Improving the Thermal Properties of Newtonian Reflectors — Part 1

Assessing your scope's state of cooling is the first step on the road to optimal performance. By Bryan Greer

PHYSICS PREDICTS THAT the aperture of a telescope will define its performance more than anything else. Yet it is an enduring mystery why the performance of Newtonian reflectors is so frequently disappointing when compared to high-quality refractors of similar aperture. Over the years many theories have been offered to account for the reflector's failings. Everything from the effects of a central obstruction to surface roughness on the mirrors to spider diffraction to scatter in the reflective coatings has been suggested as a possible explanation, but when these are analyzed thoroughly they don't fully account for the Newtonian's temperamental behavior. However, some simple analytical techniques permit us to see what is really going on, and it is now clear that the single most important factor limiting performance is the design's susceptibility to thermal problems.

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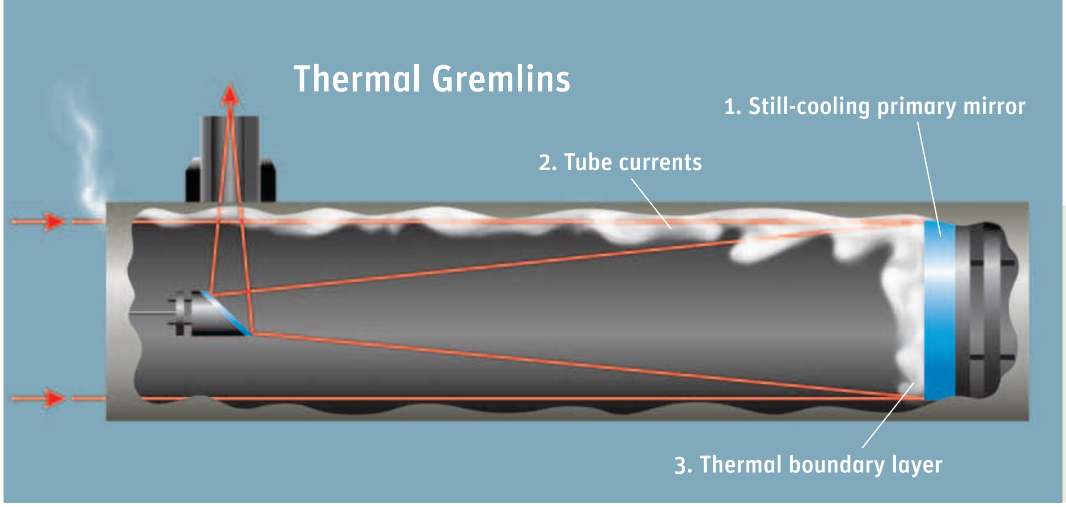
While a Newtonian reflector is capable of superb performance, its primary mirror must be at the same temperature as the outside air for it to realize its full potential.

Most observers already know that Newtonians need some time outdoors to acclimate to the night air temperature. Conventional wisdom states that thermal problems can be avoided either by allowing sufficient time for the primary mirror to come to equilibrium with the night air or by storing the telescope in an unheated shelter. This is still good advice, but my tests show that these measures alone are far from adequate. As described in my September 2000 article ("Understanding Thermal Behavior in Newtonian Reflectors," page 125), the *schlieren test* (a close cousin to the more familiar Foucault knife-edge test used by mirror makers) permits us to directly observe what is going on, and it reveals a persistent thermal chaos around the primary mirror with effects that are more damaging and long-lasting than most telescope users realize.

While the most obvious manifestations of thermal instability subside after a relatively short period of time, the telescope will continue to suffer throughout the night from residual heat stored in the mirror *and* because of continually falling air temperatures. This latter point is seldom fully appreciated. Even a telescope that begins an observing session exactly at the ambient air temperature will soon begin to exhibit image degradation as the night air temperature falls. Unfortunately, in most geographical locations the temperature simply drops too rapidly after sunset for the mirror to keep up, let alone catch up.

Identifying the Gremlins

The phrase "thermal problems" means different things to different people. There are actually three sources of thermal-related image degradation: (1) the changing shape, or figure, of a cooling primary mirror; (2) so-called tube currents, and; (3) the thermal boundary layer. It is important to distinguish among these so that we can identify and correct the problems.



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The three main thermal problems are shown here. Of these, heat radiating from the primary mirror to form a thermal boundary layer is the most important. It is worth noting that all three have as their cause a warm primary mirror.

