Sizing Up the Newtonian Secondary

Too big, too small, or just right? Making sure your reflector's secondary mirror is the correct size is a straightforward task. | **By Gary Seronik**

The Newtonian reflector has many strengths, not the least of which is that it consists of just two elements: a precisely shaped paraboloidal primary mirror and a flat diagonal secondary mirror. Yet for all its intrinsic simplicity, confusion abounds when it comes to the optimum size of the diagonal. If the response to *Sky & Telescope*'s recent review of 8-inch Dobsonian reflectors (January issue, page 60) held any surprises, it was the extent of this confusion. Many amateurs, and apparently even some telescope manufacturers, seem unsure as to how to choose the correct size for the diagonal. So how big should it be? That depends on several design parameters and some personal preferences.

Making Choices

Selecting the best size for the secondary mirror of a Newtonian telescope is an exercise in compromise. A diagonal that is too large will unnecessarily block incoming light and exaggerate image-harming diffraction effects, while one that is too small will fail to deliver all the light from the primary mirror to the eyepiece. To choose intelligently, you have to first consider what you will be doing with the telescope. Will you be using it for wide-field astrophotography, or exclusively for viewing? Will you be using it to precisely gauge the brightnesses of variable stars, or will this telescope see more duty as a high-resolution lunar and planetary instrument? These questions are important when you are deciding the size of the telescope's *fully illuminated field*. To understand what this phrase means and why it is an important con-

How big should it be? The size of a Newtonian reflector's diagonal mirror depends on several variables and user preferences. There really is no single "right" answer, but with a few simple calculations you can avoid taking a shot in the dark. Photograph by Craig Michael Utter.

sideration, let's first look at how a reflecting telescope works.

In the Newtonian design, all the optical work is done by the primary mirror. It gathers the incoming light and brings it to a sharp focus at the *focal plane*, where the image is magnified with an eyepiece. The distance from the surface of the primary mirror to the focal plane is the instrument's *focal length*. The diagonal mirror simply intercepts the converging cone of light and diverts it out the side of the tube, where the image can be viewed or photographed.

Like a telescope-making Goldilocks, you are looking for a diagonal that is sized "just right" — neither too large nor too small. If it is undersize, some light from the primary mirror will go right past the secondary and out the front of the tube, in effect making the telescope perform as if it had a smaller primary mirror. For example, one of the 8-inch telescopes we tested last January had a secondary so small that the effective aperture of the instrument was reduced to 7 inches. On the other hand, a secondary mirror that is too large will also adversely affect the telescope's performance. Obviously, the larger the secondary mirror, the less starlight will make it to the primary mirror, which is why the secondary is often called the telescope's *central obstruction*.

However, far more serious than a small loss in image brightness due to blockage is the resulting reduction in image contrast. A large central obstruction will make it more difficult to see subtle low-contrast detail, such as Jupiter's wispy equatorial festoons or the delicate surface markings on Mars. The point at which this loss of image contrast becomes noticeable is a matter of considerable debate, but most telescope experts agree that as long as the secondary mirror's diameter is less than 20 percent that of the primary mirror its effects should be all but impossible to see.

Finding the Minimum

A good place to start in your quest for the ideal secondary mirror is by figuring the absolute minimum diagonal size that will catch all the converging light rays from the telescope's primary mirror. One easy method was described on page 67 of the January issue. To make this simple calculation, you need two numbers: the primary mirror's focal ratio *(f)* and the distance from the secondary mirror to the focal plane *(L)*. Where is the focal plane? You can find it by removing the eyepiece and projecting an image of the Moon onto a small square of tracing paper taped over the end of the focuser. (A layer of frosted tape will also work for this.) Rack the focuser in and out for best sharpness and measure the distance from the paper to the center of the tube — this is *L*. The focal ratio is simply the telescope's focal length divided by the diameter of the primary mirror. For example, an 8-inch mirror with a 48-inch focal length would have an f/ratio of 6, or f/6 as it is usually expressed.

But how do you know that the focal length really is exactly 48 inches? One way to check is to use a clean length of wood or a wooden yardstick, if it is long enough. Slide this down the tube until it just makes contact with the edge of the primary mirror. Next, mark the wood where it crosses the middle of the focuser hole. Measure this distance with a tape measure, and add it to *L*. This is the telescope's focal length.

