COVER ILLUSTRATION

Divine countenance or witches' brew?

Imagine a long and challenging ascent of a mountain peak towards the end of the day with the sun nearly set. Emerging above the clouds to reach the summit, the climber looks down to see on the clouds below, a colossal figure crowned with a wreath of glorious colour, even with multiple rings. This figure seems to be related to the climber's shadow, but can also shift on its own as if in a cauldron. This could be interpreted as rapturous, divine, or satanic. Those who first witnessed this phenomenon in the Harz Mountains in Germany called it the "Broken Spectre" (cover image), and it was viewed with a sense of malevolence and foreboding. It was often believed to be present as part of a witch's brew. Yet, others would view it with divine significance, believing they had been touched with a crown by God.

Surely such a complex subtle meteorological event would have been beyond the understanding of people hundreds or thousands of years ago. We know that Olympiodorus, one of the chief Aristotelian commentators, who taught at Alexandria in the 6th century and was one of the last scholars of that city, wrote of the phenomenon. Early peoples would have wanted to ascribe this event to some cause that they could grasp, perhaps religious in nature. Authors have recognised this almost mystical phenomenon and incorporated it into their writings. Goethe writes of the spectre in *Faust* and probably reflects the fear of his time as this phenomenon was believed to be associated with festivities held by witches. Thomas Pynchon writes of the spectre in *Gravity's Rainbow*, as two of his principal characters experience the sight of the Brocken. And that sight is indeed bewitching. Interestingly, even now we don't understand it—at least not completely.

What then is the Spectre of the Brocken? As seen on the cover, the physical appearance of the spectacle consists of the lengthened shadow of the observer almost in a triangular, outsized appearance spread across a bed of white clouds below, with the sun in the opposite hemisphere. Immediately around the observer's head

Glory around an aeroplane shadow.

is a bright whitish glow. Further out and completely around the head are colourful rings, perhaps two or three orders of rings that seem to move and shimmer, and seem to be only about the observer's head but not that of a companion's. The observer's shadow has this appearance because of parallax and a function of the long shadows of late afternoon or early morning. But what about the colour and the central area of diffuse glow?

The colourful rings are diffraction rings, but cannot be explained completely by diffraction. A more difficult and challenging mathematical theory must be invoked—Mie scattering.

The Brocken Spectre and its close cousin, the "Glory" (figure), seen around aeroplanes in the antisolar horizon, are only found when the droplets in the clouds are of uniform size and are quite small—small enough to be suspended in air—perhaps in the vicinity of 10–50 μm .

When these conditions exist, the photons streaming around the head of the observer (or the aeroplane in the case of the glory) will encounter these drops and will be reflected back to the observer as if the droplets were a series of uniform spheres—which they are. The light will be reflected from the curved surfaces in an infinite number of directions, almost like an infinite number of seeds on a dandelion tuft. As these rays are reflected, each will spread out like ripples on a pond, and will contact adjacent rays also being reflected from the same surface. Some of these light waves will meet peak to peak and undergo constructive interference and thus be brighter. Other waves will encounter their neighbour trough to

peak and cancel each other out, eliminating the light at that spot in what is known as destructive interference.

Since each wavelength will reflect slightly differently, there will be individual colours that will be isolated each in turn all around the droplets creating rings. Different sized drops have different curvatures of the outer skin of the droplet and will reflect the light at different angles. It turns out that the smaller the droplets, the larger the rings.

That is hard enough to understand and grasp, but with the help of large computers, this has been modelled successfully. But there still are various twists.

The glow immediately around the observer's head is created by these small droplets sending an axial ray that reflects from the posterior skin of the droplet as well as the exact centre of the droplet directed to the eye.

As light penetrates the cloud, deeper and deeper layers reflect the light. At times some observers even believe there is a three dimensional quality to the Spectre, and there probably is. The deeper layers of the cloud, if of consistent size, will also be reflecting light back to the observer. Now, however, these light rays will encounter droplets that lie between them and the observer. The droplets that are the nearest to the observer will then be reflecting light waves and have light waves returning to the observer through and around them. This is backscattering from the deepest droplets, but forward scattering from the closest droplets. The mathematics of diffraction are distinct and different from Mie scattering and is beyond the confines of this essay, but these extra photons contribute to the spectre as well. These mathematical explanations tell us what happens, but not how, and there is much yet to learn of the phenomenon. Witches' brew indeed.

I R Schwab

University of California Davis, 4860 Y Street,
Suite 2400, Sacramento, CA 95817, USA;
irschwab@ucdavis.com

Photograph on the cover from Mount Washington Observatory/Jim Salge photograph. Thanks to Jim Tiedeman, MD, for his review and comments. Photograph on this page by autor.