A change in the figure of a cooling mirror is often cited as a major problem, but in reality this is so small in magnitude and duration that I regard it as the least significant of the three I have highlighted. The shape of a telescope mirror has to be accurate to within a few millionths of an inch for it to perform well, but when a warm mirror is suddenly placed into a cool environment, its shape changes, as the outer portion of the mirror cools slightly faster than its center. Even a low-expansion glass like Pyrex undergoes some volumetric change as a function of temperature. Fortunately, a significant change in figure for Pyrex telescope mirrors is usually short-lived and is almost never seen well into an observing session unless the ambient air temperature is falling at an unusually rapid rate.

Tube currents are caused by warm air rising off the primary mirror (or other structural components), flowing up the inside tube wall, and being partially diverted into the telescope's optical path. This causes the distorted star-test images usually seen right after the scope is taken outside. This condition will not persist for long either, since the primary mirror cannot give up heat at the required high rate for more than a few minutes. Open-framework truss-tube telescopes typically are exempt from this problem.

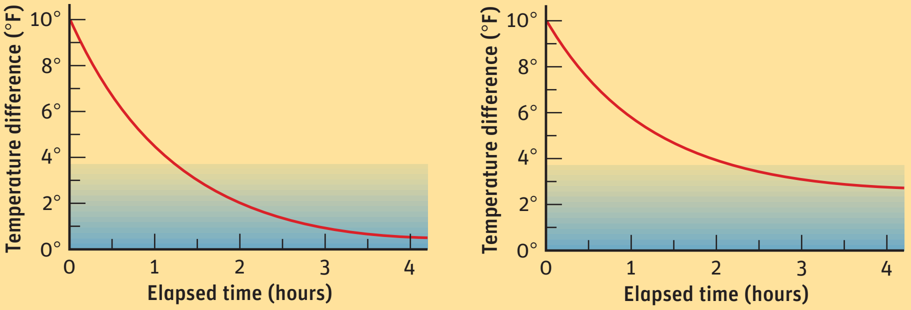
There is another potential source of tube currents unique to metal-tube telescopes. The outer surface of the tube can drop several degrees below the ambient air temperature by radiating heat into outer space (the night sky), causing air near the inside tube wall to continually cool and mix with warmer air inside the tube. (It is possible to directly observe these flows with the test I describe later in this article.) This form of tube currents *does* have the potential to be long lasting, but it is also simple to fix by insulating the tube (usually inside) with cork or foam sheeting.

The third phenomenon is the *thermal boundary layer* that develops on the face of the primary mirror while it gives off heat. This is by far the most serious of the three problems and deserves detailed attention if for no other reason than if you make improvements here, the other two thermal problems will mostly be solved as well.

Getting to Know the Thermal Boundary Layer

A boundary layer will exist on the surface of any solid body that is not at exactly the same temperature as the surrounding air. This is the zone in which the heat transfer takes place between the object and the air as they strive to reach equilibrium. The boundary layer is optically problematic because it is characterized by a steep temperature gradient (only 5 to 15 millimeters thick) and will behave like a rough, irregularly shaped lens that refracts light from its intended path. What's worse, in a Newtonian reflector the wavefront has to traverse this region twice — once on its way to the mirror and once on its way back toward focus.

The boundary-layer problem is long-lasting because telescope mirrors have an unfortunate combination of properties — they store heat well and have poor thermal conductivity. This means that mirrors take a long time to release their stored heat, and more important, they lag behind any change in the ambient air temperature. This is the case regardless of the season since it is the *change* in temperature that is the source of the problem, not the actual temperature itself. Of the three problems outlined earlier, the thermal boundary layer is the toughest to solve, and both solid-



