

# Build a Sun Funnel for Group Viewing of Sunspots & Transits of Mercury



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This simple & inexpensive device makes it easy for many people to observe the Sun simultaneously.



**Origin of the Sun Funnel:** Gene Zajac and Chuck Bueter adapted (<http://bit.ly/rt16jc>) an existing design for a 2003 Great Lakes Planetarium Association Conference workshop. The rear-screen projection material, a key ingredient, is an idea borrowed from Bruce Hegerberg's Sun Gun (<http://www.sunguntelescope.com/MAIN.html>).



Red numbers  
correspond to items  
listed on the next  
two pages.

## Supplies & Tools

# Supplies

- 1.** Blitz Super Funnel #05034, 17.75-inch x 5-inch x 5-inch (round top), \$2 to \$5 at your local hardware or auto-parts store. Online: <http://amzn.to/M9sLIK>
- 2.** Large hose clamp, 2.5-inch x 5.5-inch, e.g., Breeze #62080; \$1 to \$2 at your local hardware store. Online: <http://bit.ly/qBbvRK>
- 3.** Small hose clamp, 13/16-inch x 1.5-inch, e.g., Breeze #62016; \$0.50 to \$1 at your local hardware store. Online: <http://bit.ly/oTDjRR>
- 4.** Da-Lite High-Contrast Da-Tex rear-surface projection screen #95774, 8-inch x 8-inch; ~\$10 for 1 square foot (usually the minimum order size). Online: <http://bit.ly/nE0fTU> If you can't get this, a cheap alternative is to use two layers of a gray vinyl shower-curtain liner.

*Continued on next page →*

# Supplies, continued

**5.** Inexpensive (e.g., Huygens, Kellner, Plössl) all-metal-and-glass telescope eyepiece, 1.25-inch barrel, focal length  $\sim 5$  to  $\sim 25$  mm (tips on choosing the optimum focal length are on a later page). Use one that you already have lying around, as long as it has no plastic in it. If you don't have one, they're available from numerous manufacturers and dealers, including Celestron, Sky Instruments, Meade, Orion, and Edmund Scientific. The cheapest option is Surplus Shed (<http://www.surplushed.com>).

## Tools

**6.** Flat-head screwdriver

**7.** Small hacksaw

**8.** Medium- to fine-grit sandpaper

**9.** 12-inch ruler

# Match the Eyepiece to Your Telescope

What type of telescope? Refractor!



*Photo: Explore Scientific*

Using a Newtonian reflector or a catadioptric (mirror-lens) telescope is strongly discouraged, as concentrated sunlight can destroy such instruments' secondary-mirror holders.

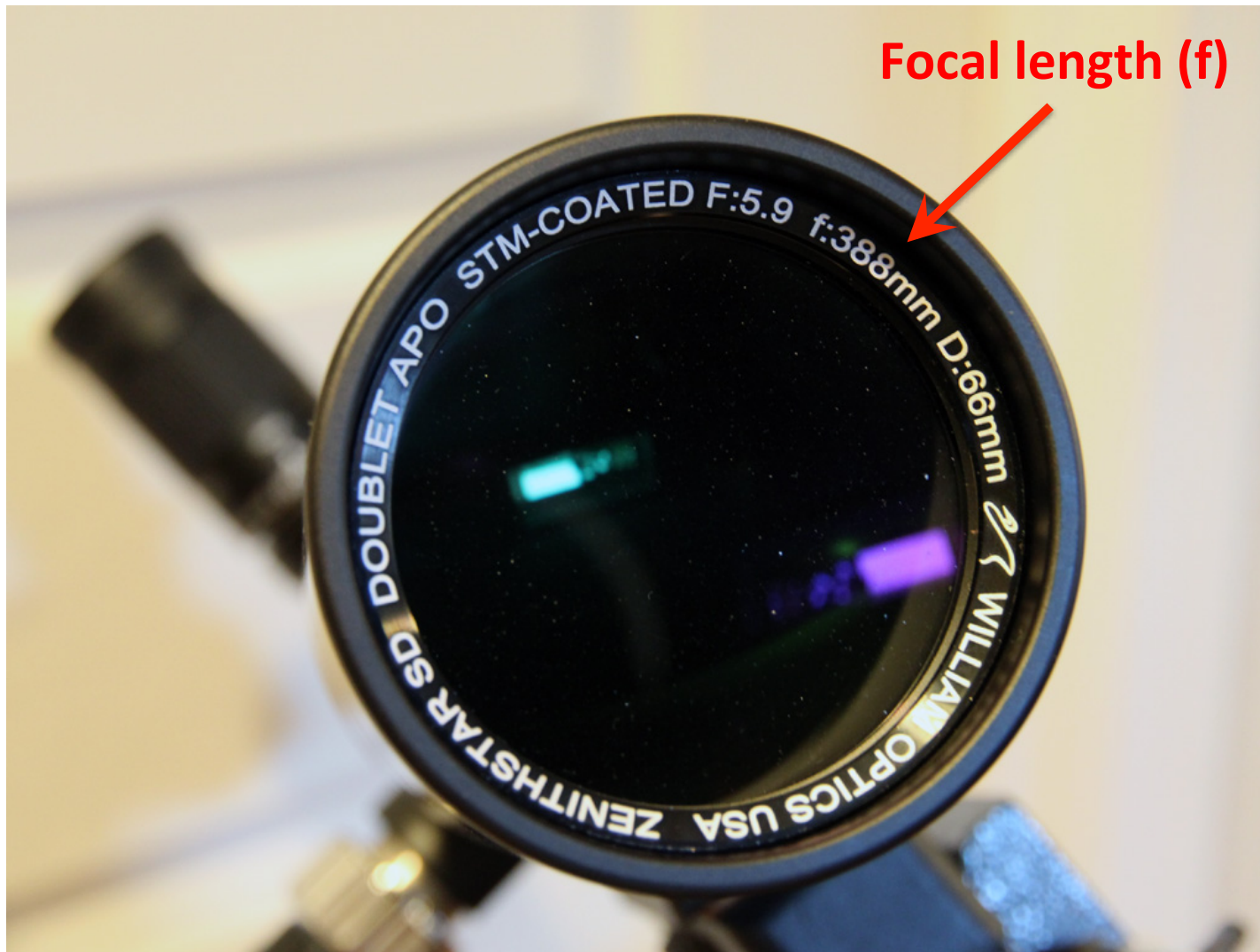




Photo: Chuck Bueter

That said, you can use a reflector if you "stop down" the aperture by placing a piece of cardboard over the front end with a small (1- to 2-inch) hole cut off to one side to let in only a little bit of sunlight. *See later in this document for more safety tips.*

A refractor's focal length is usually indicated on the barrel of the objective (front) lens.