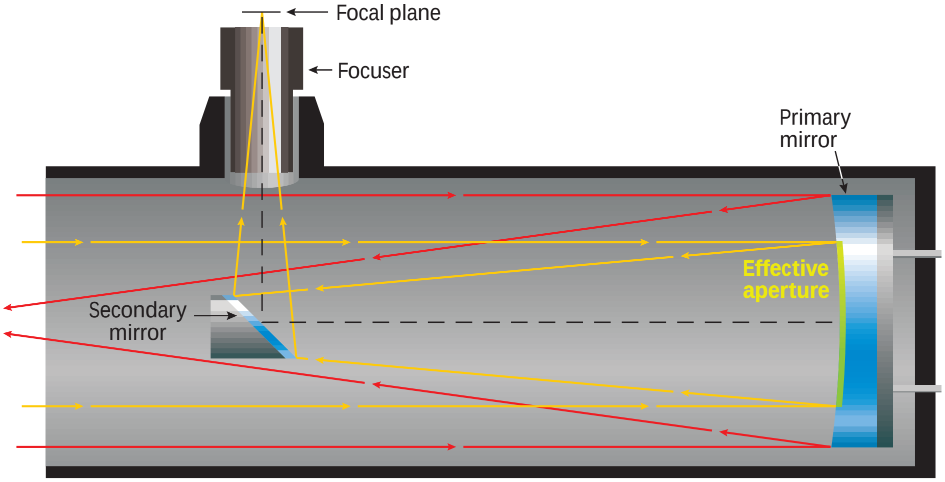
S&T: CRAIG MICHAEL UTTER

What is the value of *L*? This parameter is necessary for calculating the size of the secondary mirror and is the distance from the center of the tube to the focal plane, where the eyepiece's field stop is positioned when the telescope is focused at infinity.

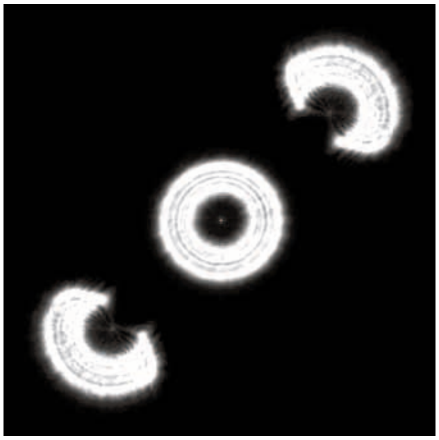
To find the minimum secondary size, simply divide *L* by *f*. In the case of an 8-inch f/6, *L* is often about 9 inches. Dividing 9 by 6 gives a minimum secondary size of 1.5 inches. The same telescope with a low-profile focuser rather than the standard tall rack-and-pinion model might have *L* as little as 6 inches. Such a configuration would allow you to use a diagonal only 1 inch across. In fact, the most effective means of keeping the secondary small is to use a low-profile focuser. *For a given telescope, no other design parameter will have as great an influence on secondary size as focuser height.*

Bigger May Be Better

While the reasons for keeping the diagonal small are compelling, in practice there are a number of potential drawbacks to going this route. Choosing a secondary that is just big enough means that you are counting on that mirror being perfectly flat right up to the very edge. While such perfect diagonals do exist (most often in the smallest sizes),



The Newtonian optical system consists of a paraboloidal primary mirror and a flat secondary that directs the converging beam of light out the side of the tube. If the secondary mirror is too small, as here, some light from the primary will miss the diagonal and go out the front of the tube. In cases such as this, the telescope effectively performs like a smaller instrument.


S&T: DENNIS DI CICCO

The amount of illumination at any part of the field of view can be estimated if you examine the image of a defocused star. In the center of the image above, the out-of-focus star is centered and the secondary mirror can be seen in silhouette. With the off-center images note that approximately 40 percent of the star's light is missing. This corresponds to a 40 percent drop in illumination.

unless you have some means of verifying the quality of the flat you should not count on it. Second, will the diagonal mirror you purchase *really* have a clear face of the required size? Diagonals are often listed by the size of the glass substrate, not the effective diameter. Since the edge of the mirror is beveled to prevent accidental chipping, the actual useful surface might be less than the size given. In addition, how much of the diagonal will the lip of your secondary-mirror holder cover? Taking these factors into account, it is best to purchase a mirror slightly larger than the absolute minimum calculated size.

A minimum-size secondary mirror allows you to take full advantage of your primary mirror's light-gathering and resolution capabilities — but only at the center of the field of view. Objects toward the edge of the field will receive less than 100 percent illumination and appear fainter. For planetary observing, which is best done with the image of the planet positioned at the center of the field of view, this is usually of little concern, but for more general viewing, fully illuminating a larger portion of the field is desirable. For variable-star observing and astrophotography, uniform illumination across a substantial portion of the field is important.

