effective. Proper mirror fixturing always trumps *flimsy* collimation assemblies.

6.1.1.5) What Does this all Mean?

<u>In summary, it means one may be better off with a used domestic scope than a new imported one!</u> It is obvious that the Chinese Cassegrain telescopes I have personally seen are designed *poorly*, and to a degree, implemented poorly. I can't say if the same applies to Chinese made Newtonians and refractors. But after being 3 for 3 on acquiring poorly designed (and poorly implemented) Chinese Maksutov-Cassegrain telescopes, and having paid well over $1k for the lot, only to have this experience, I'm not inclined to try other Chinese telescopes any time soon, at least at current prices. The *refractors* I have now are by TeleVue and Vernonscope. *Neither* is made in China.

I will not get into how to correct the poor baffle designs, since such advice should be reserved for domestic telescope makers, and certain aspects of such advice might also be export controlled. Domestic telescope makers may not even need such advice, since in general, telescopes *<u>were</u>* made properly when they were made here in the USA, or in Japan or Russia. Chinese copies of Russian Mak Newtonians gave up many advantages of the Russian designs they were based on.

Want a good telescope? Buy scopes *<u>made</u>* in the USA, Japan or Russia. These are becoming an endangered species, but are worth looking for, if only to end up with a scope that *works properly*.

It may even save money to *buy American*: You can buy a vintage USA-made SCT that may blow away a 180 mm (functionally 172 mm) Chinese Maksutov-Cassegrain telescope: A used C8 with the fork mount, tripod, and wedge often goes for less than just the OTA of a 180 mm Mak. A used C8 OTA alone can cost even less, and is more like comparing apples with apples.

Also, a C8 is advertised to have 203 mm of aperture, and it really *does* have 203 mm of aperture. No clipping of its aperture by improperly designed baffles! And it has much less glare over and around planetary images, compared to the Chinese Mak-Cass telescopes I've seen in person.

It is worth checking out a telescope in person *before* you buy. Important things to check are in-focus star images and planetary images at magnifications of at least 15x per cm of aperture. Star tests that *don't* look about the same on either side of best focus can reveal if there is spherical aberration that is not obvious in the in-focus image of a star, but that could adversely impact the contrast of planetary images. In this age of online marketing and fewer walk-in stores, this is more difficult. But maybe you can see samples of various telescopes at a local star partly.

6.2) APPENDIX B: Servicing Celestron 8 SCT (and Similar) Telescopes

Jeffrey R. Charles

First draft: 22 Sep. 2018. Revised: 23, 24 Sep. 2018.

6.2.1) Introduction.

Occasionally, it may be necessary to clean or service a Celestron 8 or similar Schmidt-Cassegrain telescope (SCT). This material covers only variations of *non*-computerized Celestron SCT's up through the Ultima. Many aspects may apply to Celestron 5, 9.5, and 11 SCT's of similar age. Newer versions (Edge, etc.) are not covered because I don't own one and have not serviced one.

6.2.1.1) Versions of the Celestron 8 (up to the Ultima):

Before getting into the actual process of servicing a Celestron 8 (C8), we will first cover a few variations of the C8 Optical Tube Assembly (OTA) and the C8 fork mount motor base. Each item is broken down into the aspects that differ. The following may not cover all variations:

6.2.1.1.1) Celestron 8 OTA Versions:

* Heavy castings, metal secondary mirror cell, metal corrector plate retainer, orange tube color.
* Thin castings, plastic secondary cell, metal corrector plate retainer, orange tube color.
* Thin castings, plastic secondary cell, plastic corrector retainer, orange or black tube color.
* Heavy castings, plastic secondary cell, plastic corrector retainer, black tube color (Ultima).

6.2.1.1.2) Celestron 8 OTA Schmidt Corrector Plate Cell Versions:

* Thick casting, metal corrector retainer, 8 screws, fiber washers for corrector, no mirror slots.
* Thick casting, metal corrector retainer, 8 screws, fiber washers for corrector, two mirror slots.
* Thin casting, metal corrector retainer, 6 screws, fiber washers for corrector, two mirror slots.
* Thin casting, plastic corrector retainer, TBD screws, rubber washers for cor., two mirror slots.