Or, you can calculate the focal length of your telescope from its diameter (D) and focal ratio (f/ratio or f/number):

$$FL_{\text{telescope}} = D_{\text{telescope}} \times f/\text{ratio}$$

Example: For the 66-mm f/5.9 refractor shown on the previous page,  
 $FL_{\text{telescope}} = 66 \text{ mm} \times 5.9 = 389 \text{ mm}$  (close enough; round-off error!)

**Best eyepiece for a full-disk (~100 mm diameter) solar image:**

$$FL_{\text{eyepiece}} \text{ (mm)} \approx FL_{\text{telescope}} \text{ (mm)} \div 43$$

*(The derivation of this formula appears later in this document.)*

Example: For the Galileoscope, a 50-mm f/10 refractor ( $FL_{\text{telescope}} = 500 \text{ mm}$ ), the eyepiece that will produce a full-disk solar image has a focal length of  $FL_{\text{eyepiece}} = 500 \div 43 = 11.6 \text{ mm}$ . There are many inexpensive 12.5-mm eyepieces available; any would make a good choice.

An eyepiece with a *shorter* focal length will produce a *larger* Sun image; an eyepiece with a longer focal length will produce a smaller Sun image.

# Sample Pairs of Telescope & Eyepiece Focal Lengths for a Full-Disk Image of the Sun on the Sun Funnel

| Telescope<br>( $FL_{\text{telescope}}$ ) | Eyepiece<br>( $FL_{\text{eyepiece}}$ ) |
|--|--|
| 300 mm                                   | 7 mm                                   |
| 400 mm                                   | 9 mm                                   |
| 500 mm                                   | 12 mm                                  |
| 600 mm                                   | 14 mm                                  |
| 700 mm                                   | 16 mm                                  |
| 800 mm                                   | 19 mm                                  |
| 900 mm                                   | 21 mm                                  |
| 1000 mm                                  | 23 mm                                  |

Don't worry about getting the eyepiece focal length "exactly right." Depending on what you have available or what you can buy cheaply, aim to get an eyepiece whose focal length is within  $\pm 10\%$  of the "ideal" value of  $FL_{\text{telescope}} \div 43$ .

**Step 1.** The funnel has a sharp little piece of plastic protruding from the side about halfway down its length.



Using the sandpaper, grind it smooth so it doesn't scratch your hands.



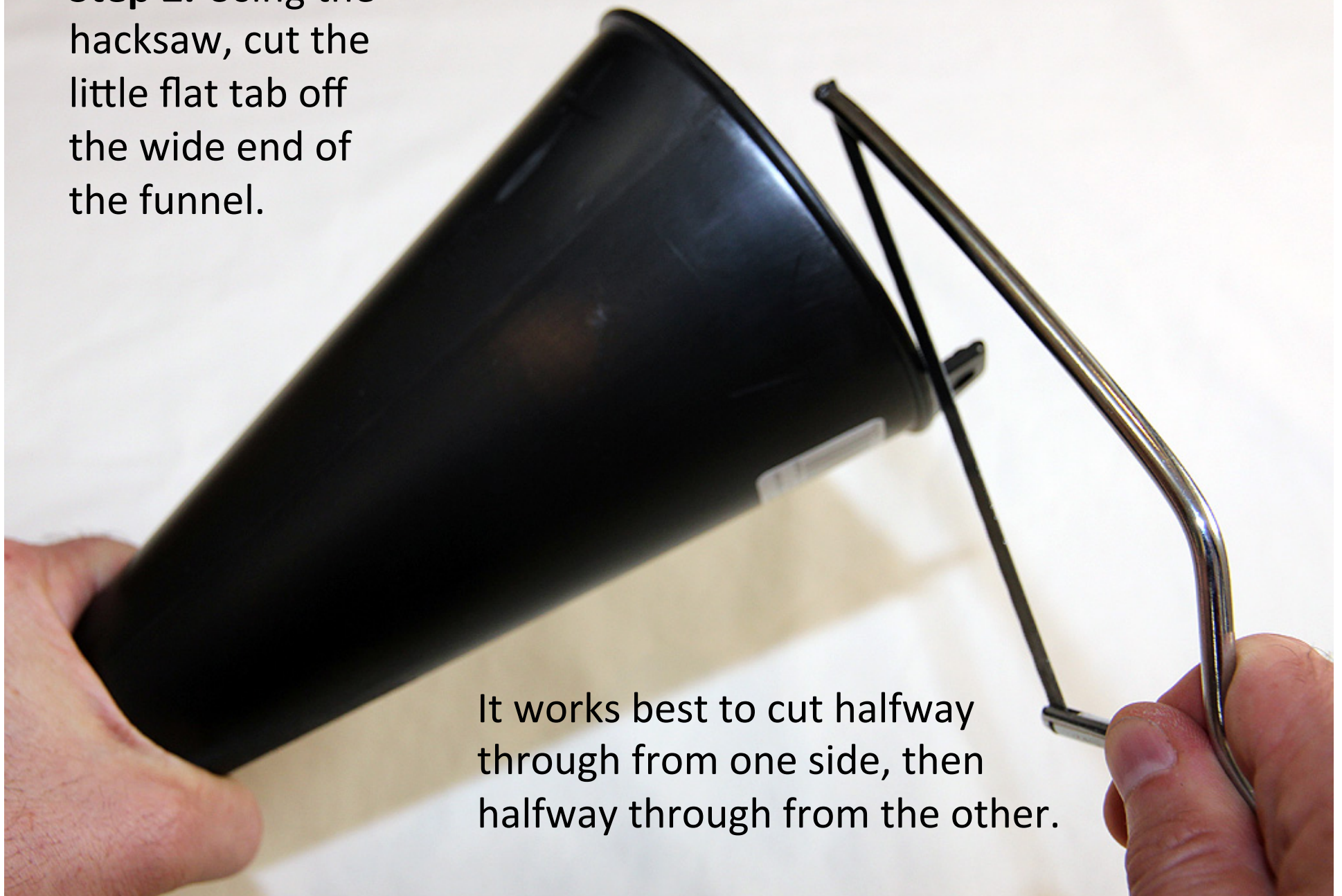


No more sharp  
piece of plastic!