Mirror Cooldown Times

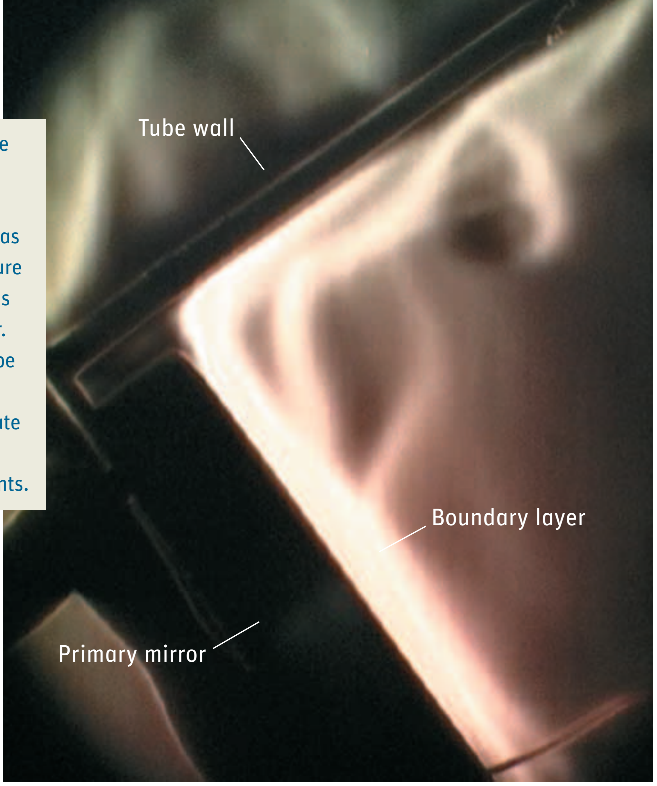
These graphs show a 1-inch-thick primary mirror (typical for a 6-inch reflector) cooling. *Left:* The mirror begins the night 10°F warmer than the ambient air temperature, which remains unchanged during the course of the night. Even in these unrealistically favorable conditions, more than an hour passes before the temperature difference (Δ*T*) between the mirror and air is small enough for nearly optimal performance (blue zone). *Right:* A slightly more realistic example showing the same mirror starting off 10°F warmer than ambient on a night when the temperature is dropping only 2°F per hour — typical for a mild summer evening. More than two hours must elapse before the telescope's performance would be near optimum. These graphs were generated with data from Alan Adler's *Cool* freeware, available at SkyandTelescope.com/resources/software.

tube and truss-tube designs are equally prone to suffer from it.

A variation of the schlieren test, aptly dubbed the *rainbow schlieren* because of its colorful appearance, can be used to quantify the peak-to-valley wavefront errors caused by the thermal boundary layer. This test shows how common it is for localized errors of $^1/_4$ to $^1/_{10}$ wave to appear spontaneously, even when the mirror is just 2°C (3.6°F) above the ambient air temperature. For mirrors left to cool on their own, this is a disturbingly common condition that will usually persist throughout the night.

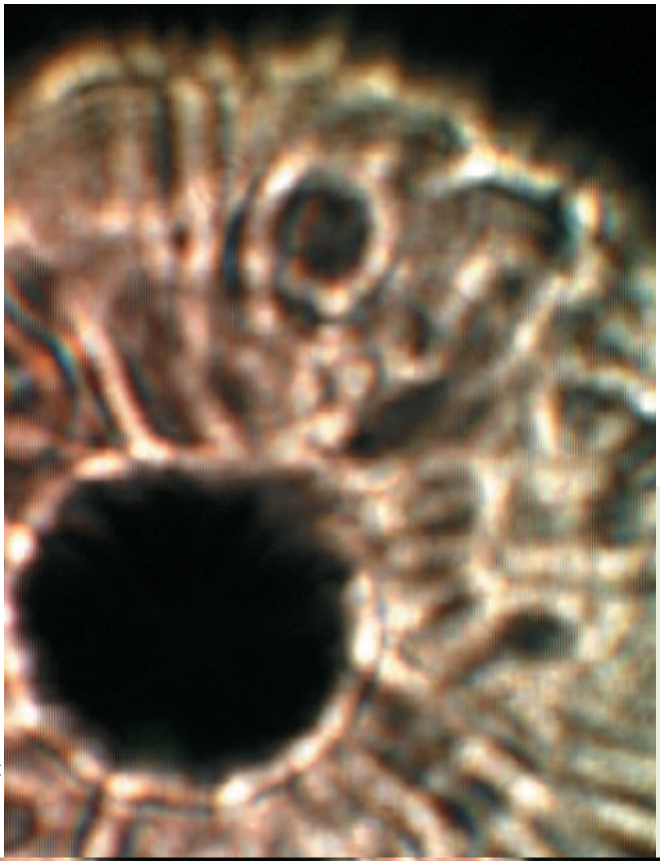
The structure of the boundary layer is irregular and in constant motion. The impact is a sporadic reduction in contrast across a wide range of spatial frequencies. Depending on the size and shape of the layer, the effect can vary from a smearing of fine planetary detail to unwanted light being spread across the field.

The boundary layer hugs the face of the primary mirror (seen here edge-on in a schlieren test) and persists as long as there is a temperature difference between the glass surface and surrounding air. The simulated telescope tube wall was placed above the cooling mirror to demonstrate how warm air rising off the mirror turns into tube currents.