6.2.1.1.3) Celestron 8 OTA Secondary Mirror Cell Versions:

* Thick front casting, metal secondary cell, secondary secured with center screw, collimated with 3 *set screws*. (Removing collimating screws to add knobs NOT recommended with this version.)
* Thin front casting, plastic secondary cell, secondary back plate pivots on raised surface at center of secondary cell, and is secured only by the three oval or *button head* collimating screws.

6.2.1.1.4) Celestron 8 OTA Focus Mechanism Versions:

* Thick casting, pin and fitting connection to primary, retaining screw inside short focus knob.
* Thin casting, pin and fitting connection to primary, retaining screw inside long focus knob.
* Thin casting, focus screw hard mounted to mirror cell, retaining ring inside long focus knob.
* Note 1: Celestron focus mechanisms retain the brass focus fitting with twin ball bearings.
* Note 2: Meade SCT telescopes do not have focus shaft ball bearings. Only have washers.

6.2.1.1.5) Celestron 8 Fork Mount Motor Base Versions: (Thick fork arms may be sand cast.)

* Thick round base casting, thick fork arms w/holes, 2 AC motors, spur gear, round power jack.
* Thin round base casting, thin ribbed fork arms, two AC motors, spur gear, oval power jack.
* Thin elongated base casting, thin ribbed fork arms, one AC motor, spur gear, oval power jack.
* Thin elongated base casting, thin ribbed fork arms, Byers worm gear, oval power jack.
* Thick elongated base casting, thick fork arms, worm gear, runs on 9V battery (Ultima).

6.2.2) Servicing the Celestron 8, Basic Steps:

This section covers servicing of the Celestron 8 OTA at a basic level. Servicing the fork mount motor base is not covered in this initial version. There were several versions of the fork mount.

6.2.2.1) Servicing the Celestron 8 OTA, Basic Steps:

Note: Servicing a C8 OTA may take between 1 and 6 hours, depending on what needs done. To begin, you'll need a proper work space and a few appropriate simple tools (Allen wrenches, etc.).

Figure 6.2.2.1A. Servicing a Celestron 8 SCT: Photos of some of the steps described below. UPPER LEFT: Preparing the focus mechanism, to facilitate later removal of primary mirror. A retaining screw or ring (depending on model) must be removed from the end of the focus bolt that is visible inside the brass fitting on the telescope. This version uses a retaining ring. UPPER RIGHT: Schmidt corrector plate removed, set in safe place. A cover is recommended. LOWER LEFT: C8 OTA with corrector plate removed. Primary mirror removal slots are at the top and bottom of the photo for this model. C-ring around primary baffle tube must be removed. LOWER RIGHT: Removing the primary mirror by tilting it so it will fit through the mirror removal slots in the front cell, without marring the mirror coating. Take care to keep the mirror edge from hitting the cell or baffle tube, since this can cause chips. The OTA is pointed vertical for this step. The focus bolt is toward the upper left of the photo, sticking out behind the mirror.

6.2.2.1.1) Part 1: Preparing the Focus Mechanism:

* Set telescope focus within a turn or two of where it is normally set when observing.
* Remove focus knob.
* Measure/note position of focus bolt end relative to back end of brass focus fitting.
* Remove focus bolt retaining screw or ring (must focus so mirror toward back to remove ring).
* Clean threads at end of focus bolt (especially if focus bolt is type with retaining ring).
* Take note of which focus direction moves mirror forward, but do not adjust focus very far.
* Replace focus knob.
* Prepare a safe, level, secure location in which to set the corrector plate and primary mirror.