**Step 2.** Using the hacksaw, cut the little flat tab off the wide end of the funnel.

It works best to cut halfway through from one side, then halfway through from the other.

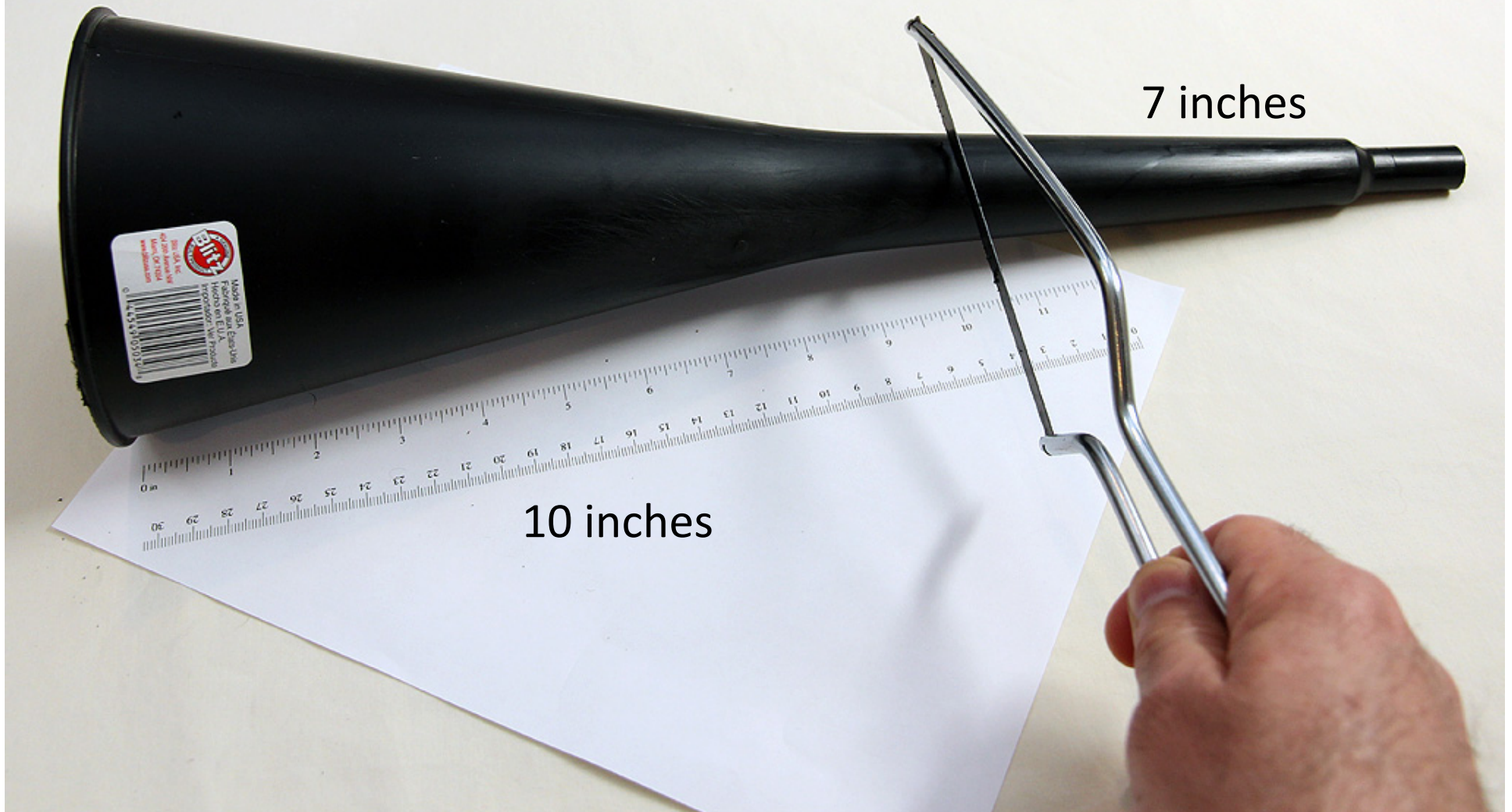


Rough edge!  
Sand it smooth  
now or in step 5.





**Step 3.** Using the hacksaw, cut about 7 inches off the narrow end of the funnel so that what's left measures about 10 inches long (use the ruler).





Try to make the cut perpendicular to the axis of the funnel, but don't panic if it ends up slightly tilted. Rotate the funnel as needed to complete the cut.





Don't bother sanding  
this rough edge yet.

