The Christmas Corona

BY JOSEPH A. SHAW

On Christmas Eve 1996, a spectacular sight occurred in the Colorado sky over Boulder. This did not involve flying reindeer, but with its vivid red and green colors did seem appropriate to the holiday season. As the last Christmas Eve full moon of this century passed behind a thin wave cloud, formed by the wind blowing from west to east over the Rocky Mountains, the small, uniform cloud droplets produced the most colorful lunar corona I have ever seen. My children, who have learned to notice optical phenomena in the sky, pointed it out to me, successfully delaying their bedtime another hour while we took photographs.

In a recent article[1] I described the color of the night sky, which is not visible to our eyes but is detectable with long-exposure photographs. Conversely, in this article I describe a colorful night-sky display that is seen at its best by human eyes, and produces a less-adequate photograph.

Coronas

So, what is a corona, and how is it formed? A lunar corona is a set of colored rings around the moon, formed when moonlight is diffracted by water droplets (or randomly oriented ice crystals) in a cloud. Sometimes non-circular rings result because of a tapered distribution of droplet sizes; this phenomenon occurs particularly often at the edge of clouds.[2] Coronas are a result of the wave nature of light, as are iridescent colors in oil films, colors around lights viewed through a foggy or icy window, or colors in light reflected from the face of a compact disc.

Have children create their own coronas by viewing a distant street light through a window fogged up with their breath. The tiny water droplets on the window will diffract the light, creating a bright band or maybe even colored rings around the light. Similar, though not necessarily circular, colored patterns can be seen by viewing a distant light through cotton, fine-mesh screen, or thin nylon stockings.

Explain that diffraction causes light to change direction, depending on the shape and size of the diffracting object (the droplets) and on the wavelength of the light. The diffraction angle is inversely proportional to the dimension of the diffracting object. In other words, the longer dimension of a hot-dog shaped particle will diffract light into a smaller angle than will the short dimension. A collection of identical droplets produces a diffraction pattern that has the same shape as that produced by one droplet, only much brighter.

The angle into which light is diffracted at the brightest part of each coronal ring can be estimated from $\theta \simeq k\lambda/D$, where λ is the optical wavelength, D is the dimension of the diffracting object, and k is a constant that depends on the ring order ($k = 1.635$ for the first-order bright ring, 2.679 for the second order, and 3.699 for the third order). This equation comes from the Fraunhofer approximation, which is valid when the distance between the observer and the diffracting object is much greater than the ratio of the square of the object dimension to the optical wavelength (D^2/λ).

Applying the above relationship to the lunar corona, shorter-wavelength blue light is found at the inside of each set of rings, and longer-wavelength red light is at the outside. Actually, most often we see just a white ring around the moon, perhaps with a blue tint on the inside and a red tint on the outside. The cause of this unfortunate affair is the wide variety of drop sizes in most clouds. Small drops make large rings, and large drops make small rings. The effect of all these colored rings overlapping each other is a white ring; only at the inner and outer edges are the colors barely perceptible.

Our Christmas Eve corona

This corona was so colorful because it was formed by a mountain wave cloud, the kind of cloud that often contains particularly uniform droplet sizes in any given region. A primary cause of this uniformity is the relatively low turbulence and nearly laminar (streamline) air flow in the cloud. Since these cloud droplets are usually small, the resulting corona contains large, colored rings. (I estimated the effective diameter of the cloud droplets from the previous equation using the angular radius of the first red ring in the picture. The angle can be estimated as the arc-tangent of the ratio of the red-ring radius over the camera-lens focal length. Using an approximate wavelength of 600 nm for the red ring, I determined from the ring diameter in a large projected image that the wave-cloud water droplet diameters were approximately 13 µm, which is indeed typical for this kind of cloud.[3] For comparison, other clouds often have droplet diameters ranging from about 5 – 50 µm.)

The photograph shown here is a compromise: The bright center is overexposed, washing out any color there, and the largest-diameter rings are not visible because they are underexposed. Our eyes are logarithmic detectors, whereas photographic film is fairly linear. It is inevitable that photographs of this kind rarely capture the scene quite as our eyes see it. The best approach to photographing coronas is to bracket your exposures so that from many exposures you end up getting two or three pictures that are a reasonable compromise.