6.2.2.1.2) Part 2: Removing the Schmidt Corrector Plate:

* Secure telescope so that the front end of the OTA is reliably locked to be pointing straight up.
* Remove screws that are used to attach the Schmidt corrector retaining ring (at the front).
* Note rotational orientation of retaining ring to OTA. Make marks if necessary.
* Remove Schmidt corrector plate retaining ring.
** If ring is stuck to the corrector, do NOT force it off. Lift gently for a while (up to minutes).
* Note rotational orientation of the corrector relative to OTA. Make marks if necessary.
* Note the locations of any shims around the edge of the corrector plate.
** If corrector edge shims are loose, remove them and note the position of each one.
* Securely grasp front of the secondary cell and GENTLY lift Schmidt corrector out of telescope.
** If the corrector is stuck, do NOT pull hard, pry, or try to force it out. Instead:
** Re-attach the corrector retaining ring with its screws, then back screws out about 1.5 turns.
*** Invert OTA so front end is down. After sitting a few hours, the corrector should come loose.
*** Point OTA with front up again, securely lock in place. Remove ring screws, ring, corrector.
* Set corrector with the attached secondary in safe, secure, clean place, with secondary down.

6.2.2.1.3) Part 3: Servicing the Secondary Mirror (ONLY DO THIS IF NECESSARY!):

* Removal or servicing of the secondary mirror may be needed if a lot of debris is inside scope.
* It is not necessary to remove the primary mirror if the secondary is all that requires service.
* Determine which type of secondary mirror cell your C8 has (see 6.2.1.1.3, above).
* Note the rotational position of the secondary mirror relative to its cell or the corrector plate.
* Prepare a short tube with a soft non-abrasive front surface (cotton, etc.) that is sized to fit inside secondary baffle, yet only contact less than outer 3mm of secondary mirror. The soft ended tube should have a flange that is large enough that the secondary baffle can rest on it, yet keep the soft end of the tube from touching the secondary mirror by a margin of 1 to 2 mm. OR:
** Prepare tapered shim stock band that fits around perimeter of the secondary, to hold it (best).
* Prepare soft non-abrasive work surface that the secondary mirror can safely fall onto.
* *Hold the corrector assembly so that the secondary mirror is pointing up.*

* **3A**: If the secondary cell uses three *set screws* for collimation, try these steps.
** Note the longitudinal position of the collimation set screws to within 0.5 mm.
** Loosen and remove center screw that holds secondary mirror in place. Note how tight it was.
** If secondary mirror rotates with the center screw, evenly tighten collimating screws a little.
** If the secondary mirror still rotates, make a shim stock band to hold it by its perimeter.

* **3B**: If the secondary cell uses three oval or *button head* collimation screws, try these steps:
** Evenly loosen all 3 collimation screws (1 turn each) until they fall out of the front of the cell.
** Note tightness of first screw while loosening it.
* Then, for <u>*either*</u> type of secondary mirror cell:
* When the secondary mirror is free, insert the prepared soft ended tube into secondary cell so that it barely does not touch the secondary mirror. Verify that the soft end of tube is not touching secondary mirror. If it touches, modify it, or (if the cell uses set screws for collimation) back off the collimation set screws to provide clearance. (This is to keep the weight of corrector plate from resting on the secondary mirror surface via the prepared soft ended tube.)
* After the above steps, invert the corrector plate *while* the soft ended tube is held in place.
* After the corrector has been inverted so its front side is up, slowly lift it off of the secondary mirror, taking care not to laterally move the secondary mirror on the soft ended tube.
* When the secondary mirror is free, service it as necessary.
* Clean the secondary mirror cell in the area normally covered by the mirror.
* If secondary cell uses set screws for collimation, return the screws to their normal positions.
* Orient the Scnmidt corrector so that secondary mirror will point up when installed.
* Rotationally orient the secondary mirror so that it is in its original orientation.
* Gently lower the secondary mirror into the secondary baffle. (Shim stock band works best.)

* **3C**: If the secondary cell uses *set screws* for collimation, try these re-assembly steps.
** Install the center screw that retains secondary mirror (install it from below), and screw it in.
** If the secondary mirror rotates, use the shim stock band from step 3A to prevent rotation.
** When the secondary mirror retaining screw is just short of having any resistance, gently rotate secondary mirror (using shim stock band) to feel for detents made by collimation screw tips.
** Verify proper rotational secondary position and tighten center screw to original tightness.