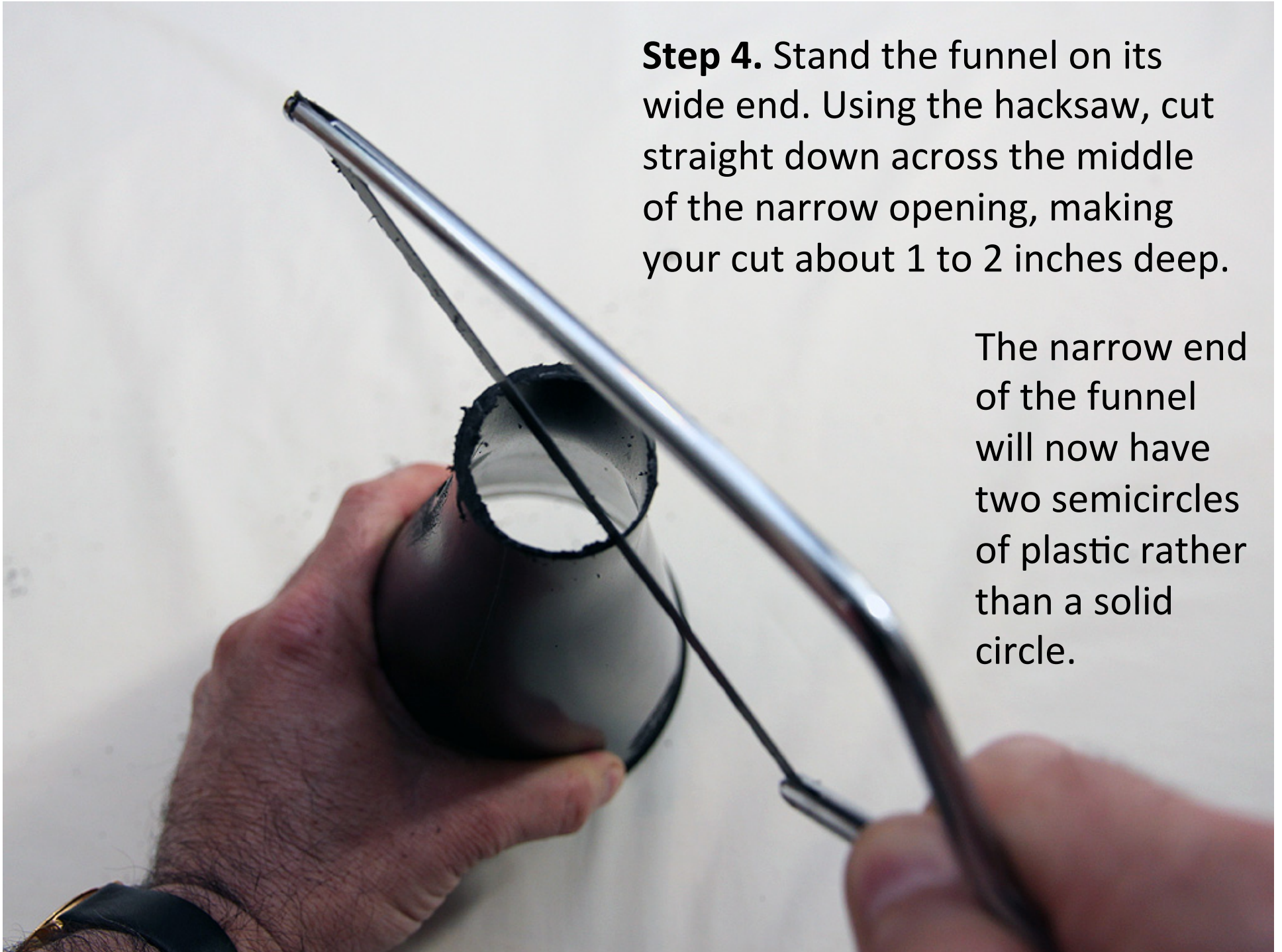


Discard this piece of plastic.



**Step 4.** Stand the funnel on its wide end. Using the hacksaw, cut straight down across the middle of the narrow opening, making your cut about 1 to 2 inches deep.

The narrow end of the funnel will now have two semicircles of plastic rather than a solid circle.





**Step 5.** Using the sandpaper, smooth all the cut surfaces on both ends of the funnel.





**Step 6.** If your eyepiece has a rubber eyecup and/or rubber grip, remove it/them.



Note that if you have a yellow thread-in eyepiece filter, you can screw it into the eyepiece barrel to produce a yellow Sun. But note, too, that the true color of the Sun is . . . white!



**Step 7.** Insert the eyepiece into the narrow end of the funnel: lens in, chrome barrel out. You may need to pry apart the two semicircular halves of the funnel's opening.



If the eyepiece still won't go in, cut away a little more of the funnel to widen the opening, then try again.



Aim to get at least a half inch of the length of the eyepiece into the funnel.

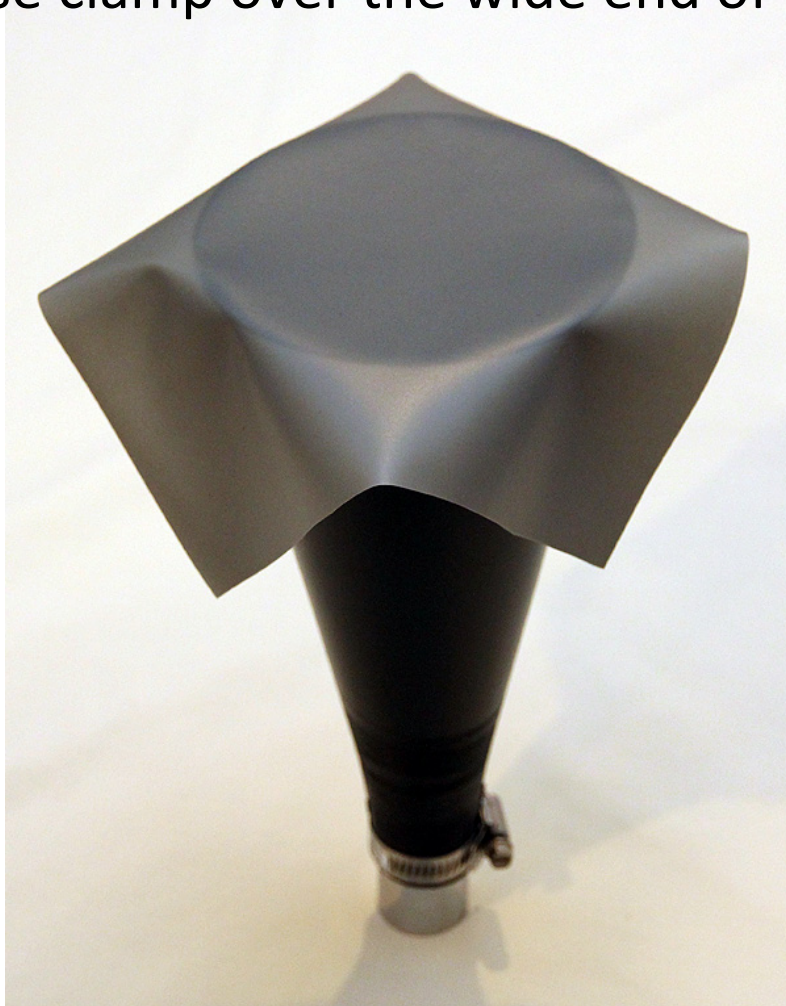


**Step 8.** Place the small hose clamp over the narrow end of the funnel and, using the screwdriver, tighten it around the funnel to securely hold the eyepiece.