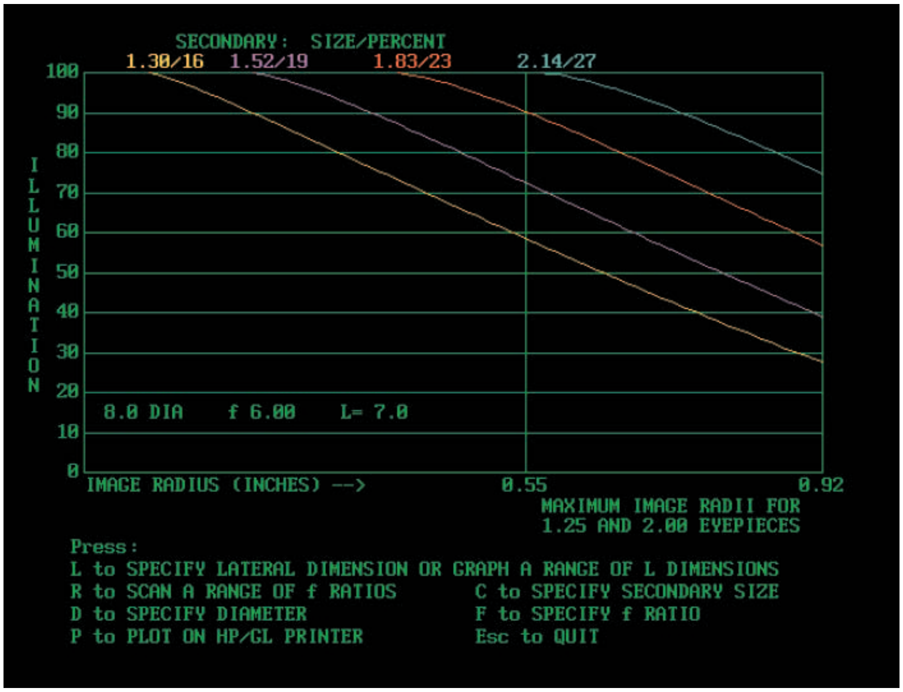
The diameter of the fully illuminated field is usually governed by the size of the secondary mirror. For example, if a ½-inch fully illuminated field is desired, simply add this amount to the minimum diagonal size to figure out the approximate diameter of the secondary. For example, if you have calculated your minimum diagonal size to be 1.5 inches, using a 2-inch secondary will yield a fully illuminated field of ½ inch across. To determine the approximate size of the fully illuminated field in an existing instrument, simply subtract the minimum diagonal size from that of the actual secondary mirror. A telescope equipped with a 1.83-inch diagonal that requires only a 1.5-inch secondary will have approximately a 0.33-inch-diameter fully illuminated field.

For most observers, the choice of secondary size will ultimately hinge on how much of an illumination drop-off at the edge of the field you are willing to tolerate. Generally, the larger the fully illuminated field, the less dimming you will see at the edge of field, though it is important to note that the illumination drop-off is much more gradual with short-focal-length telescopes than long-focal-length instruments. Planetary observers tend to be fanatical about keeping the secondary mirror as small as possible and don't mind if the edge illumination drops to zero. Deep-sky observers, on the other hand, usually prefer wide fields of view with full illumination.

In addition, many scopes are equipped with focusers designed to take 2-inch eyepieces. Indeed, the only way some instruments can deliver low-power views is with giant eyepieces featuring focal lengths in the 20- to 50-millimeter range. Naturally, the required secondary mirror will likely have to be somewhat larger than for an instrument that uses 1¼-inch eyepieces only. Alan Adler's accompanying article and computer program will guide readers through specifics of making these choices.

While you should choose carefully after weighing all the various design considerations, don't lose sleep agonizing over finding the perfect size. For one thing, you might have to settle on a diagonal slightly larger than ideal since these mirrors come in only a limited number of sizes. However, you can rest assured that even if this happens, you are unlikely to be able to see a difference. Of course, if you're like most telescope makers, seeing the difference is less important than *knowing* it's right!