BRYAN GREER

Given the transient nature of the thermal boundary layer, it's easy to see why it isn't better understood. Even without any remedial countermeasures, most Newtonian telescopes will occasionally perform superbly. Under the right conditions there will be fortuitous moments when both the atmosphere *and* the boundary layer are relatively laminar, and suddenly the image of a planet will appear crisp. The observer will then incorrectly assume that the telescope has reached thermal equilibrium, and blame an unsteady atmosphere when the view goes back to being mediocre. Mistaken identity is probably the real reason the boundary layer's true impact on image quality has not been fully appreciated until recently.



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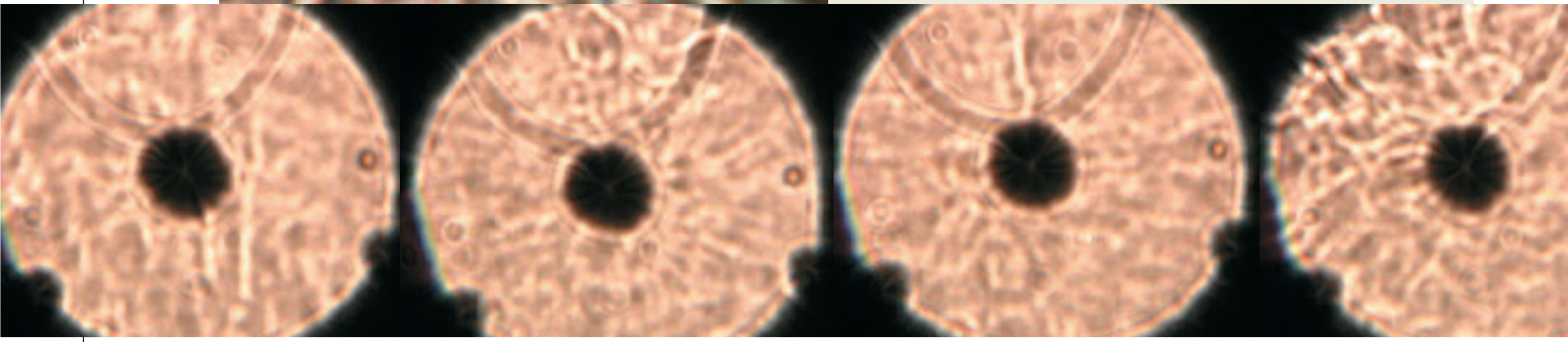
Left: This image of a defocused artificial star taken through the author's 8-inch Newtonian telescope vividly displays the optical effects of the thermal boundary layer. This is an extreme example showing a ΔT of 25°C resulting from the scope being taken outdoors into a cold winter night. Fortunately, the degree of boundary-layer turbulence shown here does not persist for long. *Below:* This is a more typical appearance of the boundary layer in the modified star test where ΔT is 5°C. These individual frames were selected from a 10-second video sequence to illustrate how the structure of the boundary layer quickly changes. Note how the scale of the boundary-layer structure varies. (The top of the mirror is up in these images.)

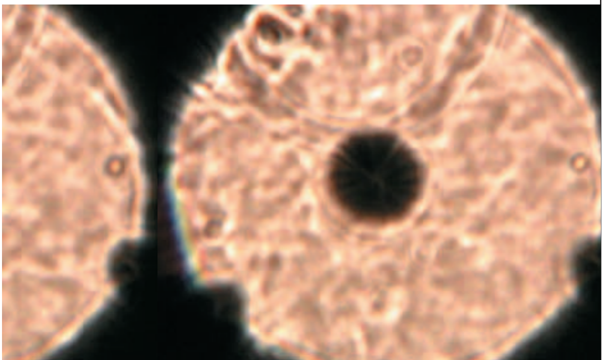


Seeing Is Believing

Before attempting any fixes, it is necessary to have a truly objective and repeatable method to determine your telescope's state of thermal equilibrium. Although the schlieren test setup I use is very sensitive and adept at revealing the boundary layer, it isn't suitable for field testing. Fortunately, it's possible to see the boundary layer with a similar level of sensitivity by employing a derivative of the well-known star test. In fact, you'll probably find the boundary-layer test even easier to perform.