**Step 9.** Turn the funnel wide end up (you might find it easiest to sit down and hold the funnel between your knees). Place the Da-Tex screen (or two layers of vinyl shower-curtain liner) over the wide opening; it doesn't matter which side faces down. Lower the large hose clamp over the wide end of the funnel...

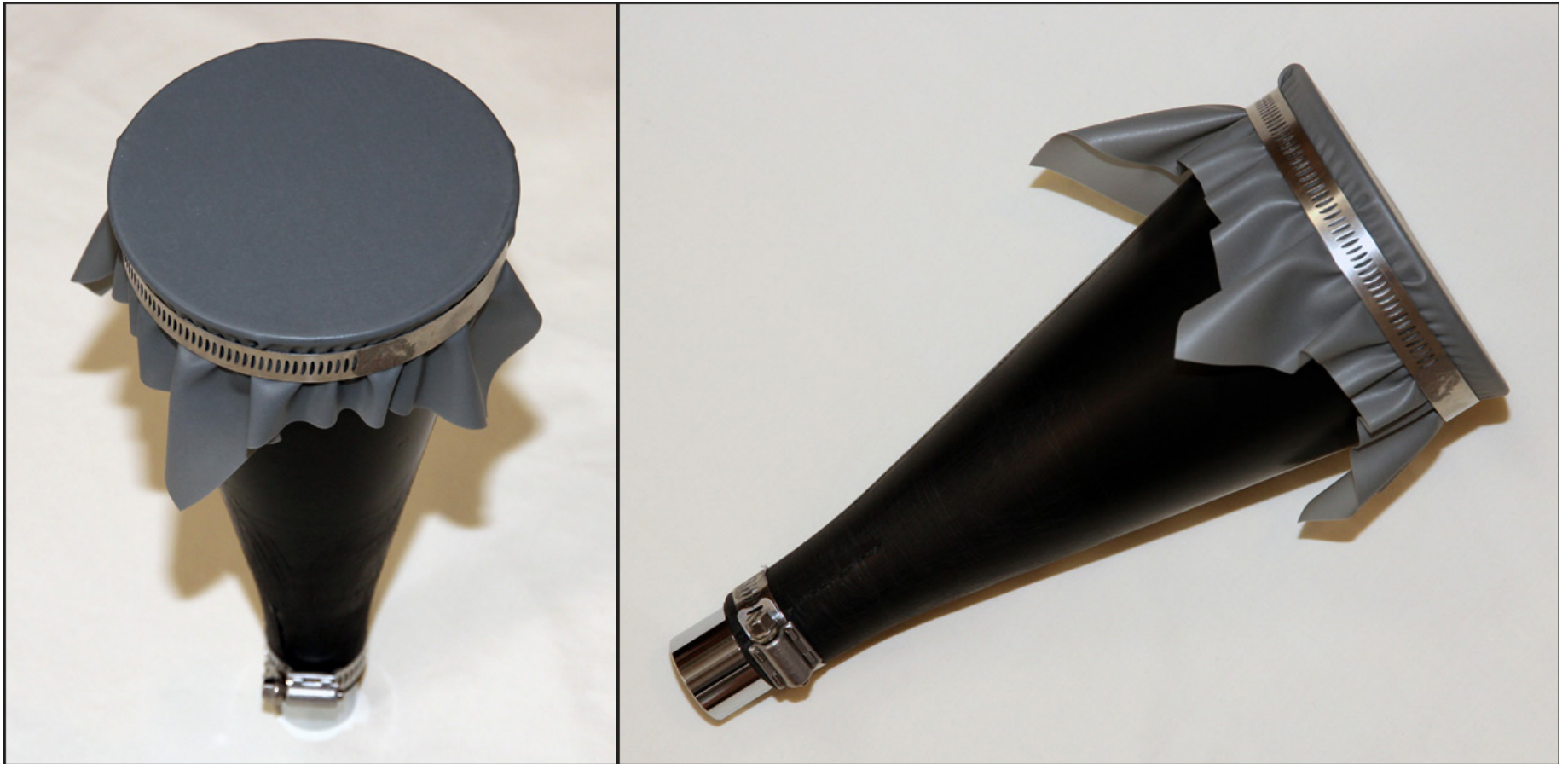




...and, using the screwdriver, tighten it around the funnel to securely hold the screen; as the clamp begins to get purchase on the funnel and screen, gently pull down all around the loose edge of the material so that the screen ends up flat and taut over the funnel's wide opening. This is an iterative process; you'll need to pull down on the material after each turn of the screw to keep it taut.



# The Sun Funnel



Congratulations! You have successfully built a Sun Funnel!



**Step 10.** Insert the eyepiece barrel into your telescope's 1¼-inch eyepiece holder, secure it with the thumbscrew(s), aim your telescope at the Sun (first taking care to cover your finder scope, if any), focus, and enjoy group viewing with your Sun Funnel!

**WARNING! ALWAYS SUPERVISE USE OF THE SUN FUNNEL. NEVER POINT AN UNFILTERED TELESCOPE AT THE SUN. SEVERE EYE DAMAGE MAY OCCUR!**



In case you're wondering...

This is not a solar filter; it's a piece of black foam-board purchased for a few dollars at an office-supply store.

