# Schlieren Photography

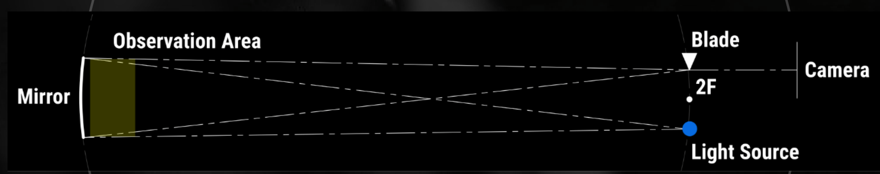
When lighting a candle, your naked eye can see the glowing yellow wick and perhaps a faint shimmer above it. But if you were to look at that same candle through a schlieren system, the empty space above the flame would erupt into a turbulent, rising column of greyscale or color. You would see the invisible plume of hot air fighting against the cooler room air, swirling like oil mixing with water.

This phenomenon occurs because light does not travel at a constant speed through our atmosphere; it changes speed based on the density of the air it passes through.

The "most important stuff" to understand about schlieren photography is that it visualizes refraction—the bending of light rays.

*The Physics:* The refractive index of air changes with temperature and density. Hot air (like that above a candle) is less dense than cold air. When light passes from cool air into hot air, it speeds up and bends. A schlieren system detects these tiny bends in light rays, converting them into changes in brightness or color that our eyes can see.

Traditional schlieren photography, developed in the 19th century by August Toepler, is an ingenious optical trick.




*Collimation:* A light source is shone through a slit and reflected off a high-quality concave mirror to create parallel light rays.

*The Disturbance:* These rays pass through the "test section" (where your candle or bullet is). If the air density is uniform, the light travels straight. If there is a shock wave or heat plume, the light rays deflect slightly.

*The Knife-Edge:* The light is focused back down to a point where a razor blade (knife-edge) is positioned to block exactly half the light.

If a light ray bends upward (due to heat), it might skip over the blade, making that part of the image bright. If a light ray bends downward, it hits the blade and is blocked, making that spot dark.

The Story of the Bullet

*In the 1930s, researchers used this method to photograph explosives and bullets. When a bullet screams through the air, it compresses the gas molecules ahead of it so violently that it creates a "surface of discontinuity"—a shock wave. To the schlieren camera, this shock wave appears as a sharp, defined line. Solid particles from the explosion might break through this wave, creating their own tiny conical shock waves, similar to the wake of a boat. This technique allowed scientists to see that these disturbances happen in mere millionths of a second.*

## The Modern Evolution: BOS

Traditional schlieren requires massive, expensive mirrors and precise alignment. In the year 2000, a digital revolution occurred: Background Oriented Schlieren (BOS).

*Mechanism:* Instead of mirrors and knife-edges, BOS uses a digital camera and a textured background (like a sheet of random dots).

*Reference:* You take a photo of the dots with no flow (air at rest).

*Deflection:* You turn on the wind tunnel or light the fire. The density changes act like a weak lens, optically distorting the background pattern.

*Processing:* Computer algorithms (like cross-correlation or optical flow) compare the two images. They calculate exactly how many pixels the background dots "moved" due to the light bending.

## Rainbow Schlieren: Coloring the Invisible

While standard schlieren gives you black-and-white images (intensity), Rainbow Schlieren gives you color (hue).

*How it works:* Instead of a metal knife-edge blocking the light, a radial rainbow filter (a bull's-eye pattern of colors) is placed at the focal point.

- *The Result:* Weak density changes might bend the light just enough to hit the blue ring of the filter. Stronger gradients (like a shock wave) might bend the light further, hitting the red ring.
- *The Benefit:* This turns the photograph into a quantitative map. You don't just see that the air is moving; the specific color tells you exactly how much the light was deflected.

The Story of the Jet Flame

When observing a jet flame with rainbow schlieren, the image becomes a varicolored map. The core of the flame might appear one color, while the mixing layers on the edges appear as different hues. This allows scientists to calculate the actual temperature distribution inside the flame based on the specific colors recorded.

The Story of the Helicopter

BOS is so flexible it can be taken out of the lab. Researchers have flown aircraft above a helicopter to photograph the invisible vortices trailing off the rotor blades. By using the natural background of the earth (like a quarry or gravel), they could calculate the density of the air simply by measuring how much the background rocks appeared to wiggle as the helicopter flew over them.