* **3D**. If secondary cell uses oval or *button head* collimation screws, try these re-assembly steps:
** Place thin wire or allen wrench through one screw hole in front of secondary cell, and insert it into a hole in the secondary mirror mounting plate. Keep it in place until first screw is installed.
** Insert a collimation screw into another hole and gently thread it in about 2 turns.
** Verify that proper rotational orientation of secondary mirror has been maintained.
** Insert a second collimation screw and thread it in two turns. Repeat with the third screw.
** Evenly tighten all collimation screws (1 turn each) until all at their original tightness.
* Then, for <u>*either*</u> type of secondary cell:
* Verify secondary mirror does not tip, rattle, or rotate when corrector cell is moved.
* Proceed with other steps of servicing telescope, as needed (see below).
* Collimate telescope after full re-assembly (see Part 10). Collimation may initially be WAY off.

6.2.2.1.4) Part 4: Removing the Primary Mirror

* Remove the metal C-ring that is 8-10 cm behind the front end of the primary baffle tube.
** Take care that ends of C-ring do not scratch primary baffle tube (can try sliding it on shims).
* Turn focus knob to move the primary mirror forward until the focus bolt at the back is free.
** This may take a LOT of focus knob rotations.
* Carefully grasp the primary mirror thimble, taking GREAT care not to touch the mirror surface.
* If the primary mirror thimble is free, slide it forward and off of primary baffle, AND,
* Carefully tilt primary mirror so both it and focus bolt will clear front corrector cell, AND,
* Carefully remove primary mirror, while orienting it so its edges pass through any mirror slots.
* Carefully set the primary mirror in a secure, clean, safe place, with its back end down.
** Note: The primary mirror is accurately cemented to its thimble. Do *not* try to separate them!

6.2.2.1.5) Part 5: Servicing:

* Perform service (cleaning, etc.) See other references for optical cleaning techniques.
* Do not attempt to clean mirrors unless they are dirty enough to obviously impact image quality, or if they have mud, mildew, or fungus on them. * Do NOT use acetone on any mirror surfaces.
* Inspect the Schmidt corrector plate for dirt, haze, or fungus. Clean it if necessary.
* Remove focus knob from brass focus fitting (for inspection and preparation for re-assembly).
* Remove focus knob assembly from back of telescope by removing the 3 screws near its edge.
* Inspect the focus knob assembly and bearings for grit, and clean and re-lube it if necessary.
* Inspect back of primary mirror thimble to ensure that it is free of grit. Clean it if necessary.
* Do not use thick, fibrous, or sticky grease on mirror thimble or primary baffle tube.
* Optional: Grind or file extreme tips of C-ring, to round off where ends will touch baffle tube.

6.2.2.1.6) Part 6: Preparing OTA for Re-assembly:

* Wash hands.
* Point the front end of OTA tube down, and blow clean air into it, to remove dust.
* Again secure telescope so front end of OTA is pointing up.

6.2.2.1.7) Part 7: Re-Installing the Primary Mirror:

* When picking up primary mirror by its thimble, note rotational location of focus bolt.
* Carefully tilt and insert primary mirror into OTA, leveling it after it is inside, AND,
* Carefully and slowly center the mirror in the OTA, and slide it down over primary baffle tube.
* If needed, rotate primary mirror as it nears back of OTA, to align focus bolt with hole in OTA.
* Replace metal C-ring, taking care not to scratch primary baffle tube or let it fall onto primary.
** OTA can be oriented so that it is *securely* pointing UP at a 15 to 45 degree angle for this step.

6.2.2.1.8) Part 8: Attaching and Adjusting the Focusing Assembly.

* This step is best performed when the telescope is oriented so that it is pointing level.
* Screw the brass focus fitting onto the back end of the focus bolt.
** In older C8's, take care *not* to slide the focus bolt end fitting off of the mirror thimble pin!

* Turn focus fitting until previously measured bolt position is reached when focuser pushed in.
* Attach the focuser cover with its three screws, and evenly finger tighten the screws.
* Attach the focus knob (this is a temporary step).
* Check focus knob for smooth action. If it is rough or tight, adjust centering of focuser cover.
* Evenly tighten (but do not over-tighten) focuser housing screws after adjustment is complete.
* After the focus works smoothly, remove the focus knob.
* Re-attach the focus bolt retaining screw or ring, then re-attach the focus knob.
* Run focuser back and forth several turns. If gets rough, try adjusting the focuser cover again.
* Clean focus knob and back of OTA to remove any new grease. * Wash hands.
* Clean off the primary baffle tube OD and mirror thimble OD, *without* touching mirror surface.
* Wash hands again.