Cut a round hole near one of the board's short edges, matching the outer diameter of your telescope's front end. Then slip the board over the scope. It will cast a shadow over the eyepiece and Sun Funnel, improving your view of the Sun.





# How to Aim a Telescope at the Sun

How do you aim a telescope at the Sun when you're not supposed to look through it, and when you're supposed to remove or cover your finder so that you don't look through that either (and so that bright sunlight doesn't melt its crosshairs)?!

One solution is to watch your telescope's shadow on the ground and adjust the aim until the tube's shadow is as small and as round as you can get it.

Another solution is to add a special-purpose Sun finder that projects a shadow or a spot of sunlight onto a target. There are several commercial units available, including these:

- Far Laboratories Helio Pod: <http://bit.ly/pclLOW>
- Tele Vue Sol-Searcher: <http://bit.ly/nkhyOk>
- Coronado Sol Ranger: <http://bit.ly/phOnds>

Yet another solution is to make something yourself based on the design of one of these products.

# Safe Sun

There are several ways to observe the Sun safely with a telescope. One is to use a special-purpose aperture filter — that is, a filter that fits over the instrument's aperture, or front opening — to block all but a minuscule fraction of the Sun's light and thereby create a comfortably bright image in the telescope's eyepiece. Most solar filters are made from metal-coated glass or Mylar-type film.

Sometimes, though, it can be hard to convince people to look through a filtered telescope; despite your most sincere reassurances, they're afraid they'll hurt their eyes. In any case, only one person at a time can view the Sun in the eyepiece.

One way around this is to project an image of the Sun onto a card or screen. Now nobody has to look through the telescope (which means no refocusing and no bumping), and many people can view the solar image at the same time. But there's a risk that someone might accidentally look into the bright beam of sunlight emerging from the eyepiece.

The solution, and an even safer way to use a telescope to observe the Sun, is rear-screen projection. That's the technique used in the Sun Funnel.

# Solar Filter vs. Solar Projection

If you have an aperture solar filter for your telescope, you don't need a projection device -- just look through the eyepiece to see a comfortably bright image of the Sun. Conversely, if you want to use a projection device, for example, so that many people can view the Sun's image at the same time, you can't use a solar filter, because then the image would then be too dim to show up on the screen.

What do we mean by "too dim"? A typical solar filter blocks 99.999% of the Sun's light, so that the image in the eyepiece — or projected by the eyepiece — is only  $1/100,000^{\text{th}}$  as bright as it would be without the filter. That's very good for direct viewing in the eyepiece, but very bad for projection (including the Sun Funnel).

With either an aperture filter or a projection system, in addition to seeing the tiny silhouette of Mercury during its 9 May 2016, transit, you can see sunspots and limb darkening (i.e., the edges of the Sun's disk are darker than the center).

Some solar filters are made to show the Sun in the light of specific atoms, such as the red light of hydrogen (H alpha, or  $H\alpha$ ), or the violet light of calcium. These produce comfortably bright images in the eyepiece but, like full-spectrum ("white light") filters, are not suitable for use with projection systems like the Sun Funnel.



# More Safe Sun

Whenever you observe the Sun, with any technique, you must put safety first.

The key to successful solar projection, including use of the Sun Funnel, is to use the right kind of telescope — one that can tolerate having full-strength sunlight pass through the optical train — and to use an eyepiece that doesn't have any plastic in it. We'll say it again: We recommend using a refractor (a telescope with a front lens) — not a reflector (unless you stop it down to a 1- or 2-inch aperture), and never a mirror-lens telescope — and a decent-quality commercial eyepiece.

Always take the utmost care when passing unfiltered sunlight through any optics, as you'll do when using the Sun Funnel or any other projection device. If you see or smell smoke, your equipment is unsuitable or set up incorrectly — get it out of the Sun immediately!

Do your solar observing in short stints. Don't leave a telescope pointed at the Sun — or even sitting out in the Sun pointed elsewhere — for hours at a time.

Most importantly, never leave a solar-observing setup unattended.

# The Galileoscope & the Sun Funnel

The Galileoscope (<http://galileoscope.org>) is an ideal telescope to use with the Sun Funnel. With more than 200,000 of these inexpensive, high-quality telescopes in use around the world, it would be a shame not to use them for public viewing, for example, during the 9 May 2016 transit of Mercury or the partial phases of the 21 August 2017 solar eclipse. But there are two problems: (1) the supplied eyepiece is plastic and would melt if used for solar projection, and (2) the Galileoscope is designed to be used "straight-through," without a star diagonal, which leaves the Sun Funnel's screen awkwardly pointed at the ground.

To solve the first problem, note that the Galileoscope has a standard 1.25-inch eyepiece holder, so it can use standard 1.25-inch metal eyepieces with glass lenses. Ideally, you want one with an 11- to 12.5-mm focal length. If you don't already have such an eyepiece, you can find a cheap one at [Surplus Shed](#).

There's not much you can do about the second problem, except to view the Sun when it appears low in the sky, i.e., in the early morning or late afternoon. At such times, with the nearly horizontal Galileoscope on a fully extended photo tripod, the Sun Funnel can be conveniently placed for group viewing of the projected solar image.