In any case, make the exposure much longer than your automatic exposure meter reads. The camera will try to expose for the bright light at the center, when in fact what you want is the much weaker light of the colored rings. It often helps to use an object in the foreground to block the direct moonlight, a necessary trick for photographing coronas produced by the sun.

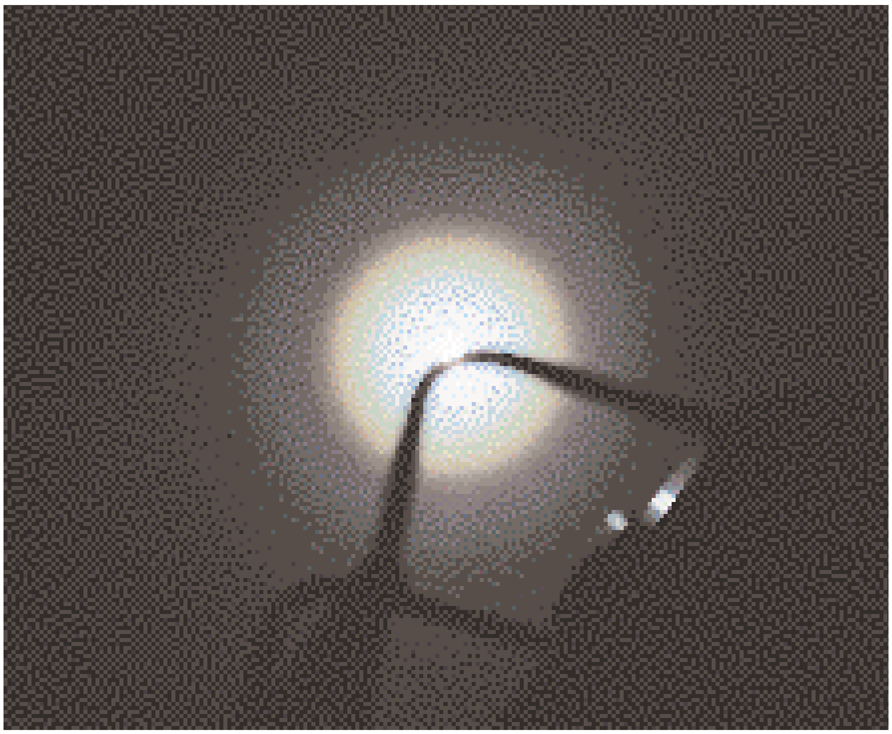
Photo courtesy of Joseph A. Shaw.

Lunar corona photographed on December 24, 1996.

Coronas produced by the sun can be even prettier than lunar coronas due to the brightness of the diffracted light. However, they are seen less often because of the sun's overwhelming brightness. To look for such coronas you have to block the sun. A street light is often used for this purpose when photographing sun coronas, but the technique will not work at night because the light from the street lamp will wash out your photo. For the picture shown here, I used a metal rail on my neighbor's camper to block some of the direct moon light.

I also used a tripod-mounted Nikon camera with a 70-mm lens to record this picture on ISO-64 Kodachrome film, using an exposure of f/3.5 for 16 seconds. With my eye I could see first-, second-, and third-order diffraction rings, but the third-order rings cannot be seen in the photograph. Therefore, such coronas are best viewed in person.

Simple coronas without spectacular color can be seen on an amazingly routine basis. Be aware of the possibilities, and you will witness a lot of interesting optics overhead. Children especially enjoy being shown such sights and will point them out to you after they are introduced to them (especially if it delays their bedtime). And that is what makes "natural optics" so much fun—sharing it with others.

References

1. J. A. Shaw, "What color is the sky at night?" Opt. Phot. News **7** (11), 54 (1996).
2. More information on coronas is available in the many excellent books on atmospheric optics, including D. K. Lynch and W. Livingston, *Color and Light in Nature,* (Cambridge Univ. Press, Cambridge, U.K., 1995); R. Greenler, *Rainbows, Halos, and Glories,* (Cambridge Univ. Press, Cambridge, U.K., 1985); M. Minnaert, *Light and Color in the Outdoors,* (Springer-Verlag, New York, N.Y. 1993), and C. Bohren, *Clouds in a glass of beer,* (John Wiley and Sons, New York, N.Y. 1987).
3. A. J. Heymsfield and L. M. Miloshevich, "Relative humidity and temperature influences on cirrus formation and evolution: Observations from wave clouds and FIRE II," J. Atmos. Sci. **52** (23), 4302–4326 (1995).

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