To see the thermal boundary layer in your telescope, insert an eyepiece that produces a magnification of 5 to 10 times your scope's aperture in inches (this is much lower magnification than the standard star test uses). For example, in an 8-inch scope, 40× to 80× is about right. Next, point your telescope at the brightest star in the sky, or even a bright planet like Jupiter or Venus. Rack the image out of focus until the secondary mirror and the spider begin to show in sharp silhouette against the bright, expanded disk of the illuminated primary mirror. Depending on your telescope's focal ratio, you may be defocusing by a half inch or more — much more than for a normal star test. Hunt around a bit until you find a point where atmospheric turbulence becomes visible as a mottled shadow pattern moving in a swift, linear fashion. The speed of this pattern varies from night to night, and it's easier to focus on when it is moving slower. If there are thermal problems within the telescope, you will see them superposed on this pattern as a blotchy shadow structure that moves much more slowly. These "thermal waves" will tend to rise slowly from the bottom of the mirror and are caused by the thermal boundary layer hugging the face of the primary mirror.

The first time you attempt this test it's best to do it when you *know* your scope has thermal problems. Taking the telescope out on a cold winter night will guarantee



Another way to monitor the thermal condition of your primary mirror is with an inexpensive indoor/outdoor digital thermometer. The "outdoor" probe is held against the back of the primary mirror with duct tape and covered with a layer of foam thick enough to isolate the probe from the ambient air. The thermometer box itself (which contains the "indoor" sensor) is attached to the outside of the telescope tube. This setup provides a handy means of comparing the temperature of the mirror with the ambient air temperature. When this photograph was taken, the ΔT was 26.9°F.

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the presence of conspicuous boundary-layer patterns for at least 30 minutes or so, and its appearance in the test described above should be obvious. (For fun, try placing your hand in front of your telescope if you want to see a really spectacular display!) As you gain experience with the test, you'll be able to detect less-distinct patterns.

If you find that the atmospheric messiness confuses you too much, the test can also be performed on a suitable terrestrial light source. A distant streetlight or other bright point source can be used as long as it is a few hundred meters distant. It is important that the light source be sufficiently small or else the contrast of the shadow patterns begins to decrease. In the absence of atmospheric turbulence, the test will now reveal even the smallest thermally induced optical errors. To get a better idea of what this test looks like, view the full-motion video examples available at SkyandTelescope.com/howto/scopes/article_1182_1.asp.

Take some time to test your scope and become familiar with the appearance of thermal problems. In part 2 I'll describe some fixes that will help cure your scope's thermal ills. If you know in advance how to check for the problems, you'll be ready to evaluate the effectiveness of the solutions I'll outline next month. ✴

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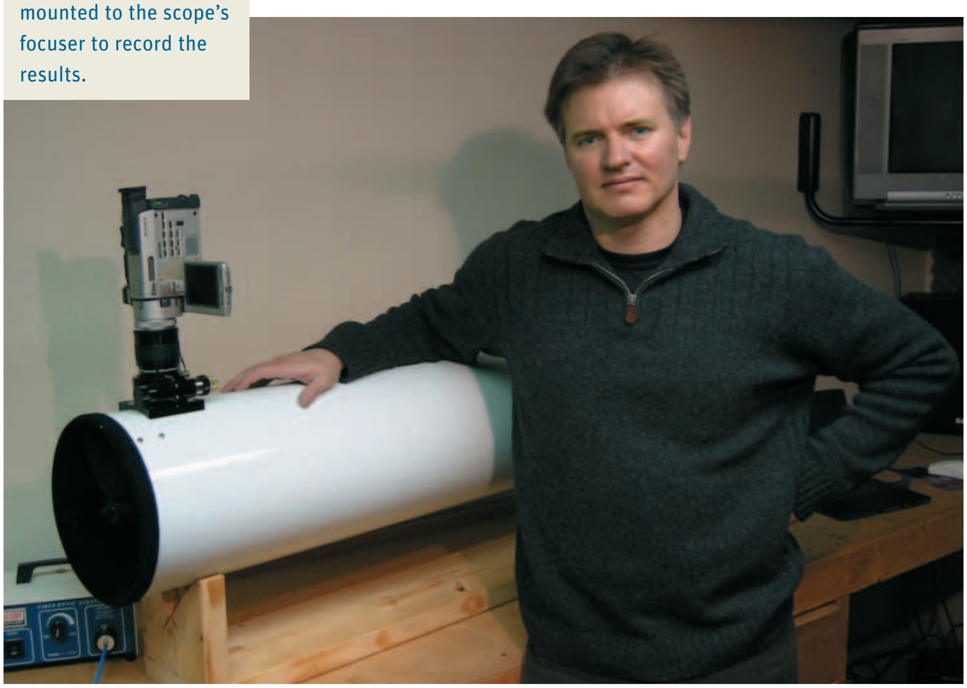

Author Bryan Greer is seen here with his 8-inch telescope set up for schlieren testing. A digital video camera is mounted to the scope's focuser to record the results.

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