# Mathematical Underpinnings of the Sun Funnel Design

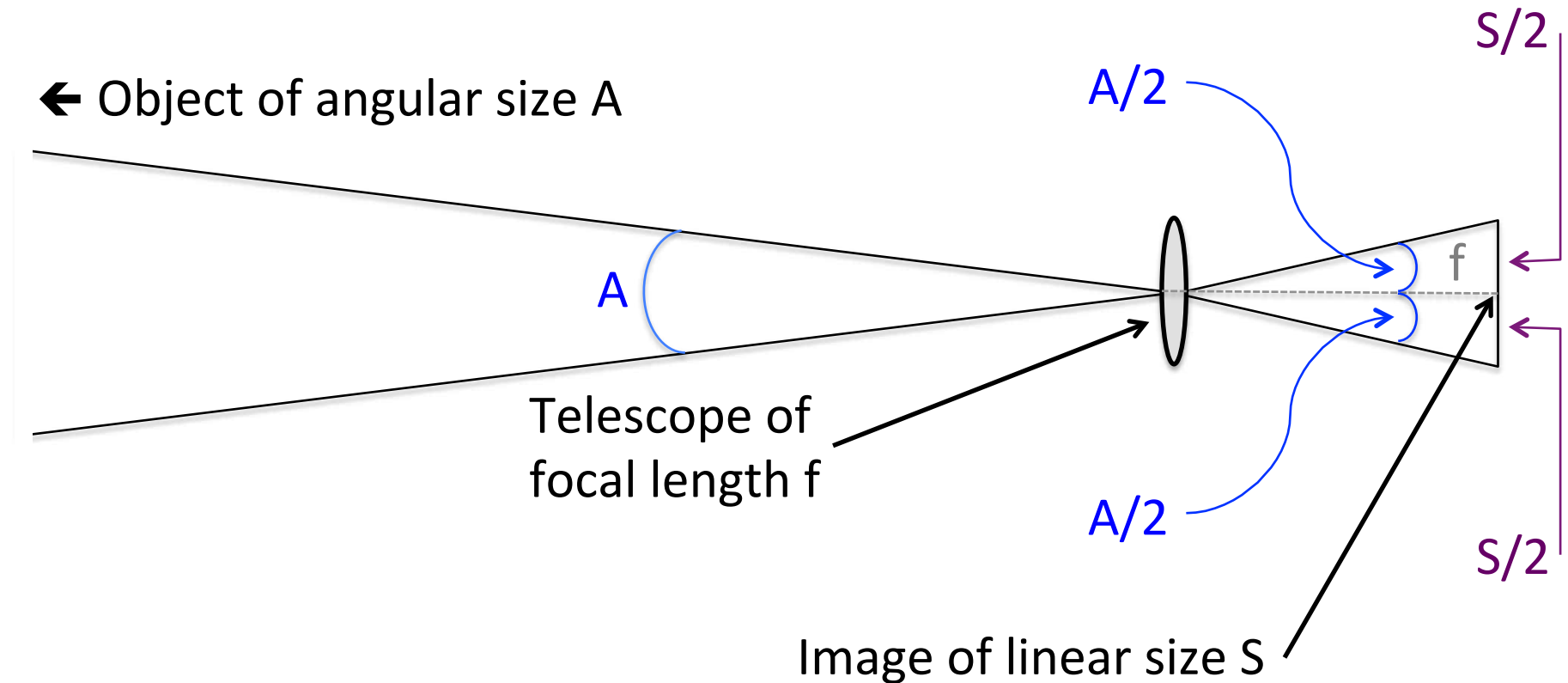
On the following pages we go through the (relatively simple) math behind the Sun Funnel. It relates the following quantities over which we have some measure of control:

- Telescope focal length
- Eyepiece focal length
- Projection distance
- Projected image diameter

and the following quantity over which we have absolutely no control:

- Sun's angular diameter

Telescope of focal length  $f$  (mm) produces image of linear size  $S$  (mm) of object with angular size  $A$  (radians).



Relationship between these quantities:

$$\tan (A/2) = (S/2) / f$$

Rearrange

$$\tan (A/2) = (S/2) / f$$

to get

$$f \tan (A/2) = S/2$$

and finally

$$S = 2f \tan (A/2)$$

Note that for the very small angles we typically encounter in astronomy,

$$\tan (A/2) \approx A/2$$

so we have

$$S = 2fA/2$$

which reduces to

$$S = fA \quad (S, f \text{ in mm; } A \text{ in radians})$$



We need to know the size of the Sun image produced by the telescope, since that's what we plan to project onto the Sun Funnel screen. Do you know the Sun's angular size,  $A$ , in radians? Probably not, so let's tweak our formula to put  $A$  into degrees instead.

There are  $180^\circ$  in  $\pi$  radians (the arc of a semicircle), so

$$S = fA \times (180^\circ/\pi)$$

or 
$$S = fA/57.3 \quad (A \text{ in degrees})$$

The Sun's average angular size is just over  $\frac{1}{2}^\circ$  (you knew that, right?), i.e.,  $A \approx 0.533^\circ$ .