6.2.2.9.1) Part 9: Re-installing the Schmidt Corrector Plate:

* **9A**: Point front end of telescope OTA down, gently blow clean air into it, to remove dust.
* Again secure the telescope so that the front end of the OTA is pointing up.
* Securely grip the front of the secondary cell, blow any new dust off of Schmidt corrector plate.
* Install the Schmidt corrector plate, being careful to restore its proper rotational orientation.
* Look through corrector to inspect inside of telescope, to see if entry of new dust was excessive.
** If internal dust is excessive, remove the corrector plate, then repeat steps 9A onward.
* Install any original shims around the edges of the Schmidt corrector plate.
* Install the corrector plate retaining ring, being careful to restore proper rotational position.
* Check to be sure that the corrector plate retaining ring is properly seated all the way around.
* Insert retaining ring screws, then evenly finger tighten them.
** If screws bind against some retaining ring holes, it may help to slightly enlarge such holes.
* Back off retaining ring screws 1/4 turn, lightly press on retaining ring, then finger tighten again.
* Do not tighten corrector plate retaining ring screws beyond a “tight” variety of “finger tight”.
* Verify that the retaining ring is fully seated and the corrector does not slide from side to side.

6.2.2.1.10) Part 10: Testing and Collimation:

* Star test telescope at different elevation angles.
* Collimate if necessary. (Collimation may not be needed if secondary not disturbed.)
** Collimation should be done on a night with good seeing, be done only after the telescope has adjusted to ambient temperature, and utilize a star with an elevation angle of at least 45 degrees.
* This completes servicing of your C8 OTA!

Comments: Collimating knobs are NOT recommended as part of proper servicing of a C8. When collimation is properly set, it should remain set for years. Many image flaws that some *think* are collimiation errors are actually caused by tube currents. Collimation knobs make it all to easy to inadvertently *lose* proper collimation adjustment!

6.2.2.2) Servicing the Fork Mount Motor Base.

This section is TBD. Method is highly dependent on the version of fork mount being serviced.
Clear skies, Jeff C.

6.3) APPENDIX C: Optics and Potential Vendors for Accessible Telescope Components
(This section is not in a formal format. It is for reference only. Vendor prices subject to change.)

Optics:

PRIMARY MIRRORS, LOCKWOOD, ZAMBUTO, WAITE RESEARCH, OTHER:

* 20" f/3.0 (Lockwood): $	* 20" f/3.3 (Lockwood): $
* 16" f/4.0: (Waite Res.) $	* 16" f/3.6: $4,000 (cheaper if slower f/ratio)
* 18" f/3/3: $5,800	* 20" f/3.0: $8,000
* 20" f/3.3: $7,200	* 22" f/3.0: $10,500 (Waite Res.)

Zambuto: 14.5" F/4.5 and longer $2,850.00

Size of telescope assembly must fit through 25-5-28 inch wide opening.
* 25.5 is width of average wheelchair, 28.0 is clearance for typical 2'-6" residential door.

Telescopes: Size and cost of available "stock" Dobsonian telescopes with mounts:

HUBBLE OPTICS: (info@hubble-optics.com)
16.0: f/4.5: $2,495 16.0: f/5/0: $2,195 18.0: f/4.0: $3,795 20.0: f/3.7: $5,595

Hubble Optics 16" mirror assembly dimensions:
Mirror Cell Frame OD: 19.50" (welded square of 1.5" angle bracket)
Telescope Width, Actual: 21.50" including protrusions.
Telescope Width, Allowance: 22.0" including protrusions.
For 18.0" version, add 2.0" to width (24.0 wide).
For 20.0" version, add 4.0" to width (26.0 wide).