Gary Seronik *builds optimized Newtonians and edits this magazine's Telescope Techniques department.*



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SECONDARY:  SIZE/PERCENT
1.30/16  1.52/19    1.83/23      2.14/27

8.0 DIA     f 6.00     L= 7.0

IMAGE RADIUS (INCHES) -->            0.55                    0.92
                                 MAXIMUM IMAGE RADII FOR
                                 1.25 AND 2.00 EYEPIECES
Press:
L to SPECIFY LATERAL DIMENSION OR GRAPH A RANGE OF L DIMENSIONS
R to SCAN A RANGE OF f RATIOS          C to SPECIFY SECONDARY SIZE
D to SPECIFY DIAMETER                  F to SPECIFY f RATIO
P to PLOT ON HP/GL PRINTER             Esc to QUIT
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The author's computer program *Sec* displays illumination graphs for several secondary mirrors at once. In this example, the plots are for an 8-inch f/6 telescope. Most observers would choose to use either the 1.30- or 1.52-inch secondary. Even at the edge of the field for a 2-inch eyepiece (0.92 inch of radius) the illumination is approximately 27 and 38 percent, respectively.

Diagonal Calculations with *Sec*

By Alan Adler

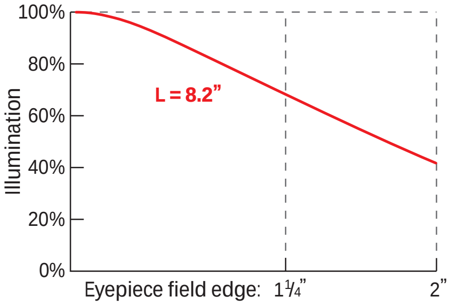
To help telescope owners understand the various factors that go into choosing the size of a secondary mirror, I wrote a small program called *Sec*. It is easy to use and runs on virtually any PC. *Sec* can be downloaded for free at http://www.skypub.com/resources/software/sec.html.

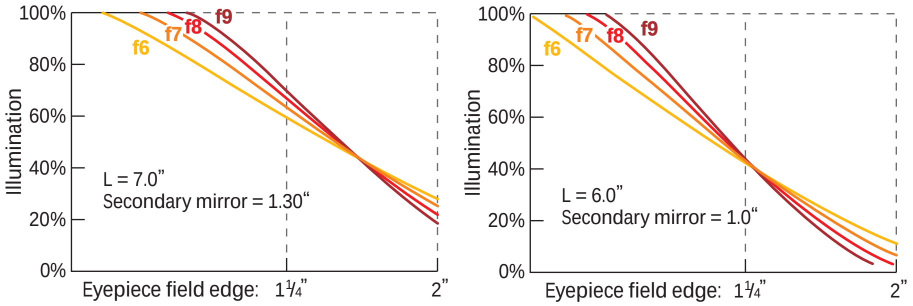
Before you start plugging numbers into the program, take a moment to estimate how much edge-of-field dimming you can tolerate. I have found that a substantial reduction of brightness at the edge of the field due to a small secondary is entirely acceptable for most observing. Some years ago I experimented with masks in front of a small refractor and found that a 50 percent decrease in brightness was barely perceivable.

Once you have executed the program, you will be asked to input your telescope's primary-mirror diameter and f/ratio. Next you will be presented with a graph showing the illumination profiles for a variety of useful secondary sizes. At a glance, you can see the amount of edge-of-field illumination offered by each diagonal. If you want to try out a specific secondary size, use the *C* option, or to investigate the effects of different focuser heights, plug in a new value for *L*.

I usually choose the smallest secondary that provides 100 percent illumination at the center, and at least 40 percent at the edge of a 1¼-inch eyepiece field. This represents a full magnitude drop at the very edge, which I find acceptable. However, if you decide to use 2-inch eyepieces, make

Plotted here is the brightness curve for Adler's 8-inch f/6 Newtonian, which is equipped with a 1.57-inch secondary mirror. The two vertical lines on the right represent the maximum possible fields of view for 1¼- and 2-inch eyepieces. Note that the brightness is about 70 percent at the edge of the 1¼-inch eyepiece and only 43 percent at the edge of the 2-inch eyepiece. In spite of this, the author has never been aware of any dimming at the edge.





These two plots based on output from *Sec* show the effects of increasing f/ratio. *Left:* Note that from f/6 to f/9 the edge-of-field illumination varies by only 10 percent when a 1.3-inch secondary mirror is used. If the *L* dimension is reduced by 1 inch, a 1-inch secondary mirror can be used. Note that regardless of f/ratio, the illumination at the edge of a 1¼-inch eyepiece is virtually the same.

sure that the brightness equals at least 15 percent at the edge of the 2-inch field. Although this amounts to light loss of approximately two magnitudes, in my telescope I find the low-power view very pleasing and have never noticed the substantial edge dimming.