So, with  $A = 0.533^\circ$ , we get

$$S = fA/57.3$$

$$S = f(0.533/57.3)$$

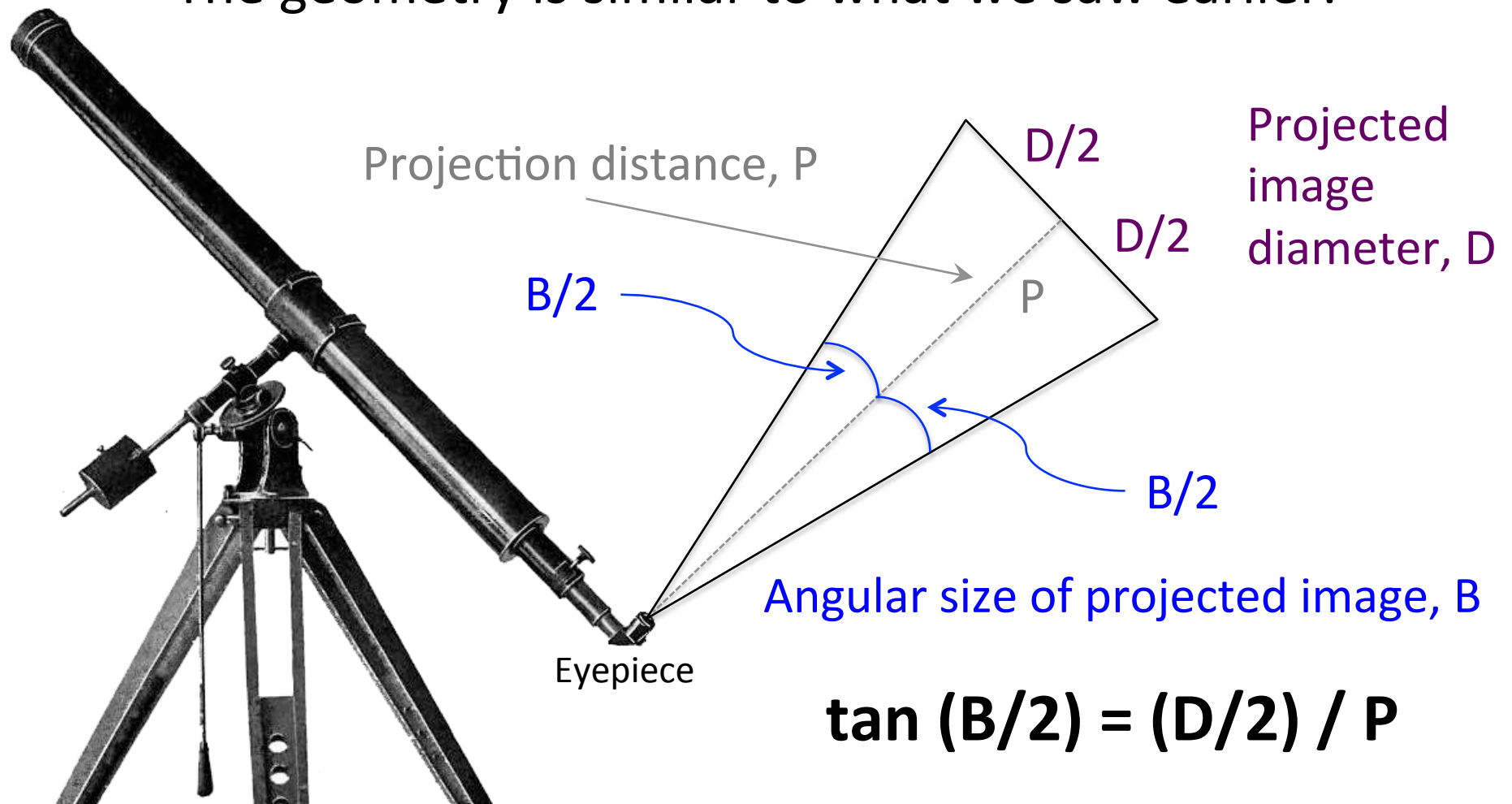
$$\mathbf{S = 0.0093f} \quad (S \text{ in mm, } f \text{ in mm})$$

Consider the Galileoscope, which has a focal length of 500 mm. When aimed at the Sun, it produces an image of diameter  $S = 0.0093 \times 500 \text{ mm} = 4.65 \text{ mm}$ .

You're not going to have much luck trying to see sunspots or Mercury's silhouette on such a tiny image!

That's why we use projection, i.e., to produce a larger image on which we can more easily see sunspots and other features of interest on the Sun's disk.

The geometry is similar to what we saw earlier:





Rearrange

$$\tan (B/2) = (D/2) / P$$

to get

$$P \tan (B/2) = D/2$$

and finally

$$D = 2P \tan (B/2)$$

Again, for the very small angles we typically encounter in astronomy,

$$\tan (B/2) \approx B/2$$

so we have

$$D = 2PB/2$$

which reduces to

$$D = PB \quad (D, P \text{ in mm; } B \text{ in radians})$$

But what is B, exactly? Remember A? It's the angular size of the image produced by the telescope. Well, B is just that angle multiplied by the magnification produced by the telescope's eyepiece. And that, in turn, is the focal length of the telescope divided by the focal length of the eyepiece, i.e.,

$$B = A \times \text{magnification} = A \times (FL_{\text{telescope}}/FL_{\text{eyepiece}})$$

so  $D = PB$

becomes  $D = PA(FL_{\text{telescope}}/FL_{\text{eyepiece}})$

with D, P, and the two FL's in mm, and A in radians.

But remember, A (the Sun's angular diameter in radians) is equal to  $0.533/57.3$ , or  $0.0093$ . So our formula for the diameter of the projected image,

$$D = PA(\text{FL}_{\text{telescope}}/\text{FL}_{\text{eyepiece}})$$

becomes  **$D = 0.0093P(\text{FL}_{\text{telescope}}/\text{FL}_{\text{eyepiece}})$**

with all quantities in mm. This can be rearranged to solve instead for the projection distance, P:

$$\mathbf{P = 107.5D(\text{FL}_{\text{eyepiece}}/\text{FL}_{\text{telescope}})}$$

again with all quantities in mm.

Alternatively, either formula can be rearranged to solve instead for the eyepiece focal length:

$$\mathbf{FL_{eyepiece} = 0.0093P(FL_{telescope}/D)}$$

again with all quantities in mm. For the Sun Funnel as described here,  $P \approx 10$  inches  $\approx 250$  mm, and the desired image size for a full-disk Sun is  $D \approx 100$  mm (since the wide end of the funnel is about 5 inches, or 127 mm, across). Thus,

$$FL_{eyepiece} = 0.0093 \times 254 \div 100 \times FL_{telescope}$$

or 
$$\mathbf{FL_{eyepiece} = 0.023 FL_{telescope} = FL_{telescope} \div 43}$$



# A Matter of Size & Degrees

The Sun Funnel was designed with small refractors, such as those with apertures in the range of 50 to 90 mm (2 to 3½ inches), in mind. There's nothing to keep you from scaling it up to a much bigger size, except that you're limited by the amount of sunlight you collect, so if you make a much bigger funnel for a small refractor, you'll end up with a disappointingly dim image.

If you want to double the diameter of the funnel so that you can double the diameter of the solar image, you'll need to double the diameter of the refractor to maintain similar image brightness. That's not too practical, as such refractors are typically quite large, heavy, and expensive. A better solution is to use a shorter-focal-length eyepiece to increase the magnification. This will blow up the Sun's image so that it "overfills" the Sun Funnel screen, but it'll make sunspots or the silhouette of Mercury appear larger and more visible.

Most refractors include a 90° star diagonal whose purpose is to make the viewing angle more convenient. If the Sun is low in the sky, it's perfectly OK to leave out the star diagonal and view or project "straight through" the scope.

Now that you have all the mathematical relationships between telescope focal length, eyepiece focal length, projection distance, and projected image size, you can design your own solar-projection device using materials other than those suggested here.

## Questions? Comments?

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