PORTABLE TELESCOPES, Starmaster:
(http://www.loptics.com/starmaster/truss-scopespecs.htm) (starmaster@ckt.net)
16.5: f/3.7: 26.00" (Ground Board & Rocker Box) $8,595 Lockwood EP Height: 64"
18.0: f/3.7: 28.00" (Ground Board & Rocker Box) $9,795 Lockwood EP Height: 69"

TEETER'S SUB-F/4 TELESCOPES:
16: f/3.8: 27.25" (rocker box w/protruding hardware) $8,900 w/optics MAX SIZE
18" f/3.7: 29.25" (rocker box w/protruding hardware) $10,575 w/optics
20" f/3.5: 31.25" (rocker box w/protruding hardware) $12,700 w/optics
22" f/3.3: 33.25" (rocker box w/protruding hardware) $14,800 w/optics

CONCLUSION: 16.5" is maximum aperture for a conventional design "accessible" telescope, due largely to width of telescope base versus interior doorway clearance in typical house, etc.

TELESCOPE LIGHT-WEIGHTING (reference):
https://www.menkescientific.com/18inchscope.pdf

6.4) APPENDIX D: Basis for Refractor Specifications (vendor data, object declinations)

(This section is not in a formal format. It is for reference only. Vendor prices subject to change.)

OBJECTIVE LENSES: (D&G Optical)
* 5" f/25 (baseline if not on porch): $795.00 BASELINE
* 6" f/20 $995.00

FEED MIRROR MAJOR AXIS REQUIREMENTS NOTES:
* 5.0" (127 mm) aperture used at 0 deg. declination: 5*SQRT2 = 7.07" (i.e. 5/COS45)
* 5.0" aperture used at +24 declination: 5*(1/COS57) = 5*1.836 = 9.180 (or just 5/COS57)
* 5.0" aperture used at +28 declination: 5*(1/COS59) = 5*1.942 = 9.708" (or just 5/COS59)
* 5.5" aperture used at +22 declination: 5.5*(1/COS56) = 5.5*1.788 = 9.836" (i,e, 5.5/COS56)

FEED MIRRORS: (Astro Systems, Waite Research or Ostahowski Optics; Waite prices shown):
* 5.00" (Major axis is 7.07") $600
* 5.50" (Major axis is 7.78") $690
* 6.00" (Major axis is 8.48") $800
* 6.25" (Major axis is 8.84") NA
* 6.50" (Major axis is 9.19") $950 MINIMUM SIZE for 5" at +24 Dec. BASELINE
* 7.00" (Major axis is 9.90") $1,150 MIN. SIZE for 5" at +29 Dec; 5.5" at +22 Dec.

RING BEARINGS
(ID mm / OD mm / THICK / TYPE / BRAND / NEW? / PRICE / Source):
* 150.0 / 180.0 / 15.0 / Cross Roller / THK / N / $149.90 / eBay Kor
* 150.0 / 210.0 / 25.0 / Cross Roller / IKO / Y / $185.00 / eBay USA
* 160.0 / 220.0 / 25.0 / Cross Roller / THK / N / $149.90 / eBay Kor
* 160.0 / 220.0 / 25.0 / Cross Roller / THK / N / $179.99 / eBay Kor
* 200.0 / 260.0 / 25.0 / Cross Roller / IKO / N / $149.99 / eBay USA

ASTRONOMICAL OBJECT DECLINATIONS:

* Sun in summer: +23	* Moon, farthest north: +28	* Vega: +39
* M31: +41deg 16m	* M51: +47deg 12m	* M8: -24deg 23m
* M7: -34deg 48m	* NGC 5128: -43deg 1m	* Omega Cent. Cluster: -47d 29m.

Clear skies to all who want them,

Jeffrey R. Charles

Change control information, for after initial publication date of 7 Oct. 2018:
181010: Updated Fig. 3.1.3.1A (36" scope), part of caption; fixed typo p. 24; add para. to p. 51.
181012: Corrected typos on pages 63, 69. 181014: Corrected typos on pages 37, 52, 62, and.63.
181024, 26: Clarified rotating focuser sector in drawing on page 9, eyepiece height goal on p. 15.
Added “1C” to start of last line on page 24, which covers telescope using 17.5" Coulter mirror.