Some Guidelines

In some respects, choosing a small diagonal trades illumination at the edge of your lowest-power eyepiece for better-contrast, high-magnification views. You might have other requirements or preferences that you want to explore — but that's the value of *Sec*; you can investigate all kinds of what-if scenarios.

Plugging numbers into a computer program like *Sec* will produce meaningful information only if the results are viewed in some kind of context. First of all, keep in mind that the benefits of squeezing the secondary dimension down to the minimum may not be perceivable. For one thing, the central obstruction caused by the secondary does not reduce the image quality of high-contrast targets such as open clusters and double stars. However, it does diminish the image quality of low-contrast planetary detail.

As mentioned in Gary Seronik's companion article, the best way to keep the secondary size down is to control *L*. An absolute practical minimum for *L* for most Newtonian reflectors is the radius of the primary mirror plus about 2 inches. That permits only an inch inside the tube and an inch for a low-profile focuser. In practice, *L* is often substantially more than the minimum since you might

The following examples cover a range of common apertures and f/ratios. All assume a lateral dimension (*L*) equal to the radius of the primary mirror, plus 3 inches. (The 3 inches would typically be allotted as 1 inch of clearance inside the tube and 2 inches for the focuser height.) All are fully illuminated at the center of the field and have acceptable edge-of-field illumination.

The values here reflect findings arrived at using *Sec:*

1. A substantial reduction of brightness at the edge of the field is entirely acceptable.
2. The benefits of squeezing the secondary-mirror dimension down to the minimum may not be perceivable.
3. Reducing the lateral dimension by moving the eyepiece closer to the central axis is often of limited benefit and can prevent the use of some Barlow lenses.
4. The benefits of larger f/ratios are overstated.

A Selection of Secondaries

Primary mirror diameter (inches)	f/ratio	Secondary mirror diameter (inches)	Obstruction (percent)	Edge-of-field illumination (percent)	
				1¼-inch barrel	2-inch barrel
6	6	1.0	16.7	44	14
8	6	1.3	16.3	58	28 *
10	6	1.52	15.2	66	37
12.5	5	2.14	17.1	81	58
14.5	5	2.14	14.8	74	55
18	4.5	3.1	17.2	92	76
24	4	4.0	16.7	90	79

* Most 8-inch f/6 scopes use a 1.52-inch secondary, but 1.3 inches works well if the lateral dimension is not excessive.

have to use less-than-optimal tube diameters or a focuser that is more than 1 inch tall. You can calculate the absolute largest value for *L* for a given secondary by multiplying the secondary size by the f/ratio. For example, an f/6 scope equipped with a 1.5-inch secondary should have an *L* no greater than 9 inches.

One of the often-stated benefits of a long-focal-length Newtonian is the opportunity to use a smaller secondary mirror. However, some experimentation with *Sec* demonstrates that this supposed advantage is overrated. The illustration at the top of page 124 plots the brightness of 8-inch scopes ranging from f/6 to f/9. All have acceptable brightness curves using the same 1.3-inch secondary mirror. The right-hand graph plots 8-inch scopes with the *L* dimension reduced to the minimum of 6 inches. This permits shrinking the secondary from 1.3 to 1.0 inch, but at the expense of reducing the edge illumination for 2-inch eyepieces to unusable levels in all but the f/6 scope.

Increasing the f/ratio and/or reducing the *L* dimension will often permit the use of a secondary one size smaller; however, the resulting image improvement will be slight. Consider this example. A 1-inch secondary produces only a 12.5 percent central obstruction, and the 1.3-inch secondary is 16.3 percent. While the small secondary would seem to be well worth pursuing, in this case the improvement in image contrast is probably not perceivable even in excellent seeing.

A superb article dealing with the effects of central obstruction was presented by William Zmek in the July 1993 issue, page 91. The author gave a simple formula for estimating the effect of central obstruction on low-contrast objects:

$$D_{\text{effective}} = D_{\text{primary}} - D_{\text{secondary}},$$

where *D* stands for diameter. Applying this formula to the previous example results in low-contrast performance equivalent to apertures of 6.7 and 7.0 inches. Even the most skilled observers would have difficulty in seeing a difference this small. Regardless of what options *Sec* presents, it is worth using Zmek's formula and the other guidelines I have mentioned here as a "reality check."

In addition to being a telescope maker, Alan Adler *is a lecturer in mechanical engineering at Stanford University and owner of Superflight, Inc. He has 35 patents in diverse fields ranging from electro optics to aerodynamic toys.*